ELECTRIC POWER RESEARCH INSTITUTE

Plant Support Engineering: Guidance for Planned Replacement of Large Power Transformers at Nuclear Power Plants

Plant Support Engineering: Guidance for Planned Replacement of Large Power Transformers at Nuclear Power Plants

1015077

Final Report, November 2007

EPRI Project Manager
K. Caraway

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

Sequoia Consulting Group, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Electric Power Research Institute (EPRI)
1300 W.T. Harris Blvd.
Charlotte, NC 28262

Principal Investigator
K. Caraway

Sequoia Consulting Group, Inc.
111 Washington Street
Plainville, MA 02762

Principal Investigator
M. Tulay

This report describes research sponsored by the EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Plant Support Engineering: Guidance for Planned Replacement of Large Power Transformers at Nuclear Power Plants. EPRI, Palo Alto, CA: 2007. 1015077.

REPORT SUMMARY

Background

Utilities continue to pursue license renewal applications and power uprates, and these initiatives are being undertaken on an aging fleet of nuclear plants. Many plants are facing the necessity of replacing large power transformers to support these initiatives. However, industry expertise to support such activities has diminished since the days of plant construction—there are fewer qualified vendors and equipment manufacturers, materials and standards might have changed, and licensees are typically not currently staffed for these major undertakings.

Objectives

- To support nuclear utilities in their efforts to replace large power transformers by providing a source of knowledge to increase staff awareness and appreciation of the major design, procurement, installation, and operational issues that must be considered

Approach

In cooperation with the Plant Support Engineering program at the Electric Power Research Institute (EPRI) a task group of utility engineers and industry experts was formed. This group confirmed key issues that a project team could encounter when replacing a large power transformer at a nuclear power plant and provided input that was used in preparing the guidance set forth in this report. Development of the report was closely coordinated and reviewed to ensure consistency with current industrywide guidance and lessons learned. Experience-proven practices and techniques were identified during this effort and compiled in this report.

This report is another in a suite of guidelines that will enable licensees to be intelligent customers when faced with replacing major plant components to support license renewal and plant life extension. This project will support nuclear utilities in their efforts to replace large power transformers by providing a source of knowledge to increase staff awareness and appreciation of the major design, procurement, installation, and operational issues that must be considered.

The project documents will result in a body of knowledge to support utility staff in being intelligent customers. Issues addressed include the following:

- Design information specific to large power transformers, including current materials information, potential instrumentation upgrades, configuration changes, and other opportunities for enhancement that will maintain or increase design margin
- Development of large power transformer design and procurement specifications
- Supplier selection and management, including vendor oversight issues

- Manufacturing surveillance guidance
- Receipt inspection guidance
- Identification of critical spares and related design information
- Installation issues, enhancements, and lessons learned
- Potential maintenance program enhancements and improvements

Results

This report emphasizes that a project to replace a large power transformer should follow a logical sequence of events that affords the project team ample opportunity to evaluate all aspects of the replacement, including interface points between the transformer and adjacent equipment or operating systems. The categorization of issues is based on the typical delegation of activities among the key organizations involved (such as design engineering, procurement engineering, purchasing, quality assurance, and supply chain organizations). The report presents an overall flow of information and the primary purpose of each element of the process. Issues addressed include initial design considerations, bid evaluation, supplier selection, specification and procurement, shipping and storage, installation, disposal of the replaced component, and maintenance planning.

EPRI Perspective

The information in this report represents a significant collection of human performance information, including techniques and good practices, related to project teams in their support of replacing large power transformers at a nuclear power plant. This report provides a single point of reference for plant engineering and management personnel, both in the present and in the future. Through the use of this report, in close conjunction with the industry guidance, EPRI members should be able to significantly improve and consistently implement the processes associated with replacing large power transformers at their plants. This will subsequently help members achieve increased reliability and availability of the new components and the systems in which they are installed.

Keywords

Component replacement
Power transformer
Project management
Transformer
Transformer replacement
Transformer specification

ACKNOWLEDGMENTS

EPRI wishes to thank the members of the Task Advisory Group:

David Wallach (Co-Chair)	Duke Energy Corporation
Robert Smith (Co-Chair)	Duke Energy Corporation
Craig Stiegemeier	ABB Inc.
Terry Hooper	AmerenAE
Simon White	British Energy
Jim Coady	Bruce Power
Scott Ellis	Bruce Power
Ken Wallace	Dominion Nuclear Connecticut
Gurunath Bijoor	Entergy Nuclear Northeast
Nick Abi-Sambra	EPRI
Wayne Johnson	EPRI Nuclear Maintenance Applications Center
Ken Caraway	EPRI
Tim Eckert	EPRI Plant Support Engineering
Kirk Robbins	Exelon
Shawn Simon	Institute of Nuclear Power Operations
James Templeton	JB Templeton Consulting
John Lackey	PowerNex Associates, Inc.
Kevin Riley	Progress Energy Carolinas, Inc.
Stan Shilling	Progress Energy Carolinas, Inc.
Robert Smith	SCE&G
Robert Thompson	Shaw Group, Inc.
Kent Brown	Tennessee Valley Authority

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Introduction and Background

Utilities continue to pursue license renewal applications and power uprates, and these initiatives are being undertaken on an aging fleet of nuclear plants. Many plants are facing the necessity of replacing large power transformers to support these initiatives. However, industry expertise to support such activities has diminished since the days of plant construction—there are fewer qualified vendors and equipment manufacturers, materials and standards might have changed, and licensees are typically not currently staffed for these major undertakings.

1.2 Scope of This Report

1.2.1 Report Structure and Organization

The structure of this report follows the basic process that a project team at a nuclear power plant would follow when replacing a major plant component such as a large power transformer. This section describes the scope of the report and defines key terms, acronyms, and abbreviations. The remainder of this report consists of the following sections:

- Section 2, Project Management and Process Overview, introduces the overall process with emphasis on the project management aspects of the entire project.
- Section 3, System and Component Design Issues, describes various design issues associated with replacing large power transformers.
- Section 4, Developing Bid Specifications and Requests for Proposals, explains how design requirements are translated into a bid specification for potential transformer suppliers.
- Section 5, Supplier Qualification and Selection, Bid Evaluation, and Purchasing, provides guidance on performing the bid evaluation and selecting an appropriate supplier and describes purchasing issues that are typically encountered during a procurement of this magnitude.
- Section 6, Manufacturing Issues, describes fabrication issues that might be encountered.
- Section 7, Shipping and Handling Issues, describes the types of shipping and handling issues that can be encountered and provides guidance for minimizing their impact.
- Section 8, Receipt Inspection Issues, provides receipt inspection guidance.
- Section 9, Storage and Staging Issues, provides storage and staging guidance.

- Section 10, Installation Issues, provides guidance on installing the replacement transformer.
- Section 11, Developing the Transformer Maintenance Strategy, describes recommended preventive maintenance activities.
- Section 12, Disposal of the Replaced Large Power Transformer, presents information about the removal and disposal of the replaced component.
- Section 13, References, provides an extensive list of references.
- Appendix A, Large Power Transformer Components and Functions, provides a tutorial of large power transformers, including a description of their components, functions, and failure mechanisms.
- Appendix B, Seismic Design and Qualification Requirements, presents an overview of seismic design requirements that apply to large power transformers.
- Appendix C, Example of a Typical Bid Specification, provides an illustrative example of a typical bid specification for a large power transformer.
- Appendix D, Example of a Typical Data Sheet, presents an example of a data sheet for a large power transformer.
- Appendix E, Vendor Evaluation Checklists, provides examples of vendor evaluation checklists that two utilities used when evaluating the quality controls at a transformer manufacturer's facility.
- Appendix F, Manufacturing Surveillance Activities and Examples, presents a list of surveillance attributes that one utility used when evaluating selected quality controls at a large power transformer manufacturer's facility.
- Appendix G, Example of Final Product Tests, provides a list of final product tests with a typical schedule and the associated standards.
- Appendix H, Example of a Transformer Installation and Startup Checklist, presents a checklist of various installation and start-up inspections and tests that one utility used to prepare a large power transformer for reliable service.
- Appendix I, Example of First-Year Oil Sampling and Thermography Intervals, presents a listing of tests and inspections that one utility conducted during the first year of operation of a new large power transformer.

1.2.2 Scope of Equipment Covered in This Report

This report applies to power transformers that are typically installed in the following three applications (see Figure 1-1):

- Generator step-up (GSU) transformers. These transformers are normally used to step the generator output voltage up to the transmission system voltage. They act as an interface point between the main generator and the transmission system. A particular station can have one or more of these transformers installed, depending on the plant configuration. If generator breakers or disconnect links or switches are used, these transformers can also be used to back-feed the auxiliary systems from the switchyard when the generator is offline. GSU transformers are also known as main power transformers or main step-up transformers.
- Unit auxiliary transformers (UAT). These transformers are normally used to step the generator output voltage down to the station auxiliary power system voltages. These transformers act as interface points between the main generator and the station auxiliary power system. A particular station can have one or more of these transformers installed, depending on the plant configuration.
- System auxiliary transformers. These transformers are normally used to step the transmission system voltage down to station auxiliary power system voltages. They act as interface points between the transmission system and the station auxiliary power system. These transformers are often referred to as reserve auxiliary transformers (RAT), station auxiliary transformers (SAT), or startup transformers, as well as other site-specific names.

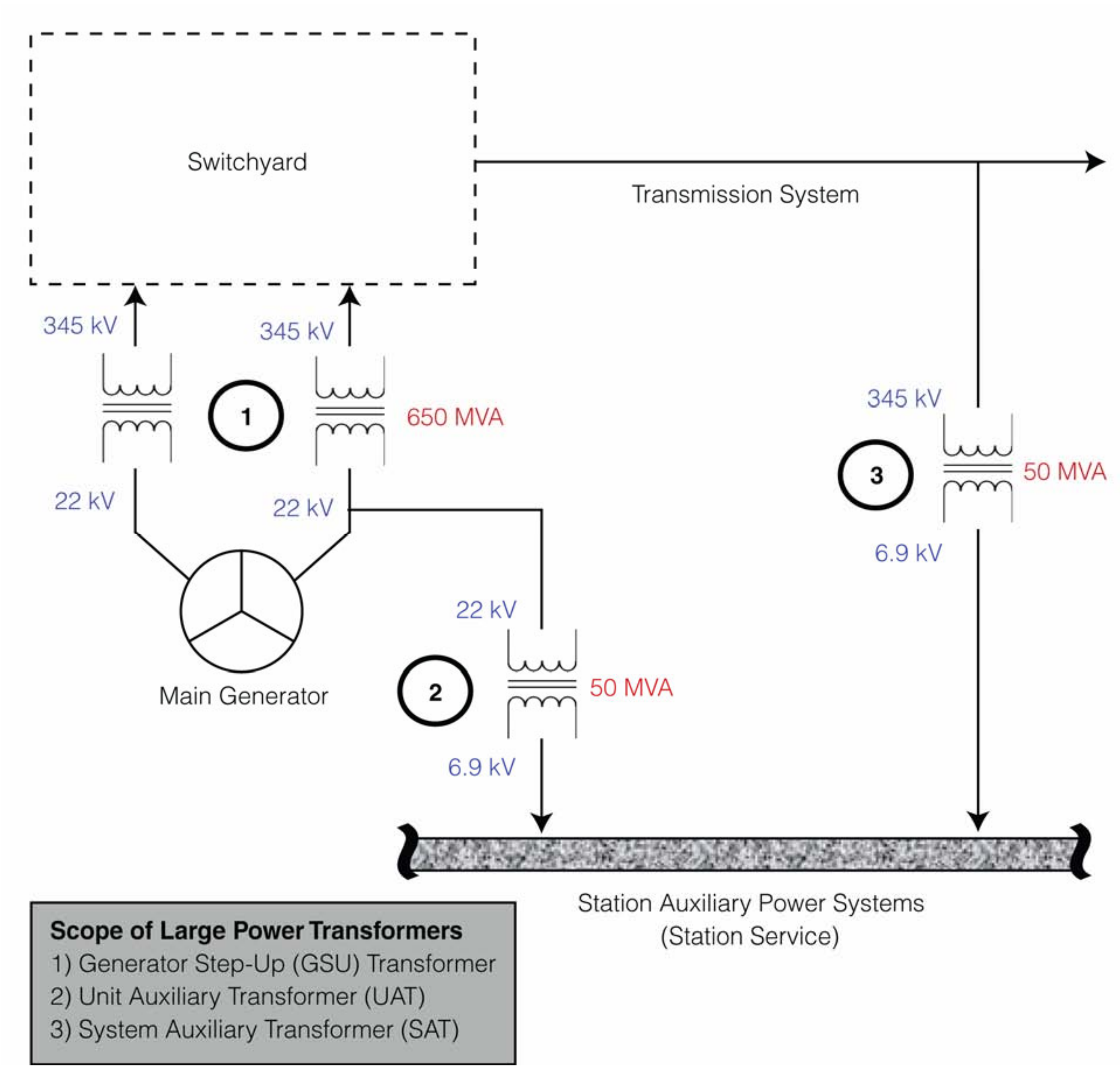


Figure 1-1
Scope of Transformers Described in This Report
Based on IEEE 765, Standard for Preferred Power Supply (PPS) for Nuclear Power Generating Stations (NPGS) [1]

Although the scope of this report is for large power transformers, project teams should review this report for applicability when procuring other transformers that have a high cost, a high risk, or a long delivery time.

1.2.3 Basic Premises of This Report

1.2.3.1 Replace Versus Repair or Refurbish Analysis

This report assumes that utility personnel have already performed a replace versus repair or refurbish analysis in accordance with site-specific procedures and that a transformer replacement has been chosen as the most cost-beneficial option. Therefore, the replace versus repair analysis is not included in the generic process provided in Section 2, Project Management and Process Overview, and is not described in the remaining sections of this report.

1.2.3.2 Applicability of Quality Assurance Guidance

Certain quality assurance (QA) implementation standards were considered in establishing a basis for the guidance provided in this report. Other QA programmatic and implementation guidance might be equally applicable. From a regulatory standpoint, the ANSI N45.2, Quality Assurance Program Requirements for Nuclear Power Plants, standards are applicable only to safety-related components; however, project teams can consider the ANSI guidance applicable to transformers, even though, in most cases, the transformers are classified as non-safety-related components [2]. The intent of this report is not to exclude any particular QA guidance, but rather to present in generic terms implementing guidance that is most common to U.S. nuclear power plant licensees. The project team might wish to become more familiar with other industrial quality standards (such as ANSI/ISO/ASQ Q9001, Quality Management Systems: Requirements) that can be implemented by a supplier or manufacturer [3].

1.2.3.3 Replacement Configuration Options

This report assumes that utility personnel have already performed a thorough review of configuration options in accordance with site-specific procedures that resulted in the selection of the most suitable configuration for replacing one or more existing large power transformers. That review and analysis considers many technical and economic factors, as well as the configuration of the transformers being replaced. It is not the intent of this report to recommend the use of any one particular configuration (such as three single-phase units, two small parallel units, or one 3-phase unit) or to provide guidance on how to select the most appropriate configuration for a given application. Therefore, the configuration review and analysis is not included in the generic process provided in Section 2, Project Management and Process Overview, and is not described in the remaining sections of this report.

1.2.3.4 Validity of Information and References

The technical and commercial information in this report, as well as the references cited, were current at the time of publication. Care should be exercised to ensure that the information is still current and appropriate when using this report. Certain industry standards are revised, and regulatory commitments are made from time to time. These issues should be reviewed before including or excluding a particular edition (such as the 1996 or 2006 edition of IEEE 765) of any standard mentioned in this report [1].

1.3 Definitions of Key Terms

- Component. A piece of equipment—such as a vessel, pump, valve, core support structure, relay, or circuit breaker—that is combined with other components to form an assembly. Components typically are designated with an identification number. Refer to the EPRI report *Guidelines for Technical Evaluation of Replacement Items in Nuclear Power Plants (NCIG-11)* (NP-6406) for additional information [4].
- Equipment designer. The engineer in the manufacturer's organization who is responsible for the design of the equipment (typically the component) to be used in the intended application.
- Fabricator. The organization in the licensee's supply chain that is responsible for fabricating parts, assemblies, and subcomponents needed to manufacture the replacement component.
- Manufacturer. The organization in the licensee's supply chain that is responsible for manufacturing and assembling the replacement component to the extent required by the licensee.
- Source verification. Activities witnessed at the supplier's facilities by the purchaser or its agent for specific items in order to verify that a supplier of a commercial grade item controls the critical characteristics of that item. Source verification is often used as an acceptance criterion. Refer to the EPRI report *Guidelines for the Utilization of Commercial Grade Items in Nuclear Safety Related Applications* (NP-5652) for more information [5].
- Standard receipt inspection. Activities that are conducted when items are received in order to check such elements as the quantity received, part number, general condition of items, and damage. Refer to EPRI report NP-5652 for additional information [5].
- Supplier. The organization furnishing the replacement component. This could include an original equipment manufacturer, a part manufacturer, or a distributor. Refer to EPRI report NP-5652 for additional information [5].
- Witness and hold points. Means to ensure that source verification activities, specific fabrication activities, or tests are witnessed by utility personnel or their agents.

1.4 Acronyms and Abbreviations

AAR	Association of American Railroads
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CT	current transformer
CTC	continuously transposed cable

DETC	de-energized tap changer
DGA	dissolved gas analysis
DP	degree of polymerization
FA	forced air cooled (new designation is ONAF)
FOA	forced oil and air cooled (new designation is ODAF)
FOB	free on board
GSU	generator step-up (transformer)
HV	high voltage
ICC	International Chamber of Commerce
IEEE	Institute of Electrical and Electronics Engineers
INPO	Institute of Nuclear Power Operations
IPB	isolated phase bus
ISO	International Organization for Standardization
LTC	load tap changer
LV	low voltage
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NMAC	Nuclear Maintenance Applications Center (EPRI)
NRC	Nuclear Regulatory Commission
NUPIC	Nuclear Utility Procurement Issues Committee
OA	oil-filled, air-cooled (no pumps or fans)
ODAF	oil-filled, force-directed oil, forced-air cooled
ODWN	oil-filled, force-directed oil, water cooled
OFAF	oil-filled, forced-oil, forced-air cooled
ONAF	oil-filled, forced-air cooled
ONAN	oil-filled, air cooled
OSHA	Occupational Safety and Health Administration
PM	preventive maintenance
QA	quality assurance
RAT	reserve auxiliary transformer
SAT	system auxiliary transformer, station auxiliary transformer
SSCs	systems, structures, and components

UAT	unit auxiliary transformer
UFSAR	updated final safety analysis report

2 PROJECT MANAGEMENT AND PROCESS OVERVIEW

2.1 Generic Process

Figure 2-1 represents a generic process that a project team could follow when replacing a large power transformer at a nuclear power plant. The process is structured as a typical Gantt chart, with each activity shown in approximate chronological order and durations roughly shown in order to depict overlaps of various activities throughout the entire process.

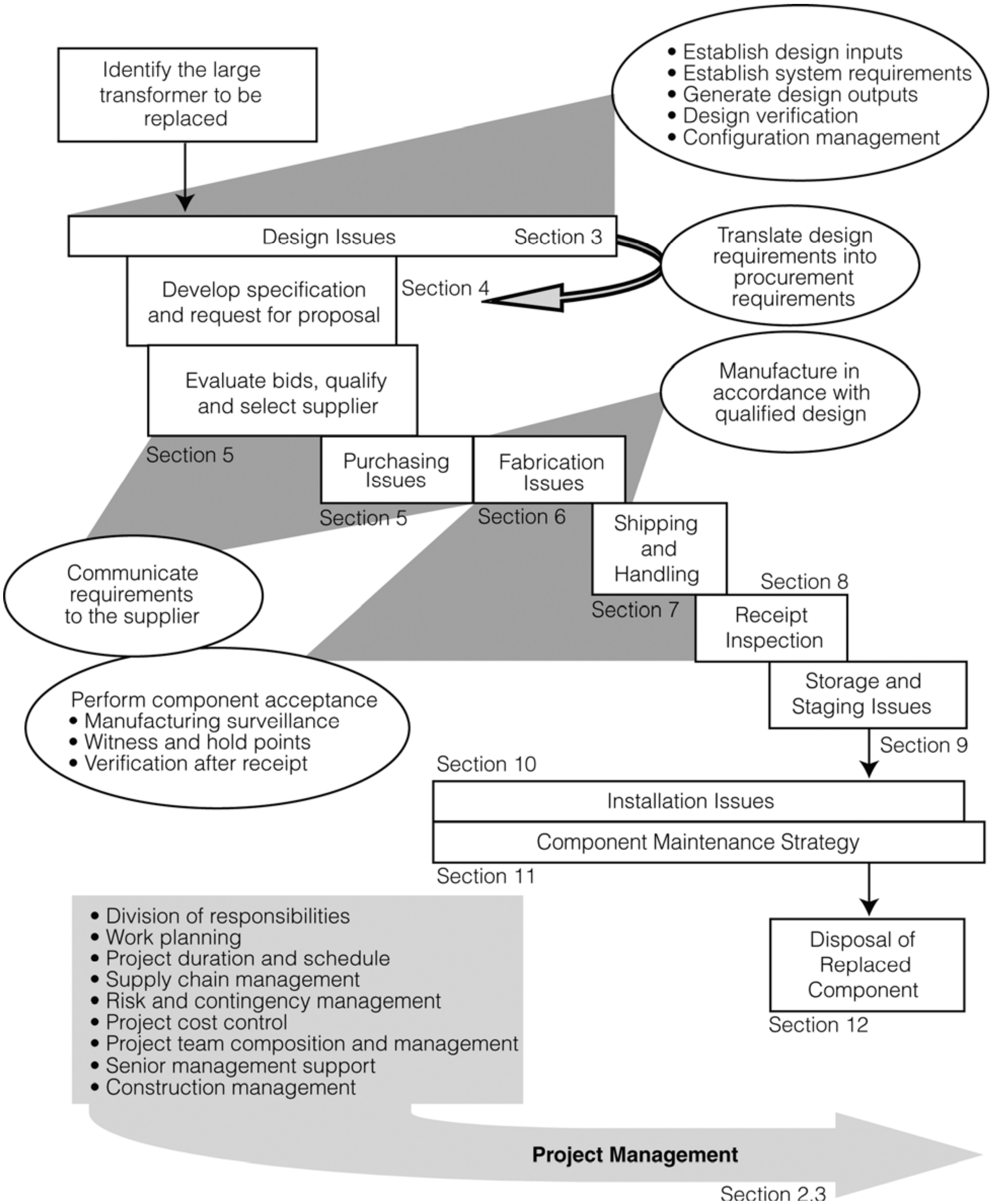


Figure 2-1
Process for Considering Key Issues When Replacing a Large Power Transformer

2.2 Key Issues and Report Structure

Figure 2-1 illustrates that a replacement project should follow a logical sequence of events that affords the project team ample opportunity to evaluate all aspects of the replacement, including interface points between the component and adjacent equipment and operating systems. The issues are categorized based on the typical delegation of activities among the key organizations involved (such as design engineering, procurement engineering, purchasing, QA, and organizations in the supply chain). Figure 2-1 also shows the overall flow of information and the primary purpose of each element of the process. Each process element is also cross-referenced to the corresponding section in this report that provides more detailed implementation guidance. Keep in mind that 1) developing a specification for the replacement component is an iterative process that is most effectively performed through close collaboration with the equipment designer and manufacturer and 2) the project team should concurrently consider other aspects of the project, including installation issues and the maintainability of the equipment.

Table 2-1 illustrates an example of the way that one licensee organized project milestones into a checklist to facilitate efficient management of all aspects of the project. Care should be taken to ensure that sufficient details are noted on the actual project plan and schedule used by the project team.

Table 2-1
Example of a Project Milestone Checklist

Activities	Planned Completion Dates	Actual Completion Dates	Comments
Engineering			
Establish scope of transformer replacement			
Clear specification and order			
Start design			
Vendor design review			
Independent design review			
Finish design			
Drawings issuing			
Preliminary outline			
Detail outline			
Schematic diagrams			
Wiring/connection diagram			
Customer approval			

Table 2-1 (continued)
Example of a Project Milestone Checklist

Activities	Planned Completion Dates	Actual Completion Dates	Comments
Procurement of material			
Conductor wire ordered			
Receive conductor wire and core steel			
Tank material			
Active part and cleats material			
Final assembly material			
Production schedule			
Shop floor release			
Core assembly			
Coil assembly			
Core and coil assembly			
Tanking			
Testing			
Heat run tests			
Impulse tests			
Applied voltage test			
Induced voltage test			
Frequency response analysis test			
Shipment			
* European railroad haul commitment			
* Overseas shipping commitment			
U.S. railroad haul commitment			
Ready to ship			
Arrive at U.S. port			
Clear customs			
Arrival to nearest rail siding			
Contract performance date			

Table 2-1 (continued)
Example of a Project Milestone Checklist

Activities	Planned Completion Dates	Actual Completion Dates	Comments
Haul and install			
Haul from rail siding to pad			
Installation and dress out			
Haul and install contract performance date			

*If required

2.3 Project Management for Replacing Large Power Transformers

2.3.1 General Guidance

One of the keys to success when replacing a large power transformer is the ability to manage the entire project and ensure that it remains on schedule and within budget and that the replacement transformer is suitable for its intended application. Although the main focus of this report is with the replacement transformer itself, the project manager must have an appreciation for the entire scope of work associated with replacing the existing transformer. This usually involves the modification of various interfacing system components, each controlled with appropriate site-specific design change processes. Figure 2-1 illustrates that project management activities span the entire duration of the project and include many issues that are neither necessarily directly related to the replacement transformer nor technical in nature. Some of these issues can include the following:

- Division of responsibilities. Assigning roles and responsibilities among the various internal and external organizations (such as architect/engineers, licensee transmission organization, independent system operator, and regional transmission operator) associated with the design, procurement, manufacture, installation, maintenance and operation of the replacement transformer.
- Work planning. Coordinating the numerous work activities associated with the replacement transformer and interfacing system components.

- Project duration and schedule. Establishing a project scope, total duration, and milestones so that all activities are appropriately planned and scheduled. The project manager should consider the following issues when establishing an overall project schedule for a large power transformer replacement:
  - Pre-design activities, including walkdowns, inspections of existing transformers, conceptual design studies, review of the transformer design and performance capabilities
  - Pre-award activities, including design engineering activities, specification development, and bid evaluation (including consideration of issues relating to compatibility with existing service conditions)
  - Manufacturing lead time
  - Transportation options and durations
  - Receiving and staging duration
  - Construction management
  - Demolition schedule
  - Installation schedule
  - Post-installation testing and startup activities
  - Turnover activities

  After these major elements have been planned, the licensee's work planning organization should be used to integrate the overall project schedule and milestones into the site's overall schedule in accordance with existing utility and site procedures.

- Senior management support. Ensuring that senior management is aware of the project scope, budget, and progress so as to provide the necessary support throughout the duration of the component replacement work activities.
- Supply chain management. Interfacing with the various organizations in the supply chain to ensure that each has the necessary capabilities and can implement those controls consistently with regard to the replacement component and other system components that require replacement or modification.
- Project communications and supplier interface. Establishing the means for sharing project information among utility personnel and organizations outside the utility (such as manufacturers, distributors, suppliers, architect-engineering companies, and third-party test facilities), including the potential need for interpreters if doing business with companies outside the United States.
- Risk and contingency management. Developing plans for addressing unexpected issues that might arise during the overall project and methods for estimating the risks associated with implementing various corrective actions.
- Project cost control. Ensuring that the component replacement project remains within the established budget.

- Project team composition and management. Ensuring that the appropriate individuals are available to support the component replacement project, including appropriate members from the supply chain. Most large projects of this nature have a project team with a charter and their own organization. This could fall under the licensee's major projects group, as well. The capital involved in a large power transformer replacement project will most likely result in a dedicated team with a known organization.
- Configuration management. Ensuring that the appropriate design change control processes are implemented effectively and that the as-built configuration of the replacement component is accurately represented and conveyed in design output documents.
- Training. Ensuring that personnel associated with the operations and maintenance of the replacement component are provided adequate training to support safe operation and reliable performance of the equipment.
- Maintenance requirements and costs. Anticipating the scope of preventive maintenance activities and frequencies, as well as their differences from the maintenance basis for the equipment being replaced.

Expectations of the project include ensuring that the replacement large power transformer satisfies design requirements for its intended applications, that it subsequently performs reliably, and that adjacent system components are modified as needed to sustain reliable system performance. Successful projects recognize the importance of maintaining close interface with both internal and external organizations.

2.3.2 Project Management Team and Interface Controls

2.3.2.1 Project Management Interface Controls

Current industry practice suggests that, for either internal or external interfaces, the project manager should perform the following:

- Identify unique interface requirements (including interface with various external organizations)
- Establish task responsibilities
- Establish appropriate lines of communication
- Establish procedures to control the flow of design information
- Address oversight issues if certain project responsibilities are outsourced

2.3.2.2 Project Management Teams

Because engineering (including site design activities) occurs sequentially and iteratively, some expertise and awareness of parameters affecting the large power transformer through all stages of its life should be considered during the specification development and design phases. Indeed, it is often the case that all kinds of expertise are essential at almost every stage of product development and usage. Therefore, the project manager should solicit and be provided a variety of expertise concurrently in each stage of the sequential process.

To ensure that the required expertise is available, the project manager should create a team composed of members who each have some of the required expertise. This team should be a multidisciplinary group that guides a component replacement from beginning to end. Table 2-2 lists the typical organizations that might comprise the project team and the estimated extent to which they would be involved.

Table 2-2
Typical Project Team for Large Power Transformer Replacements

Organization	Anticipated Level of Involvement
Chemistry management	Low (project-dependent based on application)
Component supplier	High
Engineering (design, systems, components, environmental health and safety, fire protection)	High
Health physics	Project-dependent based on application
Independent system operator or regional transmission organization	Low
Industry expert	High
Information technology, communications, and supervisory control and data acquisition (SCADA)	Low
Licensing	Low
Maintenance	Medium
Operation	Low
Outage manager or work control	Medium
Plant security	Low
Procurement engineering	Medium (unless commercial-grade dedication is necessary)
Project manager	High
Protective relay system protection	Medium (during initial design studies and testing)

Table 2-2 (continued)
Typical Project Team for Large Power Transformer Replacements

Organization	Anticipated Level of Involvement
QA or quality control (supplier verification)	Medium
Senior management	Medium
Substation maintenance	High
Supply chain	Low (during actual purchasing)
Training	Low (higher for operations and maintenance personnel)
Transmission and distribution	High
Transportation coordinator	Medium

2.3.3 General Project Considerations

Successful project managers recognize the importance of considering various aspects of the replacement during the design of the replacement component and design modifications of adjacent system components. This process is often referred to as concurrent design because the design evolves throughout the project and it occurs in concurrent engineering environments. The EPRI report *Guideline for Reverse Engineering at Nuclear Power Plants* (TR-107372) defines *concurrent design* in the following manner [6]:

> A systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. Causes developers to consider from the outset all elements of the product life cycle.

In a general way, project activities occur sequentially. Component design must occur largely before the replacement transformer is manufactured; testing and inspection begin after manufacturing has started; and then the replacement transformer is shipped, stored, installed, started, operated, and maintained.

2.3.3.1 Design Considerations

When replacing a large power transformer, the project manager should factor the following aspects of the component's use into its design to the extent that is feasible:

- Ease of installation. During the design of the replacement component, the project team should consider how and where the component will be installed. Layouts, lifting and rigging plans, and space limitations should be communicated to potential transformer manufacturers so that appropriate features can be designed into the component to facilitate its safe handling and installation. Walkdowns should also be considered as a means for sharing installation concerns with potential manufacturers during the design and bid phases of the replacement project. Examples of design features that can enhance the ease of installation of a major plant component such as a large power transformer can include the following:

- Provisions for lifting lugs and handling rollers to facilitate moving the transformer
- Jack pad locations
- Dimensional limits
- Raised and reinforced tank base to prevent tank damage during handling
- Control cabinet locations and associated plant interface wiring
- Weight and volume of the transformer
- Center of gravity with oil
- Center of gravity without oil (shipping configuration)
- Bus duct flange design and location
- Bus configuration and routing
- Bushing design, height, and location
- Scope and types of auxiliary equipment (such as coolers and monitoring equipment)

• Maintainability. The project team should work with potential suppliers to incorporate cost-effective enhancements to the component that will better support future maintenance activities. Accessibility, maintenance, repair, and in-service inspection requirements, including the conditions under which they will be performed, should be communicated to potential suppliers. This can result in special instrumentation, physical reconfiguration of the equipment, or allowances for accessibility. Features to consider that might facilitate improved maintenance include the following:

- Having an installed spare transformer
- Providing separate breakers for the fans
- Providing hinged fan shrouds that allow better access for cleaning
- Reconfiguring the fire suppression and deluge piping system into a U shape to enable access without having to remove the system
- Having additional cooling installed and operating
- Providing both normal and alternative (redundant) power supplies
- Changing the type of coolers used to improve the ease of cleaning during operation

- Equipment performance monitoring and inspection. The project team and potential manufacturers should examine ways in which the condition and performance of the replacement component can be most effectively monitored. Together, the following aspects should be considered:
  - Ability to inspect equipment (core-form versus shell-form transformers)
  - Enhancements to support equipment condition and performance monitoring (such as vibration or thermography access points or instrumentation, remote computer access, on-line monitoring capability, or improved temperature monitoring)
  - Test requirements and the conditions under which tests will be performed
- Special tooling requirements. During the design of the component, the project team and potential suppliers should determine whether there are any requirements for special tooling, during either manufacturing or operation of the replacement component. In some cases, the design can be modified early in the process to negate the need for special tooling.

2.3.3.2 Other Design Considerations That Impact Support and Interface Groups

Current industry experience suggests that the project manager should consider the following parameters during the specification development and the design of the replacement transformer:

- Environmental issues that affect transformer performance (such as insects, airborne contaminants, salt spray, trash, or wildlife contaminants)
- Personnel requirements and limitations—including the qualification and number of personnel available for operation, maintenance, testing and inspection—and human interface issues
- Transportability requirements such as size and shipping weight limitations or federal regulations
- Fire protection or fire resistance requirements
- Handling and storage requirements
- Requirements to prevent undue risk to the health and safety of the public
- Safety requirements for preventing personnel injury, including such items as restricting the use of dangerous materials, providing a means of escape from enclosures, and grounding electrical systems
  - Occupational Safety and Health Administration (OSHA) requirements
  - Industrial safety requirements
  - Hazardous materials requirements
- Special cleanliness requirements
- Interchangeability with other, similar transformers on site or on the system.

This list is not intended to be all-inclusive, and each project team should use existing plant procedures to ensure that appropriate design aspects are considered during the component replacement. The project team should clearly understand, and communicate to the supplier, whether the transformer being purchased is a spare or whether it will be going directly into service as a replacement. Also, if the replacement transformer is unique in any way, consideration should be given to ordering a spare at this time because it is typically more economical to purchase a spare at the same time the replacement is being purchased.

2.3.3.3 Evaluating Industry Experience

The project team should consider researching industry experience related to the component that is being replaced and the in-service performance of existing equipment built by potential manufacturers of the replacement component. A wealth of industry experience regarding the replacement of transformers already exists, especially considering the vast number of transformers routinely replaced at substations outside the power plant. In general, the project team should consider the following sources for researching industry experience:

- EPRI
- Institute of Nuclear Power Operations (INPO) equipment performance and information exchange database
- INPO and World Association of Nuclear Operators operating experience
- Nuclear Regulatory Commission (NRC) bulletins and licensee reportable events
- Nuclear Utility Procurement Issues Committee (NUPIC) database
- Other utility experience with similar component replacement
- Technical bulletins
- Technical information letters

3
SYSTEM AND COMPONENT DESIGN ISSUES

3.1 Understanding the Reasons for Large Power Transformer Replacement

Many plants are facing the necessity of replacing large power transformers to support initiatives such as license renewal applications, power uprates, and degradation of the existing equipment. Before any design activities are undertaken, engineering personnel should fully understand why the existing transformer is being replaced. Although the reasons might not have a significant affect on implementing the generic process described in this report, they will in most cases affect the scope of the design and procurement processes.

3.1.1 Introduction and General Guidance

One of the basic premises of this report is that utility personnel have already performed a replace versus repair or refurbish analysis in accordance with site-specific procedures and that transformer replacement has been determined to be the most cost-beneficial option. Therefore, the replace versus repair analysis is not included in this report.

The decision to replace an existing large power transformer provides the licensee an opportunity to re-evaluate and possibly change the overall configuration of the equipment. For example, a three-phase transformer could be replaced with a bank of four single-phase transformers (to gain an additional spare). Another example would be to relocate the transformer to mitigate the consequences of a spill or fire. Improved monitoring capabilities can likely improve station or system reliability. However, this report assumes that utility personnel have already performed a thorough review of configuration options that resulted in the selection of the most suitable configuration for replacing the existing transformer. This report recognizes that the review and analysis considers many technical and economic factors, as well as the configuration of the transformer being replaced. It is not the intent of this report to recommend the use of any one particular configuration (such as three or four single-phase units, two small parallel units, or a single three-phase unit) or to provide guidance on how to select the most appropriate configuration for a given application.

Replacement might be the best option for one reason or for a combination of reasons. Some of the most common reasons for replacing, rather than repairing, a large power transformer are the following:

- Degraded performance. The original transformer performance has degraded (for example, gassing), adversely affecting its availability or reliability.
- End of expected life. The transformer has reached the perceived end of its expected life, or it cannot support plant license renewal. Additional guidance regarding end-of-life issues is provided in the EPRI report *Large Transformer End-of-Expected-Life Considerations and the Need for Planning* (1013566) [7].
- Power uprate. The original transformer capacity is inadequate to support a power uprate, and field modifications (such as additional cooling or current-carrying components) are not feasible.
- Need for a spare. The utility has opted to procure a new transformer that either will be used as a spare or will be put into service in place of an in-service transformer, which will then be used as a spare.
- Improving or enhancing component performance and reliability. In some cases, a large power transformer will be replaced not only to restore system performance but also to improve it. Likewise, a large power transformer can be replaced to improve on a less-reliable design. In some cases, a component is replaced to enhance system output performance and improve equipment reliability.
- The project team should clearly understand the goals of the transformer replacement and subsequently communicate those objectives to potential suppliers in the transformer specification and as early in the project as possible. Design issues that are commonly addressed as a means to improve or enhance transformer performance and reliability can include any of the following:
  - Lower losses resulting in a more efficient transformer
  - Use of load tap changers (LTCs) to address voltage regulation issues in station auxiliary power systems
  - Improved through-fault current-withstand capability
  - Revised transformer megavolt ampere rating or temperature rise ratings to recover margin
  - Use of technologies associated with transformer accessories
  - Improved maintenance features and accessibility
  - Increased winding lightning impulse and switching impulse design levels
  - Enhanced on-line monitoring capabilities
  - Consideration of geomagnetically induced currents
  - System impedance matching

3.1.2 Advantages of Modern Large Power Transformer Technology

The following design features are considered within the power industry as advantages of modern large power transformer technology:

- Improved flux distribution based on more sophisticated modeling techniques that provide a better understanding of lead, winding conductor, and steel hot-spot temperatures. These technologies result in better control of both hot-spot temperatures and the adverse effects of magnetic field leakage.
- Use of continuously transposed cables (CTCs) with a significant increase in the number of insulated conductor strands in each cable, resulting in improvement in short-circuit withstand strength and lower load losses.
- Thermally upgraded paper allowing a 149°F (65ºC) winding temperature rise.
- Improved materials (core steel, CTCs, flux shunts, and insulation), which the project team should consider during the manufacturer's design phase.
- Use of modern tools to more accurately predict and support improved designs for electric stress and magnetic field distributions

3.1.3 Cautions Regarding Large Power Transformer Design

Consideration should be given to possible lack of conservatism in selected ratings for new transformers compared to those designed before the advent of sophisticated computer programs. Transformers are usually tested with oil that is in pristine condition. The oil in the factory-tested transformer has a very high dielectric withstand strength and a very low moisture and particle content. Margins are reduced when, for example, the particle counts in the oil become much higher than the original tested values.

Some suppliers might not have previously designed a large power transformer at or above the particular power rating needed. If this is the case, special attention should be given to the suppliers during all phases of the project (such as design, manufacturing, and testing). The licensee should ensure that the manufacturer's design margins offered with the replacement are well proven and suitable for their intended application and meet the present design requirements. Completed or potential unit uprates should specifically be considered to ensure that the replacement transformer will be capable and usable for the foreseeable future.

3.2 Large Power Transformer Components and Functions

Large liquid-immersed transformers are typically designed, built, and operated in accordance with the latest editions of IEEE C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, Regulating Transformers, and other related standards [8].

The principal parts of a transformer, which are described in Appendix A, Large Power Transformer Components and Functions, are the following:

- Tank and oil preservation
- Magnetic core
- Coils and windings
- Insulation system
- Insulating liquid
- Transformer accessories
- Cooling system
- Tap changers
- Surge arresters
- Bushings

Figure 3-1 is a cutaway view of a typical three-phase, core-form oil-filled transformer, showing many of these subcomponents, including the tank, internal connections, typical windings, and the installed bushings.

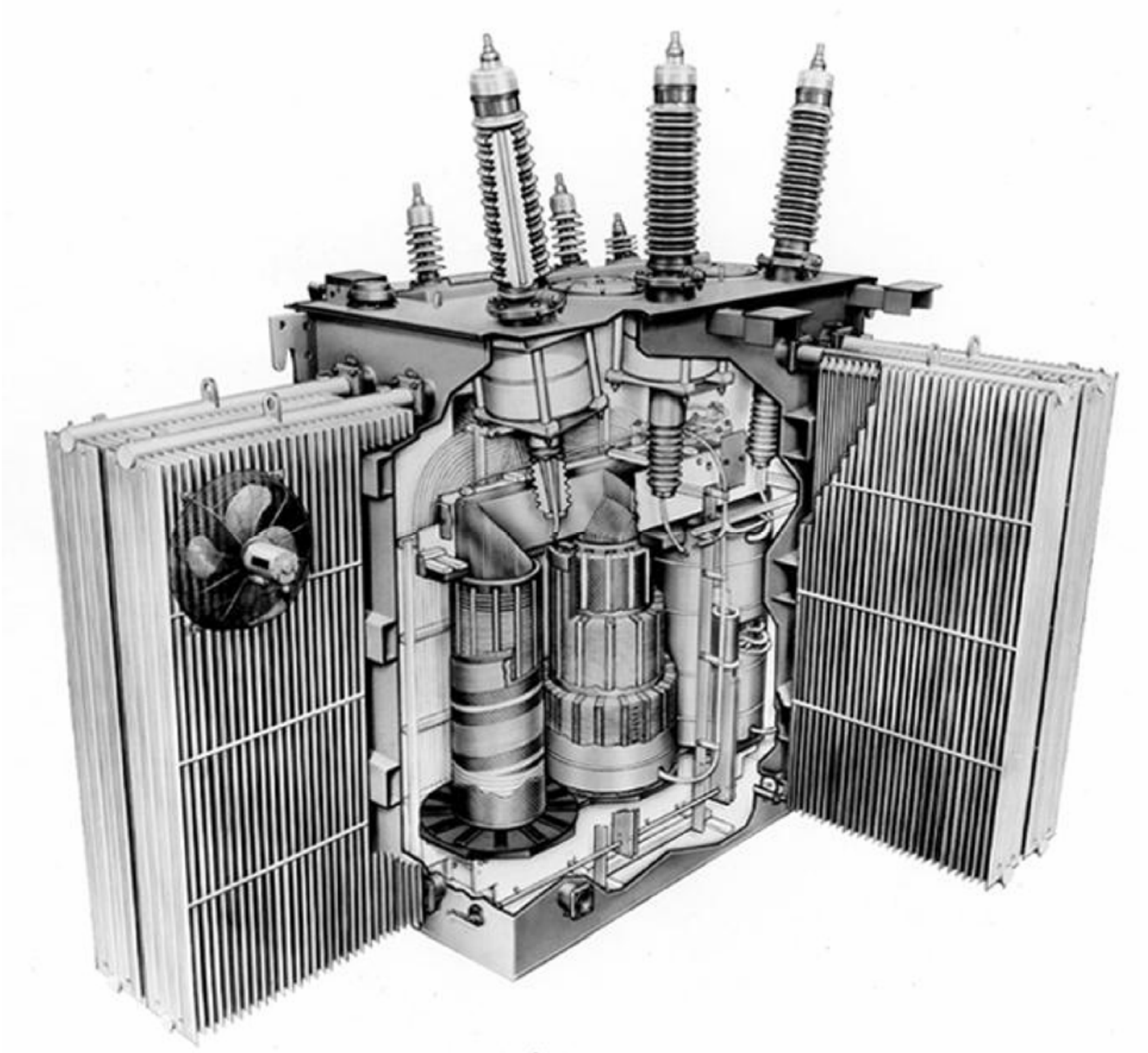


Figure 3-1
Cutaway Illustration of a Power Transformer
Courtesy of Waukesha Electric Systems

3.3 System and Component Design Relationship

The design issues encountered during the replacement of a large power transformer include those directly related to the component, as well as those associated with adjacent or interfacing system components (see Figure 3-2). In many cases, adjacent or interfacing system components require some design modification in order to make the replacement transformer suitable. In some cases, these plant design modifications are just as important to the success of the project as is the design of the actual replacement transformer.

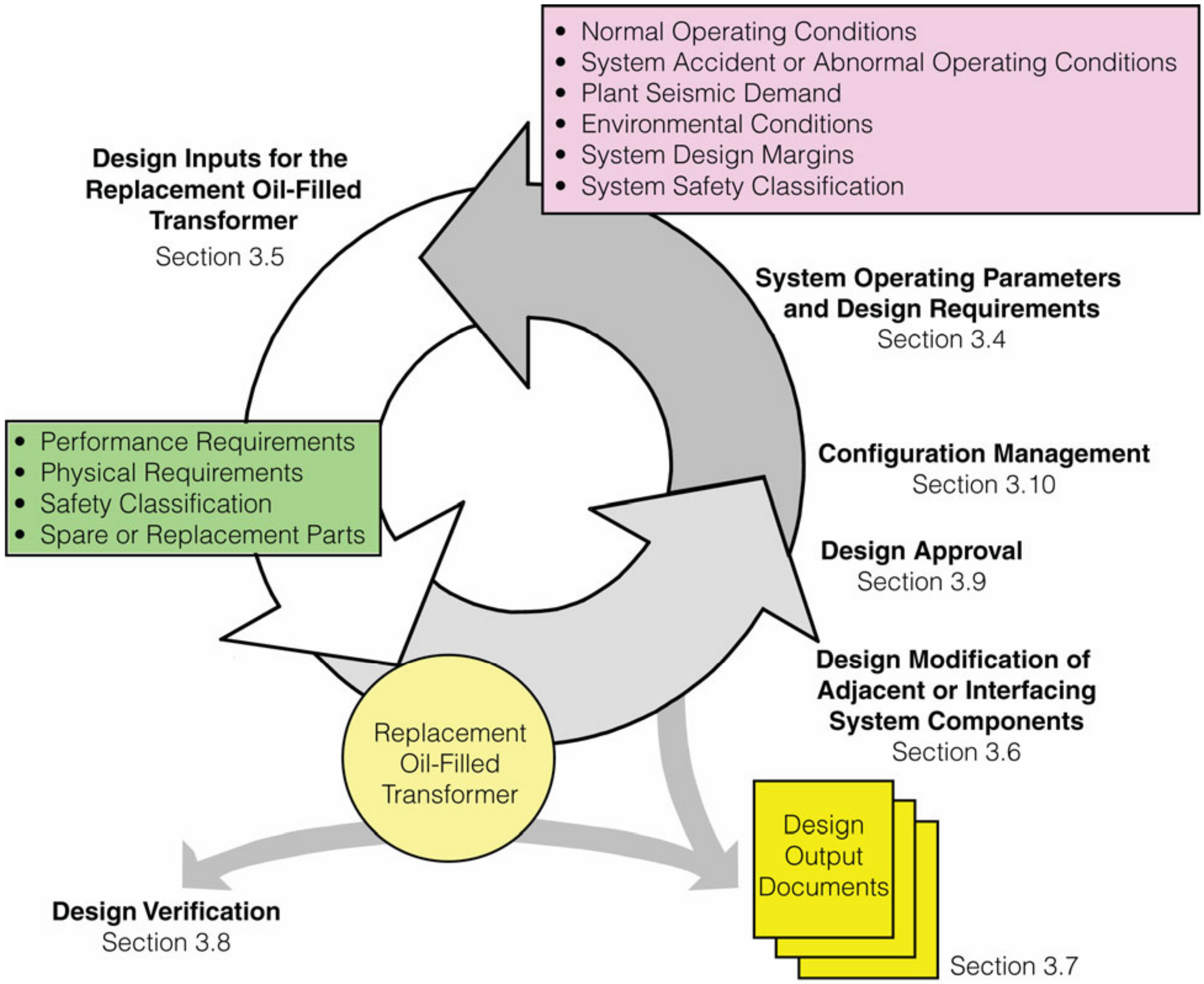


Figure 3-2
System and Component Design

The project team should understand the scope of design activities performed internally by the licensee's engineering organizations and those performed by the supplier, particularly when modifications to the plant are necessary to accommodate the replacement transformer (for example, isolated phase bus (IPB) or nonsegregated phase bus duct field modifications, physical configuration differences, location of the control cabinet, or locations of bushings). This information should, however, be provided to the transformer supplier. If extensions or other modifications are required, the project team and supplier must determine the nature of the modification and the party (supplier or site personnel) responsible for implementing it.

Design decisions regarding the bus connections and the type of bus should be closely coordinated with the transformer manufacturer. The transformer manufacturer should thoroughly evaluate the thermal and magnetic effects of the transition between the transformer, the bus, and the bus duct connections and recommend changes, as appropriate, to prevent heating problems and to ensure compliance with industry standards.

3.4 Establishing System Operating Parameters and Design Requirements

In order to obtain a transformer or any equipment that will meet or exceed the operating requirements, the parameters that affect the equipment's operation must be identified and considered in the actual design of the equipment. This section covers some of these parameters.

3.4.1 System Normal Operating Conditions

The project team should communicate the following information to potential transformer supplier and designers, as appropriate:

- Worst-case loading levels of the transformer based on the operation scenario (normal and system contingency conditions)
- Any back-feed operation requirements based on the application of the transformer and the appropriate service conditions (shutdown, startup, and normal)
- The type of protective devices and protection scheme used
- Any unusual voltage or load changes, such as those resulting from starting large motors

3.4.2 System Accident or Abnormal Operating Conditions

System operating conditions required after a design basis accident, a plant trip, or an adjacent equipment failure should be provided to potential suppliers. Failure effects requirements of systems, structures, and components (SSCs), including a definition of those events and accidents that the SSCs must be designed to withstand, should also be communicated to potential manufacturers before equipment design begins. For example, the load profile of the transformer after plant trips should be considered.

3.4.3 Plant Seismic Demands

The project team should communicate plant- or site-specific seismic loads to potential suppliers in the specification or inquiry for the replacement transformer. Seismic demands vary from plant to plant, and it is important that potential suppliers understand the loads that the particular replacement equipment could be subjected to and to which it should be designed. IEEE 693, IEEE Recommended Practice for Seismic Design of Substations, Annex D, provides detailed guidance for determining seismic qualification requirements for transformers and liquid-filled reactors [9]. Appendix B, Seismic Design and Qualification Requirements, provides a synopsis of that guidance.

3.4.4 Environmental Conditions

The component specification must communicate the various environmental conditions to which the replacement transformer will be subjected. Consideration should be given to the environmental conditions in which the transformer must operate, such as the following:

- Ambient environmental conditions (such as temperature, humidity, altitude, and atmospheric pressure)
- Environmental issues that affect transformer performance (such as insects, airborne contaminants, plants, trash, or wildlife contaminants)
- Exposure to the elements (such as sea spray or brine)
- Wind loads
- Restrictions related to transformer noise levels

The transformer manufacturer should also be made aware of environmental conditions (such as temperature, humidity, atmospheric pressure, or exposure to airborne contaminants) that are anticipated during storage.

3.4.5 System Design Margins

The project team should confirm the design margins associated with the system in which the transformer is installed. Consideration should be given to ways in which the transformer can improve design margins. Any changes to design margins should be documented on design documents such as calculations, drawings, specifications, system descriptions, design basis documents, and the updated final safety analysis report (UFSAR). In many cases, the resulting effect on actual design margins might not be ascertained until after a particular replacement transformer has been selected. Some major factors that could adversely impact system design margins and should be considered when replacing a large power transformer are the following:

- Power uprates (before or after the transformer replacement)
- Insulation coordination
- Allowable temperature rises
- Volt-ampere-reactive support to the transmission system (grid)
- Configuration changes

ANSI/IEEE C57.116, Guide for Transformers Directly Connected to Generators, presents design features that allow calculations to be made to evaluate the effects of the new GSU transformer parameters against generator bus voltage and power flow, unit stability, UAT power requirements, transmission bus voltage, and transmission bus reactive power requirements [10]. The GSU transformer parameters to be reviewed are the following:

- Megavolt ampere rating
- Tap voltage and low-voltage (LV) winding voltage
- Impedance
- Winding currents

3.4.6 System Nuclear Safety Classifications

The project team should confirm the safety classification of the system in which the transformer will be installed, as well as the classification boundaries. In most cases, the system in which the large power transformer will be installed is classified as non-safety-related. The user should determine whether site-specific requirements apply that would affect procurement and acceptance activities. This information is typically documented in the UFSAR, functional system descriptions, system design bases documents, technical specifications, and system diagrams and drawings.

There might be additional considerations (such as environmental concerns) that can have a significant impact on the plant. In the case of a rupture and spill, the ability to contain the transformer oil and prevent it from entering public waterways and wells should be considered.

3.4.7 Other Considerations

The project team should validate the relevance of design parameters that affect the design of the replacement, including the following:

- Interface requirements, including definition of the functional and physical interferences involving SSCs. Clearances should be reviewed for the replacement transformer to ensure that design and application limits are maintained.
- Sound enclosure structures
- Fire protection requirements
- Susceptibility to fire or to damage resulting from fire in adjacent structures
- Proximity to fire walls or buildings that might represent obstructions or that might restrict air circulation around the transformer
- Requirements addressing the capture and disposal of used oil
- Transportation of the transformers from and to the pad
- Auxiliary equipment power requirements

- Structural requirements covering such items as equipment foundations and bus-duct supports
- Access and administrative control requirements for plant security
- Redundancy, diversity, and separation requirements of related SSCs
- Anticipated in-service testing and inspection requirements
- Anticipated cleaning requirements
- Personnel protection (OSHA) requirements affecting equipment design
- Disposition of replaced transformer (sale versus scrap)
- Industry operating experience, failure data, and recommendations

3.5 Establishing Design Inputs for the Replacement Transformer

ANSI N45.2.11 provides the following guidance for establishing design inputs [11]:

> Applicable design inputs, such as design bases, regulatory requirements, codes and standards, shall be identified, documented and their selection reviewed and approved. Changes from specified design inputs including the reasons for the changes shall be identified, approved, documented and controlled.

3.5.1 General Guidance

The transformer specification should clearly describe the basic plant location, layout, and arrangement requirements for the replacement transformer. When replacing a large power transformer, the project team must understand the current requirements of the system in which it will be installed. The requirements can differ from those specified in the original power transformer purchase specification because design modifications might have been performed during the life of the transformers being replaced. Furthermore, the project team should understand the objectives of the transformer replacement and whether one of the objectives is to increase system output performance or improve design margins.

3.5.2 Establishing Large Power Transformer Requirements

Transformer design functions and operability can vary according to conditions such as plant startup, normal plant operation, plant shutdown, plant emergency operation, special or infrequent operation, and system abnormal or emergency operation. These performance requirements should be understood by the project team and communicated to potential suppliers; the requirements can include the following:

- Loss evaluation (efficiency with transformer in service at its rated capacity)
- Instruments and controls, including indicating instruments, controls, and alarms required for operation, testing, and maintenance
- Incipient fault monitors and on-line condition monitors

- The type of instrument, installed spares, range of measurement, and location of indication
- Capability to operate at low power levels without fans or oil pumps
- Material requirements, including such items as steel, insulation, arresters, bushings, protective coating, and corrosion resistance

In some cases, the transformer's mechanical and physical interface requirements cannot easily be ascertained from existing documentation and must be obtained by inspecting or measuring the actual component. In these cases, the project team might need to gain access to the equipment during an outage to inspect or measure the component. Depending on the plant's operating status, these outage activities might have to be planned months, or even years, before the replacement of the large power transformer.

Based on the outputs resulting from modification of adjacent or interfacing system components and the subsequent system operating parameters, the project team establishes transformer technical requirements to the degree deemed necessary to ensure that all design basis requirements are met.

In most cases, the project team must understand and communicate component-specific performance requirements to potential suppliers in order to ensure that system performance requirements are met. In some cases, it might also be necessary for the project team to determine, select, and specify physical requirements for the component and its parts.

3.5.3 Determining the Nuclear Safety Classification of a Large Power Transformer

The project team should confirm the nuclear safety classification of the transformer being replaced in order to determine the extent to which 10CFR50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, requirements apply [12]. In most cases, the system in which the large transformer will be installed has been classified as non-safety-related. The project team should determine whether site-specific requirements apply that will affect procurement and acceptance activities.

If the component is classified as non-safety-related, the project team should still determine whether other quality controls and requirements are applicable and whether those requirements are relevant during the design process. The safety classification of components varies from plant to plant, depending on the original licensing commitments and the subsequent implementation of component categorization programs. The project team should determine which of the following categorization methodologies have been used to determine the current classification of the component being replaced:

- Deterministic or functional safety classification (safety-related or non-safety-related)
- Categorization according to 10CFR50.65, Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants (maintenance rule) [13]

- Categorization according to INPO AP-913, Equipment Reliability Process Description, Revision 1 (critical components) [14]
- Risk-informed categorization according to 10CFR50.69, Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors (high safety significant or low safety significant) [15]

If the component is classified as nuclear safety-related, the project team should determine any applicable constraints related to the procurement, design, manufacture, testing, shipping, installation and operation processes and should define those constraints in the product specification to ensure the licensee’s acceptance of the replacement transformers for service.

3.5.4 Large Power Transformer Failure Mechanisms

The project team should have an understanding of typical failure mechanisms associated with the replacement transformer, should consider lessons learned, and should consider how those failures can be mitigated or prevented by applying various design parameters during the design of the replacement. Transformer failures can be attributed to dielectric breakdown, short circuits, deterioration of insulation properties, bushing failure mechanisms, tap changer failure mechanisms, and transformer manufacturing and design defects. A detailed description of failure mechanisms for large power transformers is provided in Appendix A, Large Power Transformer Components and Functions.

3.5.5 Spare and Replacement Parts

It is often beneficial to consider a maintenance strategy during the design of the replacement component. The project team should consider establishing with potential suppliers the scope of spare and replacement parts necessary to execute the anticipated maintenance, as well as the frequency with which those items should be made available. The team should also consider whether the parts will be interchangeable with existing equipment and what spare equipment is available in stock. The benefits of having an installed spare transformer should also be considered.

During the specification development and before procurement of the replacement component, the project team should consider means for proactively obtaining certain design information such as ratings, materials, dimensions, and tolerances of certain spare and replacement parts from potential suppliers of those parts. Having this part-level information provided during the procurement of the component will make acceptance of these items easier and require less engineering involvement in the future.

3.6 Adjacent or Interfacing System Components and Plant Design Modification

A key consideration when replacing a major plant component is the identification of all interface points between the new component and the existing system, including auxiliary systems associated with the existing component. Identification of interfaces should begin as early in the modification design as possible to ensure that the new component will not interfere with existing equipment and that operating parameters of interfacing systems are adequate to enable the new component to perform as designed. Interfaces can be categorized into the areas summarized in Table 3-1.

Table 3-1
Types and Examples of Key Interfaces

Type of Interface (Engineering Discipline)	Examples for Consideration
Structural	Alignment with bus connections Compatibility with noise abatement structure(s) Concrete or masonry Electrical clearances Equipment anchorage Footprint configuration Maintaining existing accessibility Oil containment/retention Physical interferences with existing structures Physical separation Seismic hazard I or II Strength of foundation and structural adequacy
Mechanical	Flooding Freeze protection Interface with fire protection system Paint and coatings Wind (including tornado)

Table3-1 (continued)
Types and Examples of Key Interfaces

Type of Interface (Engineering Discipline)	Examples for Consideration
Electrical	Adequacy of power supply Circuits and raceways Compatibility with existing circuit inputs and circuit breaking capability (for example, impedance changes) Compatibility with existing voltage and current inputs (including current transformers) Grounding Panels or enclosures Physical type and location of power connections (high-voltage [HV] connection, neutral, IPB connection and isolation) Plant computer systems Protective relaying Security/maintenance lighting
Instrumentation and Control	Adequacy of input signals Alarms (hard-wired and soft-wired) Compatibility with existing equipment performance monitoring equipment Control room interface capabilities Instrument transformers (CTs and potential transformers) Maintaining accessibility of existing instrumentation and indicators New interfaces resulting from enhanced transformer monitoring capabilities and technologies Oil level indication Physical location of instrumentation tubing, wiring, and cables Tap changer control Winding and top oil temperature indication

After identifying all the interface points with existing SSCs, the project team should postulate any adverse effects that the replacement transformer could have on interfacing equipment performance. This analysis should be a logical follow-up to determining interface points, and it should be categorized by engineering discipline, as shown in Table 3-1.

3.7 Generating and Revising Design Output Documents

3.7.1 System Design Output Documents

Unless the project team is replacing a large power transformer with an identical unit, design modifications to adjacent or auxiliary SSCs to accommodate the transformer should be evaluated. Typically, the project team will revise or update the following design outputs associated with affected system components, depending on the extent to which those system components have been modified:

- Calculations supporting the design of the replacement transformer
  - Civil, electrical, instrumentation and control, mechanical
  - Plant computer scaling and alarm setpoints
- System drawings (outline and electrical)
- Transmission studies and calculations
- Protective relay setpoint analyses
- Operating and maintenance procedures
- Functional system descriptions
- Technical specifications and UFSAR
- Fire hazard analyses
- Instrument index and setpoint index

In addition to these system design output documents, installation of a replacement large power transformer might require revisions to licensing documents and regulatory commitments such as a response to 10CFR50, Appendix A, General Design Criterion 17 (GDC 17) or Generic Letter 2006-02, Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power [16, 17].

3.7.2 Large Power Transformer Supplier Design Documents

The design of the replacement transformer should be a collaborative effort between the project team and the equipment designer. The project team should establish certain physical and performance design requirements for the replacement transformer and communicate those requirements to the equipment designer or manufacturer in a bid specification. Given these inputs, the equipment designer or manufacturer should be provided latitude to design or offer a large power transformer that meets the requirements of the design inputs they have been provided or to take documented exceptions. Section 4, Developing Bid Specifications and Requests for Proposals, provides guidance on developing the bid specification and then refining it after a qualified supplier has been selected. After the replacement transformer has been designed and manufactured, the equipment supplier will typically provide the following design output documents:

- Transformer outline and assembly drawings (including plan view, elevation, interface connections, location of center of gravity, and associated dimensions)
- Name plate drawing
- Electrical wiring and schematic drawings
- Certified factory test report
- Instruction manual, which typically includes the following:
  - Performance data sheets or curves (a certified test report)
  - Recommended spare parts lists
  - Transformer installation guidance
  - Transformer maintenance guidance
  - Transformer operating guidance
  - Vendor technical manuals for subcomponents

3.8 Design Verification

Unless the design of the replacement component is identical to that of the original, design verification of the replacement will be required to ensure that the new design is suitable for its intended application. Current industry practices—and in the case of seismic qualification, IEEE 693, Recommended Practices for Seismic Design of Substations—describe three methods for accomplishing design verification: design reviews, alternative calculations, and qualification testing [9]. Because large power transformers are typically classified as non-safety-related, the documentation requirements for design verification are less rigorous than those for safety-related components.

3.9 Design Approval

The licensee's internal design approval should be performed in accordance with existing site and plant procedures; approval might be required from numerous organizations or departments associated with the transformer replacement. Also, separate design approvals might be warranted at both the system and component levels. For example, the project team might need design approval from certain organizations for the entire transformer replacement and its effects on the system in which it is installed. The project team will subsequently approve the design of the actual transformer selected for the replacement project.

It is important that the project manager understand the level of approval necessary and the roles and responsibilities of the various organizations involved in the design and installation of the replacement component. Some design approvals that might be appropriate when replacing a key plant component such as a large power transformer are the following:

- Internal (within the licensee's organization) approval of design modifications
- Internal approval of the transformer manufacturer's design according to existing plant procedures (this approval should typically precede fabrication but might not be completed until after the supplier selection and the completion of their design)
- External approvals from federal, state, and local agencies
- Regulatory approvals and permits
- Transmission provider approval (if any ratings or parameters differ from those of the original equipment)

3.10 Configuration Management

Modifications to the physical plant, as well as modifications to operational set points, should be validated through the existing plant processes. Any modifications that could affect the design of the transformer should be communicated to the supplier. All related design output documents, as well as maintenance and operations procedures, should be updated to reflect the as-installed or as-built configuration.

4
DEVELOPING BID SPECIFICATIONS AND REQUESTS FOR PROPOSALS

When replacing a large power transformer, the project team is typically responsible for preparing the specification used to procure the item. This specification is initially communicated to potential suppliers in a request for proposal (that is, a bid request). When a particular manufacturer has been selected to furnish the replacement component, the specification might be revised to reiterate manufacturer- or component-specific design information and is typically communicated to the selected supplier with a purchase order.

The project team might also be responsible for preparing an installation specification, which is provided to the organization leading the construction or replacement effort. This can, in some circumstances, be the transformer manufacturer. Often the size and complexity of the replacement component and the timing of the component installation dictate the degree to which the licensee’s own maintenance organization is involved in the actual installation.

4.1 Developing the Bid Specification for the Replacement Large Power Transformer

Appendix C, Example of a Typical Bid Specification, provides an example of a procurement specification for the replacement large power transformer that was used by one utility. Appendix D, Example of a Typical Data Sheet, provides an example of a data sheet that is completed by the manufacturer for a large power transformer.

The guidance in this section should be considered when developing a bid specification to ensure that appropriate issues have been considered. Avoid developing the bid specification with a preconceived notion of one particular design or a specific manufacturer’s product. The specification should adequately communicate all necessary system design requirements and anticipated component-specific requirements and should remain broad enough to allow multiple suppliers to bid.

Note: The project team must correctly specify appropriate technical requirements of the replacement component, fully understand each supplier’s capabilities, and then ensure that the bidders understand the team’s expectations, including the expected quality of the workmanship.

4.1.1 Specifying Technical Requirements

Because the technical requirements specified are a translation of the design requirements, they can be grouped into the same categories as those described in Section 3, System and Component Design Issues—system design basis requirements and component-specific design attributes.

4.1.1.1 Specifying System Design Basis Requirements

System design basis requirements should include the following:

- System normal operating conditions
- System emergency operating conditions
- Abnormal operating conditions, as defined in IEEE C57.116, *Guide for Transformers Directly Connected to Generators*, if applicable [10]
- Unusual service conditions, as defined in IEEE C57.12.00, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, if applicable [8]
- Plant seismic requirements
- Environmental conditions
  - Highest and lowest expected temperatures
  - Typical weather patterns
  - Other issues (such as insects, airborne contaminants from plants, salt spray, trash, or wildlife contaminants)
- System and component safety classifications
- System parameters that exceed industry or code requirements
- Descriptions of all interface points and work associated with connecting interfaces
- Spatial limitations from adjacent structures
- Information regarding the existing transformer pad

4.1.1.2 Specifying Component-Specific Attributes

Component-specific design attributes should also be specified. These attributes typically include transformer performance requirements, including those that might exceed applicable industry standards or codes (such as rise limits at higher temperatures). Component-specific attributes include the following:

- Technical requirements, which can include the following:
  - A thorough description of the item.
  - Applicable industry codes and standards, including the applicable revision levels and specific sections. For large power transformers, the applicable codes and standards typically include the following:
    - American Welding Society (AWS) D1.1, Structural Welding Code [18]
    - ANSI D3487-00, Standard Specification for Mineral Insulating Oil Used In Electrical Apparatus [19]
    - ANSI Z55.1, Gray Finishes for Industrial Apparatus and Equipment [20]
    - ANSI/IEEE C2, National Electrical Safety Code [21]
    - ANSI/IEEE C37.21, Standard for Control Switchboards [22]
    - ANSI/IEEE C50.41, Polyphase Induction Motors for Power Generating Stations [23]
    - ANSI/IEEE C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers [8]
    - ANSI/IEEE C57.12.10, Transformers—230kV and Below, 8333/10417 kVA Single-Phase, and 100,000 KVA Three-Phase, Without Load Tap Changing; 100,000 kVA with Load Tap Changing Safety Requirement [24]
    - ANSI/IEEE C57.12.80, Standard Terminology for Power and Distribution Transformers [25]
    - ANSI/IEEE C57.13, IEEE Standard Requirements for Instrument Transformers [26]
    - ANSI/IEEE C57.19.00, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings [27]
    - ANSI/IEEE C57.19.01, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings [28]
    - ANSI/IEEE C57.91, IEEE Guide for Loading Mineral-Oil-Immersed Transformers [29]
    - ANSI/IEEE C57.93, Guide for Installation of Liquid-Immersed Power Transformers [30]
    - ANSI/IEEE C57.97, Guide for Preparation of Specifications for Large Power Transformers With or Without Load Tap Changing [31]
    - ANSI/IEEE C57.98, IEEE Standard Guide for Transformer Impulse Tests [32]

- ANSI/IEEE C57.100, IEEE Standard Test Procedure for Thermal Evaluation of Liquid-Immersed Distribution and Power Transformers [33]
- ANSI/IEEE C57.104, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers [34]
- ANSI/IEEE C57.106, Guide for Acceptance and Maintenance of Insulating Oil In Equipment [35]
- ANSI/IEEE C57.109, Guide for Transformer Through-Fault Current [36]
- ANSI/IEEE C57.110, Recommended Practice for Establishing Transformer Capability when Supplying Non-Sinusoidal Load Currents [37]
- ANSI/IEEE C57.116, Guide for Transformers Directly Connected to Generators [10]
- ANSI/IEEE C57.117, IEEE Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems [38]
- ANSI/IEEE C57.119, Recommended Practice for Performing Temperature Rise Tests on Oil-Immersed Power Transformers at Loads Beyond Nameplate Rating [39]
- ANSI/IEEE C57.131, IEEE Standard Requirements for Load Tap Changers [40]
- ANSI/IEEE C62.11, Standard for Metal-Oxide Surge Arresters for AC Power Circuits [41]
- ANSI/IEEE C62.22, Guide for the Application of Metal-Oxide Surge Arresters for Alternating Current Systems [42]
- IEEE 80, IEEE Guide for Safety in AC Substation Grounding [43]
- IEEE 112, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators [44]
- IEEE 519, Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems [45]
- IEEE 693, IEEE Recommended Practice for Seismic Design of Substations [9]
- IEEE 1538, IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid Filled Transformers [46]
- IEEE C57.12.90, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers [47]
- IEEE C57.140, Guide for Evaluation and Reconditioning of Liquid Immersed Power Transformers [48]
- National Electrical Manufacturers Association (NEMA) ICS1, General Standards for Industrial Controls and Systems [49]
- NEMA ICS2, General Standards for Industrial Control Devices, Controllers, and Assemblies [50]
- NEMA ICS6, Enclosures for Industrial Controls and Systems [51]
- NEMA MG1, Motors and Generators [52]

    - NEMA TR1, Transformers, Regulators and Reactors [53]
    - National Fire Protection Association (NFPA) 70, National Electrical Code [54]
    - OSHA requirements as they apply to nuclear plant personnel after the transformer is installed
  - Specifications for transformer subassemblies and components, as recommended by the EPRI report *GPPTS—Guidelines for the Preparation of Power Transformer Specifications, Version 1.0* (1011658), including the following [55]:
    - Accessories
    - Auxiliary power
    - Bushings
    - Conductor material
    - Control cabinets
    - Control wiring
    - Current transformer
    - De-energized tap changer
    - Load tap changer
    - Load tap changer control system
    - Oil preservation system
    - Safety equipment
    - Surge arresters
  - Coating specifications
  - A list of spare and replacement parts, including sufficient technical information to enable future procurement of these items

The level of detail specified in the technical description is dictated by the following parameters:

- The roles of the supplier, third parties, and the manufacturer in the equipment design
- The complexity of the replacement transformer
- The megavolt ampere rating of the transformer (larger transformers require more detail than that for smaller units)
- The connection details
- The manufacturing processes used in producing the transformer
- The bounding conditions that the transformer is required to satisfy
- The history of performance of the supplier and the utility's experience with the supplier

4.1.2 Specifying Quality Requirements

The quality requirements for a replacement large power transformer should be developed and specified in the procurement document to invoke the necessary supplier controls over manufacturing, design, and purchasing activities to ensure that the specified technical requirements are met. The specification should also delineate anticipated QA program responsibilities between the project team and various organizations in the supply chain. Quality requirements do not take the place of technical requirements. Large power transformers that are technically inadequate can be produced under an acceptable quality program, but they will remain technically inadequate for the application.

The quality requirements specified for a replacement transformer should be commensurate with the component's role in performing safety functions, complexity in design and manufacturing processes, production qualification requirements, and special processes. Specific quality requirements can be imposed to focus resources on controlling or imparting certain component-specific design attributes that are critical to its performance and reliability.

When specifying a replacement transformer's quality requirements, it is necessary to understand the supplier's use of sub-suppliers and material sources to ensure that appropriate quality requirements are passed on and specified correctly throughout the supply chain. The licensee's specific quality commitments from its QA program and UFSAR should be included as necessary to ensure compliance with regulatory requirements. Typically, the quality requirements specified in the procurement document will include the following:

- QA program requirements. In most cases, the replacement transformer will be classified as non-safety-related; therefore, each licensee should determine the appropriate level of quality controls to be specified. This might entail a commercial quality control program such as ISO 9000 or other QA practices commonly used by manufacturers of large power transformers.
- Frequency and types of supplier audits. Audits should be specified to inform potential transformer suppliers of the need for any performance-based audits in addition to those that they have already completed.
- Source verifications (including witness and hold points). Source inspections and the witnessing of in-process tests should be specified for manufacturing processes affecting design and performance attributes for which the quality cannot be confirmed by other available methods. Potential suppliers should also be made aware of the frequency of anticipated source inspections and the degree to which resident inspectors will be present during the manufacturing process (that is, the level of intrusiveness anticipated by the project team). The project team should consider the use of industry experience as a means for determining the scope and frequency of source verification activities.
- Receipt inspections. These inspections should be communicated to the supplier so that they are aware of the scope of verification activities that the project team will perform after the transformer is shipped. The primary value in communicating this type of information is to allow the supplier the opportunity to coordinate any special logistical support and resources needed to facilitate the receipt inspections.

- Other special quality requirements can include the following:
  - Performance testing (IEEE C57.12.00, Table 21, and IEEE C57.12.90 provide additional guidance on the types and scope of tests to be performed) [8, 47]
  - Access requirements for inspection, audit, and surveillance
  - Personnel qualification and certification
  - Performance of sub-supplier's inspection, audit, surveillance, and sampling according to established procedures or recognized standards
  - Special processes or cleanliness requirements

The project team should recognize that the following dynamics could have an adverse affect on an organization's quality capabilities and its ability to provide a replacement component in full compliance with the procurement specification:

- Recent changes in senior management and design team
- Introduction of new designs and manufacturing methods
- Changes within the QA organization
- Designation of a new QA manager
- Recent acquisition of the supplier by a larger organization
- Industry operating experience

4.1.3 Specifying Supplier Documentation Requirements

The required amount of supplier documentation varies depending on whether the replacement component has been classified as safety-related or non-safety-related. In general, supplier documentation is required in order to furnish objective evidence that the technical and quality requirements of items have been met. Documentation should be considered a tool in the verification of an item's technical adequacy and quality compliance, but it should not be used without confirmation of its validity [5, 11].

Supplier documentation requirements should correlate with the specified technical and quality requirements and should be specific regarding the content. Avoid requesting excessive or meaningless documents or test reports that are not applicable to the item. Certificates of conformance should not rely solely on generalized statements such as "This item meets the requirements of the purchase document." Instead, the documentation should be validated by the project team and should contain specific statements that enable the supplier to verify specified requirements. In any case, the project team should be involved in the acceptance process.

The range of supplier documentation typically includes the following (including consideration of the quantity and type of media):

- Supplier drawings, procedures, and specifications
- Supplier instruction manuals, which typically include the following information:
  - Transformer installation guidance
  - Transformer maintenance guidance
  - Instructions for vacuum testing and filling the transformer with oil
  - Recommended spare parts lists
  - Transformer operating guidance
  - Vendor technical manuals for subcomponents
  - Performance data sheets or curves (a certified test report)
- Certified factory test report
- Seismic qualification report, if applicable
- Certified or performance test reports (IEEE C57.12.90, Section 15, provides additional guidance regarding the content of typical test reports [47])
- Nondestructive test reports
- Personnel certifications and qualifications
- Inspection reports
- QA manuals
- Certificates of conformance or compliance
- Recommended spare and replacement parts lists
- Photographs of the transformer and subassemblies taken at the factory
- Frequency response analysis waveforms with detailed descriptions of the transformer configuration at the time of the tests (such as service bushings versus shipping bushings) and the means by which the analysis should be performed
- Shipping information, including the following:
  - All shipping documents
  - Contents or packing list
  - Routing
  - Destination and conditions of carrier’s agreement
  - Bill of lading
  - Impact recorder data

A submittal schedule should be specified in order to inform the supplier when each required document must be made available to the project team for review. Retention time for records should also be specified, as well as quality and legibility requirements for the records when necessary to ensure future reproduction capability.

4.1.4 Special Procurement Requirements

Other special requirements that can be specified in the bid specification can include the following:

- Design testing, including mock-ups
- Access requirements for inspection, audit, and surveillance
- Performance of sub-supplier’s inspection, audit, surveillance, and sampling according to established procedures or recognized standards
- Special processes or cleanliness requirements
- Witnessing of factory acceptance testing before release for shipment

4.2 Developing the Request for Proposal

At this stage of the project, the project team should have completed a conceptual design study and should have a basic understanding of the type of replacement transformer to be installed and the resulting system performance parameters to be achieved by replacing the existing transformer. The project team should compile known design basis and system operating parameters and communicate them to potential suppliers in a request for proposal, or what is commonly referred to as a bid spec. The project team should communicate the following information to potential bidders:

- The scope of work (for example, equipment only or equipment and installation)
- Information about the large power transformer that is being replaced, including all known relevant design and performance parameters for the existing transformer, such as the following:
  – Relevant information about the existing component
  – Component design information that currently exceeds design basis requirements so that these requirements are not inadvertently or unnecessarily interpreted as requirements for the replacement
  – Site footprint and concrete pad for the transformer and ancillary components
  – Existing external connections to the transformer
  – Terminations of the connections to the primary of the transformer
  – Terminations of the connections to the secondary of the transformer

- The bid specification for the replacement component (see Appendix C, Example of a Typical Bid Specification), including the following:
  - Technical requirements (for example, system design basis requirements, component-specific requirements, or system performance requirements that the project team wants to enhance by replacing the component)
  - Quality requirements
  - Supplier documentation requirements
- Anticipated supplier interface, including walk-down planning, pre-bid meetings, and bid submittal schedule
- Schedule for replacement
- Whether the project team wants to replace the component on-line or during an outage
- Commercial terms and conditions, including the type of bid (that is, fixed price, lump sum, or time and materials)
- Nuclear site access requirements and restrictions

4.3 Developing the Installation, Construction, and Commissioning Specification

The level of detail and scope of the installation, construction, and commissioning specification varies depending on who is responsible for installing the replacement transformer. In some cases, the project team will install the transformer, and therefore should develop the necessary work packages in accordance with existing site-specific procedures. In some cases, the transformer manufacturer will be the installer. Work done in this manner is often referred to as a design-procure-install contract or a turnkey contract. In this case, the specification provided to the manufacturer can include both refined procurement and installation requirements. In other cases, the installation and construction can be competitively bid as a separate contract and performed by someone other than the transformer manufacturer or the project team.

When replacing a large power transformer, the project team should consider the following issues for inclusion in the installation or construction specification:

- Description of organizational interfaces and roles and responsibilities among members and organizations comprising the installation team
- Requirements for the submittal of an installation plan and schedule
- Description of all interface points and work associated with connecting interfaces
- Description of design modifications necessary on adjacent or ancillary systems
- Scope of supporting or ancillary equipment needed for the replacement transformer (such as procurement responsibilities for items such as weld wire and insulation)
- IPB or nonsegregated phase bus duct field modifications

- Appropriate plan or section drawings, schematics, and flow diagrams depicting the removal of the old transformer and the installation of the replacement transformer
- Special lifting and handling requirements
- Lifting and rigging plans for both the old and new transformers
- Quality controls required during the installation of the replacement transformer
  - Witness and hold points for inspection and testing during the installation process
  - In-process testing required during installation of the replacement transformer
- Personnel safety issues
- Personnel qualification requirements for craft labor, inspectors, and riggers employed during the installation of the replacement transformer
- Pre-installation inspection requirements
- Special tools or scaffolding required to install the new component
- Codes and standards that are applicable to the work associated with installing the replacement component
- Instructions or restrictions by the manufacturer that could affect the warranty
- Nuclear security inspection requirements for site delivery
- Storage and staging requirements (such as power, air, or lighting)
- References to applicable procedures of the installation contractor
- Access routing and special considerations for moving the transformer into its designated position
- Supply of oil for initial fill in the field
- Post-installation testing requirements for verification of design performance parameters
- Performance acceptance criteria for the new transformer
- Scope of components to be demolished
- Limits of demolition (typically communicated on a drawing)
- Sequence of demolition and installation steps

Many of these installation issues are described in Section 11, Developing the Transformer Maintenance Strategy. They are listed here so that when issues are resolved between the project team and the transformer manufacturer they can be appropriately communicated in the appropriate specification document. The project team should also consider the guidance provided in ANSI/IEEE C57.93 [30].

4.4 Developing Service Specifications and Contracts

In some cases, the project team must develop specifications to procure various services in support of the component replacement and system design modifications. Service specifications should include the following general requirements:

- Scope of work
  - Type of service required
  - Applicable industry codes and standards
- Quality requirements
  - Inspection reports
  - Procedural and quality controls expected of the service supplier
  - Performance test reports
- Supplier documentation requirements, including certificates of conformance and compliance
- Labor relations and in-processing of off-site personnel
- Commercial terms and conditions (for additional guidance, see Section 5, Supplier Qualification and Selection, Bid Evaluation, and Purchasing)

5
SUPPLIER QUALIFICATION AND SELECTION, BID EVALUATION, AND PURCHASING

In general, the selection of a supplier should be based on evaluation of their capability to provide items in accordance with the requirements of the procurement documents. In most cases involving the replacement of a key component such as a large power transformer, engineering should research potential suppliers to assess their current technical and manufacturing capabilities and research the industry experience with each potential supplier's products. This research should result in a manageable number of potential bidders and should help to optimize the bid evaluation process. The project team must correctly specify appropriate technical requirements for the replacement component, fully understand each supplier's capabilities, and ensure that the bidders understand the team's expectations.

5.1 Supplier Selection and Qualification

The selection of a qualified supplier for a large power transformer is a crucial part of the transformer replacement project. Several issues that are unique to large power transformers should be taken into account before final vendor selection. Some unique considerations for large power transformers are the following:

- A limited number of suppliers exist for large power transformers (that is, GSU-type transformers).
- Many companies with the capability to provide large power transformers are based outside the United States, and the appropriate provisions should be made for doing business with these organizations.
- Manufacturing facilities have varying capabilities with respect to design tools and manufacturing processes, even between plants within the same company.
- The location of the vendor's manufacturing plant can affect the type of transportation that is required or available.
- The QA certification of the manufacturer should be considered.
- Options that can be supplied with the transformer, including maintenance contracts, auxiliary equipment, and spare parts stocking, can vary.
- The ability of the vendor to test the transformer at the factory versus shipping the transformer to an independent facility should be considered. Additional transportation of the transformer could lead to premature, undetected failures.
- Options for an extended warranty should be considered.

5.1.1 Selection of Procurement Sources

Current industry practice suggests that procurement source evaluation and selection measures typically include integrated actions involving several organizations (such as engineering, construction, manufacturing, operations, purchasing, and QA) based on the item being procured. Methods to be used in evaluation of supplier sources, and the results, should be documented and should include one or more of the following:

- Evaluating the supplier's history of providing a product that performs satisfactorily in actual use (available information can include data from the INPO equipment performance and information exchange database and operating experience database as well as industry peer feedback through working groups)
- Evaluating the supplier's capability to furnish replacement parts and repair services
- Evaluating the supplier's current quality records, supported by documented qualitative and quantitative information that can be objectively evaluated
- Evaluating the supplier facility's technical and quality capability and the implementation of the supplier's QA program

5.1.2 Supplier Qualification Status

Current industry practice suggests that the licensee is responsible for evaluating the supplier's QA program to ensure that it is appropriate and that it satisfies the requirements for the items or services being purchased. If the replacement transformer is being procured from a supplier with whom the licensee has already procured other items, the project team should verify the supplier's qualification status by reviewing the list of approved suppliers (typically maintained by the QA organization). If the replacement transformer is being procured from a new supplier, the QA organization should be advised so that an initial qualification evaluation (that is, a performance-based audit) can be performed.

This evaluation might require both a technical and commercial review to ensure that the supplier can meet the technical, quality, and financial requirements set forth in the purchase orders. For projects with expedited schedules, selecting a vendor from the approved suppliers list might minimize the qualification time of the vendor.

Large transformers such as GSUs for nuclear stations are typically procured infrequently by a utility. Therefore, when the decision is made to purchase a new transformer, most utility management teams will not choose an unknown supplier for a component that is so critical to the plant.

5.1.3 Supplier Quality Program Capabilities

The project team should ensure that the supplier has the technical capabilities to meet the specification requirements and QA programs to ensure that those capabilities are implemented consistently. Project teams should recognize that supplier QA program capabilities vary significantly among suppliers and, in reality, can vary significantly between manufacturing facilities within the same supplier organization. Furthermore, a supplier's commitment to a given QA program does not in itself ensure reliable performance of the manufactured component. Ideally, the supplier's program is capable of meeting the licensee's requirements. If it is not, the project team is responsible for addressing those shortcomings to achieve the necessary level of QA. In most cases, a lack of rigor in a supplier's QA program would exclude that supplier from the bid process and force the project team to concentrate their efforts on other suppliers with more rigorous QA programs.

The results of a supplier evaluation should be documented in a report that is made available to engineering personnel for assessment of the supplier's capabilities. The supplier evaluation is important because it serves to confirm that the supplier has the necessary technical capabilities and quality controls and that those capabilities and controls are being implemented properly.

In most cases when procuring a non-safety-related transformer for a nuclear power plant, the supplier would not be required to have a QA program that meets the intent of 10CFR50, Appendix B; however, the supplier should have an acceptable quality control program [12]. A factor that should be considered, however, is the division of QA programmatic responsibilities between the project team and various organizations in the supply chain. Appendix E, Vendor Evaluation Checklists, provides a vendor evaluation and audit checklist that one utility used for assessing the capabilities of a transformer manufacturer and a vendor weighting form that one utility used for comparing the capabilities of various suppliers.

5.1.4 Potential Large Power Transformer Suppliers

The licensee should investigate current suppliers and solicit input from other utilities, users groups, and transmission organizations replacing transformers to ascertain current supplier capabilities.

The project team should consider issuing requests for proposals for large power transformers only to qualified manufacturers. Supplier qualification is typically documented by the utility's QA organization on an approved suppliers list (also referred to as an approved vendors list or qualified suppliers list). The primary method by which a supplier can be qualified or approved by the utility is by undergoing an audit, which is typically performed by utility personnel. In some instances, certain suppliers can be audited by NUPIC as part of their qualification to provide safety-related components. If the selected supplier is audited by NUPIC, reports on their QA program should be accessible through the licensee's NUPIC coordinator. Although NUPIC does not generally cover non-safety-related vendors or activities, the overall audit of a company's QA program can give the project team confidence in the supplier's ability to manufacture the new transformer.

5.2 Bid Evaluation and Award

Each licensee should have established a documented system for reviewing and evaluating bids and awarding contracts. This established process should be used to evaluate bids for a replacement large power transformer. Figure 5-1 illustrates the general process for supplier selection and bid evaluation that is implemented by many utilities.

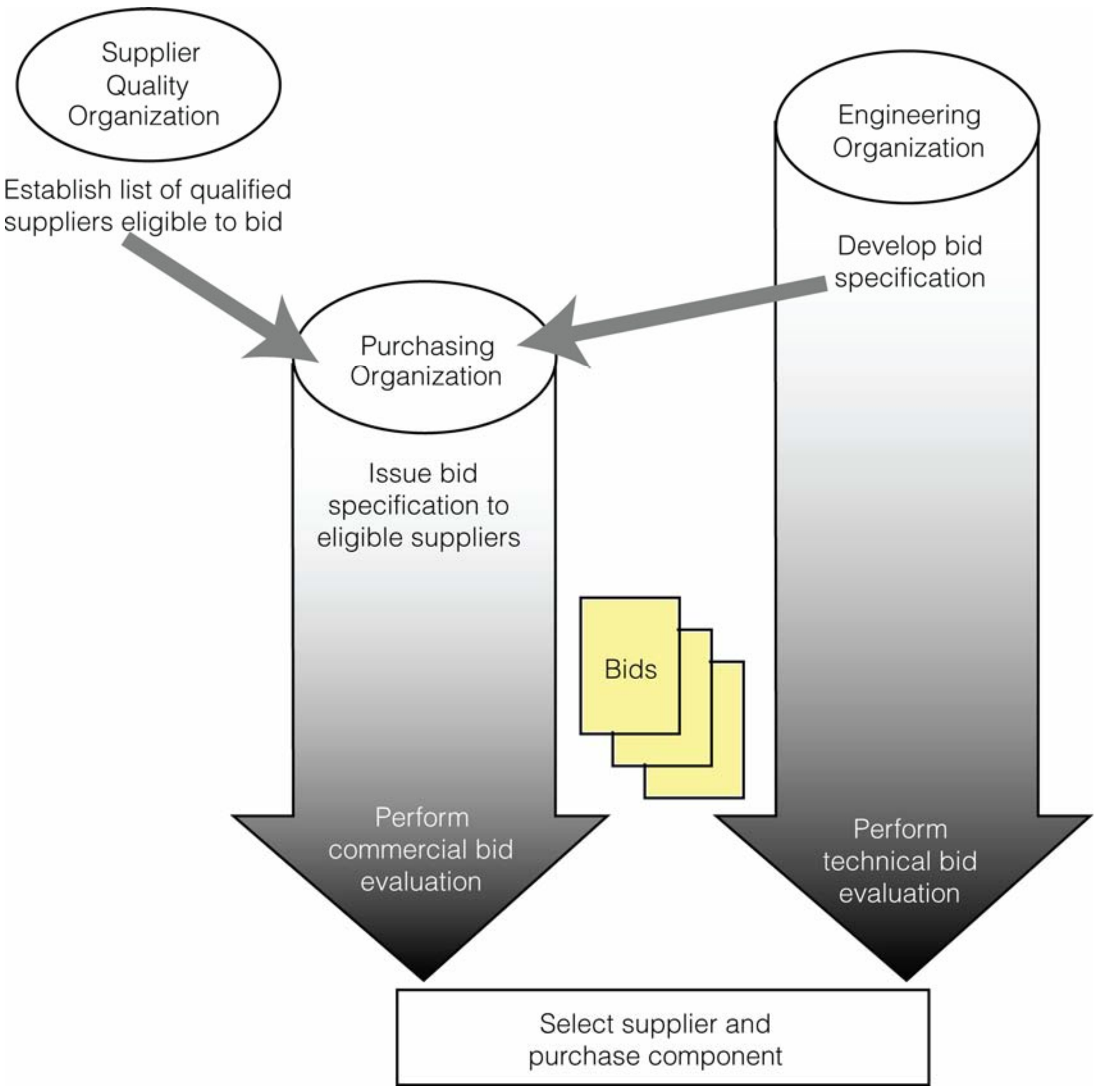


Figure 5-1
Supplier Selection and Bid Evaluation

5.2.1 General Guidance

Figure 5-1 illustrates that the licensee's QA organization is typically responsible for the initial qualification and screening of potential suppliers. After requests for proposals are issued, the bid evaluation is performed jointly by the licensee's purchasing organization and engineering organization. In most cases, the engineering organization evaluates the technical aspects of each bid, and the purchasing organization evaluates the commercial terms and price of each bid. Bids should be evaluated by individuals or organizations who are designated to evaluate the following subjects as they apply to the type of procurement and replacement component:

- Technical considerations
- QA requirements (such as supplier quality program capabilities, establishment of witness and hold points, and manufacturing surveillance)
- Supplier's personnel qualifications and skill levels (with a focus on engineering and winding personnel)
- Supplier's past performance (industry experience and references)
- Evaluation of guaranteed losses
- Alternative designs for consideration
- Evaluations of exceptions to the bid
- Schedule adherence
- Operating experience (both nuclear and nonnuclear applications)
- Ability to offer turnkey services

Other factors, although they are not quality related, that can be considered include the following:

- Equipment purchase price and price adjustments
- Supplier experience, reputation, and recognition in the nuclear industry
- Manufacturing facility location
- Ease of doing business
- Commercial terms and conditions
- Warranties
- Anticipated costs of recommended maintenance activities
- Available options
- Lead time and scheduling issues (such as backlog of orders)

Some licensees use a quality-value engineering approach to the bid selection process. A quality-value approach weights certain aspects of the bid specification more heavily than others. This weighting system helps to establish the relative importance of certain aspects of the replacement transformer and does not focus solely on cost. Modern software products allow the licensee to evaluate quantitative values (such as cost) in the bid along with qualitative values (such as QA) either from the bid or from plant observations. The overall lifecycle cost of the transformer should be considered in the quality-value approach to ensure that components with a lower initial cost do not result in significant long-term costs for the utility.

5.2.2 Obsolescence of the Replacement Component

Other issues that the project team should consider during the supplier selection and bid evaluation phase of the project are the potential for obsolescence of auxiliary components supplied with the replacement transformer and the future availability of spare parts. Auxiliary components such as coolers, fans, pumps, gas monitoring equipment, and bushings have a typical service life that is less than that of the transformer. The project team should evaluate the supplier and the technologies associated with the replacement, keeping in mind any technical issues or concerns with the large power transformer that might have caused performance degradation in the past. Select technologies and materials that are suitable for the licensee's application but not necessarily excessive for the sake of being state of the art.

5.3 Purchasing Issues and Considerations

The project team should recognize that not all issues will be presented and resolved during the bid evaluation phase and that some issues might arise after the contract has been awarded. Ideally, the project team should attempt to resolve issues as early in the process as possible. The issues presented in the following subsections are included in Section 2, Project Management and Process Overview, with respect to the overall project management responsibilities of the project team. They are reiterated here to emphasize the importance of resolving them before fabrication begins.

5.3.1 Licensee Schedule Demands

One of the first nontechnical issues that should typically be addressed as early in the procurement process as possible is the schedule for design, manufacturing, testing, shipping, and receiving the replacement transformer. All licensees have a process for planning and scheduling work activities in the plant, but the process for a large power transformer replacement is often much more involved and extensive than that for planning and scheduling routine maintenance activities. In most cases, the installation of a large power transformer occurs during a plant refueling outage. The scheduling constraints involved with ensuring that materials are available for installation during the outage should also be considered when addressing planned shipping and receiving dates for the transformer. However, if a transformer will be delivered to the site significantly ahead of the planned outage, temporary modifications will be necessary to ensure that the transformer is maintained properly until it is installed (for example, energizing the transformer control cabinet heaters and satisfying other requirements as directed by the supplier).

5.3.2 Manufacturing Lead Times

Another major issue that affects the selection of a supplier and the procurement of a replacement large power transformer is the manufacturing lead time. In all cases, the transformer is a custom-made component that is unique for each owner's or licensee's specific application. The selected supplier must manufacture the component so that it is suitable for the particular application and so that it meets all of the requirements in the design and procurement specifications.

Long lead times for large transformers are typical. At the time this report was published, lead times of up to 24 months after award of contract were required to manufacture and deliver a large power transformer, and lead times for such equipment are likely to change based on market conditions. Manufacturing lead times can vary due to influences beyond the control of either the manufacturer or the owner. Premiums might have to be paid to expedite the delivery of the replacement transformer. In some cases, expedited delivery might not even be possible from a specific vendor. Lead times often vary as a result of the following factors:

- Availability of accessories such as bushings and surge arresters
- Availability of raw materials
- Market demands
- Utility-unique design features and verification activities

Before the bid phase and during the initial qualification of the primary supplier (and possibly sub-suppliers), the project team should consider investigating the supplier's ability to manufacturer and deliver the replacement large power transformer. Guaranteed lead times should be negotiated as part of the commercial terms. After a supplier has been selected and a purchase order is being placed, the project team should only need to confirm lead times with the supplier to ensure that the transformer can be delivered to meet the demands of the site.

5.3.3 Commercial Terms and Conditions

Negotiating commercial terms and conditions is typically not within the scope of engineering organizations. The purchasing organization should take the lead role in resolving these types of issues. Special commercial considerations can include the following:

- Delivery, title, and risk of loss
- Indemnity
- Limitations of liability
- Performance incentives
- Quantified level of oversight by the project team
- Resolution of nonconformances and arbitration process
- State laws
- Transfer of responsibility during shipment, receipt, storage, staging, and installation. Factors that affect the transfer of responsibility and the timing of such transfers include the following:
  - Insurance requirements
  - Contractual obligations and stipulations
  - Security issues
  - Vendor and site capabilities

  - Installation schedule
  - Testing
  - Management direction
- Transfer, shipping, and routing of the transformer
- Type of contract, payment terms, and invoicing
- Type, schedule, and frequency of document reviews
- Warranty limitations

5.3.4 Procurement Document Preparation, Review, and Change Control

The procurement package should be finalized when the bid evaluation and qualification and selection of the supplier of the replacement transformer are completed. When a supplier has been selected and the supplier has offered a suitable replacement transformer, the detailed procurement documents can be completed. Typically, the procurement documents include the following:

- Bid specification
- Supplier's original proposal
- Exceptions that the licensee and supplier have agreed on
- Terms and conditions
- Purchase order

After the supplier has been selected by virtue of bid evaluation, the licensee's engineering organization should assemble the procurement package. The package should clearly communicate the necessary technical, quality, and commercial requirements commensurate with the system and large power transformer design requirements and the supplier's capabilities to meet them. In most cases, the licensee's existing processes and procedures should be used to prepare, review, and control changes to the procurement documents required for the replacement component.

5.4 Handling Exceptions to the Bid Specification

In most cases for large power transformers, the purchase order should be awarded to a manufacturer through competitive bids.

5.4.1 Technical Exceptions

The licensee's engineering organizations should take the lead in resolving technical exceptions to the bid specification. In some cases, input from maintenance and operations can be helpful in resolving a technical exception and reaching a feasible solution to the issue. In no circumstances should a purchasing agent or nontechnical personnel attempt to resolve a technical exception to the specification. Instead, the issue should be directed to the appropriate engineering organization.

Although the project team should strive to prevent exceptions to specified requirements through good planning and supplier selection techniques, in most cases the licensee's existing process for resolving purchasing issues should be used as needed. Technical exceptions that can arise during the specification and procurement of a large power transformer can include the manufacturer's inability to meet the following requirements:

- Ability to furnish spare and replacement part information
- Lifting and handling practices for the transformer (such as lifting lugs or holes)
- Means of design verification
- Means of seismic qualification, if required
- Shelf life limitations of applicable replacement parts
- Shipping and packaging practices
- Special manufacturing or fabrication processes
- Storage and staging practices used to prevent degradation
- Testing capabilities or requirements
- Transformer performance requirements
- Transformer technical requirements
  - Requirements described in industry codes and standards
  - Dimensional requirements including tolerances

The manufacturer should clearly delineate any technical exceptions to the specification in writing, referencing the applicable requirement and providing the basis for the exception.

5.4.2 Commercial Exceptions

The licensee's supply chain organization should take the lead in resolving commercial exceptions. In some cases, input from engineering, QA, maintenance, and operations can be helpful in resolving a commercial exception and reaching a feasible solution to the issue.

The project team should strive to prevent exceptions to purchase order requirements through good planning and supplier selection techniques, and the licensee's existing process for resolving purchasing issues should be used as needed. Commercial exceptions that can arise during the specification and procurement of a major plant component can include the manufacturer's inability to meet any of the requirements listed in Section 5.3.3, Commercial Terms and Conditions.

5.5 Acceptance Planning

Ideally, planning of verification (acceptance) activities should begin during the specification and procurement of the replacement transformer. This affords the project team an opportunity to plan the types of verifications and their schedules with the selected manufacturer and third-party organizations in advance of the final design and fabrication. After the supplier and final transformer design have been selected, however, the project team should finalize the scope and frequency of acceptance activities, including the following:

- Additional or ongoing audits of organizations in the supply chain. These audits are in addition to the initial qualification audit conducted at the transformer manufacturer's facility. They can include audits of the primary manufacturer's sub-suppliers or suppliers of raw materials.
- Source verification activities. These activities can include witnessing in-process testing, inspections, or manufacturing processes of the transformer or its subcomponents at various stages of the manufacturing and assembly process. Licensees commonly refer to these verifications as witness and hold points.
- Receipt test and inspection activities. These activities can include conducting various tests or inspections of the transformer after it has been completely manufactured, assembled, and delivered to the licensee's location. Receipt tests and inspections can be performed by the licensee's own personnel or by others, if necessary.
- Post-installation tests and inspections. These activities can include conducting various performance tests or inspections of the transformer after it is installed. Post-installation tests can be conducted to verify certain performance attributes of the transformer before placing it in service.

The project team should establish the methods of acceptance of the transformer being furnished by the supplier. Before offering the transformer for acceptance, the supplier should verify that it fully complies with the procurement requirements. If required by code, regulation, or the contract, documentary evidence that items conform to procurement documents should be available at the power plant site before the items are installed or used, regardless of acceptance methods.

When replacing a major plant component such as a large power transformer, it is recommended that all the acceptance activities in this section be used to some extent because of the typical complexity and importance of the item. Of these methods, any of which can be chosen by the project team, source verification involves acceptance during the fabrication of the replacement item and is described in more detail in Section 6, Manufacturing Issues.

The project team should retain responsibility for monitoring and evaluating supplier performance to the specified requirements of the procurement document. The methods provided can include the following:

- Establishing an understanding between the project team and the supplier of the provisions and specifications of the procurement documents
- Requiring the supplier to identify planning techniques and processes to be used in fulfilling procurement document requirements
- Reviewing documents that are generated or processed during activities fulfilling procurement requirements
- Identifying and processing necessary change information
- Establishing a method for exchanging information contained in the procurement document between the project team and the supplier

Depending on the complexity and scope of the replacement transformer, the project team might initiate both pre-award and post-award activities. These activities can take the form of meetings or other forms of communication to establish the following:

- An understanding between the project team and the supplier of the procurement requirements
- The intent of the project team in monitoring and evaluating the supplier's performance
- The planning, manufacturing techniques, tests, inspections, and processes to be used by the supplier in meeting the procurement requirements.

Project team notification points, including witness and hold points, should be identified and documented based on mutual agreement between the manufacturers and the project team. These activities should be implemented as early as practicable in the procurement process. The depth and necessity of pre-award and post-award activities depend on the uniqueness, complexity, procurement frequency with the same supplier, and past supplier performance for the specific transformer covered by the procurement document.

5.6 Validity of Supplier Documentation and Certificates

5.6.1 Supplier Certification

After a supplier's QA program capabilities and implementation have been evaluated and found to be acceptable and contractual terms have been established, the project team might request certification from that supplier as objective evidence that the specified quality controls were implemented and that purchase requirements have been met. Section 4, Developing Bid Specifications and Requests for Proposals, describes the types of quality requirements that might be specified for a replacement component and the types of documentation that are typically furnished by the manufacturer or supplier.

When it is not precluded by other requirements, documentary evidence can take the form of written certificates of conformance that identify the requirements met by the items. When certificates of conformance are used, the following minimum criteria should be met:

- The certificate should identify the purchased material or equipment, such as by the purchase order number.
- The certificate should identify the specific procurement requirements met by the purchased material or equipment, such as codes, standards, and other specifications. This can be accomplished by including a list of the specific requirements or by providing, on-site, a copy of the purchase order and the procurement specifications or drawings, together with a suitable certificate. The procurement requirements identified should include any approved changes, waivers, or deviations applicable to the subject material or equipment.
- The certificate should identify any procurement requirements that have not been met, together with an explanation and the means for resolving the nonconformances.
- A person who is responsible for the QA function and position, as described in the purchaser's or supplier's QA program, should attest to the certificate.
- The purchaser's or supplier's QA program should describe the certification system, including the procedures to be followed in filling out a certificate and the administrative procedures for review and approval of the certificates.
- The supplier should provide a means to verify the validity of supplier certificates and the effectiveness of the certification system, such as during the performance of audits of the supplier or independent inspection or test of the items. Such verifications should be conducted by the purchaser at intervals commensurate with the supplier's past quality performance.

Receipt of supplier documentation, in general, and a certificate of conformance, in particular, should be an integral part of the acceptance plan for the replacement transformer. However, acceptance of a major plant component such as a large power transformer based solely on the receipt of supplier documentation is not recommended. Instead, the project team should consider using all the verification activities included in Section 5.5, Acceptance Planning, to ensure that the transformer conforms to its design requirements and will perform all its design functions. These acceptance methods should be considered initially during the development of the specification, during the bid evaluation, and continuing throughout fabrication, receipt, and installation.

5.6.2 Supplier Documentation

The project team's engineering personnel should work closely with the supplier to ensure that the design is suitable for the transformer's intended application. Design interface should result in a qualified and suitable final transformer design, and the supplier should be required to furnish the documents necessary to demonstrate the suitability of the design, as well as supporting information regarding its installation, operation and maintenance. These documents, which constitute design outputs from the supplier and inputs to the licensee's design modification process, are typically identified in the final procurement specification and can include the following:

- Supplier drawings, procedures, and specifications
- Supplier instruction manuals, which typically include the following information:
  - Transformer installation guidance
  - Transformer maintenance guidance
  - Instructions for vacuum testing and filling the transformer with oil
  - Recommended spare parts lists
  - Transformer operating guidance
  - Vendor technical manuals for subcomponents
  - Performance data sheets or curves (a certified test report)
- Certified factory test report
- Seismic qualification report, if applicable
- Certified or performance test reports (IEEE C57.12.90, Section 15, provides additional guidance regarding the content of typical test reports [47])
- Nondestructive test reports
- Personnel certifications and qualifications
- Inspection reports
- QA manuals
- Certificates of conformance or compliance
- Recommended spare and replacement parts lists
- Photographs of the transformer and subassemblies taken at the factory
- Frequency response analysis waveforms with detailed descriptions of the transformer configuration at the time of the tests (such as service bushings versus shipping bushings) and the means by which the analysis should be performed
- Shipping information, including the following:
  - All shipping documents
  - Contents or packing list
  - Routing
  - Destination and conditions of carrier's agreement
  - Bill of lading
  - Impact recorder data

6
MANUFACTURING ISSUES

6.1 Establishing Witness and Hold Points

Manufacturing hold points ensure that the project team has an opportunity to witness and verify the conformance of the replacement component to its design requirements as the component is being manufactured, fabricated, and assembled. Although hold points might have been included in the bid specification and considered during the bid evaluation, they should be revisited after the supplier has been selected but still before the start of fabrication. The project team should then finalize the scope of oversight activities and ensure that appropriate individuals are designated and authorized to approve the activities witnessed during hold points in the fabrication process.

Witness and hold points should be established to ensure the project team has an opportunity to witness and verify the conformity of the replacement transformer to its design requirements as the transformer is being manufactured, fabricated and assembled. Witness and hold points communicate to the manufacturer 1) the attributes of the transformer that must be verified before fabrication resumes and 2) the point in the manufacturing process at which those critical attributes can be verified most effectively.

After the witness and hold points are determined and the critical attributes to be verified are identified, the project team and the supplier should coordinate how best to verify the conformity of the product. This can involve witnessing a test, inspection, or special manufacturing process or examining selected programmatic quality controls.

6.2 Manufacturing Surveillance

Manufacturing surveillance is typically a vital step in ensuring the quality of the replacement component; therefore, appropriate resources should be allocated as necessary. When acceptance planning requires licensee source verification, it should be implemented to monitor, witness, or observe manufacturing at the organization in the supply chain that is most appropriate to evaluate the activities. Source surveillance might require the assignment of personnel to a supplier’s facility.

Manufacturing surveillance is a type of source verification that affords the project team an opportunity to observe a special process that renders or imparts a critical attribute to the replacement transformer. The level of manufacturing surveillance should be based on the following factors:

- Uniqueness of the component. Unique and highly specialized components typically require more surveillance to ensure that the unique design features conform with the established, qualified design.
- Supplier capabilities and certification. Adequate supplier certification and capabilities can negate the need for additional surveillance by the project team. Conversely, if the supplier's capabilities are lacking, the project team should consider increased surveillance activities to ensure that the component conforms to its design requirements.
- Utility's participation. The project team has the option to use contract employees to perform this activity if it is cost beneficial.
- Safety significance and criticality, functions, and reliability of the replacement component.

6.3 Potential Component-Specific Issues

The project team should coordinate with the supplier to identify any component-specific design features that might warrant manufacturing surveillance. These design features might not be identified in industry codes or standards; therefore, the project team must require the supplier to provide access so that verifications can occur during manufacturing surveillance. Typical customer oversight activities of a large power transformer can include the following:

- Pre-inspection meeting
- Documentation review and approval necessary for fabrication activities (for example, drawings, calculations, inspection and test plans, and procedures)
- Witness tests and inspections during manufacturing and assembly (see Section 6.4, Witnessing Tests and Inspections)
- Witness factory performance tests and pre-shipping inspections (see Section 6.4, Witnessing Tests and Inspections)
- Review of inspection documents (for example, test certificates)

6.4 Witnessing Tests and Inspections

Similar to manufacturing surveillance, source inspection should be implemented in accordance with plans to perform inspections, examinations, or tests at predetermined points. Source inspection might require the assignment of personnel to a supplier's facility. The most common points during the manufacturing of a large power transformer that warrant source verification are the following:

- Inspection of the completed coils before they are assembled
- Core inspections, including cutting and stacking
- Complete core and coil assembly inspection before drying, including cleats and leads
- Pre-tank inspection (inspection of the core coil assembly before installing it in the transformer tank)
- Factory performance testing and pre-shipping inspection

Appendix F, Manufacturing Surveillance Activities and Examples, provides an example of a list that one utility used for conducting tests and inspections at the factory as the transformer was being manufactured. The licensee's list of source verification activities should be consistent with those specified in the final procurement document. See Section 10.9, Post-Installation Testing, regarding the scope of post-installation testing.

6.4.1 Establishing Acceptance Criteria

Before witnessing the test or inspection, the project team should coordinate with the transformer manufacturer to establish the acceptance criteria for the activity. The test or inspection should verify that the manufactured transformer or part thereof is in fact conforming to its required design values. Examples include the following:

- Material properties according to the applicable supplier requirements
- Calibration of test equipment according to National Institute of Standards and Technology (NIST) guidelines
- Special packing requirements according to ANSI requirements

Acceptance criteria for the tests associated with large power transformers can be found in IEEE C57.12.90 [47].

6.4.2 Nondestructive Examination

Each manufacturer performs various nondestructive examinations during the assembly or fabrication of large power transformers. The licensee should determine whether these examinations should be witnessed as part of their acceptance plan.

6.4.3 Shop Testing and In-Process Testing and Inspection

In many cases with the design and fabrication of a large, complex component such as a large power transformer, the manufacturer performs numerous in-process tests as the transformer is being assembled. In most cases, these tests and inspections are performed at the manufacturer's facility; therefore, these types of verification activities are often called shop testing. The in-process test or inspection is a means for the manufacturer to verify the acceptability of certain attributes of the transformer that might otherwise be difficult or costly to verify after the entire component is assembled. Tests or inspections can also be performed to verify the acceptability and operability of a discrete assembly or subcomponent before it is installed in the transformer. Depending on the function of the discrete assembly or subcomponent and its significance to the overall performance of the transformer, the project team should establish means to verify some or all of these activities before or during installation of the subcomponent. Each manufacturer's QA program should delineate the list of in-process testing performed. Examples of in-process testing and inspections that can be performed on a replacement large power transformer include the following:

- Preliminary ratio testing
- Core insulation resistance test
- Visual inspection to verify dimensional conformance to the licensee's specific outline drawing

An example of a list of manufacturing tests and inspections witnessed by one utility is provided in Appendix F, Manufacturing Surveillance Activities and Examples.

6.4.4 Final Product Testing and Inspection

Final product testing might be required by either the project team or an industry code or standard as a means to ensure that the transformer performance meets established design requirements before it is released for shipment. The final procurement specification should clearly specify the type of tests and applicable codes and standards by which each test will be conducted.

Table 21 of IEEE C57.12.00 provides a basis for establishing appropriate final product testing for large power transformers [8]. Appendix G, Example of Final Product Tests, provides a list of tests that were conducted and witnessed by one utility before releasing the new transformer for shipment.

6.5 Handling Manufacturing Nonconformances

The project team and the supplier should establish and document measures for the identification, control, and disposition of items that do not meet procurement document requirements. The requirements for handling nonconformances are not limited to nonconformances discovered after receipt of the item; they apply for any nonconformances discovered during the manufacture of the transformer, as well.

The project team should establish the most appropriate process or procedure for handling nonconformances discovered with the replacement transformer as part of the commercial terms and conditions of the procurement specification. Nonconforming items should typically not be released for shipment with expectations that the item will be corrected after its receipt on site.

Nonconformances should be handled using a graded approach in which the project team is involved in resolving only those nonconformances that reach the threshold, as determined in the final procurement specification. However, the project team should be made aware of and should monitor all nonconformances that arise during fabrication. Manufacturing nonconformances should typically be addressed in accordance with the following sequence of actions:

1. Supplier notifies the project team of the nonconformance (if it occurs without the licensee present).
2. Supplier and project team review the type and extent of the nonconformance.
3. Project team accepts the disposition of the nonconformance.
4. Project team verifies that the nonconformance was dispositioned properly.
5. Project team maintains records as appropriate.

6.6 Obtaining Required Documentation

The project team should specify the types of documentation required in order to ensure that technical and quality requirements have been met by the manufacturer and other organizations in the supply chain, as applicable (see Section 4, Developing Bid Specifications and Requests for Proposals). Documentation should be considered a tool in the verification of an item's technical adequacy and quality compliance, but it should not be used without confirmation of its validity.

The types of supplier documentation typically specified should include, as applicable, the following:

- Supplier drawings, procedures, and specifications
- Supplier instruction manuals, which typically include the following information:
  - Transformer installation guidance
  - Transformer maintenance guidance
  - Instructions for vacuum testing and filling the transformer with oil
  - Recommended spare parts lists
  - Transformer operating guidance
  - Vendor technical manuals for subcomponents
  - Performance data sheets or curves (a certified test report)
- Certified factory test report
- Seismic qualification report, if applicable

- Certified or performance test reports (IEEE C57.12.90, Section 15, provides additional guidance regarding the content of typical test reports [47])
- Nondestructive test reports
- Personnel certifications and qualifications
- Inspection reports
- QA manuals
- Certificates of conformance or compliance
- Recommended spare and replacement parts lists
- Photographs of the transformer and subassemblies taken at the factory
- Frequency response analysis waveforms with detailed descriptions of the transformer configuration at the time of the tests (such as service bushings versus shipping bushings) and the means by which the analysis should be performed
- Shipping information, including the following:
  - All shipping documents
  - Contents or packing list
  - Routing
  - Destination and conditions of carrier’s agreement
  - Bill of lading
  - Impact recorder data

Receipt of the documentation can take place during fabrication, during final product testing, or during receipt of the complete replacement transformer. In some cases, documentation specific to a particular assembly or subcomponent can be received separately, based on requirements specified in the design or procurement specification.

6.7 Cleanliness Requirements and Special Controls

Typically, the cleanliness of the manufacturing facility is an inspection attribute that is examined during the initial audit of the facility. At that time, the licensee should verify processes for ensuring oil purity, tank cleanliness, foreign material exclusion, and vapor-phase moisture removal, as a minimum. Cleanliness requirements should be consistent with the specifications provided.

If special processes have been specified and are necessary to impart, render, or control critical attributes of the replacement transformer, the project team should ensure that the appropriate and correlating special quality controls are in place to ensure that those processes have been implemented properly. If there are special quality controls, the licensee’s QA organization should typically be responsible for ensuring that those activities are implemented by the component manufacturer or other organization in the supply chain, as applicable.

7 SHIPPING AND HANDLING ISSUES

For most utilities, purchasing a 300- to 400-ton transformer is not a common occurrence, and in most cases it will have been a long time since a large GSU has been transported to a generating station. For this reason, considerable effort should be expended during the negotiations phase to address risks and title transfer. Consideration should be given to requiring that transfer of the title take place on the transformer pad at the power plant because, in most cases, the manufacturer is better equipped to coordinate shipping issues as they arise. The project team should remain involved with the supplier in reviewing the process and ensuring that the issues identified in this report receive due consideration.

Because the transport of large transformers is not commonplace, the on-site rail lines that were used for delivery of the initial transformer and other heavy equipment might not have been adequately maintained and might require replacement or repairs before a heavy load can traverse them. Coordination of these repairs should be factored into the delivery schedule to prevent delivery delays and budget impacts.

The items for determining the transportation route listed in Section 7.2.1, Route Inspections and Verification of Transportation Route, should receive attention and evaluation at the beginning of the bidding proposal process. Inadequate preparation and negotiation of the contract with the vendor on these issues could result in schedule delays and budget shortfalls.

7.1 Determining the Optimum Shipping Method

When replacing a large power transformer, the method or methods of shipping the transformer from the point of manufacture to the site should be evaluated and determined before the item is manufactured because the design might be affected by shipping and handling constraints. The following key issues should be considered:

- The extent to which the transformer is assembled before arrival on site. In most cases, the transformer accessories will be shipped separately.
- Cost and schedule constraints.
- The size, weight, and overall configuration of the replacement transformer (large size might prohibit the use of some means of transportation).
- Shipping method (such as truck, rail, ship, aircraft, or barge).

- Transformer's susceptibility to damage during shipment, including physical damage from dropping, bumping, or severe vibration and moisture intrusion into the windings
- Manufacturer's packaging of the transformer

In general, the mode of transportation used should be consistent with the protection classification of the item and with the packaging methods used. When power transformers are transported from an initial location (such as a transformer factory, repair facility, storage facility, or existing substation) to a new destination, various methods can be used to accomplish the transport. Some methods include shipment by ocean vessel, barge, railroad, heavy-duty trailer transport, or heavy haul transporter. Depending on the shipping weight and dimensions of the transformer, it might be most convenient and cost-effective to transport the transformer by road or highway on a suitably equipped, heavy-duty tractor trailer. Often, however, the most effective and economical method of transporting a large transformer is to move the transformer between inland locations by railroad because of the extreme weight (often up to several hundred tons) and shipping dimensions of the transformer. The project team should conduct a detailed study to verify which transportation method is most suitable as early in the procurement process as practical.

When larger transformers are shipped, frequently a heavy haul transport method is used for at least some portion of the move to the final destination. Heavy haul transport is the transportation mode in which large pieces such as transformers are loaded onto a specialized transport system consisting of a multi-wheeled heavy-duty trailer containing several axle groups and are usually transported over the road, or in some instances off road. Some situations that might require heavy haul transport are the following:

- Suitable rail access is not available at the initial location or the final destination of the transformer.
- The transformer's shipping dimensions and weight are too large for existing rail lines that serve the initial location or the final destination of the transformer. Allowable rail clearance dimensions and weights vary widely depending on the actual location and condition of the route that the transformer will travel. Rail clearance dimensions must be verified and checked with the proper parties in order to determine when rail is feasible and when other methods of transport must be considered.
- A transformer is moved a relatively short distance, and rail shipment access is unavailable or impractical (for example, when a transformer is moved between two locations in the same area or from a nearby substation, switchyard, or power plant).

Great care, research, and planning are needed to determine the most suitable method, or combination of methods, of transporting the transformer. When shipping weight and transportation regulations permit, the transformer (filled with insulating liquid) can be shipped by truck. For larger units shipped by rail, the insulating liquid is shipped separately, and the transformer is filled with dry air. Dry nitrogen can also be used, but it must be removed and purged with proper procedures before personnel enter the unit. Internal gas pressure during shipment should be high enough to ensure that it will remain positive during any expected low temperatures in transit, especially during mountain crossings. Long-distance or long-duration shipments of transformers might require external gas bottles and regulator controls to ensure that positive pressure is maintained throughout the shipment. Transformers that are filled with dry nitrogen for shipping should be labeled with external caution notices affixed to the tank indicating how such a unit should be handled and that vacuuming might be needed to remove all the nitrogen.

When the shipping weight and transportation regulation permit it, the transformer can be shipped with oil. Typically, for larger transformers the insulating oil is shipped separately, and the transformer is filled with dry air under pressure to prevent ingress of moisture. Radiators, coolers, bushings, fans, pumps, and control cabinets can also be shipped separately. The transformer is then reassembled and filled with oil on site after it is in place on the mounting pad. Some manufacturers might substitute nitrogen for dry air. When nitrogen is used, precautions must be taken to purge the transformer with dry air to accommodate personnel entry, and the dry air must be maintained at a positive pressure.

7.1.1 Shipping FOB Factory Versus FOB Destination

Power transformers that are shipped free on board (FOB) factory become the purchaser's property as soon as they leave the factory and are accepted by the carrier. The purchaser is responsible for transit damage and also for obtaining proof that damage occurred in transit. The purchaser must initiate filing of the necessary claim forms and obtain proof that any damage occurred as a result of shipment. The manufacturer can assist the purchaser in this effort.

Power transformers that are shipped FOB destination are owned by the manufacturer during shipment and become the purchaser's property when they are accepted at the destination. The manufacturer is responsible for transit damage and also for obtaining proof that damage occurred in transit. The manufacturer must initiate filing of the necessary claim forms and obtain proof that any damage occurred as a result of shipment. The purchaser can assist the manufacturer in this effort.

Consideration should be given to transferring the title when the transformer is placed on the pad because, in most cases, the manufacturer is better equipped to coordinate shipping issues as they arise. The terminology describing various shipping means and title transfer are standardized by the International Chamber of Commerce (ICC). These terms are known as Incoterms (short for International Commercial Terms), and they are recognized as the standard trade definitions most commonly used in international sales contracts. The ICC introduced the first version of Incoterms in 1936. Since then, ICC has updated those terms six times to keep pace with the development of international trade. The project team should coordinate closely with the purchasing organization to ensure that title transfer is clearly specified and that appropriate terminology is used in the specification.

7.1.2 Barges and Ocean Vessels

Shipment of transformers over water can be accomplished by storing the transformer in the hold of a ship or on barges. The licensee and shipper should ensure that the shipment can sustain a 30° list. Usually, the accessories such as bushings, radiators, pumps, and fans are shipped separately (but typically on the same vessel) in containers.

Water shipments can expose the transformer’s exterior to excessive moisture; therefore, liberal use of desiccant in control boxes, current transformer compartments, and so on, is strongly recommended. In addition, it is prudent practice to cover and seal off exposed instruments, dial gauges, and so on, to prevent the ingress of moisture, seawater, or both.

If ocean transportation is used, the manufacturer or its representative should accompany the equipment during loading onto the ship and inspect the blocking and bracing to ensure that the equipment is properly secured before shipping. The manufacturer or its representative should also inspect the equipment before it is unloaded from the ship to determine whether any damage occurred during transport on the ship.

7.1.3 Rail Transport

Usually only the larger power transformers are shipped by rail and classified as dimensional freight. The accessories or parts are generally removed for transport and shipped on flat deck cars on the same train. Alternatively, they can be shipped by truck.

If the transformer is to be shipped a long distance, it is likely that two or more railways will be involved, and each can have different requirements and guidelines. Approval from each of the railways is required. The rail route that the shipment will follow must be thoroughly cleared with the accepting carrier for both weight and dimensional clearances. Railroad carriers will not guarantee a routing clearance for an extended period of time. Shipment of an extraordinarily large transformer might require confirmation of dimensional clearances and the use of a specific railcar to permit its transportation. Shipment on other railcars must be confirmed for each individual shipment.

To transport dimensional freight by rail, the shipper must provide the railways with a shipping drawing or diagram, which assists the railway in determining the type of railcar to be used and the route the railcar will take to the destination. The shipping drawing or diagram specifies the profile that a transformer must have in order to allow transport through tunnels and under bridges and overpasses and to avoid damaging switches along the rail track. A specific railcar that is lowered a certain amount when loaded with the transformer and additional blocking underneath the unit might be required in order to fit into the envelope.

The railways or transportation consultants should verify the shortest and safest route from origin to destination. This will also provide the lowest cost of transport. Large railway yards should be avoided whenever possible in order to reduce the risk of damage as a result of switching and shunting of railcar loads.

Speed restrictions might be necessary on certain parts of the route. Despite its huge weight, a transformer can rise up on the railcar at high speeds and cause damage when the clearance between the top of the transformer and a bridge, tunnel, or overpass is tight. The transformer also rocks sideways more at higher speeds than at lower speeds. If the transformer is wider than the railcar, and the train passes other trains where the two tracks are close together, the transformer can rock from side to side and contact adjacent cars, resulting in extensive damage to both the transformer and railcars. This is particularly a problem in areas where the train that is hauling the transformer must increase speed to go up a small rise or a hill; trains coming the other way might have to be halted to avoid potential damage as a result of the rocking transformer.

For very heavy transformers, the discontinuous rail system can cause a significant number of small (1–3 g) bumps in the Z axis (vertical direction) that result in transformer damage even though each bump is within the design limits of the transformer manufacturer. Loading a heavier railcar in front of and behind the transformer railcar can minimize the impact of these bumps.

7.1.3.1 Transformer Design and Preclearance with Railways

The physical dimensions and weight of a transformer determine the type of railcar and the railway route that the transformer will travel. Large power transformers are usually shipped without oil to reduce weight, and they are filled with dry air or nitrogen to keep the unit dry. Accessories such as bushings, control cabinets, coolers, and other such items are removed for shipment.

To eliminate possible delays in loading and shipping transformers, accurate dimensions and weight must be provided to the railways well in advance of transporting to ensure that the proper type of railcar is available for planned loading. Accurate information should include shipping drawings or diagrams of the transformer with shipping dimensions, weight, and centers of gravity. Based on this information, the railways will provide the shipper with a pre-clearance. If more than one railway is involved between origin and destination, each railway might require a copy of the pre-clearance to verify transport on their rail lines. The pre-clearance will be used by the railways to inspect and verify dimensions for final release after the transformer is loaded on the railcar for transport.

Detailed instructions for securing a transformer to an open-top railcar can be obtained from the railroad. The originating railroad will inspect the loaded car to verify that it complies with appropriate rules and regulations on loading of railcars, including blocking and tie-down. Oversized loads will be measured by the originating railroad at this time and will be reported to all carriers involved in the route. Oversized loads are also measured at each carrier interchange.

Two design options should be considered to allow for rail or truck shipment of tanks that are otherwise too tall: a design that includes a removable top section and shipping cover, or a design that enables the transformer to be laid down for shipment.

Some manufacturers design a large transformer's tank with a flanged joint near the tank top. The top section of tank is bolted or welded onto this flange for assembly, processing, and testing in the factory. Removing the top section for shipping provides a shipping height that is only marginally higher than the active part within. A special shipping cover is bolted or welded to the flange to allow for a dry, pressurized shipment to the destination. Final installation of the transformer includes removal of the shipping cover and installation of the top tank section, which is of sufficient height and design for installation of bushings and other ancillary components for service. It is advisable to store the shipping cover for possible future use in shipping the transformer back to the factory or to another location.

For tall, narrow transformer tanks (primarily single-phase units), manufacturers can design the tank and internal bracing to allow the transformer to be laid down for loading onto the chosen railcar, effectively converting height into length. When it arrives at its shipping destination, the transformer is moved upright for installation. Some transformers are provided with special steel cradles to upright the equipment at the site. In such cases, it is advisable to store the cradle for possible future use in shipping the transformer back to the factory or to another location. If special external or internal shipping members are used for the laydown position support, they should also be retained.

7.1.3.2 Types of Railcars Suitable for Transporting Transformers

Depending on the dimensions and weight of a particular transformer, various types of railcars can be used. Some railcar options are the following:

- Flatcar. If the transformer’s weight and dimensions permit it, a simple flatcar of appropriate weight capacity is generally the least expensive and most readily available option.
- Depressed-center car. To allow for a transformer’s large shipping height, the transformer can be loaded (either upright or laid down, depending on the design) onto a depressed-center car to comply with overall shipping restrictions.
- Side-rail car. Some transformers are designed for support during shipment by a heavy steel rail along each side and extending between two halves of a special railcar. This method of shipping allows for a shipping height using the full height of the transformer, without having to allow for a flatcar or depressed-center car in the height. Transformers designed for this type of shipment can be recognized by the special support points on the tank sides.
- Schnabel car. Many large, heavy transformers (primarily GSU transformers) are designed with heavy steel members integrated into the tank and extended out each end near the bottom. The extension members are designed for coupling to each half of a special railcar called a Schnabel car. This design allows the full height and width of the transformer tank to be used as total shipping dimensions. The transformers for this type of shipping are of special tank design, not only in the inclusion of the beams and coupling extensions but also in that the upper portion of the tank is designed to withstand the compressive forces applied by the Schnabel car.

In general, the load capacity of the car should be selected according to the weight of the load. A high-capacity car, for example, should not be used to carry a light load because of excessive vibration and shock to the load. When the transformer’s shipping weight is close to the car’s weight capacity, the transformer will receive a much smoother ride. Conversely, the car must be capable of transporting the weight of the transformer.

To reduce the chances of shipping damage due to rough handling, several measures can be taken. Railcars with shock absorbers or cushion couplers can be requested. Empty idler cars (such as boxcars) that lead and follow the loaded car to further cushion longitudinal impacts can also be ordered. Instructions on the bill of lading that prohibit railcar humping can help to ensure proper handling.

Signage (on the bill of lading) stating which end of the railcar is to lead for the last segment of travel to the rail siding can be beneficial in some specific unloading situations. Clear marking of the A and B ends of the car or transformer will help to ensure proper orientation for off-loading.

When the railcar is delivered to the shipper, the car should be inspected to ensure that it is in good condition. Wood-floor cars should have all floorboards in place and in good condition. Steel floors should be reasonably flat and free of protrusions.

After the transformer is loaded, the railcar springs should be checked to ensure that they are not excessively compressed. Also, the distance between the top of rail and the bottom of depressed-center cars should be checked after loading to determine whether required railroad clearances are being met.

7.1.3.3 Loading, Blocking, and Bracing the Transformer to the Railcar

General Guidance

Loading, blocking, and bracing of transformers on designated railcars must be completed in conjunction with the railways to ensure that they meet Association of American Railroad (AAR) standards. Manufacturers, shippers, rigging or crane operators, and port personnel should be familiar with AAR standards.

The material and method used to load, block, brace, and secure transformers should be assessed before loading or immediately after the type of railcar is determined or assigned in the pre-clearance. In some cases, wood planks are placed under the transformer to cushion the unit and provide evidence of any movement during transport.

Two or more impact recorders are usually included with each shipment. The second unit can act as a backup in case one fails during transport (experience has shown them to fail fairly often). The second unit might also be necessary for transports that use more than one form of transportation or have a duration longer than the battery life of the recorder.

It is recommended that the shipper or manufacturer consult the railways to ensure that the material and method are approved and that a railway inspector is present before the process of loading, blocking, bracing, and securing begins. Final approval of material and method used to block, brace, and secure onto railcars will be provided by the railways after inspection of the work on the railcar. The railways will issue a final release or clearance at this time.

If more than one railway is involved in the transport between origin and destination, each railway might require an inspection of the blocking, bracing, and securing and provide a release before the railcar is transported on their individual rail lines.

Block and Tie-Down Guidance

When using steel deck cars, 1- x 6-in. (2.54- x 15.24-cm) or larger wood planks or sheathing should be placed beneath the transformer’s weight-bearing surfaces to provide cushioning. Load the transformer so that its centers of gravity align with the centerlines of the car to prevent tilting and to equally distribute the load on the axles. Wood cushioning will also help prevent the transformer from sliding along the deck of the railcar.

The AAR standard is quite specific regarding the design, quantity, and positioning of blocks and tie-downs. Other parties such as insurers might require additional blocks and tie-downs beyond those listed in the guide. Blocking members typically consist of steel plates or structural shapes that butt against the transformer’s base and are welded to the car deck. Tie-downs typically are steel rods or steel cables connected to fittings on the transformer and anchored to the car. The shipper is responsible for providing and installing these items.

Bottom blocking, consisting of steel channels or bars, should be positioned against the transformer’s base or bottom plate and welded to the car. In addition to blocking the bottom of the transformer on the car, the transformer can also be bolted to the car floor. This is done with long bolts through a hole in each jacking pad and the car floor.

All top and bottom tie-down rods and bolts should be secured with two sets of nuts and prick-punched. This permits retightening in transit. Nuts should not be welded. Spring-loaded tie rods are not recommended. All top tie-down rods should be brought as close to vertical into the railcar pocket as possible. Crisscross rods are to be used only when some obstruction prevents using vertical rods.

7.1.3.4 Dimensional Clearance and Release for Transport on Rail

After loading, blocking, bracing, and securing a transformer onto a railcar are complete, the railway will inspect the work. If it meets the AAR and pre-clearance criteria, a final dimensional clearance and release will be issued, authorizing transport. The dimensional clearance and release also contains information such as speed restrictions, congested tracks between origin and destination, switches, bridges, or rock cuts that might present a risk in transit. This report is provided to train crews and it can be obtained on request for rider service or shipper information. Dimensional loads of transformers will not be transported by rail until the release is issued. If more than one railway is involved in the movement, each railway might require a final release before it travels on their individual lines. All these items should be discussed with the rider so that potential issues and problem areas can be sorted out before shipping and so that the rider can assess the areas of risk and mitigate them during transport.

7.1.3.5 Arrival at Destination

When the transformer arrives at the destination and before it is offloaded, a physical check should be done of the exterior for any possible damage or shifting. The nitrogen or dry air system should be checked to determine whether the unit is still pressurized. The bump recorder should be checked for major bumps or shocks. A knowledgeable person should check the bump recorder, and any discrepancies should be discussed with the shipper. The rider, if one was used, should also be interviewed to determine whether any events of note occurred.

7.1.4 Heavy Haul Transport

Truck shipment requirements from the factory directly to the substation site and from the rail siding to the substation site are set by consultation with the trucking firm. The carrier will secure the proper travel permits and determine the government-approved route.

7.1.4.1 Planning for Heavy Haul Transportation

This section describes some of the considerations for the heavy haul transport of power transformers, shown as a list of procedures that are presented in a sequential order. These procedures are often part of an iterative process, and many of the procedures and steps are repeated several times until an accurate and safe transportation plan is obtained.

7.1.4.2 Identifying Suitable Heavy Haulers

When it has been determined that heavy haul transport of the transformer will be necessary to move the transformer to the final destination, one of the first steps required is the selection of a suitable heavy hauling and rigging company to perform the required services. Some important criteria to evaluate when comparing and selecting a heavy haul and rigging company are the following:

- Experience with similar projects. Consider companies that have moved equipment or items of similar weight and dimensions to those of the transformer being transported. This will help to ensure that the company has the knowledge, skills, and equipment required to accomplish the move. It is particularly helpful if the company has previous experience in moving large transformers and is familiar with some of the inherent special needs and considerations with moving a large transformer.
- Access to proper equipment. Verify that the heavy haul company owns adequate equipment or has access to adequate equipment that can handle the weights and dimensions of the transformer to be moved. Care should also be taken to verify that such equipment is relatively modern, is in good working condition, and has been maintained properly.
- Familiarity with local requirements and regulations. Verify that the heavy haul company is knowledgeable and familiar with the local conditions at the destination and is also familiar with any local regulations and special requirements for transporting large equipment in the

area. Heavy haul contractors often make several inspection visits to the site and the proposed haul route near the site even before beginning actual work in order to familiarize themselves with the conditions and the local requirements.

- Adherence to proper policies. Verify that the heavy haul company has proper QA programs and safety programs in place to ensure that their work is well-planned and is performed safely and according to applicable regulations or requirements.

7.1.4.3 Determining Actual Shipping Dimensions for the Transformer

After choosing a heavy haul and rigging company to perform the move, the next task is usually the confirmation of the accurate shipping dimensions of the transformer to be moved. Many or all of the external accessories mounted on the transformer tank are removed for shipping to aid in reducing the shipping dimensions to meet any dimensional restrictions that might be encountered on the transportation route. Frequently, large power transformers also have the oil drained from the transformer main tank and accessories in order to reduce the shipping weight of the transformer and reduce the risk of having an oil leak or oil spill during the movement of the transformer.

To confirm clearance of the transformer when being moved through the shipping route, it is necessary to obtain an accurate profile, weight, and dimensions of the transformer in its shipping condition. In the case of new transformers, most manufacturers provide shipping drawings of the transformer showing the critical dimensions of the shipping profile, dimensions and shipping weight of the unit, and other pertinent information regarding the shipment of the transformer. In the case of older transformers, these data should be included in the transformer's instruction book or drawing package. If the data are lost or unavailable, other methods must be used to determine the shipping dimensions and shipping weight of the transformer.

7.1.4.4 Selecting Proper Heavy Haul Equipment

After accurate shipping weights and dimensions are determined, the heavy haul company must select a suitable heavy haul method and equipment in order to properly accomplish the move. The first concern is that the equipment can safely and properly accommodate the weight and dimensions of the transformer and can move the transformer the required distance in a feasible manner.

Often, the process of selecting the most suitable heavy haul equipment becomes an iterative process in conjunction with determining the most feasible transportation route. Many times, a specific transportation route requires a specific weight distribution or maximum shipping dimensions in order to safely move the transformer along certain parts of the route. Depending on the route, the type of surface that the equipment will move over, and any special features (such as bridges and overpasses), a specific maximum wheel weight or axle weight must not be exceeded in order to prevent damage to the road surface or bridge and to provide stability during the movement of the transformer. The following subsections describe examples of possible equipment that can be used.

Heavy-Duty Flatbed or Low-Bed Trailers

Heavy-duty flatbed or low-bed trailers are often available with various numbers of wheels and axles for moving small to mid-size transformers. The trailers are pulled using prime moving equipment such as large trucks and tractors. These trailers are suitable for moving over distances of up to several miles.

Specialized Trailers

Specialized trailers might be available for handling the weights associated with mid-size and larger transformers. These can include platform trailers with up to several axles and multiple wheel sets on each axle in order to achieve better weight distribution and axle loads for heavier transformers. These specialized trailers are suitable for moving over distances of up to several miles.

Specialized trailer and dolly systems with center decks or beams and multiple axles spread over a large distance in order to achieve adequate weight distribution for large loads can be considered. The trailer systems can sometimes be configured to lower the ride height of the transformer as far as possible by using a central span that supports the transformer, sometimes from the sides of the tank, as opposed to setting the transformer on top of a trailer. Thus the transformer base can ride as low to the ground as possible and still maintain adequate clearance during transport. These specialized trailer systems are pulled using specialized prime movers and are suitable for moving over distances of up to several miles.

Platform Trailers

Platform trailers can be modular, in which case multiple trailers can be connected together in order to provide proper weight distribution. These specialized trailers are also pulled with large prime moving equipment such as large, specialized trucks and tractors. These specialized trailers are suitable for moving over distances of up to several miles.

Self-Propelled Hydraulic, Modular Platform Trailers

Self-propelled hydraulic, modular platform trailers have multiple axles with several wheels on each axle and independent, hydraulic control of the ride height of each wheel. These trailers have multiple steering axles and are self-propelled, allowing the transporter to make very sharp turns and maneuver within small areas. They are also modular, and several groups of trailers can be connected together, depending on the weight of the load and the weight distribution needed. These self-propelled platform trailers are generally used to move over relatively short distances because they travel only at a walking speed.

7.1.4.5 Tie-Down and Blocking Requirements

Tie-down and blocking are typically the responsibility of the carrier. Chains and chain blocks are typically used to secure the transformer to the truck bed. As with rail shipment, there are government standards for securing these loads. Damage to the transformer can occur during truck shipment as a result of unexpected changes in routes, undocumented changes to mapped routes including recent road paving work, and so on. Impact recorders can be used at the discretion of the manufacturer or requested by the purchaser to monitor truck shipments. Oil spills are an environmental issue; therefore, all valves and fittings should be plugged and dry.

7.2 Transportation Routing

The conveyance used for transport should be certified to be structurally adequate to withstand the loads imposed during loading, while en route, and during unloading. To ensure safe transit, the project team should investigate the route before shipment. The following issues should be considered when transporting a replacement component:

- The extent to which the transformer is assembled before shipping
- The cost and schedule constraints
- The size, weight, and overall configuration of the replacement transformer (large size can preclude the use of certain routes)
- The shipping methods (truck, rail, ship, aircraft, barge, or a combination of two or more)
- State or local transportation routing requirements
- The transformer’s susceptibility to damage during shipment
- Modifications or upgrades that might be needed (such as replacing railroad ties or rails or improving the load-bearing capacity of roadbeds or bridges)
- The need for escorts or riders (escorts or riders can accompany shipments when additional surveillance is required during transit of certain items)
- Insurance (adequate insurance must be provided for the entire length of the journey)

7.2.1 Route Inspections and Verification of Transportation Route

After the shipping dimensions of the transformer have been confirmed and suitable heavy haul equipment has been identified, typically the next process is the study and determination of the most feasible transportation route for moving the transformer.

The heavy haul company will verify the allowable axle loadings on the proposed transportation routes and also verify that all other obstacles in the transportation route can be negotiated safely. Route inspections are often performed to ensure that no unidentified or hidden obstacles are present in the route and that the move can be performed safely.

Some areas of concern to watch for when determining the transportation route are the following:

- Verification of transportation clearance dimensions of the transformer and transporter along the route.
- Verification of any required bridge crossings, overpasses, tunnels, or other challenges to be negotiated along the transportation route. If there are bridge crossings, care must be taken to ensure that the bridge is still in good condition and capable of handling its rated load. The maximum allowable axle loading for crossing the bridge is often a key consideration when determining whether the bridge can be crossed safely. If it is determined that the bridge cannot safely support the weight of the loaded transporter, it might be necessary to reinforce the bridge, or in extreme cases, even have the bridge rebuilt if no other transportation route alternative exists.
- Verification of maximum allowable axle loading on the road surfaces of the transportation route.
- Verification of road surface conditions along the transportation route. The transporter must be supported by a solid road surface capable of handling the axle loading of the transporter while moving the transformer. Loose soil at the edges of roadways can sometimes cause the transporter to lose stability, causing the transformer load to shift or fall off the transporter completely.
- Identification of any road surface modifications needed. If the transformer and transporter are to be moved across unpaved areas, it is often required to lay matting or steel plates on the ground surface in the area that the transporter will travel. If done properly, this can distribute the load of the transporter across a larger area and prevent the transporter from losing stability or sinking into the ground.
- Determination of any regrading required on the transportation route. Sometimes, especially when moving on an unpaved or off-road surface, regrading of certain parts of the route might be required in order to safely move the loaded transporter. Too much of an incline can strain the tie-downs that secure the transformer to the transporter during movement and can also strain the prime mover that is pulling the transporter up an incline.
- Verification of any utility services that must be cleared. Sometimes when transporting a transformer along the transportation route, some utility services such as distribution power lines, telephone lines, and cables can interfere with the transportation dimensions of the transformer. Care must be taken to check that the utility services can be moved, lifted, or relocated during the movement of the transformer. Additional precautions must be taken to move electrical wires, keeping proper insulation from grounded parts.
- Verification that all electrical clearances will be maintained between electrical wires and grounded parts. Especially when moving through areas where overhead electrical wires exist, care must be taken to ensure that proper electrical clearance is kept between the electrical wires and grounded parts. When moving in substations or areas with high voltage lines, heavy hauling companies might not be familiar with the required clearance distances and might not be able to distinguish between higher and lower voltage lines. In such cases where movement in areas with high voltage electrical wires will occur, it is a good practice that the utility party involved with the move be consulted to verify that proper electrical clearances

are maintained, especially when the transportation height of the transformer is relatively high, or the overhead lines are relatively close to the ground, or when any cranes are planned to be used in the area. In some cases, lines must be de-energized in order to complete the move safely or an alternative route must be found.

- Verification of adequate space for maneuvering. When the transporter nears the end destination, it must be verified that there is sufficient available space in the area for the transporter to be maneuvered. Especially when the transformer's final orientation differs from its position while in transport, when there is only one entrance and exit at the site, or when there are many obstacles that must be negotiated, care must be taken to verify that the transport equipment can be safely maneuvered and turned within the confines of the site.
- Verification of permission to transport over private property. In some cases, the proposed transportation route will pass over areas of privately owned property. In such cases, it is necessary to check that permission can be obtained for movement of the transformer across the private property. The owner of the private property must be identified and contacted to verify that permission can be obtained.

7.2.2 Heavy Haul Transportation

The following subsections describe some considerations and procedures that apply when the transformer is ready to be moved.

7.2.2.1 Condition of Heavy Haul Equipment

Before beginning any planned transformer move using heavy haul equipment, it is important that all equipment is checked to confirm that it is of adequate rating and in proper working order. Records should be made available and reviewed to verify that the equipment has been maintained properly, as well.

If a piece of equipment such as a trailer or other critical component should break down during the transformer move, it could lead to a dangerous situation, including severe damage to the transformer, injury to personnel, or worse. A few precautionary measures, safety checks, and maintenance actions performed in advance of the move can eliminate much of this unnecessary risk.

7.2.2.2 Inspection of Transformer Before Receiving

When performing a heavy haul move of a transformer, the transformer is usually first transferred from another means of transport, such as an ocean vessel, barge, or railcar. Therefore, one of the first steps is to inspect the transformer for any signs of shipping damage before receiving the unit and moving it onto the heavy haul transporter. This inspection process should include the following:

- Verification of impact recorders. Ensure that impact recorders have been attached to the transformer before moving the transformer. It is a good practice to attach two impact recorders to the transformer as a backup in case one of the impact recorders malfunctions during the move. If the transformer was moved on another mode of transportation (ocean vessel, barge, or railcar) before receiving and loading it onto the heavy haul transporter, the impact recorder should be checked to determine whether any severe impacts have occurred to the transformer on the previous mode of transportation. If indication of an impact that exceeds the transformer manufacturer’s criteria is observed, the proper parties should be notified in order that further inspections or actions can be taken. After checking the impact recorder that uses a paper reel as the recording medium, it is a good idea to place a mark on the paper at the point where the handling of the transformer begins in order to provide a later reference that can pinpoint which mode of transportation the transformer was on when an impact occurred.
- Verification that positive pressure is maintained inside the transformer. During the receipt inspection, the transformer should be checked to verify that 1) no oil has leaked if the unit was shipped oil-filled or 2) positive pressure has been maintained if the unit was filled with a dry gas for shipping. The gas pressure can be confirmed by checking the pressure gauge. The ambient temperature at the time of the measurement should also be recorded.
- Check for signs of physical damage to the transformer. Perform a visual inspection to check for signs of physical damage that might have occurred during the previous mode of transport. If any damage is observed, document the damage and notify the proper parties so that further inspections or actions can be taken.
- Check that proper handling instructions are marked on the transformer. Before handling the transformer, be sure that critical handling instructions are clearly marked and visible on the transformer, including the shipping weight and the location of the shipping center of gravity. Also, key handling points on the transformer such as lifting lugs, jacking pads, and pulling eyes should be labeled by painted marks or other methods of permanent marking on the transformer.

7.2.3 Transportation to the Destination

During the transportation of the transformer on the heavy haul transporter, the transporter should remain on the designated and permitted route at all times. The driver of the transporter should ensure that the transporter remains on a stable road surface during the movement of the transformer and that all traffic laws and special permit requirements are followed.

Care should be taken when moving the transformer near overhead wires or tree branches. It is for this concern that long, flexible wooden strips are often placed on top of the transformer during movement. The strips face parallel to the direction of travel and extend well beyond the front and rear of the transformer, and as a result, they sag so that the ends are lower than the top of the tank. If a wire or other obstacle hits one of the strips, this provides a warning that the obstacle is in the path of the transformer. This warning system can also help to prevent some wires or trees from potentially impacting and causing damage to the top of the transformer during movement. The transformer and heavy haul transporter must be moving very slowly for this warning system to be effective.

7.3 Packaging for Shipping

The need for physical protection of items from movement or contact with other items is much more of a concern when the item is in transit than when the item is in storage or after it has been installed in the plant. Therefore, a reduced level of packaging might be adequate when the transformer is staged on site. Consideration should be given to how much of the packing materials should be discarded when the replacement component is staged for installation and protection from physical damage is no longer a concern. In most cases, the packaging used during shipping must be removed in order to move the transformer into place and maneuver it through the access route established in the plant.

The following issues should be considered when determining the type and extent of packaging for a replacement large power transformer during shipping:

- The manufacturer’s recommended means for packaging the transformer to provide adequate protection during shipment
- Physical size, weight, and overall configuration of the replacement transformer
- Shipping methods (truck, rail, ship, aircraft, barge, or a combination)
- Transformer’s susceptibility to damage during shipment
- Security requirements and inspections at points of shipment, entry, and receipt
- The possibility of theft and vandalism during shipment of the transformer

Typically, for domestic transport, a large power transformer is skid mounted, with connection openings adequately protected or covered, and is shrink wrapped. For overseas shipments, the transformer can be containerized with bracing or can be export crated (completely boxed).

7.3.1 Shipping Preparation for the Accessories

In addition to moving the main body of the transformer on a heavy haul transport trailer, the accessories that have been removed from the transformer for shipping are often transported separately by packing the accessories in crates and cases and shipping them on conventional flatbed trailers. Just as with the transformer itself, care must be taken to ensure that the accessories and components of the transformer are not damaged or destroyed during transport.

7.3.2 Packing the Accessories

When shipping the accessories separately, care must be taken to properly design the shipping crates and cases to adequately support the accessories during the shipping, handling, and transportation process. The crates should be designed to be lifted and handled easily and to support the weight of the accessories contained within them. The crates should firmly hold the contents secure and should prevent any accidental damage to the contents during handling.

Care must also be taken when securing accessories that are not enclosed in crates or cases, such as radiators or coolers. When securing radiators and coolers, care should be taken to avoid damaging delicate fins or panels by tightening straps across them without appropriate edge protection. This will prevent both damage to the accessory and unnecessary paint scuffs or scrapes. One method of protecting the edges of the radiators or coolers is to use lumber along the length of the fins where the straps wrap around the edges. This helps to more evenly distribute the strap pressure across the entire radiator or cooler.

7.3.3 Material Compliance

When transformer accessories are packed outside the United States and are shipped for importation, the assembled crates must meet certain guidelines associated with export packaging. The most important aspects involve proper labeling and documentation to allow inspectors and handlers to identify the contents of the crates, handle them properly, and ship them to the correct location. Only fumigated wood or other approved materials should be used in the construction of the crates in order to allow the crates to pass import inspection and ensure that plants, animals, insects, and so on, that are not native to the United States are not accidentally contained in the packing materials. Shipping containers that fail to meet these requirements can greatly delay the delivery of the accessory components by having the materials held up or rejected by U.S. Customs inspectors.

7.3.4 Proper Shipping Marks

To ensure the proper handling of the accessory crates, verify that the proper shipping marks are provided and are visible on the outside of the crates. The shipping marks show how to identify the contents of the crates and also show the end destination of the crates. In addition, instructions for any required special handling of the crates should be clearly marked on them to ensure that the contents of the crates are not damaged during shipment.

7.3.5 Detailed Packing Lists and Documentation

A detailed packing list should be attached to the accessory crates for easy identification during the shipping and handling of the crates. The packing list should show descriptions and quantities of the components contained in the case and the total shipping weight of the case in order to ensure that it is handled properly. A proper packing list aids in accounting for all components of the transformer and is useful in inventorying and determining whether any parts are missing.

7.3.6 Package Marking

Any accessories or crates that contain components or materials requiring special care during shipping should be clearly labeled. For example, all crates containing bushings, surge arresters, or other large porcelain parts should be clearly labeled "Fragile—Handle with Care" and should contain the proper warning indications.

Other instructions for special handling of accessories or crates should be attached as needed to ensure that sensitive components are not damaged during shipping. Special handling instructions for crates containing certain transformer accessories can include the following, among others:

- This End Up or This Side Up
- Fragile—Handle with Care
- Sling Here
- Use No Hooks
- Keep Dry
- Keep Away from Heat
- Center of Gravity

7.4 Using Sensing and Monitoring Devices During Shipment

An impact recorder, which records the g force magnitudes of impacts versus time, should be affixed firmly to a structural component of the transformer's main tank or core to minimize any high-frequency resonance that might occur as a result of unsupported structures. In addition, consideration should be given to mounting a recorder on the railcar. Mechanical chart type and electronic data logging recorders are commonly available to record longitudinal, vertical, and lateral impacts, as well as the time and date when an impact occurred. Electronic impact recorders should have a method to prevent tampering (such as stopping the device or deleting data) until at the final destination or when the manufacturer or purchaser deems it necessary to retrieve the information. Impact recorders should be left in place on the transformer until the transformer is rigged into its final position. The instrument will provide a permanent record of any impacts that the load experiences in transit. The recorder must run long enough to allow for delays in shipment. For electronic impact recorders, the recorder should be set up so that it does not overwrite or remove any existing data in the event of a shipping delay. For larger transformers or those of critical importance, consider using duplicate recorders. Recorders attached directly to the car might be sufficient for some transformers.

Several types of impact recorders are available to measure impacts during transportation. Older style recorders use paper traces to record impacts. Electronic recorders are increasing in popularity and offer the advantages of not running out of tape and having a longer battery life. Both styles measure impacts in five zones from 0 to 10 g. Impacts that exceed design criteria in any of the three axes can result in damage. Depending on the design criteria, longitudinal impacts $\geq$5 g are considered rough handling.

Sealed vibration recorders (also known as bump recorders) should be considered when transporting a large power transformer. These sealed, three-dimensional recorders measure acceleration in g force in the longitudinal (X axis), lateral or horizontal (Y axis), and vertical (Z axis) directions. They are available in both analog and digital models. The analog recorder uses a paper chart with time on one axis and the three acceleration directions (X, Y, Z) on the other axis. It has a frequency range of up to approximately 12 Hz. The paperless, digital recorder allows data to be downloaded to a computer and analyzed by a software application (which is provided by the manufacturer of the digital sealed vibration recorder). It has a frequency range of up to 100 Hz. Care must be used when interpreting the data from a digital recorder as compared to that from an analog recorder because a bump at 100 Hz has less energy than that of a bump at 12 Hz.

7.5 Customs Requirements and Homeland Security Issues

Care should be taken to ensure that current U.S. Customs and Homeland Security requirements are met. The following issues should be considered when transporting a replacement large power transformer from overseas:

- Special requirements for overseas shipment required by either the United States or the country of origin
- Inspections required at the point of shipment
- Inspections required at the point of entry
- Special packaging needed to accommodate inspections during transport
- Requirements for special identification and markings
- The modes of transportation being used and requirements specific to those modes
- Requirements for special permits or documentation
- Point of transfer of ownership
- Insurance

7.5.1 Safety and Environmental Requirements, Regulations, and Laws

Care must be taken to ensure that the transportation plan will comply with all applicable safety, environmental, and other requirements and regulations in all areas along the transportation route. In addition, it should be confirmed that the transportation plan complies with the additional safety and handling requirements of the transformer manufacturer, the purchaser, and the owner of any equipment being used. The heavy haul company should also verify with the transformer manufacturer that the transportation plan will not risk damaging the integrity of the transformer and its internal or external components, especially when nonconventional movements are planned.

7.5.2 Permits

Ensure that all necessary permits for moving the transformer along the proposed transportation route have been obtained before beginning the actual move of the transformer. Depending on the size of the transformer and the roads that the transportation route follows, it might be necessary to transport the transformer on sections of the route only at night or during off-peak traffic times, or the road might have to be closed completely to other traffic during the movement of the transformer. In addition, part or all of the proposed transportation route might travel across private property. In such cases, it is necessary to obtain permission to transport the transformer across the private property. Permission must be coordinated and obtained in advance of the actual movement of the transformer.

7.5.3 Escorts and Riders

For critical shipments, particularly when transit time is important, an escort familiar with railroad operations (commonly referred to as a rider) can accompany the shipment. Escorts, however, have very little control in managing events during transit. The escort can attest to how the load was handled and can report daily on progress and delays. Special freight team service can be arranged, and is sometimes required, for special routes in which the transformer-loaded car travels in a separate train and is not normal freight service.

7.6 Lifting and Handling Issues

When lifting and handling a large power transformer, the following issues should be considered:

- Loading. The weight, lifting points, or center of gravity indicated on the crate, skid, or package by the shipper should be used to ensure proper handling during loading, transfer between carriers, and unloading.
- Rigging. Rigging requirements should be established by the project team before transport and handling of the manufactured transformer. To avoid surface damage, care should also be taken to ensure that carbon steel rigging equipment does not come in direct contact with stainless steel, except when the rigging equipment is attached to lifting lugs, eyes, or pads.
- Handling precautions. Austenitic stainless steel and nickel base alloy materials should be handled in such a manner that they are not in contact with lead, zinc, copper, mercury, or other low melting elements, alloys, or halogenated material.
- Packaging and preservative coatings. Packages and preservative coatings should be visually inspected after loading, and damaged areas should be repaired before shipment. Items shipped with desiccants should be inspected after loading to ensure that sealed areas are intact.
- Sealed openings. Sealed openings should be visually inspected after loading to ensure that closures are intact. Materials used for resealing should be in accordance with ANSI standards or licensee procedures.

- Stacking. Where special care is deemed necessary to avert damage, written instructions covering the location and stacking limits of the crates or boxes on the transport vehicle should be specified and marked on the container.
- Bracing. The type of bracing and tie-down methods to be used with the mode of transportation selected for special shipments of replacement components should be specified by the project team.
- Lifting devices. If lifting lugs or lifting eyes are provided, always use chains or lifting cables with ratings that are greater than the published weight of the transformer. For general guidance on establishing and applying appropriate lifting and handling requirements, refer to the EPRI report *Lifting, Rigging, and Small Hoist Usage Program Guide* (1007914) for guidelines [56].

7.6.1 General Handling Guidance

7.6.1.1 Complete Transformer

The transformer should always be handled in the normal upright position unless information from the manufacturer indicates that it can be handled otherwise. If a transformer cannot be handled by a crane or moved on wheels, it can be skidded or moved on rollers or slip plates, depending on the compatibility of the transformer base design and the type of surface over which it is to be moved. Transformers built in accordance with current standards have bases designed for rolling in two directions.

7.6.1.2 Lifting with Slings

Lifting lugs and eyes are typically provided for lifting the complete transformer, and the necessary additional means are provided for lifting the various parts for assembly. The lifting lugs and eyes are designed for vertical lift only. When lifting the complete transformer or a heavy piece, the cable should be attached so that it provides a vertical force to each lug. As an added precaution to prevent buckling the tank walls, the cover should always be securely fastened in place. Lifting cables of appropriate length should be used so that the transformer will be lifted evenly. The transformer manufacturer’s instructions for minimum angles of lift for slings and cables should be reviewed, as well as whether spreader bars are required. Lifting lugs on most transformers are designed to lift the transformer completely assembled and filled with dielectric liquid. The approximate total weight of the transformer is given on the nameplate and on the outline drawing.

It might not be possible to lift an entirely assembled transformer because of interference with bushings or other parts. It is usually not possible to lift the transformer with slings if the cover has been removed for any reason.

7.6.1.3 Raising with Jacks

Jack bosses or pads are provided on all transformers in this class so that the transformers can be raised by means of jacks. On some transformers, jacks can be placed underneath the transformer bottom plate at points designated by the manufacturer. The drawings or manufacturer's instruction book should be consulted.

7.6.1.4 Anchorage

A properly designed anchorage system is one of the most important requirements to enable the transformer to withstand the seismic demand at the installation location (which, in some cases, might be negligible and not applicable). The recommended anchorage system is made by welding the transformer base to structural steel members embedded in or firmly anchored to a concrete foundation. Bolted anchorage systems can also be used. Follow the manufacturer's instructions regarding the bolt sizes, strength, location, and procedures.

7.6.2 Availability of Transformer Design Information

Before the completion of the design and manufacture of the transformer, the heavy haul transportation company should ensure that appropriate information is available to confirm that the transformer can be moved and handled in the means necessary for execution of the transportation plan. Such information should be clearly shown on the shipping outline drawing provided by the transformer manufacturer. Features such as the jacking points, pulling eyes, and lifting lugs should be clearly marked and easily identifiable to the heavy haul company. A shipping center of gravity should also be shown on the shipping outline drawing and confirmed with an indication mark on the actual transformer tank because this is an important piece of information for safely handling the transformer.

7.6.3 Loading Considerations

7.6.3.1 Loading the Transformer onto Heavy Haul Transportation Equipment

After the transformer has been inspected, the next step is to transfer or offload the transformer from the previous mode of transportation onto the heavy haul transport equipment. The transfer is usually accomplished by one of the following methods:

- Using hydraulic jacks to lift the transformer up, placing cribbing and sliding beams beneath it, and then sliding onto the heavy haul transporter
- Using a crane to lift the transformer and move it to the heavy haul transporter
- Using a gantry system to lift the transformer and move it to the heavy haul transporter

When preparing to move the transformer from the previous mode of transportation, ensure that each type of transport equipment has the proper braking in place to prevent movement of either piece of transportation equipment during the movement of the transformer. In addition to proper braking, blocks should be placed in front of and behind the wheels of a wheeled transportation vehicle such as a trailer system. Measures should be taken to ensure that barges remain stable and in place during transfer movements involving offloading from barges.

When moving the unit from a previous mode of transportation that includes a suspension system for the transporter, such as a railcar or another trailer system, the railcar or trailer should be jacked up to remove the weight from the suspension system (such as springs). After the weight has been removed, blocking should be placed under the railcar or trailer to ensure that it does not move while the transformer is being transferred to the heavy haul transport system. Stabilizing the railcar or trailer by blocking is particularly important when rolling or skidding the transformer to another mode of transportation because even a slight tilting of the railcar or trailer will apply unintended loading to the rails or beams that are supporting the roll or skid and will prevent continuation of the transfer.

7.6.3.2 Securing the Load

When the transformer has been positioned onto the heavy haul transporter, the transformer must be secured firmly to the transporter to ensure that it does not shift or slide during the movement on the transporter. The transformer should be secured by adequate means that provide for bracing in all possible directions of movement of the transformer. The bracing materials should be sized properly, taking into account the size and weight of the transformer. After the transformer is secured to the transporter and before the transporter is moved, the bracing structures and materials that secure the transformer to the transporter should be inspected, verified, and approved by an appropriately trained professional.

7.6.4 Offloading Considerations

After the transformer is successfully transported to its destination, the next step is to offload the transformer from the heavy haul transporter to the end destination (such as a designated concrete foundation at the site). Before offloading the transformer to the final destination, confirm that the final destination is ready to accept the transformer.

7.6.4.1 Offloading Accessories

When the accessories arrive at the destination, they are usually offloaded using a mobile crane or a forklift, depending on the size and weight of the equipment or crate.

When using a crane for offloading, verify that both the crane and the rigging have the lifting capacity to safely move the part or crate, including the weight of the crate. Also, the crane must have the reach to extend far enough to move the package from the trailer to its final location. In general, it is best to ensure that the crane hook is located over the center of gravity of the crate or part being lifted to ensure that it does not sway, tilt excessively, or lose stability while being moved. Only an appropriately trained operator should operate the crane.

When using a forklift to offload the crates, verify that the crates have been designed to facilitate offloading with a forklift without damaging the parts contained in the crate or package. Special care should be taken when lifting crates containing fragile porcelain products such as bushings or surge arresters with a forklift. Improper positioning of the forks can easily damage the porcelain if the forks come into contact with the bushings or surge arresters. Only an appropriately trained operator should operate the forklift.

7.6.4.2 Offloading Using Hydraulic Jacks and Sliding System

The requirements for offloading are similar to those for loading (see Section 7.6.3.1, Loading the Transformer onto Heavy Haul Transportation Equipment). However, when preparing to move the transformer from the heavy haul transporter, ensure that the transport equipment has the proper braking in place to prevent movement of either piece of transportation equipment during the movement of the transformer. In addition to proper braking, blocks should be placed in front of and behind wheels on a wheeled transportation vehicle such as a trailer system.

When moving the transformer from the heavy haul transporter, the transporter should be jacked up to remove the weight from the suspension system (such as springs). After the weight has been removed, blocking should be placed under the trailer to ensure that it does not move while the transformer is being transferred to its end destination.

If hydraulic jacks are used to lift the transformer, ensure that the transformer is lifted evenly at all four jacking points to prevent the transformer from becoming unstable during the jacking process. In addition, ensure that the hydraulic jacks are located on firm areas capable of handling the weight of the transformer over the concentrated area of the footprint of the hydraulic jack. There should also be adequate pieces of hardened blocking material or plywood placed between the interface point of the hydraulic jack and the transformer jacking plate in order to prevent the jack from slipping during the lifting of the transformer.

7.6.4.3 Offloading Using Cranes or Gantry Systems

When cranes or gantry systems are used to lift the transformer, ensure that all rigging materials are in good condition and are adequate for lifting the transformer. In general, it is a good practice to use a high factor of safety in determining the size and capacity of the rigging materials used to lift the transformer, such as a safety factor of at least seven between the rigging material’s maximum load capacity and the load actually placed on them during the lifting of the transformer. This will reduce the risk of having a catastrophic accident while lifting the transformer with rigging materials. When using cranes, it is also important to verify that the capacity of the crane can handle moving the transformer, taking into account the weight of the transformer and the reach over which the crane must be extended to move the transformer to its desired location.

7.6.4.4 Uprighting of Large Shell-Form Transformers

In some cases, large single-phase, shell-form transformers for extrahigh voltage applications can be shipped to the end destination in a laydown configuration that requires uprighting of the transformer to its proper operating orientation before it is placed on the destination foundation. These transformers have been designed specifically for transportation in the laydown configuration and should have handling points that enable them to be uprighted into the final orientation at site. The uprighting process is usually performed using a gantry system or two large cranes. The transformer manufacturer should provide details and instructions for the uprighting procedure, and care should be taken to ensure that these procedures are followed.

8
RECEIPT INSPECTION ISSUES

The receipt inspection should be an integral part of the acceptance plan when replacing a major plant component such as a large power transformer. The project team should use care when developing a receipt inspection plan in order to ensure that appropriate physical and performance attributes are adequately verified and that the replacement transformer is not damaged in any way during shipment and during the receiving activities. To facilitate receipt inspections, the licensee should ensure that plant and site security issues have been addressed in order to allow free access of the transformer through security and to the location where it will be inspected and subsequently unloaded.

If receipt inspection is required, the requirements should be coordinated with source verifications that have been performed. It might be necessary for the manufacturer to seal the enclosure openings after a source verification to avoid the need for the licensee to conduct an internal inspection when the transformer arrives at the plant. During receipt inspection, emphasis should be placed on ensuring that items have not sustained damage in shipment that would influence subsequent assembly, construction, installation, or operation. Sampling can be used during receipt inspection when conducted in accordance with established procedures or recognized standards. These measures must also include provisions for dispositioning (accept, reject, or hold) and handling items received and services performed.

Receipt inspection should be used to supplement the QA and verification activities that have taken place before and during the manufacture of the transformer, and it should be performed to verify that the supplier has met all requirements of the purchase order.

8.1 Developing Appropriate Inspection Attributes

The inspection attributes can be instructions to verify the receipt of certain supplier documentation, which typically is described in the final procurement specification. The supplier documentation furnished should provide objective evidence that certain physical and performance attributes of the replacement transformer have been verified as conforming to the manufacturer’s design. When certain component attributes have not been verified before receipt, or when additional assurance is needed to verify the conformance of a particular component attribute, the project team can opt to verify a particular physical or performance attribute of the transformer through a test or inspection.

8.1.1 Reviewing Documentation Received

The receipt inspection should include provisions for receiving documentation (such as drawings, certifications, test results, and other materials) that is offered as objective evidence in satisfaction of requirements. In many cases, the supplier's QA program has been audited and approved by the licensee's QA organization; therefore, many of the acceptance activities should have already taken place through the implementation of the performance-based audits and source verification activities. Additional acceptance activities occurring during receipt of the transformer should primarily ensure that appropriate and accurate documentation has been received in accordance with the requirements of the final procurement specification. These documents typically include the following:

- Supplier drawings, procedures, and specifications
- Supplier instruction manuals, which typically include the following information:
  - Transformer installation guidance
  - Transformer maintenance guidance
  - Instructions for vacuum testing and filling the transformer with oil
  - Recommended spare parts lists
  - Transformer operating guidance
  - Vendor technical manuals for subcomponents
  - Performance data sheets or curves (a certified test report)
- Certified factory test report
- Seismic qualification report, if applicable
- Certified or performance test reports (IEEE C57.12.90, Section 15, provides additional guidance regarding the content of typical test reports [47])
- Nondestructive test reports
- Personnel certifications and qualifications
- Inspection reports
- QA manuals
- Certificates of conformance or compliance
- Recommended spare and replacement parts lists
- Photographs of the transformer and subassemblies taken at the factory
- Frequency response analysis waveforms with detailed descriptions of the transformer configuration at the time of the tests (such as service bushings versus shipping bushings) and the means by which the analysis should be performed

- Shipping information, including the following:
  - All shipping documents
  - Contents or packing list
  - Routing
  - Destination and conditions of carrier's agreement
  - Bill of lading
  - Impact recorder data

8.1.2 Testing and Inspecting Component Attributes

When receiving activities are used to verify either physical or performance attributes of the transformer (that have not already been verified by the supplier through audit or source verification), the project team must establish the appropriate acceptance criteria before verifying the attributes. These acceptance criteria should represent the manufacturer's design criteria for the item and should include tolerances as allowed by the item's design.

8.1.2.1 Inspections Before Unloading

For an item as large and complex as a large power transformer, it is important to follow a careful receipt inspection process. Recording the condition of the transformer when it is received and identifying the source of any damage that might have occurred during shipping and handling are fundamental to the process. Transformer manufacturers typically maintain receipt inspection instructions and checklists in the instruction manual for the transformer. Although the purchaser might wish to perform additional inspections, the manufacturer's instructions should be adhered to in order to maintain the warranty. There might be additional requirements for a manufacturer's field engineer or supervisor to be present during the receipt inspection and off-loading process for warranty verification.

After the transformer is received and before it is removed from the truck or railcar, the impact recorder chart or the electronically stored impact data or both, as well as the transformer tank, should be thoroughly inspected for any evidence of rough handling during transit. If no probable damage is noted from the recorder data, the receipt inspection can proceed. If damage might have occurred, the manufacturer and carrier should be notified immediately. If the licensee suspects that damage has occurred to the external surfaces of the transformer, internal inspection of the transformer and its accessories might be warranted.

Warning: A power transformer tank is considered a confined space, and entry requires climbing a ladder. No person should be allowed to climb the ladder without proper fall protection training and equipment. No person should be allowed inside the tank without confined space certification and support. Observe the cautions in Section 8.1.2.2, Internal Inspectors After Unloading the Transformer, regarding the gases used in the tank for shipping.

Inspections of Transformer Externals

When a transformer is received, a thorough external inspection should be done before the unit is removed from the car. Inspect carefully for any apparent damage or shifting of the transformer during transit. If there is evidence of damage or rough handling in transit, an inspector representing the carrier and the manufacturer should be notified. In all cases, the manufacturer's instructions should be followed. For shipments equipped with impact recorders, representatives from the purchaser and carrier should be present to inspect the transformer and examine the impact recorder chart or electronically stored impact data or both at the site location.

Note: Rough handling for which shippers and riggers are responsible generally begins at 1.5 g in the longitudinal, vertical, and transverse directions. The project team should understand the g forces experienced during transit, and agreement should be reached between the licensee and supplier regarding acceptable limits.

Low-amplitude g forces can cause extensive damage when they affect the transformer for a long duration. Therefore, both the duration and the magnitude of g forces are important factors to consider during receipt inspections. A transformer might be able to withstand a large g force magnitude for a relatively short duration, but a lower magnitude g force of longer duration can result in significant damage. Electromechanical impact recorders do not accurately indicate duration. For this reason, electronic impact records that can provide these data are recommended. All questionable impact recorder data should be resolved through discussions between the manufacturer and the purchaser.

The impact recorder charts or electronically stored impact data or both should be checked for accelerations that exceed the manufacturer's specified limits and should be reviewed by the licensee. The hauling agent should be present when the seal is broken or the electronic recorder is interrogated. The guy rod tension, tie rods, blocking, and welds to the railcar must also be checked.

For gas-filled shipments, the gas pressure should remain positive even in the coldest weather. When the transformer arrives at the site, check the gas pressure in the tank and in the supply cylinder, if one is provided. If the gas pressure is zero, there is a possibility that outside air and moisture might have entered the tank; the manufacturer should be notified. Check the oxygen content and dew point of the gas in the tank. It can be safely assumed that the transformer has not been contaminated in transit with outside air or moisture if the dew point of the gas indicates a relative humidity of less than 1% and the oxygen content is below 1% (if shipped in nitrogen). Moisture content—in terms of temperature, pressure, and dew point—should be essentially the same as it was when the unit was shipped. The specification should require the manufacturer to test the dew point of the shipping gas when the transformer leaves the factory. If this is the case, the dew point (moisture content) of the shipping gas should be described on the shipping documents or on a tag at the gas sample valve. If the oxygen content and dew points are outside these values, drying might be necessary; the manufacturer should be notified.

An increasingly popular test is a sweep frequency response analysis test. The test can be requested as a factory test; to be of maximum benefit, it should be repeated as a receiving test. There is a complication in that the test results are somewhat different if done in oil or without oil. Test results can also be affected by ambient temperature, tap position, and so on. The specification should contain instructions for performing this test in the factory under conditions that can be repeated when the unit is received and preferably before it is unloaded. For example, tests can be done without oil, and winding leads can be brought out through small test bushings. After all, the premise of the test is to detect changes in the winding characteristics.

In general, before unloading the transformer, the following visual inspections of external attributes should be performed:

- Verify that the tank and compartments are sealed.
- If the transformer is shipped with oil, check oil levels in the transformer tank, compartments, and bushings, and verify there are no leaks. Most large power transformers are shipped without oil.
- If the transformer is sealed with a dry air blanket, verify positive pressure and test to confirm that the dew point has not changed from the value recorded at factory before shipment.
- Verify that the instruction book and drawings are with the unit (the typical location is in the control cabinet).
- Verify that shipping braces, rock guards, protective covers, and compartment doors are secured.
- Verify that tie-down rods or cables are straight and tight.
- Verify that any conduits on the sides of the tank have not been damaged or shifted.
- Verify that current transformer shorting jumpers are in place.
- Check the core ground, if it is available from the tank exterior.

Inspections of Transformer Internals

Some licensees and manufacturers recommend that an internal inspection be made of the transformer on the railcar in all cases. Others recommend an internal inspection on the railcar only if an external inspection indicates possible shipping damage or if there is no provision to check the core ground externally. If an internal inspection is made on the railcar, it should be made after notifying the carrier and the manufacturer and with their respective representatives present. If there is provision for checking the core ground, this should be done. On some transformers, it might be necessary to break the seal to gain access to the core grounding strap. It should be necessary to release the tank pressure to zero to facilitate opening the access covers. A net positive pressure should be maintained by introducing breathable dry air until the opening is again closed and sealed and the desired positive pressure is restored.

Breathable dry air should be continuously supplied into the transformer while the access cover is removed whenever anyone is inside. Extreme care must be taken that the oxygen content is between 19.5% and 23%. The carbon monoxide level should be <25 mg/kg, and the lower explosive limit should be <20% or as otherwise indicated by OSHA requirements. The dew point should be kept as close as possible to the value that was measured at the factory. The transformer should not be left open any longer than necessary—preferably less than 2 hours—for a proper inspection.

If the delivering carrier will not permit internal inspection of the transformer on the transport vehicle, but possible internal or hidden damage is suspected, this concern should be noted on the acceptance slip. When the transformer has been removed to the installation site or to some other convenient location to permit internal inspection, the process described in Section 8.1.2.2, Internal Inspections After Unloading the Transformer, should be considered. The project team leader should also request that a representative of the carrier be present during the inspection for suspected damage.

8.1.2.2 Internal Inspections After Unloading the Transformer

Atmospheric Conditions Permitting Internal Inspection

Moisture can condense on any surface that is cooler than the surrounding air. Excessive moisture in insulation or dielectric liquid lowers its dielectric strength and can cause a failure of the transformer. The transformer should not be opened under circumstances that permit the entrance of moisture, such as on days of high relative humidity (≥60%), without precautions to limit the entry of moisture. If the transformer is brought to a location warmer than the transformer itself, the transformer should be allowed to stand until all signs of external condensation have disappeared. There should be a continuing determination of tank oxygen content and a supply of dry purging air.

Inspection Guidance

Access for internal inspection and assembly is typically obtained through an access hole.

Warning: After the access cover is removed, the transformer should not be entered until the shipping gas (including dry air) is completely purged with breathable dry air and the oxygen content is between 19.5% and 23%. This replacement of gas with dry air is necessary to provide sufficient oxygen to sustain life. If the unit was initially shipped in dry nitrogen, there is a possibility of trapped nitrogen pockets. In this case, a sufficient vacuum should be held for a predetermined period of time and the vacuum released with and refilled with dry breathable air. Shipping gas can be effectively removed from the tank by temporarily filling it with dry oil or by partially evacuating the tank to remove the shipping gas.

During the entire internal inspection process with personnel inside the tank, a minimum flow of 20 cfm (9.4×10^{-3} m^3/s) of breathable dry air with an additional 5 cfm (2.4×10^{-3} m^3/s) for each additional person (or follow the local OSHA requirement, if available) is required to purge the tank. The oxygen content and combustible gas content must be checked periodically to ensure that the levels are acceptable.

In addition to monitoring the oxygen and combustible gas content, most utilities require the issuance of a confined space entry permit to ensure adequate ventilation, continuous gas monitoring, the presence of a safety watcher during the entire inspection event, and a plan in place for extrication of an incapacitated worker from inside the transformer tank.

To avoid the danger of any foreign objects falling into the transformer, all loose articles should be removed from the pockets of anyone working above, in, or on the open transformer tank. Any tools should be tied with clean cotton tape or seine cord and securely fastened to the outside of the transformer tank when practical. The use of tools with parts that can become detached should be prohibited around the transformer openings. If any object is dropped into the transformer and cannot be retrieved, the manufacturer must be notified.

The manufacturer's recommendations for the inspection should be followed. Inspection will include, for example, removing any shipping blocking; examining for indications of core shifting; testing for unintentional core grounds; visually inspecting windings, leads, and connections including clamps, braces, and blocks; inspecting tap switches, including contact wipe, alignments, and contact pressure; inspecting current transformers, including supports and the condition and clearance of leads; examining bushing draw leads; and checking for dirt, metal particles, moisture, and so on. If any internal damage that might have resulted from rough handling is found during this inspection, the carrier and the manufacturer should be notified. The manufacturer should also be notified if any foreign material is discovered. All tools should be accounted for after the internal inspection.

8.1.3 Testing and Inspecting Supporting and Auxiliary Items

In some cases, the project team might be responsible for testing and inspecting supporting and auxiliary items, which can include the following:

- Spare or replacement items for the transformer
- Tools needed to install the replacement transformer
- Installation materials (such as bar stock, shims, or blocks)
- Consumables used during installation (such as weld rod, lubricants, and rags)

As with testing and inspecting the transformer itself, if receiving activities are used to verify either physical or performance attributes of supporting or auxiliary items, the project team should establish the appropriate acceptance criteria before receipt. These acceptance criteria should represent the supplier's or manufacturer's design criteria for the item and should typically also include tolerances. To begin the inspection of accessories, the licensee should first locate the packing list and check the number of boxes and crates and identify the location of each one. Crates or containers should be opened, and the contents should be checked against the packing list. A copy of the outline drawing should be located in the pocket of the door in the control cabinet. After these preliminary activities, the inspection of accessories can commence.

8.2 Site-Specific Testing and Inspection Requirements

8.2.1 General Guidance

Depending on site-specific procedures and requirements, there might be cases in which special testing and inspection requirements must be addressed when procuring a replacement major plant component such as a large power transformer. Typically, these special requirements should be established through close coordination between the engineering and QA organizations. The special testing and inspection requirements should be determined as early in the procurement process as possible.

If there is any indication of rough handling, the transformer should remain on the carrier. Both the manufacturer's service department and the transportation company should be notified. The licensee should photograph the damage and note "possible internal or hidden damages" on the receipt for shipping. If the transformer is in acceptable condition, the gas-regulating and sealing equipment should be placed into operation as soon as possible.

8.2.2 Testing and Inspection Performed Before Energizing Transformer

Most large power transformers are shipped with radiators, fans, pumps, valves, pipe sections, bushings, instrumentation, and controls removed. All these items that were tested on the transformer at the factory will be reinstalled on site. After the transformer is reassembled on site, tests should be performed to verify the quality of the field assembly and the installed condition of the transformer.

After the site assembly is completed, the licensee should conduct a visual inspection to verify that all components are installed in accordance with the manufacture's recommendations and that there is no apparent physical damage. The scope of this inspection should typically include the following components:

- Bushings
- Conservator (if included)
- Cooler control cabinet
- Coolers, radiators, and fans
- Dissolved combustible gas monitor (if included)
- Gas detector relay (if included)
- Oil level gauge

- Oil pumps
- Oil temperature gauge
- Pressure relief device
- Sudden gas pressure relays
- Surge and lighting arresters

A final internal inspection should be performed before vacuum testing and filling the transformer with oil. The inspection should be performed in accordance with instructions in Section 8.1.2.2, Internal Inspections After Unloading the Transformer.

The oil filling should be performed in accordance with the step-by-step instructions in the vendor's technical manual. Any change in the fill procedure must be reviewed with the vendor. Precautions should be taken to ensure that oil temperatures are maintained sufficiently high to avoid static electrification, which can result in immediate or delayed failures.

The following electrical tests can be performed when the transformer is fully assembled and filled with oil (although they are not presented in chronological order):

- Transformer turns ratio test. The ratio between the HV winding and the LV winding is measured on all tap positions. The measured ratio for all tap settings is compared to factory test results, nameplate information, and data from the vendor technical manual.
- Polarity test. The voltage between HV winding and LV winding is checked by applying a low-voltage single-phase source to the HV winding. The equivalent terminals of the LV winding and HV winding are connected together (that is, H2 to X2), and the voltage is measured between the other terminals (that is, H1 to X1) of the LV and HV winding. Correct polarity is indicated by this measured voltage being less than the supply voltage.
- Winding resistance measurement. The resistance of each winding is measured, and the value is adjusted for temperature.
- Transformer winding power factor test. Using a power factor test set, measure the insulation power factor and capacitance (milliamps, watts, percent power factor, and capacitance) between windings and between each winding and ground.
- Winding insulation resistance check. The insulation resistance between windings and between each winding and ground are measured. Results should be comparable to the values obtained from factory testing.
- Excitation current measurement. Using a power factor test set, measure the excitation current from the HV winding with the LV winding open circuit. Results should be comparable to the values obtained from factory testing.
- Bushing power factor test. Using a power factor test set, measure the power factor and capacitance (milliamps, watts, percent power factor, capacitance) between each winding and each winding to ground. Results should be comparable to the values obtained from factory testing.

- Core insulation resistance measurement. The insulation resistance between core and ground should be measured.
- Polarity tests. Check the polarity of bushing current transformers (CTs) using the inductive kick method to verify that leads are marked correctly at the termination points.
- Voltage ratio and saturation curve tests. Perform a voltage ratio test and saturation curve test of bushing CTs to verify that the factory test results have not changed.
- Insulation resistance check. Perform bushing CTs insulation resistance check. The insulation resistance to ground should be measured.
- Circuit tests. Test all auxiliary, monitoring, and protection circuits. Perform a point-to-point wiring check with a circuit tester, and ensure that all conductor terminations are tight and at the correct terminal location. Check all cables to ground and conductor to conductor. Verify rotation of power circuits for cooling fans and pumps. Ensure that all conductor terminations are tight and at the correct location.
- Simulated functional test. When possible, simulate typical transformer top oil temperatures and verify that 1) fans and oil pumps operate in automatic and sequence on and off in accordance with the control system design requirements and 2) alarms are annunciated on local annunciators.
- Oil quality tests. Take oil samples for oil quality tests and for dissolved gas analysis (DGA) and verify that the results are in conformance with the purchasing specification. These tests should be a baseline for future in-service oil sample tests.
- Frequency response analysis. Conduct a frequency response analysis. The test is performed at maximum, minimum, and rated tap positions. The results will be a baseline for comparison to future frequency response analyses as well as to show that there has been no structural change during shipment and reassembly at the site. This test should be done while the transformer is in shipping condition for comparison to the factory tests, and then repeated after assembly and filling with oil. (To ensure comparable results, the same type of tests should be performed before and after shipment—that is, sweep frequency response analysis or frequency response analysis—in accordance with applicable test procedures.)

9
STORAGE AND STAGING ISSUES

9.1 Storage Level Determination and Requirements

Nuclear licensees have used the guidance of ANSI N45.2.2, Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants (During the Construction Phase), for many years in establishing the necessary controls to package, ship, receive, store, and handle incoming components and replacement parts for both safety-related and non-safety-related items [57].

Section 2.7 of ANSI N45.2.2 provides detailed guidance on how to classify a procured item with respect to protective measures to prevent damage, deterioration, or contamination of the item [57]. Specifically for large power transformers, the storage level most commonly used is Level C. Items classified to Level C are those that require protection from exposure to the environment, airborne contaminants, acceleration forces, and physical damage.

The EPRI report *Packaging, Shipping, Storage and Handling Guidelines for Nuclear Power Plants* (TR-107101) provides additional, component-specific guidance that might be helpful when replacing a key plant component [58].

9.2 On-Site Storage and Staging Capabilities

Nuclear licensees have used ANSI N45.2.2 guidance for many years in establishing the necessary controls for storing incoming components and replacement parts [57]. During this time, however, licensees have shifted their capabilities more toward the long-term storage of spare and replacement parts, and less toward the short-term storage and staging of large components such as large power transformers that were originally used to construct the plant. With the current requirements to replace certain major plant components, licensees should evaluate methods to again provide adequate storage and staging facilities for these larger pieces of equipment.

The project team should also consider the following issues related to the storage and staging of a large power transformer:

- Structural loading capacity of storage and staging areas
- Division of responsibility among organizations in the supply chain and utility organizations involved in the storage and staging of the replacement transformer to address issues such as the following:
  - Lighting
  - Electrical power
  - Fire protection
  - Compressed air supply
  - Monitoring and periodic testing

The following sections provide general guidelines for short- and long-term storage of a power transformer and its components and accessories. The transformer manufacturer might have specific requirements that must be followed to maintain warranty during the storage period. Each project team should consult with the manufacturer and refer to the instruction book that accompanies the transformer.

9.3 Storage Guidelines

Unless otherwise agreed or specified in the procurement documents, most manufacturers deliver the transformer ready to be placed into service. The transformer manufacturer typically has specific requirements that must be followed to maintain warranty during the storage period.

Note: The licensee should consult with the manufacturer and refer to the instruction book that accompanies the transformer to ensure that proper storage requirements are met.

In the absence of supplier guidance, the general guidelines in the following subsection can be used for the short- and long-term storage of a power transformer and its components and accessories.

9.3.1 Storage of a Large Power Transformer

The information presented in this section is based on the guidelines provided in ANSI/IEEE C57.93 [30].

9.3.1.1 General Storage Guidance

The transformer should be stored on a solid foundation suitable for the anticipated length of the storage. If timbers or cribbing are used, the timbers should be closely and evenly spaced. Transformers should not be stored on rollers, blocks, or jacks.

The preferred method of storage is to store the transformer with the accessories fully installed and the transformer filled with oil. Heaters in the control cabinet should be connected to a power supply and energized to prevent condensation. The transformer tank, installed bushings, and accessories should be grounded, and the unit should be protected from lightning. Oil containment should be provided to contain oil in case of any leaks or spills. In geographical areas with high seismic activity, filling transformers with oil can help to dampen internal motion during a seismic event.

Detailed records, including pressure readings, should be kept of all inspections of the stored equipment. The frequency and recording of inspections might be a condition for maintenance of warranty by the manufacturer.

9.3.1.2 Methods and Duration of Storage

Methods for protecting the active components of the transformer during storage are the same as those used during shipment, which is actually a storage period in itself. They include filling the tank with dry air, dry nitrogen, or dry oil.

Three time periods are typical in terms of storage requirements: less than three months, up to six months, and greater than six months. The time period starts when the unit is without oil as it leaves the factory. Generally, but not universally, storage in dry air is acceptable for less than three months, storage in dry nitrogen is acceptable for up to six months, and oil filling is generally recommended for greater than six months. In such cases, insulation dry-out and oil processing should be carried out in the same manner as if the transformer were being placed into service. Some manufacturers begin the first three-month period from the time of shipment; others begin the period when the transformer is received.

Regardless of the storage period, the best method of storage is to fully assemble the transformer on its permanent foundation and vacuum fill it with oil. When a transformer sits without being oil filled, the impregnated insulation is draining oil. This is the limitation to prolonged storage in dry gas. If the gas is air, the oxygen can combine with residual oil and eventually convert the oil to sludge.

Nitrogen, because it is an inert gas, is more compatible with transformer cellulose-based insulation; however, it can take considerable time to pull a vacuum to remove the nitrogen gas and to purge the gas with dry breathable air before a person can safely enter the unit. In addition, storage under these conditions will require additional processing when filling the unit with oil. Before a transformer is stored in dry gas, the dew point should be checked against the manufacturer’s requirements.

When the transformer is finally vacuum-filled with oil, the vacuum period before oil filling should be extended. A period of extended vacuum of 24 hours is recommended; the period must be at least 1 hour for each month of storage.

When a transformer stored in dry gas is installed, a minimum of 72 hours should be allowed between oil filling and energizing to allow for oil impregnation of the insulation that drained during storage and for clearing of trapped gas bubbles.

Storage for Less Than Three Months

The transformer, filled with dry air or dry nitrogen, must be kept under positive pressure at all times while in storage. Check the manufacturer’s instructions for specific values. An elevated pressure should be initially applied to the main tank for several hours, and the unit should be checked for leaks. Both the reserve air supply and the tank pressure should be monitored and recorded daily during the first week or two as required by the manufacturer. These readings should be taken at approximately the same time each day, and the time and temperature should be recorded. If pressures remain stable, the interval between readings can be extended.

Transformers that are received already filled with oil from the factory can be stored without further attention, but positive pressure must be maintained in the gas space.

Storage for Up to Six Months

Some manufacturers permit storage in dry nitrogen for up to six months, but storage in oil is preferred. An unassembled transformer can be vacuum filled with oil to its proper level, and the space above the oil can be pressurized with dry air or nitrogen. An elevated pressure should be applied for several hours, and the tank should be checked for leaks. Both the cylinder pressure and the tank pressure should be monitored and recorded daily during the first week or two as required by the manufacturer. These readings should be taken at approximately the same time each day, and the time and temperature should be recorded. If pressures remain stable, the interval between readings can be extended.

Alternatively, the transformer can be fully assembled, vacuum filled with oil, and made ready for operation. If the transformer is equipped with pumps, in general the project team should cycle the auxiliary cooling system periodically according to the manufacturer’s instructions. Typically, personnel should run half of the pumps for 30 minutes, and then run the other half for 30 minutes, every three to six months. Otherwise, the transformer should be tested and maintained as though it were operational. Depending on the construction style and environmental location of storage, static electrification can be an issue. The project team should ensure that storage testing methods evaluate static electrification hazards.

Storage for More Than Six Months

The transformer should be fully assembled, vacuum-filled with oil, and made ready for operation. When storing the transformer for more than six months, certain in-storage maintenance activities are typically required. These recommended activities are described in Section 9.4, In-Storage Maintenance Activities.

9.3.2 Storage of Transformer Accessories and Components

Transformer accessories and components include items such as radiators, coolers, tap changers, bushings, pumps and motors, fans and motors, control cabinet, gaskets, connectors, tapes, relays, and gauges. The objectives during storage of these accessories before they are installed on the transformer are to retain control of spare and support auxiliary components, to ensure that environmental storage meets the manufacturer’s requirements, and to prevent deterioration and damage to the equipment.

Certain equipment should be stored in a clean and dry environment. This includes bushings, which should be stored in their shipping crates with their upper parts elevated from horizontal, and components such as relays, connectors, wiring, gaskets, and gauges. If adequate indoor storage is available, the motors and control cabinet, if shipped loose, benefit from indoor storage; otherwise, a silica gel basket should be placed in the control cabinet. Anything stored outdoors should be kept off the ground to keep it out of standing water and should be covered to protect it from weather. Fan motors are very susceptible to corrosion during storage if they are not properly stored. If they are received and stored with drain plugs installed, condensation can occur, accompanied by heavy internal rusting. If they are received without drain plugs installed, the motors must be protected from water ingress. Openings (flanges and tapped holes) to oil-cooling equipment, such as radiators, coolers, and conservator tanks, should be sealed, and if practical, the equipment should be filled with dry gas or oil, particularly if storage of over three months is anticipated.

Transformer mechanism cabinets or LTC mechanism cabinets should be stored indoors or should have their anticondensation heaters connected to prevent internal moisture accumulation or corrosion.

9.4 In-Storage Maintenance Activities

Depending on how long the replacement transformer will be in storage or staged before installation, the project team should determine whether any in-storage maintenance activities are required. The project team should coordinate with the manufacturer to determine what requirements might apply and how often these activities should be performed. The EPRI report *Packaging, Shipping, Storage and Handling Guidelines for Nuclear Power Plants* (TR-107101) stresses the importance of considering in-storage maintenance requirements as a factor when determining the most appropriate packaging, shipping, storage, and handling of items [58].

Typical in-storage maintenance activities for large power transformers are most often required when the transformer will be stored for more than six months. The transformer should be tested and maintained as though it were operational, including annual check of oil quality, condition of silica gel breathers, operational condition of relays, and cleanliness of the complete transformer.

9.5 Licensee Lifting and Handling Capabilities

One of the major considerations when replacing a large power transformer is how the transformer will be physically moved from its mode of transportation to its storage or staging area. In many cases, special lifting and rigging is necessary to safely conduct the move. Detailed guidance is provided in the EPRI report *Lifting, Rigging, and Small Hoist Usage Program Guide* (1007914) and should be used as a basis for determining the most appropriate lifting and handling methods, developing a lift plan, and safely moving the equipment into its storage or staging area [56].

The primary source of lifting guidance should be the manufacturer. When specific guidance has not been provided, the following guidance should be considered. If lifting lugs or holes are provided, always use chains or lifting cables with ratings that are greater than the published weight of the transformer. For larger units, never lift by the tightening bolts, the connections, or the studs around them.

9.6 Materials Management

A primary issue that should be addressed by the project team is ensuring that the replacement transformer and its spare and replacement items are controlled and tracked in accordance with existing, site-specific processes. In most cases, this entails ensuring that the transformer has been assigned the correct equipment identifier and that the spare and replacement items have been assigned appropriate unique stock codes or identifiers.

If spare or replacement parts for the replaced transformer are still in inventory, appropriate personnel should determine whether those parts can be used for other, identical components elsewhere in the plant. If they cannot be used elsewhere, those parts should be purged from the system and properly disposed of.

10
INSTALLATION ISSUES

10.1 Pre-Installation Requirements

10.1.1 Determining the Optimum Access Route

Before installing a major component replacement such as a large power transformer, the project team should evaluate the possible access routes available to move the transformer from its storage or staging area to its final plant location. The evaluation should consider the following factors:

- Requirement for any special lifting or handling equipment
- Impact of routing on plant operations, if applicable
- Impact of routing on existing plant equipment and the extent to which plant modifications might be required in order to physically move the replacement transformer into place
- Personnel safety considerations
- Physical space limitations and known interferences
- Ability to change the physical orientation of the replacement transformer during the routing
- Susceptibility of damage to the transformer during the routing

10.1.2 Establishing Lifting and Rigging Requirements

The primary source of lifting guidance should be the manufacturer. That guidance should be implemented in accordance with the site's lifting and rigging requirements. When specific guidance has not been provided, the guidance provided in this section should be considered.

The EPRI report *Lifting, Rigging, and Small Hoist Usage Program Guide* (1007914) provides a generic process for establishing lifting and rigging requirements that would be appropriate for moving a replacement large power transformer [56]. The report states that the first step in the generic process is to ensure that a technical person or a group of technical personnel adequately plan and evaluate the lift. The qualifications and certifications of the technical personnel should be verified in order to effectively implement the process described in this section. Under no circumstances should a lift be conducted relying solely on an individual's skill-of-the-craft knowledge or experience.

EPRI report 1007914 stresses that in order to ensure safe and effective lifting, each lift should be planned and evaluated, as needed [56]. Typically, the evaluation should include at least the following elements:

- Analyze the load
- Determine the weight of the load
- Determine the load's center of gravity
- Establish the means to stabilize the load
- Consider clearances available and the load path
- Consider the history of similar lifts and lessons learned

Each step of the process is detailed in the report, and should be used when replacing a major plant component such as a large power transformer [56].

10.1.3 Developing a Lift Plan

The lift plan can vary depending on the complexity of the lift, the weight of the load, the criticality of the equipment being lifted, or the schedule. Lift plans can vary in the level of detail contained in the plan, the degree to which the utility's engineering organization is involved in its development, and the degree to which the plan can be used generically. The lift plan can constitute a checklist, and can include sketches or drawings as means to convey the conduct of the lift. Some lift plans are applicable to only one lift, whereas some are generic for a particular type of lifting or rigging equipment. Lift plans can be grouped into the following types:

- Pre-engineered lift plans with significant engineering involvement
- Preplanned lifts that are primarily driven by the scope of the work order
- Field-planned lift plans that are developed in the field by craft personnel
- At-the-job lift plans developed solely for one particular lift

10.2 Interferences

Ideally, physical interferences should have been identified during the design phase of the project when all interface points were identified and evaluated. The project team should consider the use of optical scanning technology and three-dimensional modeling as tools to assist in identifying and addressing physical interferences.

However, cases can arise in which the physical layout of the plant does not match drawings, and interferences can result. In these cases, the project team should implement existing procedures for resolving nonconformances, and depending on the severity of the interference, coordinate resolution with various engineering disciplines and organizations as necessary.

10.3 Plant Conditions (On-line Versus Outage) for Installation

The project team should clearly establish, as early in the design and specification process as possible, whether the transformer replacement will occur when the plant is on-line or if it must be replaced during an outage. The EPRI report *Guidance for Developing and Implementing an On-Line Maintenance Strategy* (1009708) can be used when making this key decision [59]. Unless the transformer is small or skid mounted, the replacement is typically performed during an outage and not while the unit remains on-line.

10.4 Expertise Required to Install the Equipment

During the design and specification phase of the project, the project team should determine who is best suited to install the replacement transformer. In some cases, the manufacturer of the equipment will also be the installer. When this is the case, the specification provided to the manufacturer can include both procurement and installation requirements. Work done in this manner is often referred to as a design, procure, install contract or a turnkey contract. In these cases, the project team can typically delegate the authority to the transformer manufacturer to provide the craft labor and technical skills required to complete the entire installation. Any shortfalls in personnel availability, expertise, or certification should be addressed by the project team and should be met using alternative sources. In most cases, it is recommended that the manufacturer’s technical representatives be present during installation activities.

10.5 Sequence of Installation Steps

The information presented in this section is based on the guidelines provided in ANSI/IEEE C57.93 [30].

10.5.1 General Guidance

The sequence of installation steps should be closely coordinated between the project team, the component manufacturer, and the installer (if different than the manufacturer).

If the transformer will be replaced during a system outage, the sequencing should begin with the safe shutdown of the system. The sequencing should also include the following:

1. Integrate activities into the overall outage or work schedule (a readiness review is recommended to ensure that the sequence is feasible).
2. Complete all necessary demolition work and remove existing equipment.
3. Perform design modification of existing SSCs to accommodate the new transformer.
4. Disconnect, protect, and reroute mechanical, electrical, and instrumentation and control interfaces.
5. Handle the new component as it is moved through its access route.

6. Place the transformer.
7. Reconnect the interfaces.
8. Perform in-process testing and inspection.

10.5.2 Key Installation Issues Related to Large Power Transformers

Foundation. The foundation should provide direct support of the transformer's base so that the transformer is not damaged by its own weight. If necessary information is not provided on the outline drawing, the manufacturer should be contacted, depending on the particular base design.

Foreign materials. Care should be taken before connecting any piping to the transformer to ensure that all foreign objects have been flushed out of the system. The project team should ensure that foreign material exclusion precautions are taken during assembly and installation of the transformer.

Pipes. Ensure that no excessive stress is placed on the transformer by the cooling equipment.

Working space. It is necessary to leave an adequate amount of free space around the equipment to provide access and make future service possible.

An example of an installation and startup checklist for a large power transformer is provided in Appendix H, Example of a Transformer Installation and Startup Checklist.

10.5.3 Assembly of the Transformer

The transformer manufacturer typically has specific requirements that must be followed to maintain warranty during assembly of the transformer.

Note: The licensee should consult with the manufacturer and refer to the transformer instruction book to ensure that assembly follows the detailed process provided.

In the absence of supplier guidance, licensees can use the general guidelines provided in the following subsections for the assembly of a power transformer. This information is based on industry guidance provided in ANSI/IEEE C57.93 [30].

10.5.3.1 General Guidance

The transformer tank and bushings (if installed) should be solidly grounded before the start of installation. Ensure that all safety and environmental codes are understood and followed by all the people involved. Always refer to the manufacturer's instruction manual before and during assembly for the manufacturer's specific assembly requirements.

Moisture ingress should be minimized by opening only the necessary tank access ports at any time. Ensure that all the tools required for the assembly operation are readily available to avoid unnecessary exposure of the core, coils, and insulation to moisture. To prevent unnecessary, prolonged exposure, avoid opening two or more access ports that result in air drafts inside the tank of the transformer. If rain or other precipitation is expected, seal or protect all openings from moisture ingress. During the entire time that a transformer is open, it is advisable to continuously purge the transformer with cold (≤58°F [≤50°C]), dry air.

After the internal inspection has been completed, bushings, radiators, and cooling equipment should be installed. The radiators, coolers, and bushings will be handled in different ways as prescribed by the manufacturer of the equipment, but in general they should be lifted vertically during handling and installation. This equipment must be free of condensation or other forms of precipitation before installation. Many different types, thickness, and shapes of gaskets can be used in assembling the various components. The manufacturer usually provides specific instructions for these. If temporary shipping covers or bushing pockets are used, remove and replace them with the permanent device, and pressure test the transformer. There might also be temporary internal shipping braces that must be removed.

The manufacturer might require liquid filling before the shipping cover is removed. Evacuate the transformer and fill it with breathable dry air, making certain that the oxygen content of the entire gas space is between 19.5% and 23%. The carbon monoxide level should be <25 ppm (<25 mg/kg). During the internal work, such as internal inspection or installation of bushings, maintain a continuous supply of breathable, dry air for the safety of personnel and to minimize the entrance of moisture. Continue to monitor the internal air quality while people are working inside the tank. If internal work will take more than one day, the transformer should be sealed under positive pressure overnight. Ensure that a pressure regulator is installed in the dry air tanks to prevent overpressure in the transformer tank during this process. The transformer should then be purged with breathable, dry air before work is resumed. Manufacturers might require that the dew point be monitored during the assembly process.

Extra gaskets are often provided so that gaskets used during shipping can be replaced with new gaskets for final assembly, If this is the case, ensure that the shipping gaskets are removed so that gaskets neither fall into the transformer nor remain in place, which can result in stacked gaskets that will not seal properly.

10.5.3.2 Assembly of Bushings

Bushings should be absolutely clean and dry when installed. Gaskets and gasket recesses should be carefully cleaned. Gaskets should be carefully placed and uniformly clamped so that tight seals are formed. Current-carrying connections should be thoroughly cleaned and solidly bolted. Cone-disk washers, if used to maintain bolt pressure, should be compressed to the manufacturer’s recommendations. The bushing central cavity should be swabbed to remove particulate contaminants. Instructions for handling the high-voltage bushings should be included with the bushing crate.

When the transformer bushings are to be externally connected to a rigid bus or tubing bus, provision must be made for thermal expansion of the conductors in order to prevent excessive mechanical stress on the bushing. Mechanical loading on ends of bushings should not exceed design limits.

The bushing should undergo power factor and capacitance testing before it is installed onto the transformer. When a test tap is provided, regardless of bushing size or rating, the capacitances of the C1 and C2 insulation areas should be measured. It is important to determine whether the bushing should be operated with the test tap grounded or ungrounded when the transformer is placed in service. Furthermore, the installation of bushing monitoring systems (if supplied) should be reviewed with the manufacturer of the transformer and bushing to ensure that there are no unintentional stresses on the bushing. After bushings are installed, they should be grounded.

10.5.3.3 Assembly of Heat Exchangers and Piping

If the coolers or radiators are opened when they are at a lower temperature than the ambient air, condensation can take place that will be difficult to completely remove. Radiators, coolers, piping, valves, pumps, and fittings, especially those that are unsealed in shipment or are never assembled to the transformer in the factory, should be thoroughly cleaned and flushed (if contaminated) with clean, warm (77–95°F [25–35°C]) dielectric liquid before being fitted to the transformer. Ensure that all gaskets are properly seated on the gasket seats at the time of installation. If it is necessary to mount a gasket in a vertical plane, the use of gasket cement to hold the gasket in place during installation might be required. The manufacturer’s installation supervisor should provide guidance in this installation.

Radiators or heat exchangers are usually capable of withstanding full vacuum. If they are not, they should not be installed until after the tank has been filled with dielectric liquid under vacuum. If liquid-to-water heat exchangers are provided, it is recommended that the water passage be drained and vented to atmosphere before drawing a vacuum on the transformer tank. Pressure test the liquid passages of the heat exchangers with filtered dielectric liquid.

10.5.3.4 Assembly of Other Accessories

The liquid-level gauge, temperature gauges, and other accessories should be installed in accordance with manufacturer’s instructions. Gas detector relay piping, which is removed for shipment, will usually have breakpoints identified to facilitate reassembly. Check the tap winding ratio and the operation of the tap changer to be sure that it operates properly in both directions and that full contact area on all taps and adequate contact pressure is maintained on all contacts. A winding ratio test on the de-energized tap changer is recommended before filling the transformer. Check the operation of the liquid-level gauge before sealing the tank. The conservator tank and associated piping should be inspected and cleaned as necessary to remove any debris. All current transformers should be checked for ratio and polarity before filling the transformer. If they are present, all fiber optic winding and oil temperature probes should be tested for proper operation before oil filling the transformer. Install a refrigerated condenser on the tank cover, if necessary, for drying the transformer. The core should be tested to ensure that there are no unintentional grounds.

10.5.3.5 Assembly of Control Systems

Control systems for modern transformers have many sensitive electronic components. To avoid damaging those components during installation and commissioning, refer to the instruction manuals provided by the manufacturer.

10.5.4 Vacuum Treatment

The transformer manufacturer typically has specific requirements that must be followed to maintain warranty during vacuum treatment of the transformer.

Note: The licensee should consult with the manufacturer and refer to the transformer instruction book accompanying the transformer to ensure that detailed instructions regarding vacuum treatment are followed.

In the absence of supplier guidance, licensees can use the general guidelines provided in the following subsections for vacuum treatment of a power transformer and its components and accessories. Many smaller transformers in this size range do not require preliminary oil filling or heating of the core and coils before vacuum filling. Check the manufacturer’s specific requirements. If field drying of the insulation because of moisture ingress is not required, as determined by moisture content in terms of temperature, pressures, and dew point, proceed with vacuum treatment and final filling as described in the following subsections.

10.5.4.1 Cautions

Ensure that the transformer tank and all fittings, including the conservator tank, radiators, pumps, and valves, are suitable for vacuum. The conservator tank and bladder, if present, must be pressure equalized. If any of these fittings are not designed to withstand vacuum, they must be removed or valved off.

Ensure that the LTC is suitable for vacuum or has its pressure equalized. Also ensure that instrumentation is suitable for vacuum (older Hydran brand sensor units must usually be not only isolated but also removed from the transformer during application of a vacuum). Finally, ensure that no additional structure load is to be put on top of the transformer under vacuum. Work on top of a transformer under vacuum should be avoided. A transformer under vacuum should not be moved.

10.5.4.2 Preparation of the Transformer

Leave the pressure-relief device blanked off until after the final vacuum filling, unless the manufacturer's instructions indicate that the device can withstand full vacuum. If separate liquid-expansion tanks, inert-gas equipment, or other devices that will not withstand full vacuum are provided, they should be isolated from the main tank before the vacuum is applied. In some transformers, the barriers between the main tank and other compartments such as the wall-mounted and insert-type LTC will not withstand full vacuum on one side with atmospheric pressure on the other side. Where such conditions prevail, equalized vacuum, or at least a partial vacuum, must also be established on the other side so that the pressure differential will not damage the barriers.

In addition, care should be taken to ensure that there are no rigid external connections made up to the bushings, tank-mounted arresters, or insulators during vacuum operation. Tank deflections to these items with rigid connections to the porcelains could result in porcelain breakage. After all parts have been assembled, the tank should be sealed and pressure tested to ensure that all joints are tight. Pressure test the entire assembly at a minimum gauge pressure of 2 lbf/in^2 (14 kPa) and a maximum gauge pressure of 5 lbf/in^2 (35 kPa). Some manufacturers also recommend using a vacuum test to determine that the pressure rise with the tank sealed does not exceed manufacturer's recommendations.

With either pressure or vacuum tests, it is important to be sure of the pressure differential conditions permissible on the LTC diverter switch barrier board, which might not be capable of withstanding any pressure differential. Check all gasketed joints with a suitable leak detector. The tank should hold the gas pressure for at least 4 hours without leakage. All leaks detected in this manner must be eliminated before starting the vacuum filling. Table 10-1 lists a number of precautionary notes regarding the preparation of the transformer. These precautionary notes were adapted from information provided in ANSI/IEEE C57.93 [30].

Table 10-1
Precautionary Notes for Preparing the Transformer for Installation

Note	Cautionary Guidance
1	Any air leakage into the transformer tank while a vacuum is being drawn on the transformer can seriously contaminate the transformer insulation. When drawn into a vacuum, air expands and drops in temperature, consequently releasing moisture. If the core and coils are cold, the moisture released from the air will condense on these parts and will be absorbed into the paper insulation. To avoid this hazard, all leaks should be eliminated before starting the vacuum processing, and the core and coils can be heated. This can be done by applying heat externally, by short circuiting, or before vacuum treatment, by partially filling with dielectric liquid circulated through a heat exchanger. If external heat is applied, it must be at a moderate temperature to avoid overheating the insulation. The method of applying current to heat the windings is considered risky and is not recommended. Recommendations of the manufacturer regarding the maximum allowable temperature should not be exceeded.
2	As an aid to field personnel using vacuum equipment calibrated in various units, a table is included in ANSI/IEEE C57.93 for ready conversion.
3	If a liquid other than conventional transformer oil is used, personnel should check with the manufacturer regarding specific procedures to follow concerning testing, filling, handling, and using the liquid. A small amount of silicone-based oil will cause extreme frothing of conventional hydrocarbon-based mineral oil when it is vacuum processed.

If preliminary liquid filling was used and all leaks have been eliminated, drain the liquid and proceed with the vacuum treatment. The liquid can be drained as quickly as desired, but a rapid rate can create a partial vacuum within the tank. The drain valve should be closed immediately after the tank is empty to prevent entrance of air through the drain connection. Because unforeseen delays can occur before the vacuum treatment is applied, it is recommended that the dielectric liquid be replaced with dry gas during the draining process. Be certain that sufficient gas cylinders are available to fill the tank. After the liquid drain valve is closed, continue to admit dry gas until a positive gauge pressure exists in the tank.

10.5.4.3 Vacuum Treatment

The principal function of vacuum treatment is to remove trapped air and moisture from the insulation and enable the insulation to attain its full dielectric strength. Small gas bubbles have much lower dielectric strength than that of the dielectric liquid, and they can lead to failure if they are located at a point of high stress. Removing most of the gas from the transformer and from the liquid by vacuum filling greatly reduces the hazard of the small bubbles of free undissolved gas that remain in the windings and insulation. Vacuum alone might not be adequate for excessive moisture removal; heating of the core and coils might also be required at lower ambient temperatures.

The degree of vacuum required depends on the voltage rating of the windings and insulation; it should be determined in consultation between the manufacturer and purchaser before assembly begins. In general, a vacuum treatment at pressures of the order of 2 mmHg (266.6 Pa) absolute pressure might be sufficient for transformers rated less than 138 kV. For higher-voltage transformers, vacuum treatment at pressures of <1 mmHg (<133.3 Pa) absolute pressure might be required. An additional benefit of treatment at high vacuum is that the moisture introduced into the transformer insulation during assembly can be removed before the transformer is energized.

A vacuum pump capable of evacuating the tank to the required degree of vacuum in approximately 2–3 hours is recommended. Connect the vacuum pump to the vacuum fill connection on top of the transformer with pipe or reinforced hose of sufficient size to minimize line losses. If no connection was provided for this purpose, an adapter plate for the pressure-relief outlet, with a suitable pipe connection, can be fabricated. In order to obtain an accurate vacuum value, it is essential that the connection of the gauge or manometer be as close to the tank as possible and preferably at a different location from the vacuum hose. Check all pipe joints for leaks by pulling a high vacuum or by pressure testing before connecting to the transformer. Close all liquid and gas valves. Start the vacuum pump and continue pumping until the tank pressure is constant. Close the vacuum pump valve, and check for leaks in the tank or piping. If all joints are tight, there should be no appreciable increase in residual pressure (the rate of rise depends on the volume of oil in the transformer, but it is typically <1.0 mmHg [<133.3 Pa] in 30 minutes).

10.5.4.4 Vacuum Leakage Tests

Detailed guidance for performing vacuum leakage tests is provided in ANSI/IEEE C57.93, and the testing is based on the 1982 *CEA Commissioning Guide for Electrical Apparatus* [30, 60]. An excessive leak rate can be dangerous to transformer insulation when a large capacity vacuum pump is used. Atmospheric air will enter the transformer and can deposit moisture in the transformer.

10.5.4.5 Processing Dielectric Liquid

If dielectric liquid is delivered in tankers or drums, check the quality of the fluid while it is still in the containers. For acceptable properties of the insulating liquid as received, after processing, and before energization, consult manufacturer- and site-specific instructions and IEEE C57.106 [35].

If liquid-storage facilities are available, a sufficient quantity of new dielectric liquid to fill the transformer should be dried and stored in the clean liquid-storage tank with a desiccant dryer before starting to fill the transformer. If liquid-storage facilities are not available, continue circulating dielectric liquid through the processing equipment until the prescribed dielectric strength is consistently obtained. A sample of the liquid should be taken before filling and retained for future checks such as power factor tests.

Dielectric liquid passing through filter papers or ungrounded or unbonded hoses can acquire an electrostatic charge that will be transferred to the transformer windings as the transformer is filled. Under some conditions, the electrostatic voltage on the winding can be hazardous to personnel or equipment. To avoid this possibility, all externally accessible transformer bushing terminals, the tank, and the liquid filtering equipment, including oil hoses, should be properly grounded during filling.

10.5.4.6 Vacuum Filling

After attaining the required vacuum and holding the vacuum for the required period of time according to the manufacturer’s instructions, filling can begin. Fill with processed, warm dielectric fluid, as specified by the manufacturer. An oil temperature of 140–176°F (60–80°C) is recommended because higher-temperature oil will speed up the impregnation of solid insulation.

The dielectric liquid should be introduced from a point opposite the vacuum pump above the core and coils in such a manner that it will not stream on the paper insulation. Fluid inlet and vacuum connections should be separated as far as possible to keep liquid spray from entering the vacuum pump. The liquid line should be connected to the upper filter-press connection or other suitable connection on top of the tank. The processed liquid is admitted through this connection, with the rate of flow regulated by a valve at the tank to maintain a positive liquid pressure external to the tank at all times and to maintain the vacuum at or near its original value. The filling rate should not exceed 0.5 in./min (1.25 cm/min).

Filling, at least to a point above the core and coils, should be in one continuous operation. If the vacuum is broken for any substantial period, it might require draining and refilling to prevent formation of gas bubbles. Maintain a positive inlet liquid hose gauge pressure during the entire filling process. Gas bubbles or water in the liquid will expand in proportion to the vacuum obtained and will be drawn out by the vacuum pump.

Do not allow dielectric liquid to enter the vacuum pump. For transformers with nitrogen pressure systems, fill the tank to the indicated level; for conservator-type transformers, fill as high as possible (perhaps 4 in. [10.2 cm] from the top) before removing the vacuum. Break the vacuum with dry bottled gas to a positive pressure. For nitrogen pressure systems, this should be a gauge pressure of 2–5 lbf/in^2 (14–35 kPa).

To remove vacuum equipment for nitrogen-pressure-type transformers, activate the automatic gas equipment and maintain continuous positive pressure. For conservator-type transformers, install the conservator and any remaining fittings and accessories. Complete the filling of the transformer, and fill the conservator in accordance with the manufacturer’s instructions. It is recommended that the pressure-relief device be installed before oil filling. Overfilling without pressure relief can cause tank damage.

To bleed off any trapped air, open all designated vent points until a solid stream of oil emerges after operating the pumps, in case of forced-oil-cooled transformers. The assembled transformer should not be energized until a certain period of hold time as has elapsed, in order to allow the insulating oil to absorb residual gas and thoroughly impregnate the insulation. Recommended hold times are provided in Table 10-2.

Table 10-2
Recommended Hold Times Before Energization [30]

Voltage Class	Hold Time Before Energization (Hours)
69 kV	12
138 kV	24
230 kV	24
345 kV	48
500 kV	48
765 kV	72

10.5.5 Field Drying of Insulation

If the internal inspection reveals signs of moisture in the transformer or if the gas seal on the tank was damaged in transit, field drying might be necessary. If possible, determine the extent of the moisture and the manner in which it entered the tank. Ask the transformer manufacturer for recommendations concerning additional checks and steps for drying out the transformer. The goal of field drying is to attain a comparable value of residual moisture content to that found in the factory. If drying is determined to be necessary, one or more of the following methods can be used:

- Circulating hot oil. This method is slow and is not as effective as the vacuum methods
- High vacuum. This method is used with and without heat. Heat increases the efficiency and decreases the drying time required. It is the method generally used for large megavolt ampere units, for high voltage, and for reduced insulation classes.
- Hot air. The method is not as effective as the vacuum method.

Other methods or combinations of these methods can be used if facilities are available. The equipment detailed in Annex C.1 of ANSI/IEEE C57.93 provides the necessary capability for the vast majority of cases [30]. A thorough knowledge of vacuum technology and of vapor pressure will greatly assist field personnel in their job performance. Detailed guidance regarding the implementation of these methods is also provided in ANSI/IEEE C57.93 [30].

10.5.6 Completion of Drying

As soon as the transformer is considered dry, it is essential that the tank be immediately filled with dielectric liquid to cover the core and winding. Filling under vacuum is much preferred. During the entire drying process, regular readings of winding temperatures and of insulation resistance between windings and between each winding and ground should be recorded.

Some methods of measuring insulation resistance and power factor can result in excess voltage stress on windings that are not in oil. As the drying proceeds, the insulation resistance will fall as a result of the increase in temperature and release of moisture. The resistance will then begin to rise; the rate of increase slows down as the drying nears completion. When the insulation resistance flattens out to a constant value, the transformer is not completely dry but it has reached the maximum degree of dryness obtainable with the drying system being used.

Power factor tests can be used instead of or in addition to insulation resistance tests for determining the progress of the drying. The power factor will increase as the temperature increases, decrease as moisture is extracted, and flatten out as the drying nears completion.

Caution: An explosive mixture of liquid vapors and air might exist at some stages in the drying procedure.

10.5.7 Reprocessing

Reprocessing is performed on a transformer to increase the dielectric strength of the transformer's internal insulation system. It is the most common field method for drying and re-impregnating the cellulose insulation. Reprocessing is not typically required for the majority of new medium or large power transformer installations. Reprocessing on new or aged transformers should not exceed the mechanical or thermal design limitations of the transformer or the transformer's ancillary equipment. Reprocessing can be performed for the following reasons:

- The transformer manufacturer might require reprocessing for the installation of a new transformer. When reprocessing is required, the manufacturer should provide the process criterion along with limiting mechanical and thermal criterion as part of the instruction literature.
- The transformer manufacturer might require reprocessing on a new transformer for the following additional reasons:
  - The transformer core or coil assembly has been out of oil for a period of time that will require re-impregnating the cellulose insulation. The period of time and reprocessing criterion should be determined by the original manufacturer and the licensee, based on all available information on the existing insulation condition.
  - It has been determined that the cellulose insulating materials absorbed an unacceptable amount of moisture during shipment or storage.
- The licensee might determine the need to reprocess a transformer for one of the following reasons:
  - It is deemed necessary to re-impregnate the cellulose insulating materials after they have been out of oil for a prolonged period of time.
  - It is deemed necessary to remove excessive moisture from the transformer's insulating system (cellulose or oil).

10.5.7.1 Considerations for Reprocessing

The most important factors to increase the dielectric strength of the insulation system using reprocessing are temperature, vacuum, and set time (often referred to as absorption). These factors are required to remove moisture from the transformer oil, to remove moisture from the cellulose insulation, or to re-impregnate the cellulose insulation. The intent is to heat, filter, and degas the oil while circulating the oil through the transformer tank under vacuum. After heating the cellulose, the oil is drained from the tank and vacuum is applied to the exposed, heated, cellulose insulation. Final oil filling can occur after using one or more of the following methods to determine dryness:

- Attaining a designated period of vacuum time
- Monitoring the oil quality, vacuum, and moisture extraction
- Measuring the amount of extracted water
- Monitoring the relative humidity and dew point of the internal tank

After the set time is attained, an insulation power factor measurement is recommended; it should be the final verification of the integrity of the insulation system.

10.5.7.2 Methodology for Reprocessing and Absorption

This section provides generic field instructions for reprocessing and transformer set time before energization. In addition to the cautionary notes provided with the items in this section, the manufacturer’s instruction literature should be consulted for other electrical, mechanical, or thermal design limitations that can prohibit the use of this or other reprocessing field processes. Mechanical and thermal recommendations for reprocessing are described in this section.

Oil should enter the transformer tank through the top main cover or at the top main tank walls as close to the cover as possible. Table 10-3 lists a number of precautions that should be considered when reprocessing a large power transformer. These precautionary notes were adapted from information provided in ANSI/IEEE C57.93 [30].

Table 10-3
Precautionary Notes for Reprocessing the Transformer

Note	Cautionary Guidance
1	If ambient temperatures are 41°F (5°C) or less, the oil should be heated gradually and directed so that it does not splash on porcelain bushings. Failure to comply can break the bushing porcelains as a result of thermal shock.
2	Most field processing units are capable of heating transformer oil above 185°F (85°C) using resistive heating elements or other means through heat exchangers. Field heating of transformer oil above 185°F (85°C) can scorch the oil, causing combustible gases to dissolve in the oil. These gases can misrepresent the baseline of future DGA. Vacuum connections should be at the top of the transformer tank, as far away from the oil entrance as possible.
3	Review the transformer instruction literature to ensure that the main transformer tank, auxiliary tanks, terminal boards between compartments, and all ancillary items are rated for designated full vacuum (14.7 psi [103 kPa]) at elevated temperatures. Epoxy or nonmetallic terminal boards might not be rated for full vacuum at elevated temperatures. Ancillary devices such as fault pressure relays or monitoring devices might require removal or valving off, if they are not rated for full vacuum.
4	Conservator tanks with rubber bladders can be designed for full vacuum. Before applying vacuum to a conservator tank designed for full vacuum, ensure that the conservator tank and the rubber bladders are in equalization. Vacuum applied to the conservator tank without equalization to the rubber bladder can damage or weaken the rubber bladder.
5	If external bushing connections are made, be certain that there is sufficient slack in the external line connections to allow for bushing movement caused by flexing of the transformer cover or walls. Failure to relieve this stress at the bushing connection can result in damage to the bushing seals and loss of oil.

Oil discharge from the main transformer tank should be from the bottom of the tank. A positive-displacement oil pump should be used at the tank discharge valve within 5 ft (1.5 m) of the tank wall. Vacuum should be maintained at the best possible level with the lowest possible oil level in the transformer tank to maintain oil discharge without pump cavitation. A minimum oil head of approximately 3 ft (91 cm) is required to maintain oil flow (5.3 cfm [2.5 L/s]) under full vacuum with a positive displacement pump. The vacuum level will initially be affected by the oil quality and moisture level in the oil. Ideally, the oil level in the main tank should be below all major insulation. Additional recommendations for the oil circulation and vacuum drying process include the following:

- Before vacuum and oil circulation, close all the bottom valves to cooling equipment. Close all valves to ancillary items that will not withstand full vacuum.
- Oil circulation through the tank should continue until the moisture and gas content of the oil are acceptable and the cellulose insulation is heated sufficiently to facilitate moisture extraction under vacuum.
- When ambient temperatures are less than 32°F (0°C), an oil level greater than 3 ft (91 cm) might be necessary to act as a heat sink to obtain the desired temperatures. Thermal blankets on the exposed tank walls might also be necessary.

- Circulate 185°F (85°C) oil through the tank until the oil discharge temperature stabilizes at 122°F (50° C) or greater.
- When the oil discharge temperature stabilizes at ≥122°F (≥50° C), drain the oil to a level below the coil assemblies or drain it completely.

Vacuum should be applied as indicated in Table 10-4 based on one of the following options:

- Attaining a designated period of vacuum time
- Monitoring the oil quality, vacuum, and moisture extraction
- Measuring the amount of extracted water
- Monitoring the relative humidity and dew point of the internal tank

Table 10-4
Recommendations for Vacuum Drying (Insulation Exposed) and Final Oil Fill [30]

Voltage Class (kV)	Vacuum (mmHg) Final Oil Filling
69	1000 µm (1 mmHg)
138	1000 µm (1 mmHg)
230	1000 µm (1 mmHg)
345	750 µm (0.75 mmHg)
500	500 µm (0.5 mmHg)
765	500 µm (0.5 mmHg)

Table 10-5 provides recommended minimum set times (absorption), after final oil fill. Extended set times can be required if the core or coil assembly was out of oil for a prolonged period.

Table 10-5
Recommend Minimum Set Times after Final Oil Fill [30]

Voltage Class (kV)	Minimum Set Time, Absorption (Hours)
69	48
138	48
230	48
345	60
500	72
765	96

The final verification of the dielectric strength of the insulation system should be determined by an insulation power factor test. An acceptable insulation power factor value for a new transformer is <0.5% or the value specified by the manufacturer (refer to IEEE 62, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus, Part 1: Oil Filled Power Transformers, Regulators, and Reactors, Clauses 6.1.6.2 and 6.1.6.8) [61].

10.6 Special Tools and Accessories Required

The information presented in this section is based on the guidelines provided in ANSI/IEEE C57.93 [30].

The project team should have identified any requirements for special tools during the installation of the replacement transformer when the transformer manufacturers were initially being reviewed and selected. The transformer manufacturer typically has specific tools and accessories that must be used when assembling and installing the large power transformer in order to maintain warranty of the equipment.

Note: The licensee should consult with the manufacturer and refer to the transformer instruction book to ensure that proper tools and accessories are used.

In the absence of supplier guidance, use the information in this section as a brief overview of special tools and accessories that are often required during transformer assembly and installation.

During installation, the project team should ensure that the appropriate tools are available, have been inspected, are being used properly, are calibrated, and are being used by qualified or certified personnel. Specifications can vary depending on the size of the transformer and the ambient temperatures. The following special tools and consumables should be made available during the installation of the transformer:

- A degasification trailer capable of delivering 30 gpm (1.9 L/s) at 158°F (70°C), <10 ppm (<10 mg/kg) water, 190 kW heating capacity. The trailer intake filter should be 0.197 mil (5.0 µm), and the trailer discharge filter should be 0.0197 mil (0.5 µm). The oil heating should be done with heaters of 3.23 W/in^2 (0.5 W/cm^2), or other limitation described by the manufacturer, to avoid damaging the oil.
- A vacuum pump with a capacity of 150–300 cfm (70–140 x 10^{-3} m^3/s) or greater and attainable blank-off pressure of ≤0.02 torr (2.67 Pa). A booster pump of 1200–1600 cfm (0.57–0.76 m^3/s) is an additional option.
- Positive displacement pumps (40 gpm [2.5 L/s] or more) for oil discharge from the main transformer tank.
- Optional monitoring and test equipment, including the following
  - On-line total dissolved gas monitor
  - On-line hygrometer or standard dew point equipment

– Cold trap for cryogenic-vacuum processing
– Moisture content and dielectric strength oil test equipment
– Oil power factor tester and insulation power factor tester

The project team should also ensure that adequate drainage is available.

10.7 Special Quality Control Requirements

Another issue related to replacement of a large power transformer is the requirement for special quality controls during the installation phase. In most cases, the project team should coordinate quality control activities with the QA organization during the design and specification phase of the project. In some cases, industry codes and standards will dictate that certain quality controls be applied during the installation. The equipment manufacturer and the installation contractor might also prescribe certain quality controls.

The project team should address the requirement for quality controls during the development of the installation specification. Typical activities that can require quality controls and documented evidence of satisfactory completion include 1) witness and hold points for inspection and testing during the installation process and 2) in-process testing required during installation, which can necessitate special provisions to enable the inspections to occur.

10.8 Personnel Safety Issues

The project team should ensure that personnel safety issues addressed in the installation specification are mitigated during the installation of the replacement transformer. Typical concerns that might apply when replacing a major plant component include the following:

- Working in proximity to equipment being lifted
- Working in a high-temperature or high-humidity environment
- Working in confined spaces

It is the responsibility of each person operating or repairing equipment to take the necessary precautions to comply with all applicable safety regulations. The project team should ensure that personnel involved in the installation of the replacement component meet all applicable requirements of OSHA and the ANSI/IEEE C2 National Electrical Safety Code [21].

10.9 Post-Installation Testing

10.9.1 General Guidance

The project team should ensure that post-installation testing is conducted in accordance with the requirements specified in the installation specification and the manufacturer's recommendations, including oversight by the manufacturer's field engineer or supervisor. The project team and manufacturer should work closely to establish the following:

- Baseline performance criteria for the replacement transformer
- System operating conditions under which the transformer will be tested
- Acceptance criteria for meeting established performance standards
- The type of post-installation test that is most appropriate for measuring performance data
- Procedures and instructions for conducting the post-installation tests
- Qualification requirements for personnel conducting the prescribed tests
- Means of measuring the results of the post-installation tests
- Benefits of preservice and in-service inspections
- Instrumentation and calibration requirements

The project team should ensure that all warranty-related baseline testing is included (transitioning from acceptance into routine maintenance activities).

10.9.2 Functional Tests

Proper operation of various auxiliary devices can be confirmed by performing these functional tests:

- Verify that the appropriate groups or banks of cooler pumps and fans operate at the appropriate set points.
- Verify that all alarms operate at appropriate set points.
- Verify that remote locations receive alarms, if applicable.
- Cycle the load tap changer both manually and electrically.

Some utilities prefer not to include a no-load (de-energized) tap changer in their regular maintenance list because after the tap setting is chosen and set, there is no movement of the tap changer contacts while the transformer remains in operation. The decision not to cycle the tap changer has caused tap changer failures in older equipment. When the tap changer was cycled, contacts were not completely made, and the transformer failed when it was energized.

Other utilities prefer to cycle the no-load tap changer to ensure its electrical and mechanical integrity. After the tap changer is cycled, a transformer turns ratio test is performed to verify that the contacts are made up and that there is no open circuit. Consult the tap changer manufacturer because some require the tap changer to be exercised during maintenance outages and others do not.

10.9.3 Tests After the Transformer Has Been Assembled and Filled with Dielectric Liquid

Tests should be performed and the test reports preserved to ensure that the transformer is ready for service and to provide a basis for comparison with future maintenance tests. The following tests are suggested. All or any portion of these tests can be made, depending on the equipment available and the importance of the particular transformer.

- Test the insulation resistance on each winding to ground and between windings.
- Test the insulation power factor or dissipation factor on each winding to ground and between windings. Capacitance should also be measured on each connection, and core insulation should be tested.
- Test the power factor or dissipation factor on all bushings equipped with a power factor tap or capacitance tap. Both C1 and C2 insulation should be measured.
- Perform a transformer turns ratio test on each tap. If it is an LTC transformer, check the winding ratio on all LTC positions.
- Check the winding resistance of all windings with a Kelvin bridge or another suitable test device and compare with factory test results.
- Check the operation of liquid-level and hot-spot temperature indicating and control devices.
- Check the dissolved gas, dielectric strength, power factor, interfacial tension, neutralization number, and water content of the dielectric liquid.
- Check the oxygen content and total combustible gas content of the nitrogen gas cushion in sealed tank transformers. A total combustible gas test, if applicable, and a test of the dielectric fluid for dissolved gas in oil should also be performed soon after the transformer is in service at operating temperature, in order to provide a suitable post-energization reference benchmark.
- Check the operation of auxiliary equipment, such as LTCs, liquid-circulating pumps, fans, and liquid or water flow meters in accordance with the manufacturer’s instructions.
- Check the polarity and excitation current at reduced test voltages.
- Check the resistance, ratio, and polarity of instrument transformers, when provided. These tests should be made at the terminal blocks in the control cabinet.
- Check the frequency response measurement compared to factory results, if applicable. All these tests should be within acceptable limits before energization.

Appendix I, Example of First-Year Oil Sampling and Thermography Intervals, provides a summary listing of recommended tests and inspections that should be conducted during the new transformer's first year of operation.

10.10 Energization

The transformer manufacturer typically has specific requirements that must be followed to maintain warranty during energization of the large power transformer.

Note: The licensee should consult with the manufacturer and refer to the transformer instruction book for detailed energization procedures.

In the absence of supplier guidance, use the general guidelines provided in this section for the energization of a power transformer and its components and accessories. At this stage, all necessary verifications and tests should have been done and the results checked to be in conformance with established tolerances or limits. The project team should now energize the transformer using the manufacturer's procedure and hold it at the rated voltage and no load for the recommended period of time. If no manufacturer guidance is available, the information in Table 10-6 should be considered. During this energizing period, before loading the transformer, it is recommended that following surveillance actions be taken:

- Check for excessive audible noise and vibration.
- Monitor the temperature of oil and record it at time intervals (every hour) until stabilization is achieved.
- Monitor the temperature of winding hot spots and record it at time intervals (every hour) until stabilization is achieved.
- Monitor the ambient temperature.
- Operate and check the performance of the LTC through all positions, if applicable.
- Operate and check the performance of cooling pumps and fans, if applicable
- Inspect for oil leaks and check all oil level indicators and gas detector relay, if applicable.
- Take oil samples at the beginning and at the end of the energizing period for DGA. Oil sampling in LTC diverter switch compartment, if applicable, could be interesting for investigation and monitoring purposes (see Note 2 of Table 10-6).

Table 10-6
Recommended Minimum Energization Times [30]

Voltage Class	Energizing Period (Hours)	Suggested Minimum Energizing Period (Hours)
230–800 kV	24	12
120–170kV	12	8
<120kV	8	8

Notes:
1. If there is a difference between the time recommended in this table and the manufacturer's recommended time, ensure that the process meets at least the manufacturer's time.
2. The DGA results with the transformer energized and in no-load condition obtained at the end of the energizing period should be retained for reference and diagnostics, if needed. In case there is doubt with a certain amount of gas concentration in the results, it will be necessary to proceed with the analysis of oil samples taken in the beginning of the energizing period for comparison and evaluation

At this point, the transformer is ready for service. However, the transformer should be observed carefully (particularly in critical low ambient temperature areas in which case gradual loading would be recommended) for the first few hours after load is applied. Below are some surveillance actions recommended at this time:

- Monitor the load and temperatures of oil and winding hot spots and record them at time intervals (every hour) until stabilization is achieved
- Check for excessive audible noise and vibration
- Check the gas detector relay, if applicable
- Check for good operation of the LTC, if applicable
- After 24 hours under normal load, take oil samples. The DGA results should be kept as a base reference for follow-up and maintenance.

Make daily inspections during the first few days for any oil leak, sudden increase of temperatures, and abnormal operation of the gas detector relay (if applicable) and accessories (such as bushings, LTC, and de-energized tap chargers [DETC]). After a week, retest the dielectric liquid for moisture content and DGA. After at least one month of operation, take oil samples for DGA. Additional preventive maintenance activities are provided in Section 11, Developing the Transformer Maintenance Strategy.

11
DEVELOPING THE TRANSFORMER MAINTENANCE STRATEGY

This section provides summary guidance to the project team regarding the maintenance strategy for the new large power transformer. Maintenance activities for transformers used as spares should be evaluated using industry experience and the manufacturer's recommendations.

11.1 Inputs Regarding Preventive Maintenance

11.1.1 Power Transformer Manufacturer

The project team should coordinate with the component manufacturer beginning during the design and procurement phases to begin developing the preventive maintenance program for the new component. The large power transformer manufacturer should be required to furnish recommendations regarding the types of preventive maintenance activities and their frequency. Ensure that the maintenance activities recommended by the manufacturer for the new transformer are fully integrated into the licensee's preventive maintenance (PM) program. This will ensure that all of the recommended actions are taken at the prescribed frequencies and will prevent the warranty from being violated.

11.1.2 EPRI Preventive Maintenance Database

The project team should research the EPRI PM database to determine whether EPRI has developed specific guidance for the replacement transformer. As part of the EPRI PM basis database program, there is an ongoing effort to develop technical guides and documentation of industry experience regarding PM optimization. The EPRI report *Power Transformer Maintenance and Application Guide* (1002913) was also used as a basis for the guidance contained in this section [62]. Additional information can be found at www.epri.com by searching on keyword PMDB.

11.1.3 Industry Experience

As another source of input, the project team should consider the PM experience with similar models to the new transformer. Care should be taken to consider differences in the type of component and technologies associated with the new transformer when drawing on past maintenance experience.

Because of their electrical location in a power system, transformers are often subjected to heavy electrical and mechanical stresses. To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. The life of a transformer is highly dependent on the heat prevailing in the windings and core of the unit; therefore, it is important that the temperature be periodically monitored. Also, as is the case with all liquid-filled electrical equipment, the integrity of the dielectric liquid is extremely important and should be maintained at a high quality. If the liquid is removed so that the winding is exposed, all the liquid should be removed and the transformer should be vacuum-filled.

11.1.4 Conclusions

It is assumed that each licensee has already developed a maintenance strategy that was successfully implemented over the life of the power transformer that is being replaced. If this is not the case, the project team can consider the guidance contained in the EPRI report *Power Transformer Maintenance and Application Guide* (1002913) as a basis for developing an enhanced maintenance program for the new equipment [62]. The primary source of recommended preventive maintenance practices should continue to be the manufacturer of the new equipment. Given these two inputs, the project team should assess the effectiveness of the existing maintenance strategy, consider recommendations provided by both the EPRI Nuclear Maintenance Applications Center (NMAC) and the manufacturer, and enhance or revise the PM activities and frequencies only as deemed appropriate.

11.2 Preventive Maintenance Guidance for Large Power Transformers

Large power transformers, like other machinery, are subject to degradation and will eventually require some form of maintenance to ensure continued performance and also to extend the operating life. Transformer failures can be attributed to dielectric breakdown, short circuits, deterioration of insulation properties, corrosive sulfur contamination of the insulating oil, bushing failure mechanisms, and LTC failure mechanisms.

11.3 Determining Critical Spares

During commissioning of the transformer, certain parts might be required. Typically, spare gaskets and bushings are required as contingencies during commissioning a large power transformer. If they are not used, they should be entered into the licensee’s inventory and materials management process.

It is often beneficial to consider a maintenance strategy during the design of the replacement transformer. Subsequently, the project team should consider establishing with potential suppliers the scope of spare and replacement parts necessary to execute the anticipated maintenance, as well as the frequency with which those items should be made available.

The licensee should ensure that the spares are suitable for installation into the specific transformer and that the manufacturer is consulted. The actual number of spare parts should be based on each owner's experience, the perceived criticality of the item, and the system application. Typical spare or replacement items for a large power transformer include the following items:

- Bushings
- Contactors
- Dryer assembly or desiccant
- Fan and pump motors
- Fans
- Oil
- Oil pump
- Relays

During the design and before procurement of the replacement large power transformer, consideration should be given to establishing means for proactively obtaining from potential suppliers certain design information such as materials, dimensions, and tolerances of certain spare or replacements parts. Having this part-level information provided during the procurement of the component will make acceptance of these items easier and require less engineering involvement in the future.

Care should be taken to ensure that the manufacturer's recommendations for shelf life are considered for replacement gaskets. The EPRI report *Packaging, Shipping, Storage and Handling Guidelines for Nuclear Power Plants* (TR-107101) provides additional guidance and should be considered for long-term storage of spare or replacement parts [58].

11.4 Establishing Condition Monitoring Requirements

11.4.1 General Guidance

The project team should research the EPRI PM database to determine whether EPRI has developed condition monitoring guidance for the replacement component. As part of the EPRI PM basis database program, there is an ongoing effort to develop templates as an addendum to the PM basis. The EPRI report *Equipment Condition Monitoring Templates: Addendum to the Preventive Maintenance Basis, TR-106857, Volumes 1-38* (1000621) provides detailed guidance on condition monitorig [63].

Additional EPRI reports that can be considered when establishing condition monitoring requirements for the replacement component are the following:

- *End-Use Performance Monitoring Handbook* (TR-106960) [64]
- *Equipment Condition Assessment: Application of On-Line Monitoring Technology* (1003695) [65]
- *Guideline for System Monitoring by System Engineers* (TR-107668) [66]
- *SysMon 2.0 User's Guide: System Monitoring by System Engineers, 37 System Templates* (1000260) [67]
- *System Monitoring and Reporting Tool (SMART) Study: Generic Application Evaluation* (1002964) [68]
- *System Monitoring by System Engineers: 37 System Monitoring Plans* (TR-107434) [69]

For large power transformers, the owner should monitor the new equipment in accordance with the manufacturer's recommendations with consideration of the adequacy of the assessments conducted on the replaced transformer and the general recommendations provided in the EPRI report *Power Transformer Maintenance and Applications Guide* (1002913) [62].

11.5 Station Operating Experience for Large Power Transformers

It is assumed that each licensee has already incorporated site and fleet operating experience into the PM program for the large power transformer being replaced and will continue to consider these issues as they apply to the maintenance of the new equipment. Current events and operating experience can be found by searching the INPO web site and evaluating the results documented in the most current version of the INPO Significant Operating Experience Report (SOER) 02-3, *Large Power Transformer Reliability* [70].

11.6 Modifications to the Large Power Transformer

Requirements for large power transformers are typically covered in the procurement specifications; therefore, no modifications should be anticipated.

12
DISPOSAL OF THE REPLACED LARGE POWER TRANSFORMER

When replacing a major plant component such as a large power transformer, much of the technical focus is often on selecting a suitable replacement, procuring the item, and ensuring that it performs in accordance with its design. However, a key part of any replacement project is the decision regarding the disposal, remanufacture, or reallocation of the old component after it is removed from the plant.

Movement of a large power transformer requires planning and can be a costly endeavor. In many cases, the old transformer cannot be moved from the pad fully assembled because of its size. The following factors should be considered as early in the design and procurement processes as feasible:

- Ensuring that the necessary personnel, tools, permits, and resources are available to properly dispose of the old transformer after it is removed from service
- Assessing the need and capabilities to relocate the old equipment to a storage location for use elsewhere
- Coordinating the remanufacture or repair of the transformer so that one movement off the pad results in direct transportation to the repair facility

12.1 Disposal Facility Capabilities

If a large power transformer is to be scrapped, the project team should study feasible means of disposing of the replaced equipment and determining the capabilities of the disposal facility and organization, in parallel with the specification and design of the replacement transformer. During this evaluation, the project team should determine the following regarding the organization's capabilities:

- Work zone requirements
- Salvaged material or transformer transportation capabilities
- Duration of dissection and salvage process, if performed at the field location

12.2 Decontamination Versus Long-Term Storage

Radioactive decontamination is not applicable for large transformers.

12.3 General Environmental Concerns

The project team should consider general environmental concerns when planning for the safe disposal of the removed transformer and any auxiliary equipment. These concerns can include the following:

- Hazardous chemicals and materials. Some debris resulting from polychlorinated biphenyl-contaminated or used oil can be categorized as hazardous waste, which requires special handling above a lower limit with a legal maximum at some higher level. In addition, substantial time is needed to drain all the oil from a used transformer.
- Federal, state, and local permits or environmental impact studies or statements.
- Cutting and burning operations associated with the dissection of the transformer for salvage in the field.

12.4 Opportunity to Reuse, Remanufacture, or Repair Replaced Component

The project team should determine whether there are opportunities to refurbish the replaced transformer and use it in another plant application. After repair or remanufacture, the transformer might be able to serve as a spare in the same application from which it was removed. In some cases, the replaced transformer can be salvaged or sold to an interested third party. Typically, the engineering organization is not responsible for making these decisions but might be consulted for input.

12.5 Opportunity to Salvage Replaced Component

Typically, the oil and some of the accessories (such as coolers, bushings, and conservator tanks) must be removed. If a deluge system exists, it might require partial or complete dismantling. A removed deluge system should be tagged and stored for reuse with the replacement transformer in its entirety or as parts. A temporary location at the station should be identified to store the transformer until the new transformer has been in service for some designated period of time and a decision has been made for the disposition of the removed transformer. If the transformer might be salvaged, the storage location should coincide with the scrapping location, if possible. If the transformer is to be stored for more than three months and is to remain as a candidate for remanufacture or further service, it should be stored with oil. Shorter storage times allow for the transformer to be stored pressurized with nitrogen or dry air.

If the decision is made to scrap the transformer, consideration should be given to removing parts or accessories (including bushings, coolers, and gauges) to serve as spare parts for similar transformers. Each item should be inspected or tested before being placed into inventory. In addition, the project team should consider conducting forensic analysis of the old transformer while it is being scrapped as a means to assess its long-term performance, wear, and reliability. This analysis can include furan testing of oil and degree of polymerization tests performed on insulating paper removed from windings near the predicted hottest spot. These results should be documented for future reference.

Because of the expense of moving it, a large transformer is typically scrapped at the location from which it was removed. Smaller transformers might be hauled away for salvage. The project team should determine a safe and accessible location for the salvage company to perform the salvage operation. This location should be selected so that normal plant operations are not impacted. A salvage company will disassemble and salvage the materials from the transformer and haul them away from the work location, taking proper precautions to avoid impacting the environment. The salvage company should be responsible for removal of the entire carcass whether or not there are materials of interest.

12.6 Shipping and Handling Issues for Contaminated Equipment

If the replaced transformer contains polychlorinated biphenyls or other hazardous materials and will be shipped off site, the project team should consider requirements for special shipping and handling. Care should be taken to ensure that all federal, state, and local regulations are studied and met by the project team before moving the equipment off site.

13
REFERENCES

13.1 In-Text References

1. IEEE 765. IEEE Standard for Preferred Power Supply (PPS) from Nuclear Power. Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2002.
2. ANSI N45.2, Quality Assurance Program Requirements for Nuclear Power Plants. American National Standards Institute. Washington, DC.
3. ANSI/ISO/ASQ Q9001, Quality Management Systems: Requirements. American Society for Quality, Milwaukee, WI: 2000.
4. *Guidelines for Technical Evaluation of Replacement Items in Nuclear Power Plants (NCIG-11)*. EPRI, Palo Alto, CA: 1989. NP-6406.
5. *Guidelines for the Utilization of Commercial Grade Items In Nuclear Safety Related Applications*. EPRI, Palo Alto, CA: 1988. NP-5652.
6. *Guidelines for Reverse Engineering at Nuclear Power Plants*. EPRI, Palo Alto, CA: 1998. TR-107372.
7. *Large Transformer End-of-Expected-Life Considerations and the Need for Planning*. EPRI, Palo Alto, CA: 2006. 1013566.
8. IEEE C57.12.00. IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2000.
9. IEEE 693, IEEE Recommended Practice for Seismic Design of Substations, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2005.
10. ANSI/IEEE C57.116. Guide for Transformers Directly Connected to Generators, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1989.
11. ANSI N45.2.11, Quality Assurance Requirements for the Design of Nuclear Power Plants. American National Standards Institute. Washington, DC.
12. 10CFR50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.
13. 10CFR50.65, Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.

14. INPO AP-913, Equipment Reliability Process Description, Revision 1. Institute of Nuclear Power Operations, Atlanta, GA: 2001.
15. 10CFR50.69, Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.
16. 10CFR50, Appendix A, General Design Criterion 17 (GDC 17). Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.
17. NRC Generic Letter 2006-02, "Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power." United States Nuclear Regulatory Commission, Rockville, MD: February 2006.
18. AWS D1.1, *Structural Welding Code*, American Welding Society, Miami, FL: 2006.
19. ANSI D3487-00, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus, American National Standards Institute, Milwaukee, WI: 2006.
20. ANSI Z55.1, Gray Finishes for Industrial Apparatus and Equipment, American National Standards Institute, Milwaukee, WI: 1967.
21. ANSI/IEEE C2, National Electrical Safety Code. Institute of Electrical and Electronics Engineers, Piscataway, NJ.
22. ANSI/IEEE C37.21, Standard for Control Switchboards, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1985.
23. ANSI/IEEE C50.41, Polyphase Induction Motors for Power Generating Stations, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2000.
24. ANSI/IEEE C57.12.10, Transformers—230kV and Below, 8333/10417 kVA Single-Phase, and 100,000 KVA Three-Phase, Without Load Tap Changing; 100,000 kVA with Load Tap Changing Safety Requirement, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1997.
25. ANSI/IEEE C57.12.80, Standard Terminology for Power and Distribution Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2002.
26. ANSI/IEEE C57.13, IEEE Standard Requirements for Instrument Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1993.
27. ANSI/IEEE C57.19.00, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1991.
28. ANSI/IEEE C57.19.01, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2000.
29. ANSI/IEEE C57.91, IEEE Guide for Loading Mineral-Oil-Immersed Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1995.
30. ANSI/IEEE C57.93, Guide for Installation of Liquid-Immersed Power Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1995.

31. ANSI/IEEE C57.97, Guide for Preparation of Specifications for Large Power Transformers With or Without Load Tap Changing, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1971.
32. ANSI/IEEE C57.98, IEEE Standard Guide for Transformer Impulse Tests, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1986.
33. ANSI/IEEE C57.100, IEEE Standard Test Procedure for Thermal Evaluation of Liquid-Immersed Distribution and Power Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1999.
34. ANSI/IEEE C57.104, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1991.
35. ANSI/IEEE C57.106, Guide for Acceptance and Maintenance of Insulating Oil in Equipment, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1991.
36. ANSI/IEEE C57.109, Guide for Transformer Through-Fault Current, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1993.
37. ANSI/IEEE C57.110, Recommended Practice for Establishing Transformer Capability when Supplying Non-Sinusoidal Load Currents, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1998.
38. ANSI/IEEE C57.117, IEEE Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1986.
39. ANSI/IEEE C57.119, Recommended Practice for Performing Temperature Rise Tests on Oil-Immersed Power Transformers at Loads Beyond Nameplate Rating, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2001.
40. ANSI/IEEE C57.131, IEEE Standard Requirements for Load Tap Changers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1995.
41. ANSI/IEEE C62.11, Standard for Metal-Oxide Surge Arresters for AC Power Circuits, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1999.
42. ANSI/IEEE C62.22, Guide for the Application of Metal-Oxide Surge Arresters for Alternating Current Systems, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1997.
43. IEEE 80, IEEE Guide for Safety in Substation Grounding, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2000.
44. IEEE 112, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2004.
45. IEEE 519, Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1992.
46. IEEE 1538, IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid Filled Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2000.

47. IEEE C57.12.90. IEEE Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1999.
48. IEEE C57.140, Guide for Evaluation and Reconditioning of Liquid Immersed Power Transformers, Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2006.
49. NEMA ICS1, General Standards for Industrial Controls and Systems, National Electrical Manufacturers Association, Rosslyn, VA: 1993.
50. NEMA ICS2, General Standards for Industrial Control Devices, Controllers, and Assemblies, National Electrical Manufacturers Association, Rosslyn, VA: 2000.
51. NEMA ICS6, Enclosures for Industrial Controls and Systems, National Electrical Manufacturers Association, Rosslyn, VA: 1993.
52. NEMA MG1, Motors and Generators, National Electrical Manufacturers Association, Rosslyn, VA: 2006.
53. NEMA TR1, Transformers, Regulators and Reactors, National Electrical Manufacturers Association, Rosslyn, VA: 1993.
54. NFPA 70, National Electrical Code. National Fire Protection Association, Quincy, MA: 1996.
55. *GPPTS–Guidelines for the Preparation of Power Transformer Specifications, Version 1.0*. EPRI, Palo Alto, CA: 2006. 1011658.
56. *Lifting, Rigging, and Small Hoist Usage Program Guide*. EPRI, Palo Alto, CA: 2003. 1007914.
57. ANSI N45.2.2, Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants (During the Construction Phase). American National Standards Institute. Washington, DC.
58. *Packaging, Shipping, Storage, and Handling Guidelines for Nuclear Power Plants*. EPRI, Palo Alto, CA: 1997. TR-107101.
59. *Guidance for Developing and Implementing an On-Line Maintenance Strategy*. EPRI, Palo Alto, CA: 2004. 1009708.
60. *CEA Commissioning Guide for Electrical Apparatus*. Canadian Electricity Association, Ottawa, Ontario, Canada: 1982. Available from CEA Technologies Inc., CEATI Life Cycle Management of Substation Equipment and Apparatus (LCMSEA) Interest Group, http://www.ceatech.ca (accessed October 4, 2007).
61. IEEE 62, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus, Part 1: Oil Filled Power Transformers, Regulators, and Reactors. Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1995.
62. *Power Transformer Maintenance and Applications Guide*. EPRI, Palo Alto, CA: September 2002. 1002913.
63. *Equipment Condition Monitoring Templates: Addendum to the Preventive Maintenance Basis, TR-106857 (Volumes 1-38)*. EPRI, Palo Alto, CA: 2000. 1000621.

64. *End-Use Performance Monitoring Handbook*. EPRI, Palo Alto, CA: 1996. TR-106960.

65. *Equipment Condition Assessment: Application of On-Line Monitoring Technology*. EPRI, Palo Alto, CA: 2004. 1003695.

66. *Guideline for System Monitoring by System Engineers*. EPRI, Palo Alto, CA: 1996. TR-107668.

67. *SysMon 2.0 User's Guide: System Monitoring by System Engineers, 37 System Templates*. EPRI, Palo Alto, CA: 2000. 1000260.

68. *System Monitoring and Reporting Tool (SMART) Study: Generic Application Evaluation.* EPRI, Palo Alto, CA: 2001. 1002964.

69. *System Monitoring by System Engineers: 37 System Monitoring Plans*. EPRI, Palo Alto, CA: 1998. TR-107434.

70. INPO SOER 02-3. Large Power Transformer Reliability, Institute of Nuclear Power Operations, Atlanta, GA: 2002.

71. ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus. ASTM International, West Conshohocken, PA: 2000 (2006).

72. ASTM D1816, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes. ASTM International, West Conshohocken, PA: 2004.

73. NFPA 850, Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations. National Fire Protection Association, Quincy, MA: 2005.

74. IEEE 62.2, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus. Institute of Electrical and Electronics Engineers, Piscataway, NJ: 2004.

13.2 Bibliography

10CFR21, Revision 2, Reporting of Defects and Noncompliances. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC: 1995.

10CFR50.2, Definitions. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.

ANSI N18.7/ANS 3.2, Administrative Controls and Quality Assurance for the Operational Phase of Nuclear Power Plants. American National Standards Institute, Milwaukee, WI: 1976.

Condition Assessment of Two Generator Step-up (GSU) Transformers for New York Power Authority. EPRI, Palo Alto, CA: April 2004. 1009477.

CSA-C88-M90, *Power Transformers and Reactors*. Canadian Standards Association, Mississauga, Ontario, Canada: 1999.

IEEE 344, Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations. Institute of Electrical and Electronics Engineers, Piscataway, NJ: 1987.

Guidelines for Technical Evaluation of Replacement Items in Nuclear Power Plants, Revision 1. EPRI, Palo Alto, CA: 2004. 1008256.

NRC Generic Letter 89-02, "Actions To Improve the Detection of Counterfeit and Fraudulently Marketed Products." United States Nuclear Regulatory Commission. Washington, DC: March 1989.

NRC Generic Letter 89-09, "ASME Section III Component Replacements." United States Nuclear Regulatory Commission. Washington, DC: May 1989.

NRC Generic Letter 91-05, "Licensee Commercial Grade Procurement and Dedication Programs." United States Nuclear Regulatory Commission. Washington, DC: April 1991.

NRC Regulatory Guide 1.100, Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants. United States Nuclear Regulatory Commission. Washington, DC: March 1976.

Power Transformers. EPRI, Palo Alto, CA: 1987. EL-5036-V2.

"Presence of Corrosive Sulfur Can Lead to Transformer Failure," in *NMAC Memo*. EPRI, Palo Alto, CA: November 2005. 1012925.

Reliability and Preventive Maintenance: Balancing Risk and Reliability: For Maintenance and Reliability Professionals at Nuclear Power Plants. EPRI, Palo Alto, CA: 2002. 1002936.

Supplemental Guidance for the Application of EPRI Report NP-5652 on Commercial Grade Items. EPRI, Palo Alto, CA: 1994. TR-102260.

Transformer Condition Assessment and Diagnostic Modes,. EPRI, Palo Alto, CA: July 2002. 1001940.

Transformer End of Life Assessment Method—Development of Scoring System. EPRI, Palo Alto, CA: December 2004. 1008813.

A
LARGE POWER TRANSFORMER COMPONENTS AND FUNCTIONS

The EPRI report *Power Transformer Maintenance and Application Guide* (1002913) was used as a basis for the guidance contained in this section [62].

A.1 Main Components of the Large Power Transformer and Their Functions

Large liquid-immersed transformers are typically designed, built, and operated in accordance with the most current version of ANSI/IEEE C57.12.00 or other similar standards [8]. This section describes the main parts of a transformer, which include the following:

- Tank and oil preservation
- Magnetic core
- Coils and windings
- Insulation system
- Insulating liquid
- Transformer accessories
- Cooling system
- Tap changers
- Surge arresters
- Bushings

A.1.1 Tank and Oil Preservation

The transformer enclosure or tank that houses the core and coil provides mechanical protection for the core and coil assembly. It is made of mild steel plates of appropriate thickness and contains the oil that is used to cool and insulate the core and coil assembly. The tank and its internal structural members are high in permeability, and as a result, they are prone to collecting leakage flux, especially in large capacity transformers. Stray flux can be reduced by design (for example, by minimizing the perpendicular dimension of metallic materials to the flux path), by using some nonmagnetic steels, or by using internal tank wall shielding (that is, flux shield).

Figure A-1 shows a typical transformer tank before the core is inserted, with the flux shield visible on the inside wall.

Figure A-1
Typical Transformer Tank
Courtesy of Smit

Gaskets are used throughout the transformer to prevent the leakage of oil from pumps, manways, and accessory devices. Gaskets have several important jobs in sealing; it must perform the following:

- Create a seal and hold it for a long period of time
- Be impervious and not contaminate the insulating oil
- Be easily removed and replaced
- Be elastic enough to flow into imperfections on the mating sealing surface
- Withstand high and low temperatures and remain resilient
- Be of sufficient strength to resist crushing under applied load and resist blowout

Several types of gasket material are commonly used on large transformers, and each has its particular application. The main influences on gasket material selection are the design of the gasket joint, the operating temperature extremes, the type of fluid contained, and the internal pressure of the transformer.

- Cork-nitrile performs well at high temperatures, but it should be used only if the joint does not have grooves or limits.
- Cork-neoprene sets easily, but it should be used only if the joint does not have grooves or limits.
- Nitrile performs better than cork-neoprene when exposed to higher temperatures, but it should be used only if there are recesses or expansion-limiting grooves. Nitrile is not sunlight-resistant and will deteriorate even if only the edges are exposed.
- Fluoroelastomer (such as Viton brand) should be used only for gaskets and O-rings in temperatures that exceed 149°F (65ºC) or for applications requiring motion (shaft seals, and so on).

Several types of oil preservation systems are used to protect the oil from air, moisture, and contamination and to provide space for the expansion of the oil. Common oil preservation systems are described in the following subsections.

A.1.1.1 Sealed Tank System

The sealed tank system (see Figure A-2) maintains a constant overall fluid (oil) and gas (nitrogen) volume throughout the entire operating range of the transformer temperature.

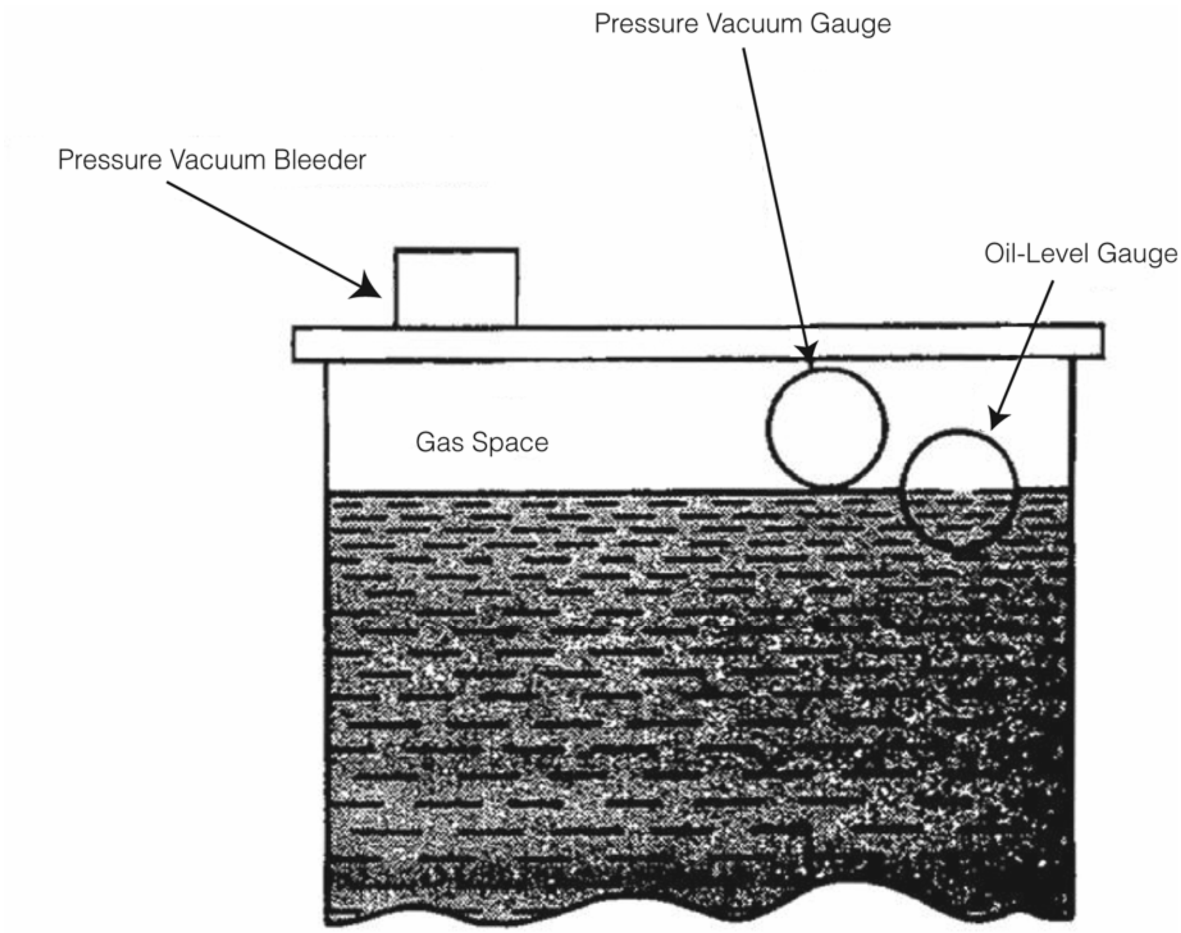


Figure A-2
Sealed Tank
Source: EPRI Report 1002913 [62]

The transformer tank and other components are tightly sealed, thereby allowing no air or moisture either into or out of the tank during normal circumstances. As the temperature of the fluid and void space gas increase, the fluid expands, and the gas pressure within the tank increases; likewise, a decrease in temperature results in a drop in pressure. If the decrease in temperature is of sufficient magnitude, a vacuum (with relation to atmospheric pressure outside the tank) will be created, thereby potentially drawing outside air into the tank in the event of leakage.

Transformers using this type of oil preservation system are equipped with a pressure-vacuum bleeder to allow the nitrogen to be expelled if the internal pressure gets too high and to allow outside air to enter if the internal pressure gets too low, thereby protecting the main tank from possible damage. This type of system could be used on smaller capacity transformers such as unit auxiliary transformers (UATs) or reserve auxiliary transformers (RATs).

A.1.1.2 Inert Gas Pressure System

The inert gas pressure system (see Figure A-3) uses a blanket of nitrogen to pressurize the void space above the oil volume to a pressure that is slightly greater than atmospheric pressure. Leakage occurring in the tank or other components will therefore occur only in the outward direction; this outward leakage prevents the induction of moisture or oxygen and displaces any other gases that can accumulate over time. Variations in loading and ambient temperature cause changes in the volume of the oil fluid, which requires either addition or purging of the nitrogen in order to compensate for contraction or expansion.

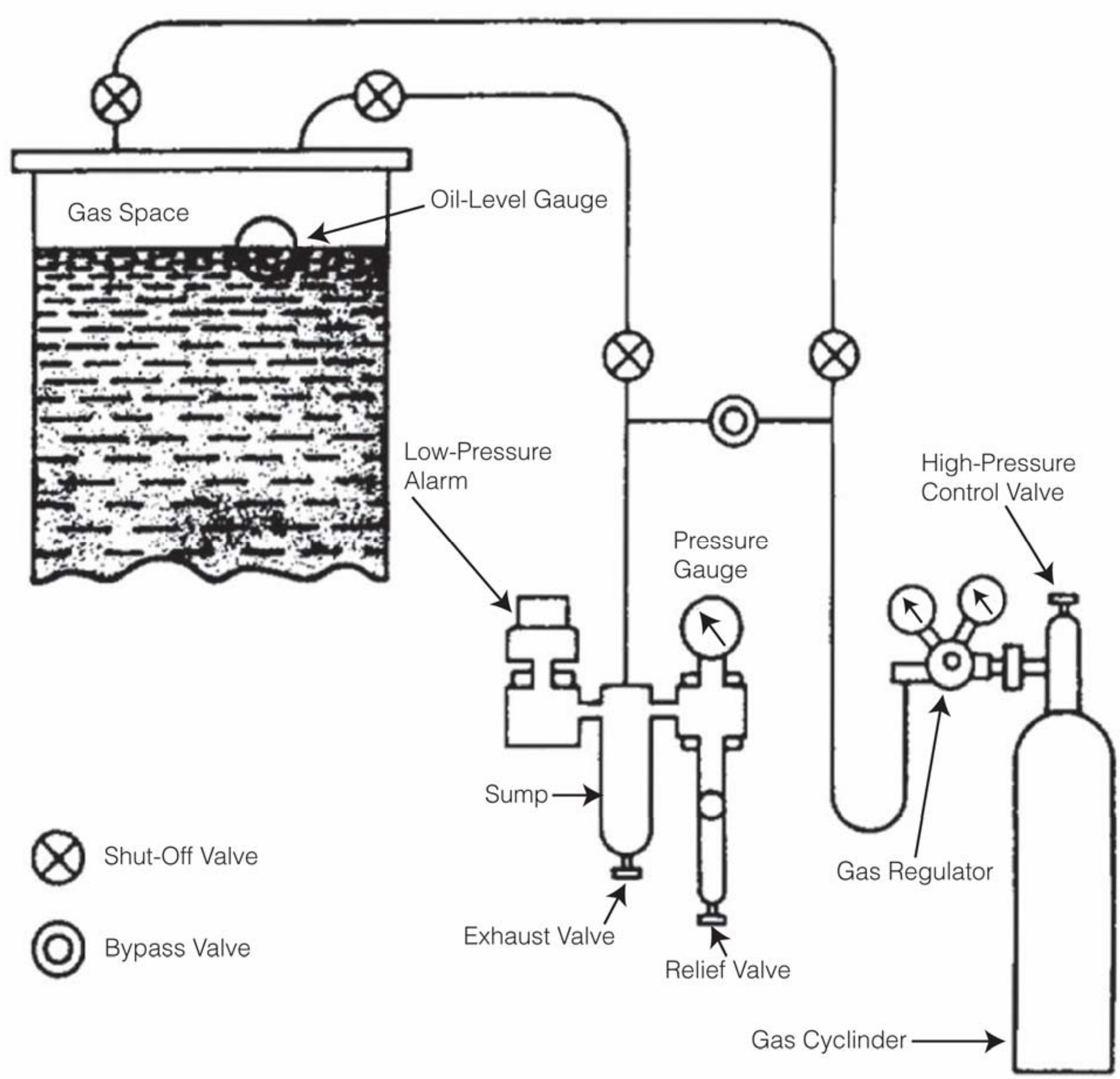


Figure A-3
Inert Gas Pressure System
Source: EPRI Report 1002913 [62]

During periods of contraction, the nitrogen is supplied from storage bottles located near the transformer; a regulating valve maintains a slight positive pressure in the void space. During periods of expansion, another valve controls the venting of excess gas, thereby preventing over-pressurization. The regulating valves are calibrated to prevent simultaneous venting and charging of gas. Periodically, the gas bottle inventory must be verified, and empty bottles should be replaced or recharged. This system will most often be used on UATs and RATs.

A.1.1.3 Sealed Conservator System

The third type of oil preservation system is the sealed conservator system (see Figure A-4). In this system, the entire volume of the tank is kept continually filled with fluid from a surge tank (conservator) mounted above the main tank. As the volume of the fluid decreases or increases, the surge is made up by or exhausted to the conservator tank. The void space (open to atmosphere) and fluid volume in the conservator are separated by a diaphragm (air cell or bladder), which prevents the contamination of the oil by moisture, gases, or other contaminants. The cycling of the air to the bladder can pass through an air dryer that is filled with desiccant. The desiccant serves to remove moisture from the air to minimize the flow of moisture through the bladder membrane into the transformer oil. A float-type level sensor measures the level of the conservator tank. The main tank is always completely filled. This system is often used on larger transformers such as generator step-up (GSU) transformers.

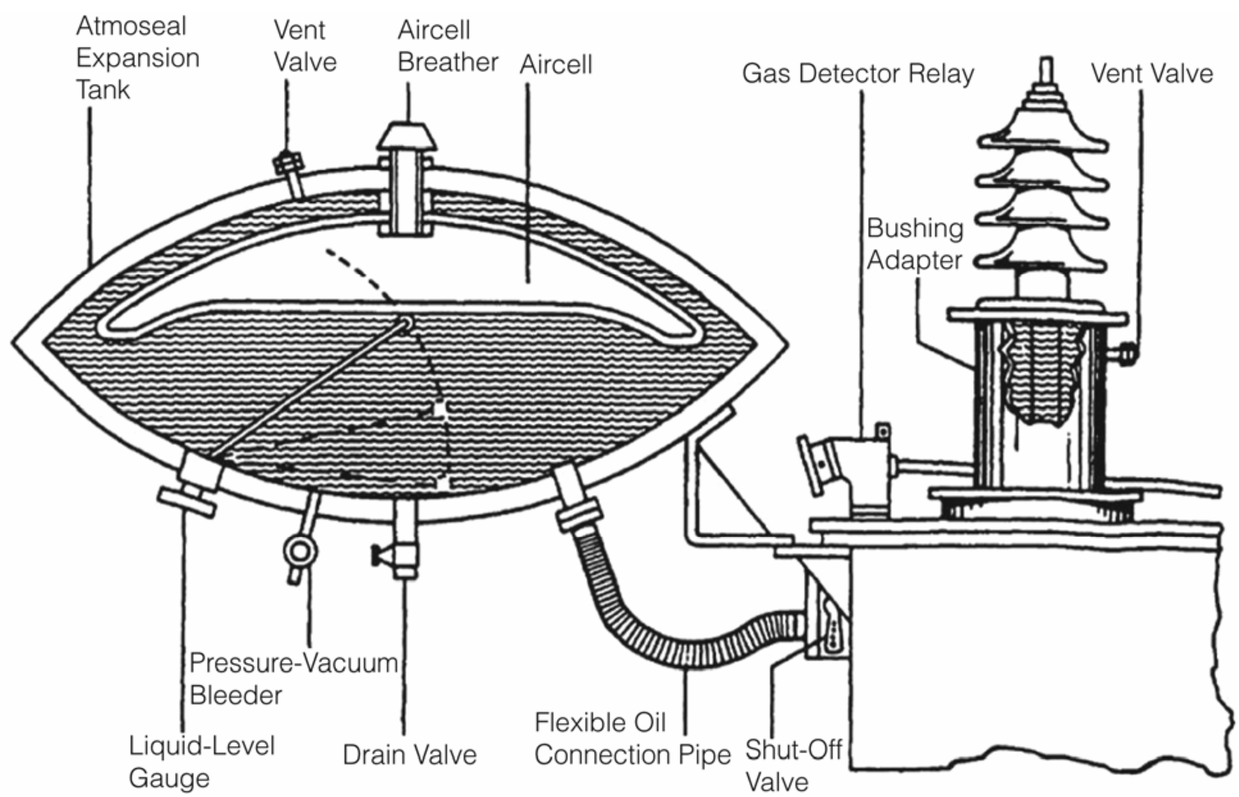


Figure A-4
Typical Oil Preservation Sealed Conservator System
Source: EPRI Report 1002913 [62]

A.1.2 Magnetic Core

The core is the part of a transformer in which the magnetic field oscillates. It provides a low-reluctance path for the flux linking primary and secondary coils. The material is a high grade of iron to which a small percentage of silicon has been added. The core is formed of thin sheets that are coated with an insulating material. The thin sheets form a high-resistance path to eddy currents. This material limits circulation of stray currents in a transformer core. Without the thin, laminated sheets, the resultant heat and loss of power would be excessive.

Several years ago, soft iron was used to manufacture transformer cores. Later on, silicon that was alloyed with low carbon content was used with the soft iron to improve transformer losses. Further improvements were made over the years for maximum core magnetization and minimum core losses by introducing high-permeability grain-oriented silicon steel. Additional improvements were made in the industry with the introduction of laser cutting of the steel, which made possible the manufacture of laminations with minimal edge defects. This helps to prevent flux intensification on the edges of the laminations (see Figure A-5). Step-lap core designs are almost always used in new large transformers to improve the heating at core leg and yoke joints. This results in lower core loss and lower sound levels.

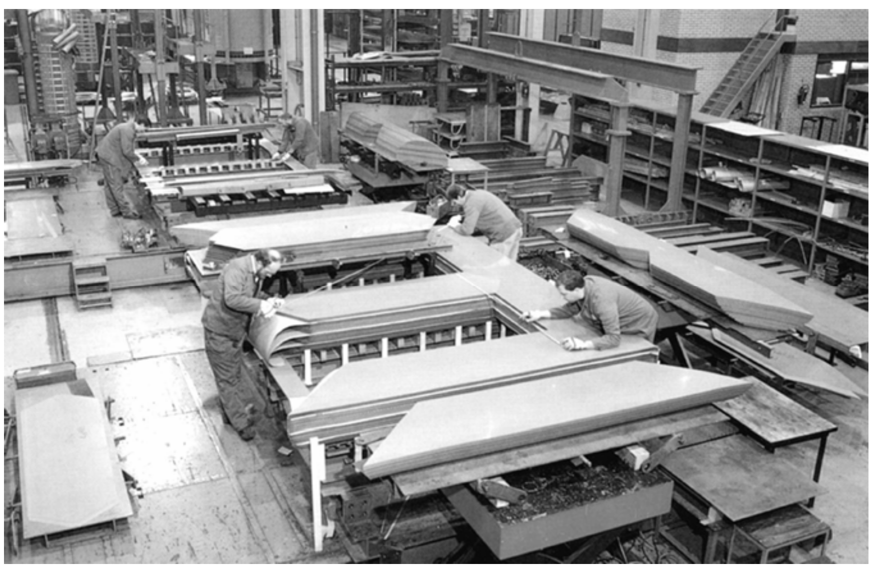


Figure A-5
Construction of Laser-Cut Core Laminations
Courtesy of Smit

Core laminations are properly secured by a clamping structure. The whole core assembly is clamped together by steel frames to hold the transformer windings together and to brace them to withstand the mechanical forces that are generated during normal operation or under fault conditions (see Figures A-6 and A-7).

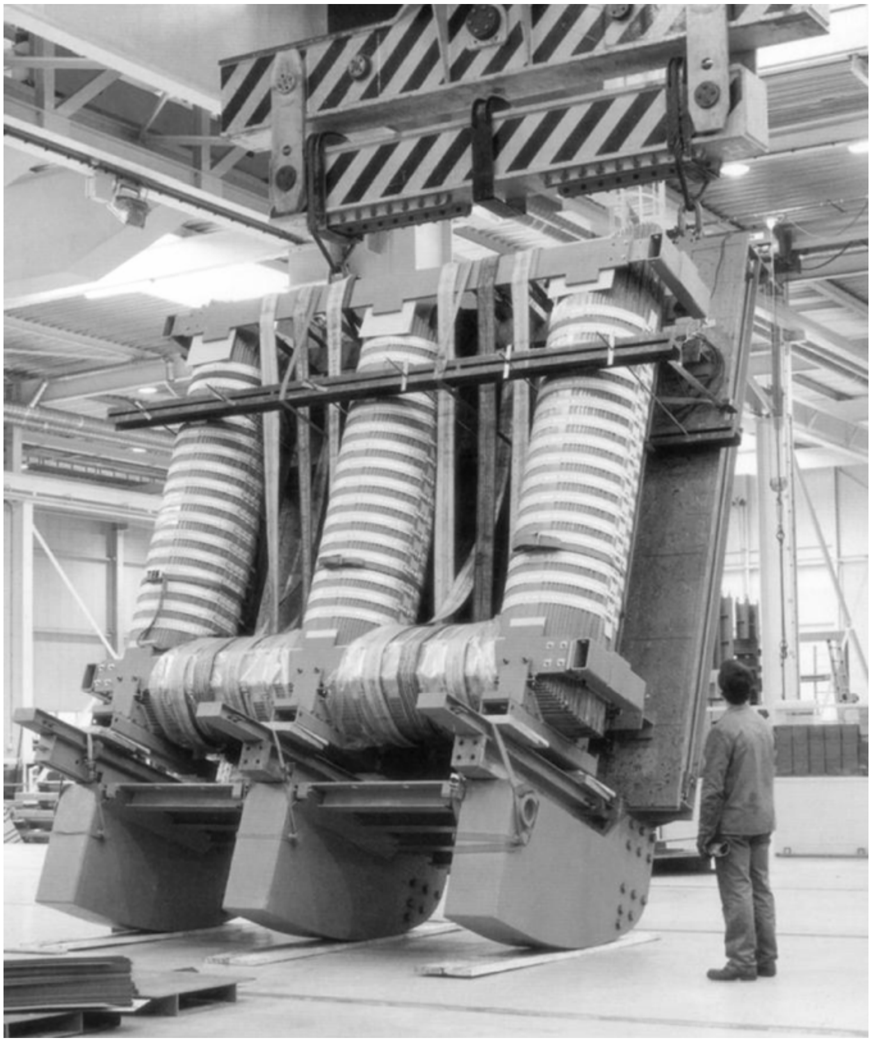


Figure A-6
Clamping of Core Laminations
Courtesy of Smit

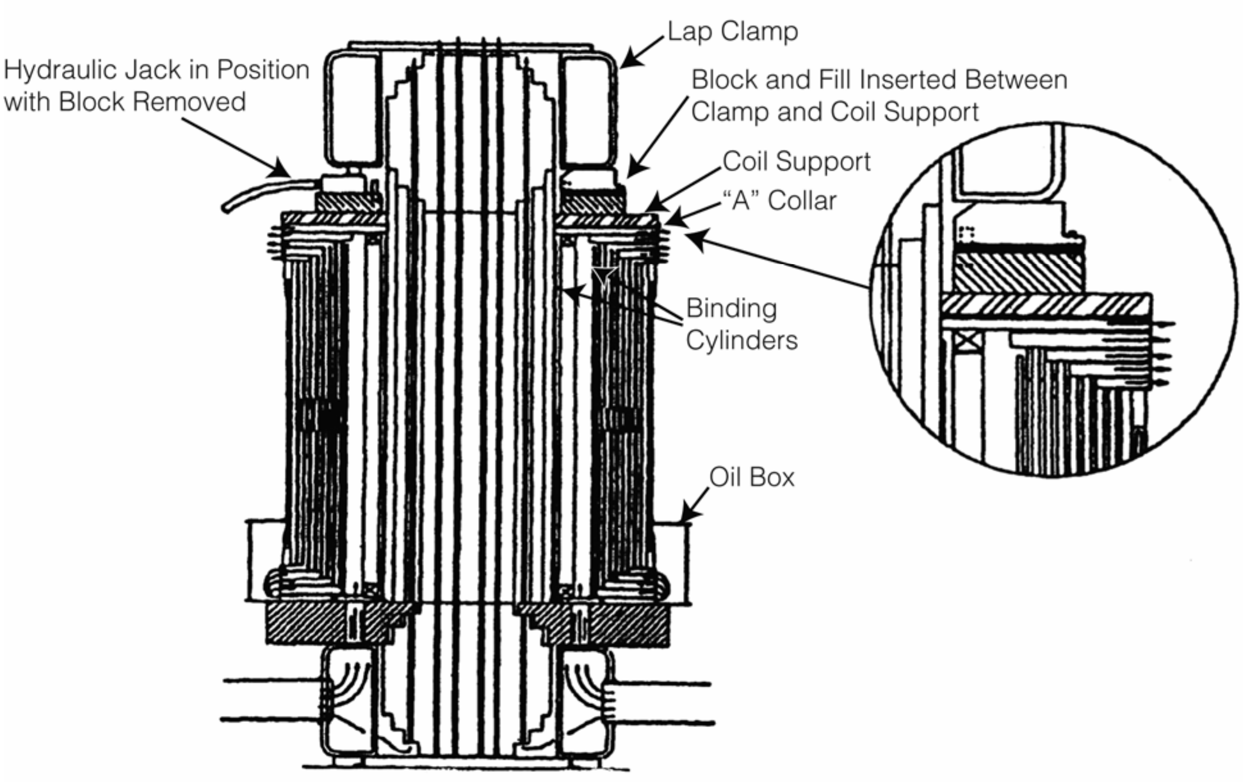


Figure A-7
Clamping of Core Laminations
Courtesy of General Electric

Transformer magnetic cores are classified into two general forms: core form and shell form. These two types differ in the arrangement of the iron and copper with relation to each other.

A.1.2.1 Core-Form Transformer

In the core-form transformer, the windings surround the laminated core (see Figure A-8). Three-phase transformers are usually designed with a three-legged core. In cases of large capacity transformers, four or five-legged cores could be preferable if there are limitations due to shipping height restrictions. A five-legged core is typically more expensive than a three-legged core.

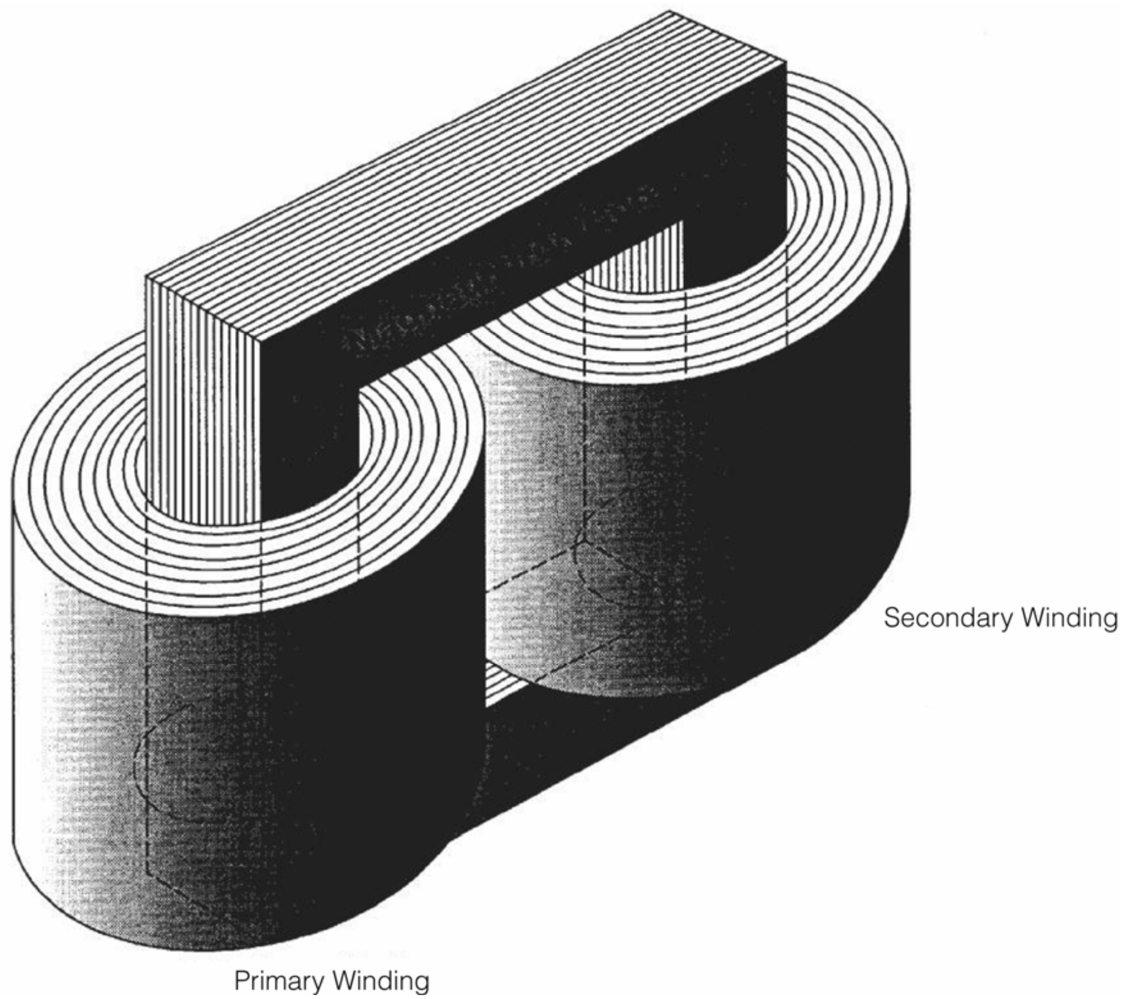


Figure A-8
Example of a Single-Phase Core-Form Design with Both Legs Wound
Source: EPRI Report 1002913 [62]

This type is better suited to higher voltages, which require windings with many turns and heavy insulation. The coils are typical disc, layer and helical types. The core-form design uses a multiple leg magnetic core that distributes flux more evenly which reduces the harmonics in the transformer. Also, this provides better distribution of induced currents across the full circuit.

A.1.2.2 Shell-Form Transformer

In the shell-form transformer, the magnetic core surrounds the windings (see Figure A-9). The coils are typically disc- or oblong-shaped and are stacked in the form of pancakes to form the winding configuration. The low-voltage coils are normally located adjacent to the core iron to minimize the amount of high-voltage insulation required to ground. In a shell-form transformer, the core leakage flux is reduced to a minimum because the coil windings surround the inner core, and the outer core surrounds the coil. Shell-type transformers are suited for transformers of moderate voltage, requiring few turns and little insulation, large currents, and low frequency with corresponding magnetic flux. Use of the shell-form transformer might require a flux shield to be installed because the core is external to the windings. Shell-form transformers are typically smaller than similarly rated core-form transformers. They require less material but more labor for manually stacking core laminations. Shell-form transformers are better suited for larger megavolt ampere ratings.

Shell-form transformers are labor intensive because of the manufacturing and assembly of the windings and insulation materials. They also require much more core material than a core-form transformer. The shell-form transformer design has been good in the past for short-circuit withstand capability. They are normally more expensive to build and repair than core type designs.

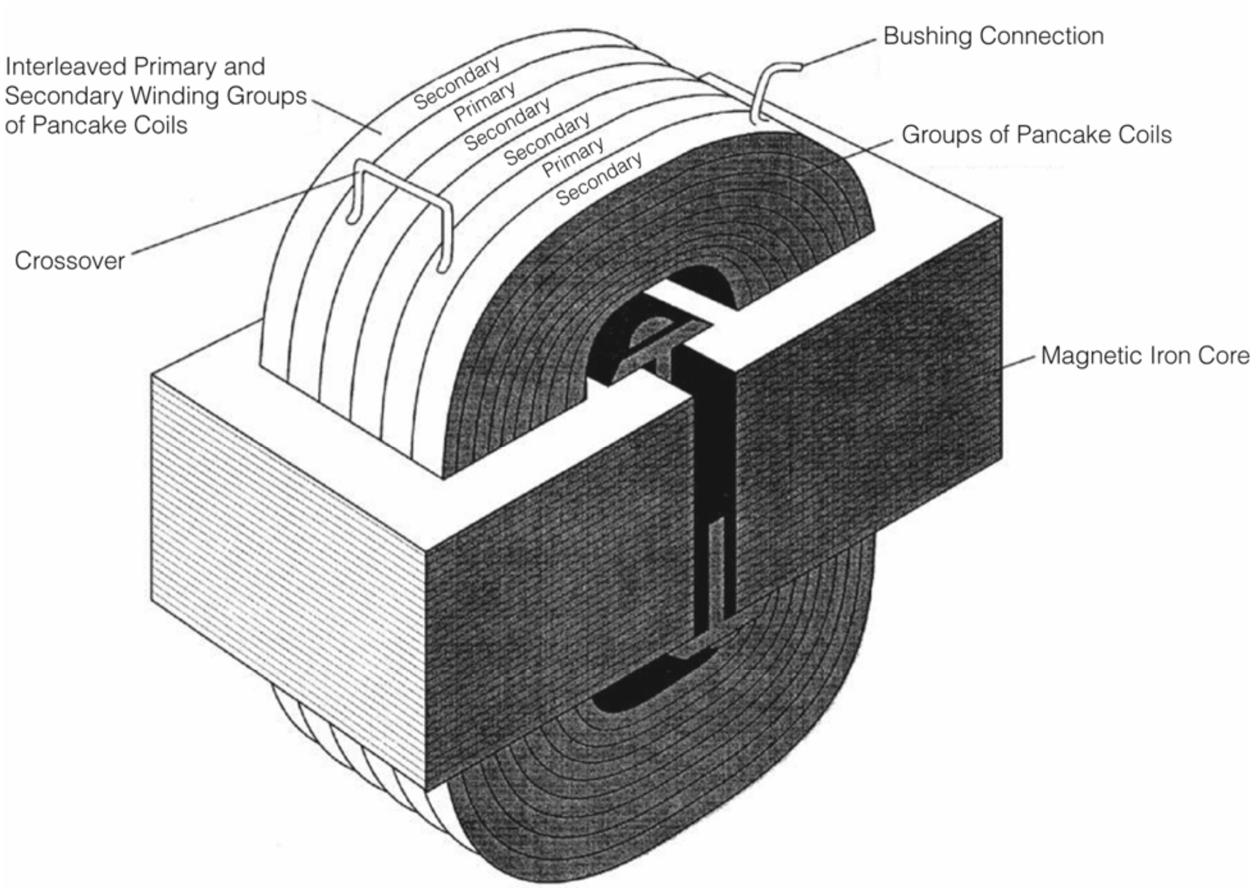


Figure A-9
Shell-Form Transformer
Source: EPRI Report 1002913 [62]

A.1.3 Coils and Windings

Transformer winding coils are designed and wound around the core according to the transformer ratio (that is, the number of turns). An individual coil turn can consist of many copper strands that are insulated individually and commonly known as continuously transposed cable (CTC). The entire CTC is typically wrapped in paper insulation. The turns are constructed by winding them over a winding cylinder, which is mounted on a winding mandrel (see Figure A-10).

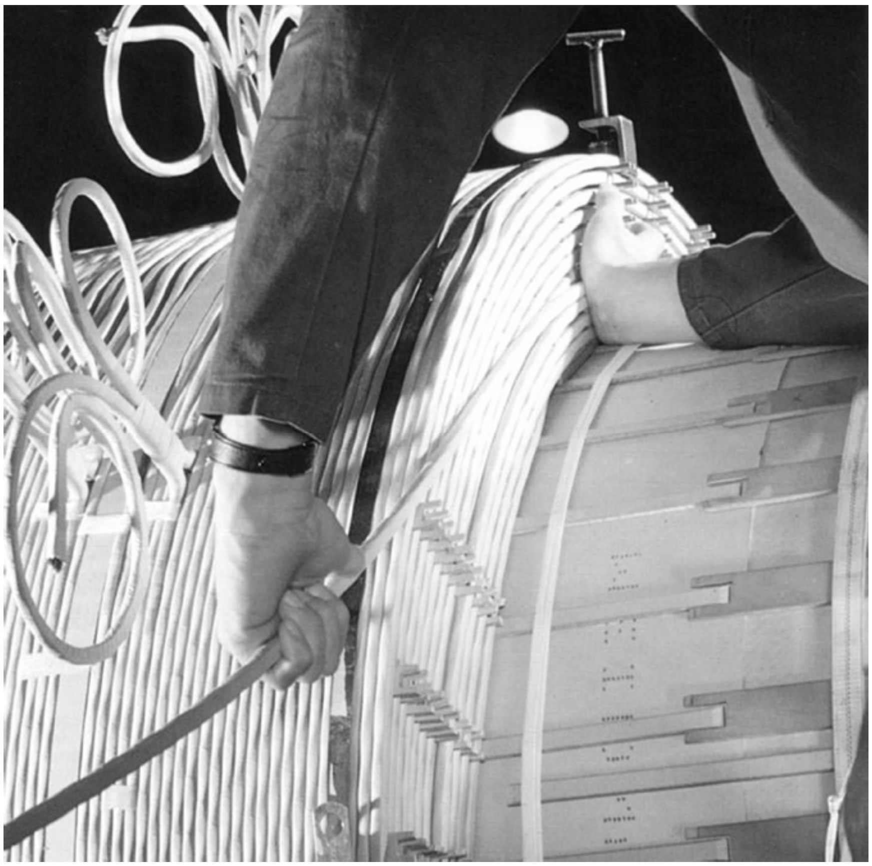


Figure A-10
Construction of Cylindrical Windings
Courtesy of Smit

A.1.3.1 Coils

Some of the basic types of transformer coils are disk, helical, and layer.

A disk coil is used when the numbers of turns in each section is large and the current is relatively small, such as for an HV winding. This coil consists of physically parallel winding sections that are connected electrically in series (see Figure A-11). Each section of the winding contains one or more turns. Radial spacers and sometimes other insulation materials are placed between each section to provide insulation between sections and to allow oil to cool the copper conductors. Axial spacers are used along the winding cylinder to provide both dielectric and cooling clearances.

There are two major types of disk windings. The common disk (described in the previous paragraph) and an interleaved disk winding used in HV windings to reduce impulse voltage stresses near the line lead. In this type of winding, conductor turns in each section are reconnected between two adjacent sections in such a pattern to increase the capacitance between sections and thus reduce the impulse voltage drop between sections. This type of winding design has been used by transformer manufacturers for many years.

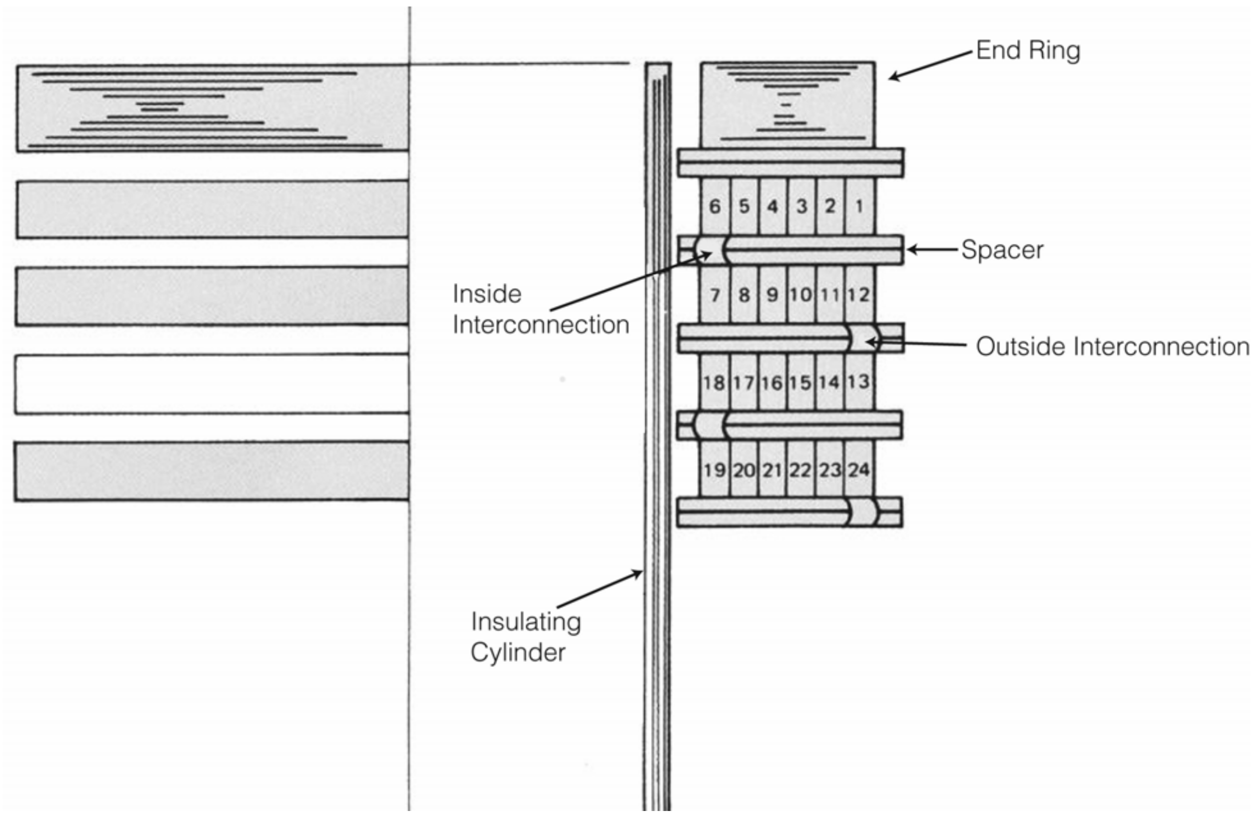


Figure A-11
Disk Winding
Courtesy of Waukesha

A helical coil or winding is frequently referred to as a screw winding because of its shape and the way it is constructed (see Figure A-12). Radial spacers and sometimes other insulation materials are placed between sections of a helical coil or winding for insulation and cooling purposes. The helical winding is suitable for high current applications where the number of turns in each section is no more than one. This is often used in a LV winding of a GSU.

A layer winding consists of one or more layers of coils that are placed on top of each other but separated from on another by paper or pressboard insulation. Vertical spacers are used between each layer of the winding to allow for cooling and dielectric strength issues. This type of winding is often used in GSU applications in the LV winding, where a large CTC can be used.

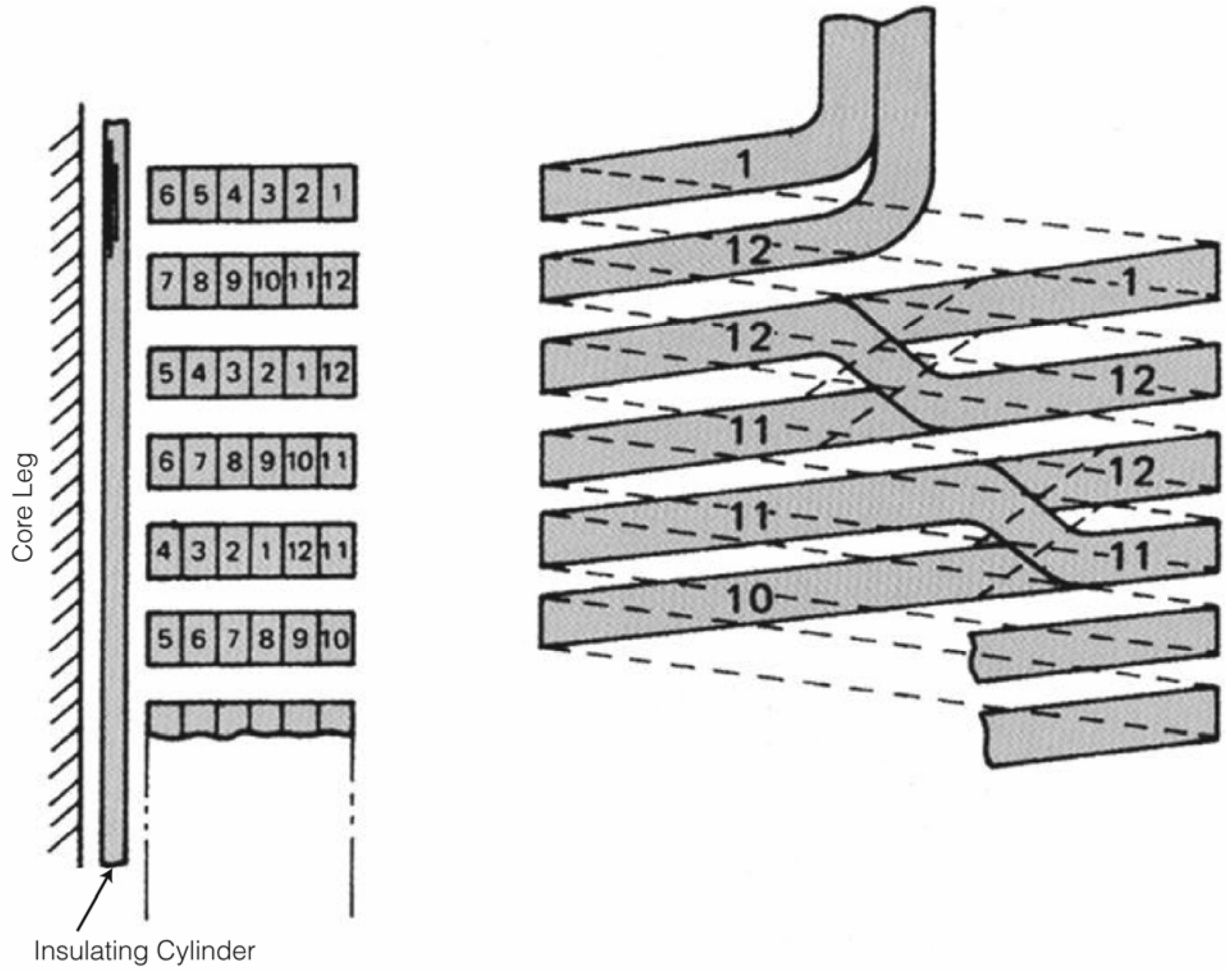


Figure A-12
Helical Winding
Courtesy of Waukesha

A.1.3.2 Winding Configuration

The delta-to-wye (Δ-to-Y) connection is used for the GSU application in order to reduce the winding current on the LV side and to reduce the voltage to ground levels on the HV side. The delta-connected primary permits single-phase line loads to be connected between the secondary neutral and the line leads. The delta winding provides a path for third-harmonic and zero-sequence currents to flow.

The wye-to-wye (Y-to-Y) connection is used when tying together two high-voltage transmission systems of unequal voltage. The configuration allows grounding of the neutral on either the primary side, the secondary side, or both.

The wye-to-delta (Y-to-Δ) connection can be used for power distribution and transmission. This permits single-phase and three-phase loads to be drawn simultaneously from the delta-connected secondary at the same voltage.

Two winding transformers are designated as high voltage (HV or H) and low voltage (LV or X). When there are more than two windings, the windings are designated as H, X, Y, and Z.

The auxiliary transformers, in many cases, have three or four windings. The UATs and RATs or system auxiliary transformers (SATs) require two secondary windings to supply power to the plant's auxiliary loads. In addition to the two secondary windings, a delta tertiary can be added to provide a low-impedance path for the zero-sequence currents when a wye-wye connection is used. The tertiary winding is typically internal to the tank without external connections and bushings.

A.1.3.3 Number of Windings

The GSU transformer is usually a two-winding transformer with primary and secondary windings. The primary winding is usually connected in delta (Δ), but the secondary is the high voltage and is wye (Y) connected. Figure A-13 shows various transformer primary and secondary phase relationships.

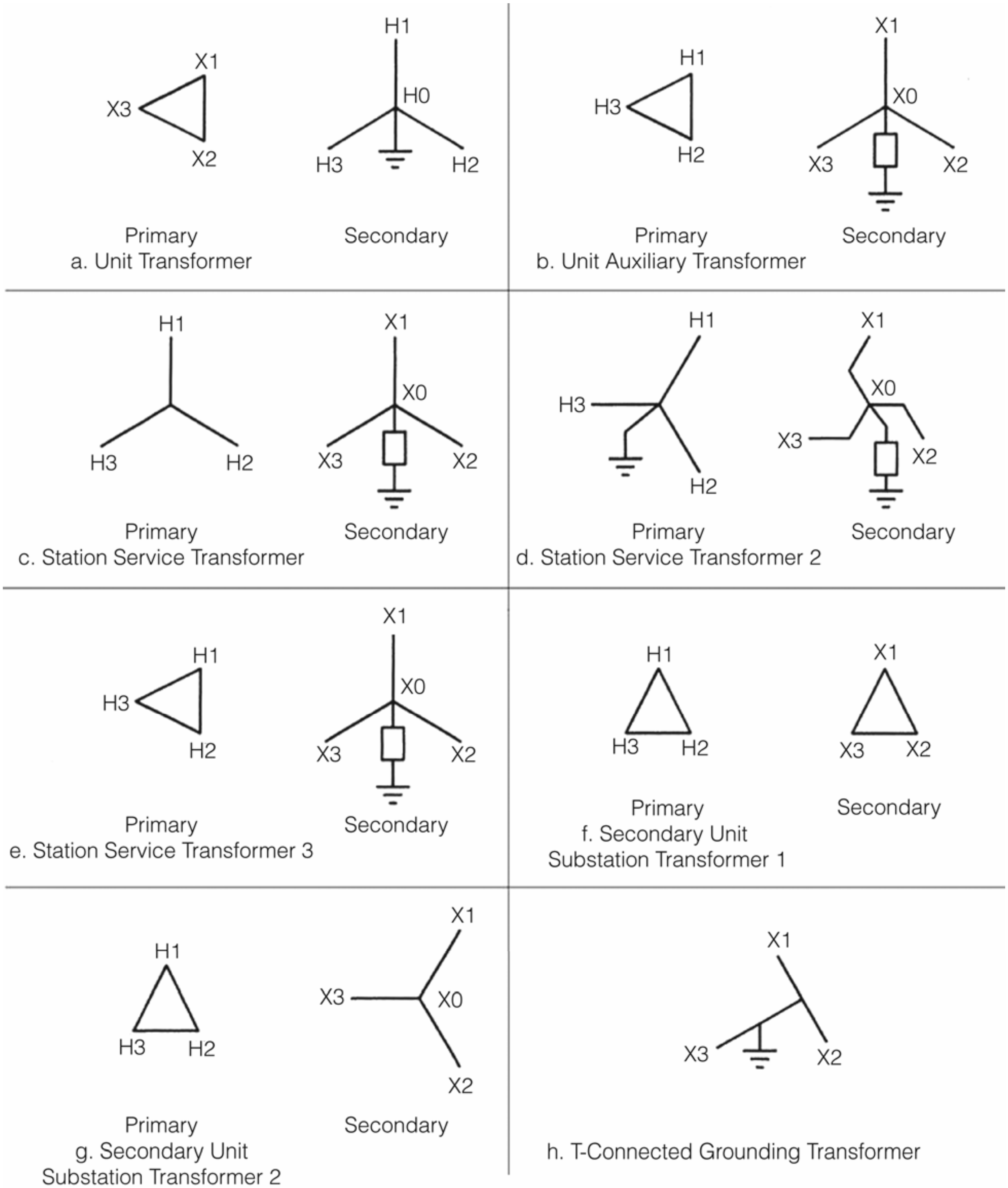


Figure A-13
Transformer Primary and Secondary Phase Relationships
Source: EPRI Report 1002913 [62]

A.1.3.4 Tertiary Windings

A number of large power transformers have been manufactured with a delta-connected, stabilizing winding in wye-wye-connected transformers. The stabilizing winding is an auxiliary winding used particularly in wye-connected transformers to 1) stabilize the neutral point of the fundamental voltages and 2) protect the transformer and the system from excessive third-harmonic voltages.

The stabilizing winding provides an internally closed circuit for zero-sequence and third-harmonic currents. The presence of a delta-connected, low-impedance path allows current to circulate around the delta in the event of an unbalance in the loaded phases so that this unbalance is reduced and not so greatly fed back through the system.

The tertiary winding must be strong enough mechanically, have the required thermal capacity, and have sufficient impedance with respect to the two main windings to withstand the effects of a short-circuit across the phases of the main windings.

A.1.4 Insulation System

Various types of materials have been used to insulate winding conductors from each other and from ground, but by far the most widely used is cellulose insulation. Cellulose insulation is made from high-quality pulp that has been refined to remove chemicals found in ordinary paper. When dried and impregnated with good-quality oil, cellulose insulation has high dielectric strength, good mechanical properties, and long life at normal transformer operating temperatures. Other types of insulation, such as enamels, are commonly used to insulate the copper strands that make up a coil. Laminated wood and cellulose-based board are used to build support structures.

A.1.4.1 Paper Conductor Insulation

Paper insulation is applied to winding conductors in layers by a taping machine using a spiral wrap. More than one thickness can be applied, depending on the dielectric and mechanical requirements.

The thermal properties of paper insulation can be improved by treating them with certain chemicals; this has been done since the 1960s. These thermally upgraded papers allowed the average winding temperature rise for a transformer to be increased from 131°F (55ºC) to 149°F (65ºC) and the hottest spot temperature rise to increase from 149°F (65°C) to 176°F (80º C). This made it possible to obtain more kVA from a transformer without increasing its physical size. Upgraded papers are used mostly in North American transformers. The IEEE Loading Guides published before 1995 contained Arrhenius life plots for both non-upgraded and upgraded insulation used in transformers classified as 131°F (55ºC) and 149°F (65ºC) rise units, respectively. In 1995, the revision of the Loading Guides dropped the Arrhenius life plots and equated the predicted life at a reference hotspot temperature of 230°F (110ºC) to 180,000 hours for both power and distribution transformers. In place of the tensile strength basis, the end-point was set as the degree of polymerization (DP) of the paper decreasing to a value of 200, which was roughly equivalent to a life of 150,000 hours. The International Electrotechnical Commission has adopted the IEEE definition of thermally upgraded paper. They have also incorporated a sub-clause that illustrates the difference in aging rate between upgraded and non-upgraded paper.

As paper ages, it becomes brittle. A measure of the brittleness can be determined by a DP test. The cellulose molecules in paper consist of long chains of glucose rings. As the paper ages, the length of the glucose rings shortens, which causes brittleness of the insulating paper. The DP test measures the average number of glucose rings in a paper sample. New insulating material has a DP of 1100–1200 (insulation end of life is generally considered to occur when the DP is reduced to a value of 200). To perform this test, it is necessary to remove a sample of paper from the transformer, usually from a lead because it is more accessible than winding insulation. Deterioration is not uniform in a transformer because of many factors; therefore, the DP test will give a general idea about the situation, with the caution that some other locations might have lower DP values than those of the sample from the lead.

A.1.4.2 Paper Barrier Materials

Besides the insulation that is applied to the windings, insulating barriers must be used between parts of the winding and between separate windings. Because these materials are not applied directly on the winding conductor, they are not required to be thermally upgraded. They are made in sheets with various thicknesses determined by the transformer designer.

A.1.4.3 Insulation Coatings

Enamels are frequently used for strand insulation when the voltage between strands is low or for low-voltage applications. One of the problems encountered when using synthetic insulating materials is that they can deteriorate over time when used in hot oil. Obviously, it is important that all enamel coatings be checked for compatibility with transformer oil.

One of the most widely used enamel insulation coatings is the polyvinyl formal family of polyester resins (such as Formvar brand coatings). Epoxy resins are also used in some applications because they have higher temperature resistance than the polyvinyl formals. However, the epoxy resins are more costly than the polyvinyl formals. CTCs often contain an epoxy resin that, after heating in an oven, causes the strands in the cable to become bonded. This has improved the short-circuit withstand strength of these cables significantly.

A.1.4.4 High-Temperature Materials

In certain applications, such as mobile transformers, it might be desirable to operate the transformer at higher temperatures. Nomex brand insulation films have been used for such applications. Nomex film consists of a polyester material that has a high temperature characteristic and is compatible with transformer oil. Compared to paper insulation, it is quite expensive.

A.1.5 Insulating Liquid

The core losses and copper losses in the transformer are converted to heat. Unless some means is provided for continuously removing the heat from the core and windings, they will get progressively hotter and eventually result in failure of the transformer.

Oil is used to provide heat transfer and improve insulation properties. Most insulating and cooling oils have several characteristics that are important to the function of power transfer in transformers. These characteristics are the following:

- High dielectric strength. Provides a resistance to the flow of electric current.
- Low viscosity. Flows easily, even at low temperatures, to provide good heat removal. Low viscosity also makes cooling oil better able to quench arcs and dissipate arcing.
- Purity. Is essentially free from corrosive or damaging elements that could injure insulation or the materials of construction.

The oil used in transformers is a highly refined mineral oil. When new, its properties generally conform to ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus [71].

Transformer oil is a good insulator when its moisture content and contamination level are very low. Besides being an excellent insulator itself, transformer oil causes the paper insulation used in transformers to also be a good insulator when it is impregnated with the oil.

In the past, transformer oil was produced from crude oils by the acid-refining process. The present method used is the hydro-refining process. Although the processes are different, the oils being produced are, for all practical purposes, the same.

Transformer oil will maintain its good dielectric properties if the moisture is kept low (such as <10 ppm [<10 mg/kg]) and particle contamination is kept low. Moisture content values >10 ppm (>10 mg/kg) might or might not be acceptable, depending on the relativity humidity of the oil, which depends on the oil temperature at the time the sample is collected. IEEE C57.106 suggests a limit of 50 kV for continued use of service-aged oil in transformers 230 kV and above when measured by ASTM D1816, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes (0.08-in. [2-mm] gap) [35, 72].

Most power transformers have been designed and installed with mineral oil. Additives are inserted into the insulating fluid to improve long-term characteristics. These can include oxidation inhibitors and antisludging additives. Natural ester fluids are now also available.

To improve cooling, heat exchangers are designed and installed on transformers that are located nearest the points where the internal heat is generated. Typically, on larger transformers, heat is transferred to and from the oil by pumping the oil through the heat exchangers. The transfer of heat through the heat exchangers by pumps is far more effective from a transformer cost viewpoint than the self-cooled or fan-cooled units, especially if space limitations are critical.

Technically, the oil-filled, air-cooled (ONAN) rating is the best option from both a reliability and maintainability viewpoint, but usually cost and space limitations dictate a pumped-oil design.

The core, coils, and supports that make up the transformer's solid insulation are impregnated with insulating liquid mineral oil. The primary functions of the insulating oil are to insulate the primary from the secondary windings and ground and to transfer the heat from the windings to external cooling equipment. Oil penetrates and fills the spaces between the core and coils, thus maintaining the quality of paper and other cellulose-based insulation material.

A.1.6 Transformer Accessories

Transformers have various types of installed accessories that are used to monitor and provide protection for transformers. The primary components and how they operate are described in the following sections.

A.1.6.1 Oil Level Indicator

The oil level indicator is a self-contained, float-operated instrument that is used to indicate the level of the insulating fluid in liquid-immersed transformers (see Figure A-14). A common indicator design uses a pivoted float arm located in the tank. This arm is magnetically coupled to a shaft and pointer arrangement outside the tank, thereby allowing a completely sealed interface. When the position of the float changes, the magnetic coupling is rotated; this moves the pointer a proportionate amount. In addition, the indicator includes alarm switches for monitoring functions.

Figure A-14
Liquid Level Indicator
Courtesy of Qualitrol

A.1.6.2 Oil Temperature Indicator

The oil temperature indicator consists of a temperature-sensing bulb, indicating device, and a switch. The indicating device is connected through a capillary tube to the sensing bulb that fits into a well near the top of the transformer tank (see Figure A-15). The indicating device has an analog scale, usually in degrees Celsius, and an indicating needle that is operated by the sensing element. Switches are actuated by the needle or the sensing element. These switches can be used to control fans, pumps, or annunciator circuits. The indicator has switches for automatic control of one or two stages of cooling fans and an alarm switch. These devices typically include an extra pointer that indicates the highest temperature reached for a particular period. This pointer remains in place until it is manually reset.

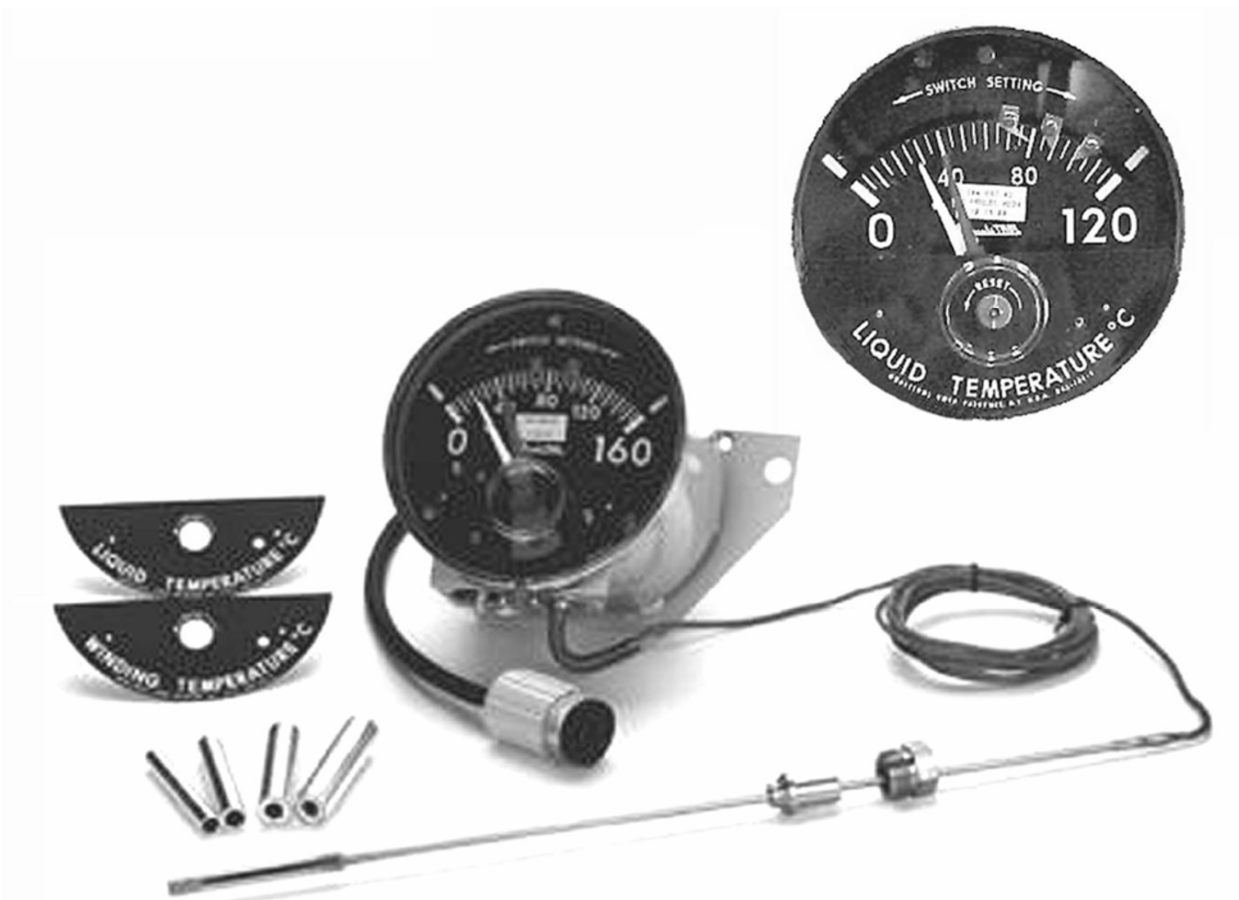


Figure A-15
Front View of a Liquid and Winding Temperature Indicator
Courtesy of Qualitrol

A.1.6.3 Winding Temperature Indicator

The most common type of winding temperature indicator over the years has been a capillary-type temperature indicator with the bulb in a drywell near or on the tank top with a heater coil also mounted on or around the well. Simulation of the heater current is from the secondary of a current transformer (CT); additional heat in the well is proportional to load levels. For remote indications, resistance temperature detectors were located in these same type wells, wired to transducers.

In addition to the resistance temperature detector-type device described above, other electronic devices are available that use fiber optics for high-accuracy temperature monitoring. These devices are user-friendly, with computer-aided set-up software combining microprocessor technology and advanced digital signal processing.

A.1.6.4 Gas Detector Relay (Buchholz Relay)

A gas detector relay is used on transformers with conservator tanks. The relay is actually mounted on an accumulation box on top of the transformer. The gas accumulator box is beneath the top cover of the transformer (see Figure A-16). Under normal conditions, the gas accumulator is filled with oil. During abnormal conditions in the transformer tank, gases are generated from the deterioration of insulation or decomposition of oil around hot spots. Gases are generated by an incipient condition and rise to the center of the crested transformer cover, passing through the gas collector to the gas relay. If a significant amount of gas is generated, an alarm or protection trip is actuated.

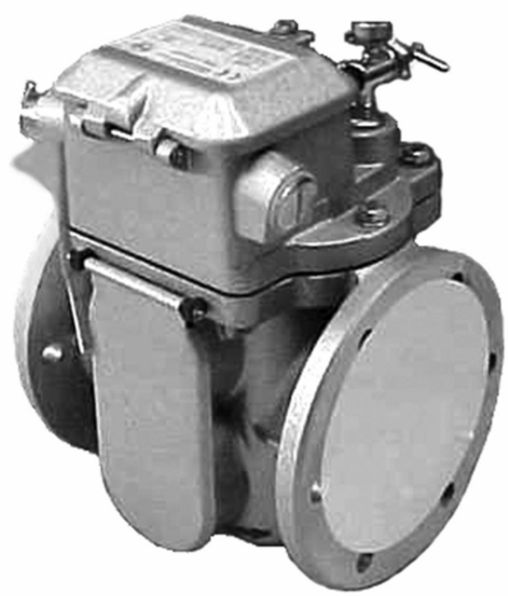


Figure A-16
Gas Detector Relay
Courtesy of General Electric

In common usage outside of the United States is a three-function device for alarming and tripping in response to low oil level, free gas accumulation, or electrical fault inside the tank. This device is mounted in the oil pipe that connects the main tank and the conservator. Although the function of low oil level and gas accumulation is similar to that of the separate devices, the nature of its fault detection delays the activation of relays for 18 cycles or longer.

A.1.6.5 Pressure Relief Device

The pressure relief device is designed to limit increasing pressure in the transformer. The tank or enclosure design pressure (approximately 10 psig [0.69 bar]) is sufficient for the normal operating pressure range, but it is not sufficient to withstand pressures resulting from internal faults. The pressure relief device uses one or more springs held in compression attached to a relief diaphragm (see Figure A-17). When pressure on the diaphragm is sufficient to compress the springs, the diaphragm moves, thus relieving the pressure from the tank. The valve reseats after pressure is reduced.

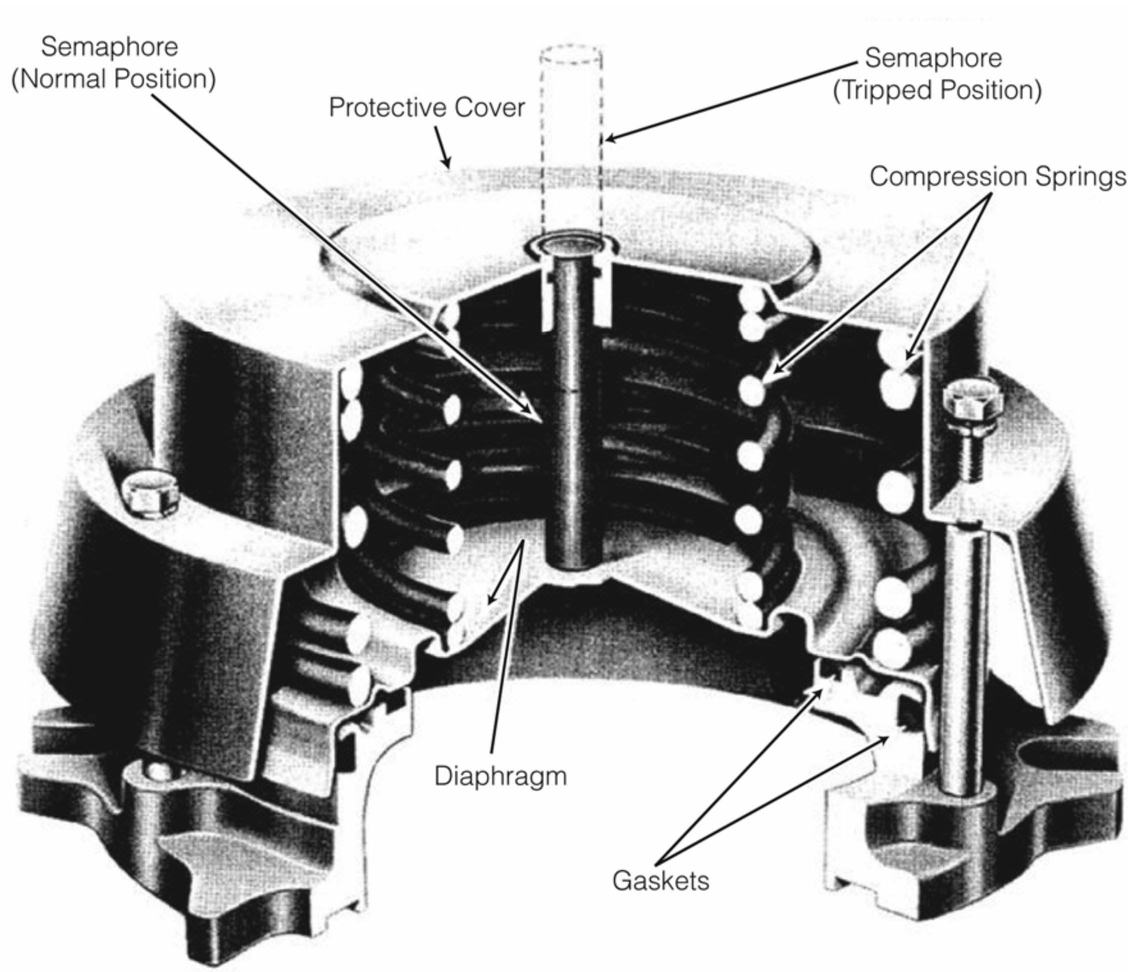
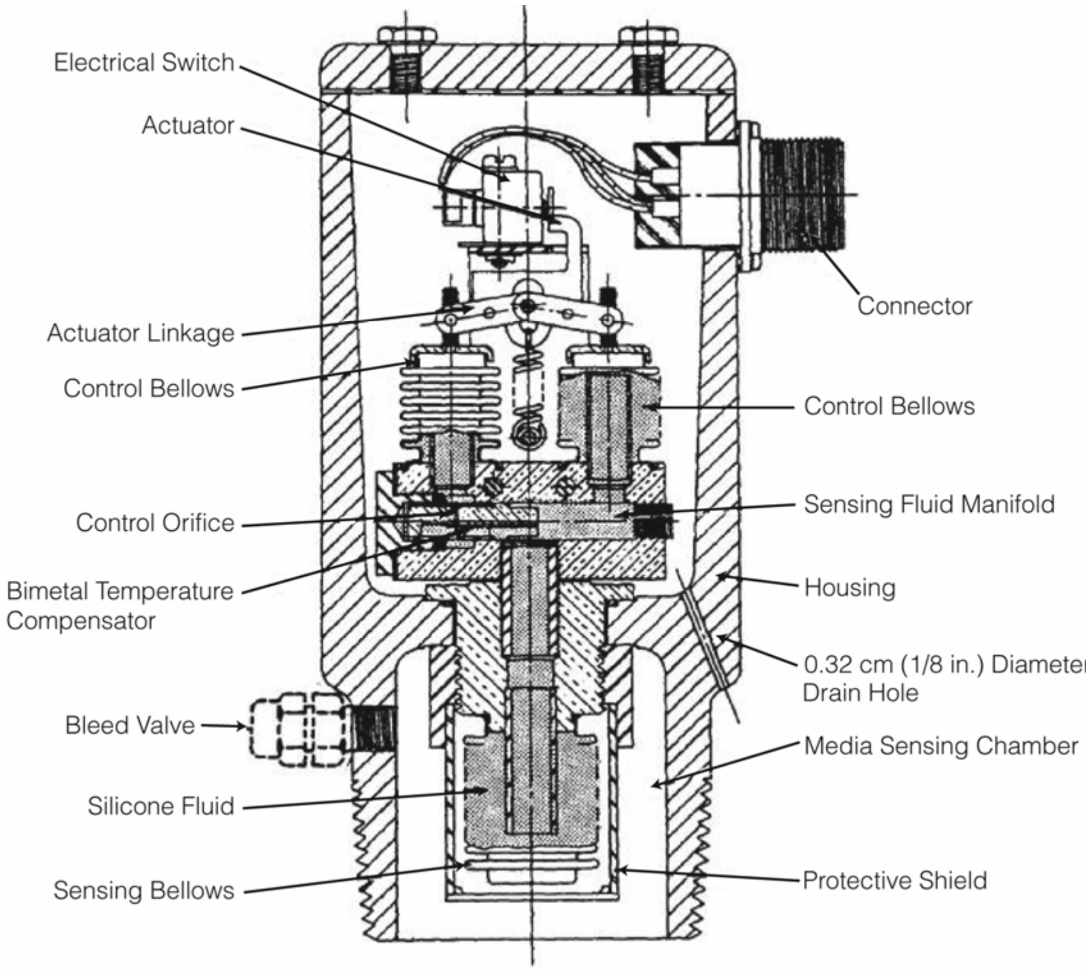


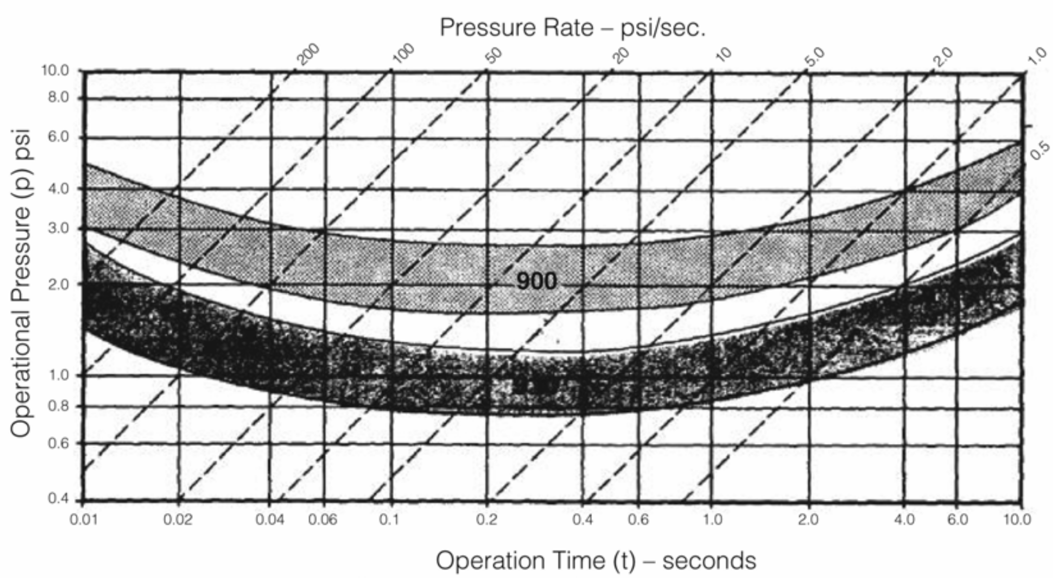
Figure A-17
Pressure Relief Device
Courtesy of Siemens-Westinghouse

A.1.6.6 Sudden Pressure Relay

The sudden pressure or fault pressure relay detects sudden pressure transients produced within a transformer tank during operation. It senses the rate of pressure change during internal faults. If the internal pressure exceeds the safe limits, the relay activates the tripping scheme to de-energize the transformer. This relay does not act as a pressure relief device and does not protect the transformer tank from major electrical faults.

The Qualitrol 900 and 910 series rapid pressure rise relays are examples of this type of device. They use a series of bellows to mechanically determine the rate of fluid pressurization (see Figure A-18). The 900 series models are designed for mounting under oil, and the 910 series models mount in the gas space. Pressure transients applied to the sensing bellows result in the displacement of fluid of a known viscosity (such as silicone oil) through various orifice channels. At low rates of pressurization, the fluid flows through the different-size orifices at nearly equal rates, thereby allowing force equilibration. At higher rates of pressurization, the smaller orifices create a significant pressure drop on the downstream side of the orifice, resulting in a force imbalance with those orifices of larger diameter. This force imbalance is applied to a spring-loaded rocker arm assembly that actuates an electrical contact when it is displaced from its null position. Depending on the configuration of the supporting wiring, this contact closure either provides a remote alarm or causes the transformer to be de-energized.





Response Curve for 900, 910 Series Rapid Pressure Rise Relay

Figure A-18
Response Curve for 900, 910 Series Rapid Pressure Rise Relay
Courtesy of Qualitrol

When the rate of pressure increase is reduced, and the differential fluid flow and resulting force imbalance cease, the relay rocker arm returns to its null position and the relay resets. The sudden pressure relays are also usually temperature-compensated to allow relatively stable pressurization rate detection throughout the design ambient temperature envelope.

This relay has been involved in a large percentage of Significant Operating Experience Reports (SOERs) for nuclear plants (followed by bushing events, and then design or procedural issues). Some of the problems with the sudden pressure relay events were attributed to fabrication deficiencies and spurious operation). A study conducted by the Institute of Nuclear Power Operations (INPO) in 2002 on events from two previous years found 10 failures of the sudden pressure relays leading to station trips. Some of these relays are extremely sensitive to light faults because they can operate on low-pressure changes.

A.1.6.7 Deluge and Fire Protection

Large power transformers can fail from either an internal or external electrical fault that results in overpressure of the tank. In cases where an internal pressure increase is rapid, the pressure relief device might not be adequate to prevent tank failure. Tank failure could release substantial quantities of insulating liquid and could initiate a fire.

National Fire Protection Association (NFPA) 70, National Electrical Code, and NFPA 850, Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations, specify the type of protection required for oil-filled outdoor transformers [54, 73]. Protection includes the following:

- Containment
- Detection and water spray system
- Fire barriers
- Separation

According to NFPA requirements, a containment collection system must be provided for the GSUs and auxiliary transformers [54.73]. The containment collection system should consist of a pit or a diked area and a drainage system for removal of rainwater. The pit or diked area should be of sufficient size to hold the oil contained in a large transformer, and the design should consider the effect of simultaneous activation of the deluge system, which could carry the oil outside the containment after a significant transformer failure.

Fire detectors are installed on top and around the transformer to activate the deluge systems in case of a fire. Because of false activation, thermal line wire (such as a thermistor wire or Protectowire cable), has been replacing fire detectors. Like the detectors, the wire is installed on top of and around the transformer and is terminated at both ends in a control cabinet to activate the deluge system.

In addition to the transformer relay protection for large power transformers, the following are considerations for relay and deluge activation:

- Transformer differential relay operation should initiate the deluge system.
- Transformer sudden pressure relay operation should initiate the deluge system.
- Manual stations and the deluge valve weight switch (if installed) should initiate the deluge system only. The manual stations should be equipped with a protective guard to prevent accidental activation.
- Thermal detection should be connected to activate an alarm only.
- Transformer oil cooling systems should not be tripped from the deluge system.
- When possible, the deluge system should be exercised regularly with the transformer de-energized to flush the piping system of impurities.
- The spray nozzles should be directed so that the stream is aimed down at the transformer case and not directly at the bushings.
- The deluge header pressure switch should be connected to activate an alarm only.

A.1.6.8 Nitrogen Regulation System

The nitrogen regulation system is used to maintain positive pressure of nitrogen gas in the tank from an external gas cylinder. It prevents the oil from coming into direct contact with the surrounding atmosphere.

The gas regulation system consists of the gas cylinder, high- and low-pressure valves, bypass valve, pressure bleeder, hoses, alarm contacts, and gauges. A high-pressure regulator with an adjusting screw is connected between the high-pressure gauge and low-pressure regulator and the piping to the tank. The nitrogen regulation hoses are connected to the top of the transformer tank. The gas cylinder is usually enclosed in a metal cabinet near the transformer.

The transformer is equipped with a nitrogen pressure indicator with a ±5 psi (±0.34 bar) range. The pressure indicator must show >0 and some positive pressure up to 5 psi (0.34 bar). When the pressure in the tank drops below 0.5 psi (0.034 bar), gas is admitted into the transformer and is turned off as soon as the pressure rises above 0.5 psi. The nitrogen regulator is equipped with a bleeder valve device to expel gas when the internal tank pressure exceeds 8 psi (0.55 bar).

Alarm contacts are activated when the pressure in the nitrogen storage cylinder drops below 300 psi (20.68 bar) to warn personnel that a new gas cylinder is needed. The regulating system continues to operate until the cylinder is emptied. Prompt action is required to prevent complete gas depletion. Additional alarms are provided to function when the transformer tank pressure drops below 0.25 psi (0.017 bar) or exceeds 8.5 psi (0.59 bar).

A.1.7 Cooling System

Many large power transformers are designed and built with a self-cooled rating and a cooling system to increase its rating by increments of one-third with the additional cooling. The self-cooled capacity is obtained by convection with radiators; the forced-cooled ratings are obtained with fans or pumps. Many large power transformers are designed and built with a single directed-oil or forced-oil rating.

The cooling process within the transformer is accomplished by drawing warm oil from the top of the transformer tank and cooling the oil through the radiators. Oil then flows into the manifold, through the pump, and into the bottom of the transformer, where it is distributed by a system of baffles. In some cases, the pump has adequate clearance around the impeller to permit free passage for self-cooling when it is not running.

A.1.7.1 Fans and Radiators

For oil-filled transformers, fans and radiators are mounted at various locations around the transformer. Radiators are used to transfer heat from the oil to the surrounding atmosphere. Fans are usually mounted on the radiators to assist the radiators in heat removal. Fans for forced circulation increase the capacity by a single increment (class OA/FA or ONAN/ONAF) or in two increments (class OA/FA/FA or ONAN/ONAF/ONAF).

Fan assemblies are supplied with different motor horsepower ratings and fan blades, depending on the transformer design. Fan motors are protected by a thermal element mounted inside the motor. Individual fan assemblies are connected to the power source with conduit and flexible cable to permit removal of a fan for repair work. The fan assemblies, motors, cables, and conduit boxes are of weatherproof design and are suitable for outdoor use. The correct fan rotation is achieved when the airflow from the fan is through the radiator tubes and away from the transformer tank.

A.1.7.2 Oil Pumps

The transformer oil pump is an electrically operated pump that forces oil from the transformer tank through the radiators or heat exchangers (see Figure A-19). The winding temperature device usually controls the pump operation, unless the transformer is a directed oil design (class ODAF or ODWN), in which case the pumps operate as soon as the transformer is energized.

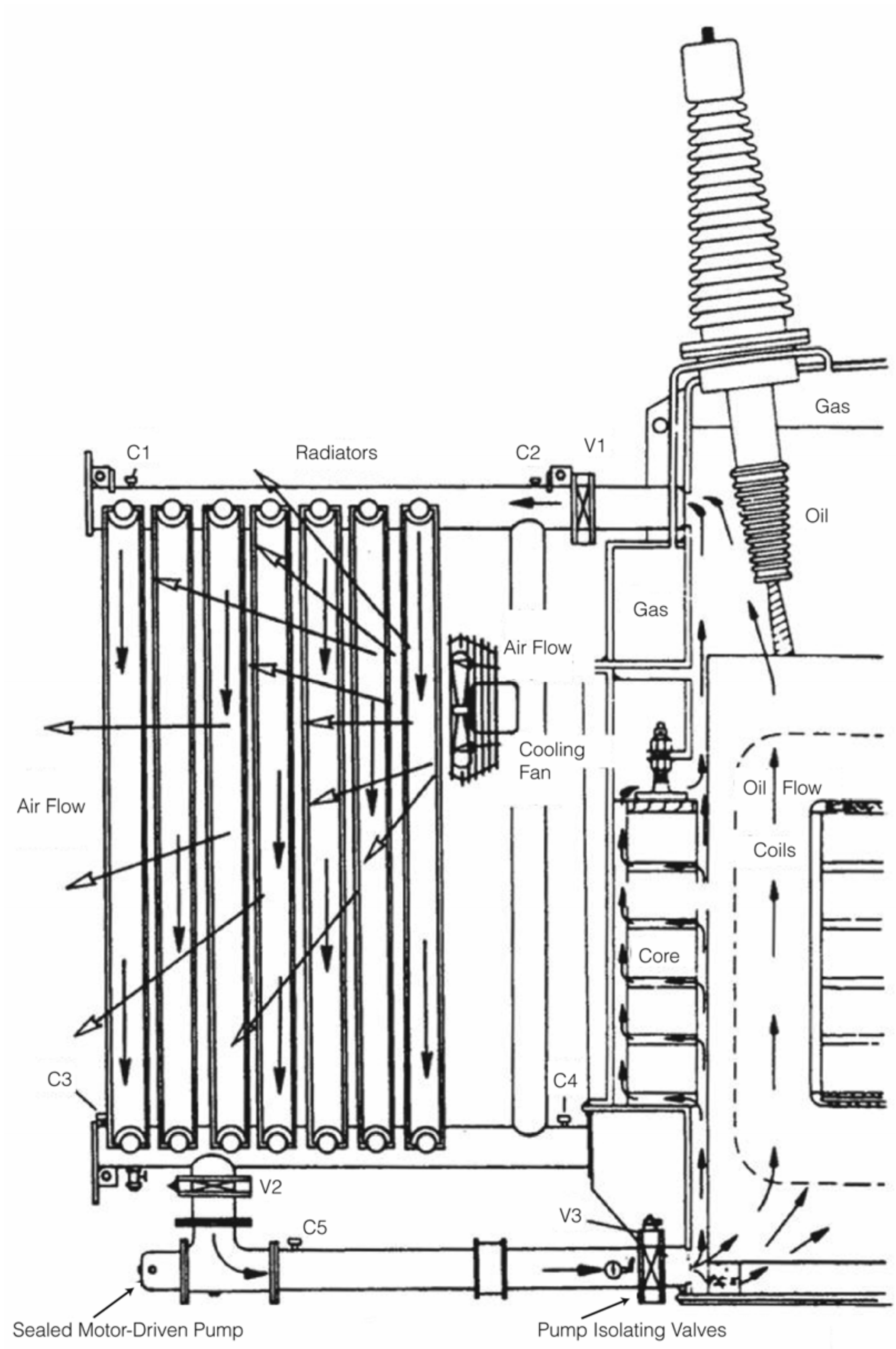


Figure A-19
Typical Class OA/FOA/FOA (ONAN/OFAF/OFAF) Cooling System
Courtesy of McGraw Edison

Transformers equipped with oil pumps also have a means of indicating oil flow. A typical oil-flow indicator is a vane-operated device that is found on either the suction or discharge pipes of the transformer oil pump. The dial on the flow indicator is designed to indicate that the pump is running as well as the rate of oil flow; if the oil flow is not sufficient, the alarm is activated. The correct rotation is indicated on the pump with an arrow and the oil flow indicator.

A.1.8 Tap Changers

Transformers can be provided with a mechanical switching device to adjust the voltage ratio by either adding voltage taps to the winding or removing them from the winding. The change is achieved either manually with the transformer off-line (no-load) or automatically with the transformer under load (load tap changer [LTC]).

A.1.8.1 De-Energized Tap Changers

De-energized tap changers (DETC) use manually operated switching equipment that changes the turns ratio of the three phases simultaneously and by the same amount for three-phase transformers. In the case of single-phase transformers, each transformer has its own manually operated DETC device. The DETC device is located in the main tank, along with the core and coils, and the operating handle is normally located externally, on the side of the transformer tank.

The DETC must be operated only when the transformer is de-energized. Conventionally, a transformer has two full-capacity 2-1/2% no-load taps above and two below the rated voltage. In a step-down transformer, the taps above rated primary voltage are less likely to be used than those rated below primary voltage. For that reason, some transformers are purchased with one tap above and three taps below rated voltage. Also, the taps could be specified to be closer together than 2-1/2%, or omitted altogether, particularly in power plant applications. If the taps are changed, the impedance of the transformer will also change marginally, and in some cases, a short circuit study should be completed.

Before initial energization or after the taps have been changed, the transformer turns ratio test should be performed to check that the contacts have seated properly and, therefore, that each winding has the same ratio.

A.1.8.2 Load Tap Changers

An LTC provides the mechanism to change taps without interruption of the load current. They are often used in distribution substations, and they are becoming more common in power plants. A conventional LTC in the United States has 32 voltage taps at 5/8% spacing, 16 above and 16 below rated voltage, to produce a voltage range of ±10%.

When changing from one tap to the next, the present tap and the next tap must be switched from one to the other without causing an open circuit. Therefore, one contact must move and connect to the next tap position before the other contact moves off its tap position (make before break).

This results in an unacceptably high circulating current between the taps; in order to limit that current, transition impedance must be connected between the adjacent taps.

LTC transformers are more commonly used for UAT and RAT applications. For GSU applications, voltage control is typically achieved with generator field adjustments, making LTCs impractical.

A.1.9 Lightning and Surge Arresters

Transformers are subject to surge voltage from lightning, switching operations, and system disturbances. Some of these disturbances can create abnormally high voltages that reach the transformer terminals.

The use of modern surge arresters has made possible the reduction of the required basic impulse-insulation levels of much transmission system equipment, and especially transformers. The primary function of early arresters was to protect the system insulation from the effects of lightning. Modern arresters not only dissipate lightning-caused surges but also control other system surges caused by switching or faults. Surge arresters are seldom called on to dissipate full lightning current because transmission systems are generally shielded with ground wires, thus reducing the possibility of direct strokes to the phase conductors.

The modern surge arrester is a metal oxide surge arrester, which has largely replaced the older silicon carbide arrester that was widely used. The metal oxide surge arrester is fabricated from nonlinear resistance metal oxide (zinc oxide) materials. A metal oxide arrester consists of a varistor embedded in a ceramic insulator. In an overvoltage or other transient condition, the nonlinear resistance lowers so that the excessive voltage is shunted to ground. With the nominal operating voltage, the metal oxide arrester has a very high resistance; therefore, it has only an insignificant leakage current. For that reason, no additional spark gap is required. This allows for a faster reacting arrester than the spark gap type. Metal oxide varistors will pass more leakage current as they age and degrade. The proper selection and application of the surge arrester is an integral part of the selection and design of the transformer insulation. Figure A-20 shows a cutaway of a typical lightning arrester.

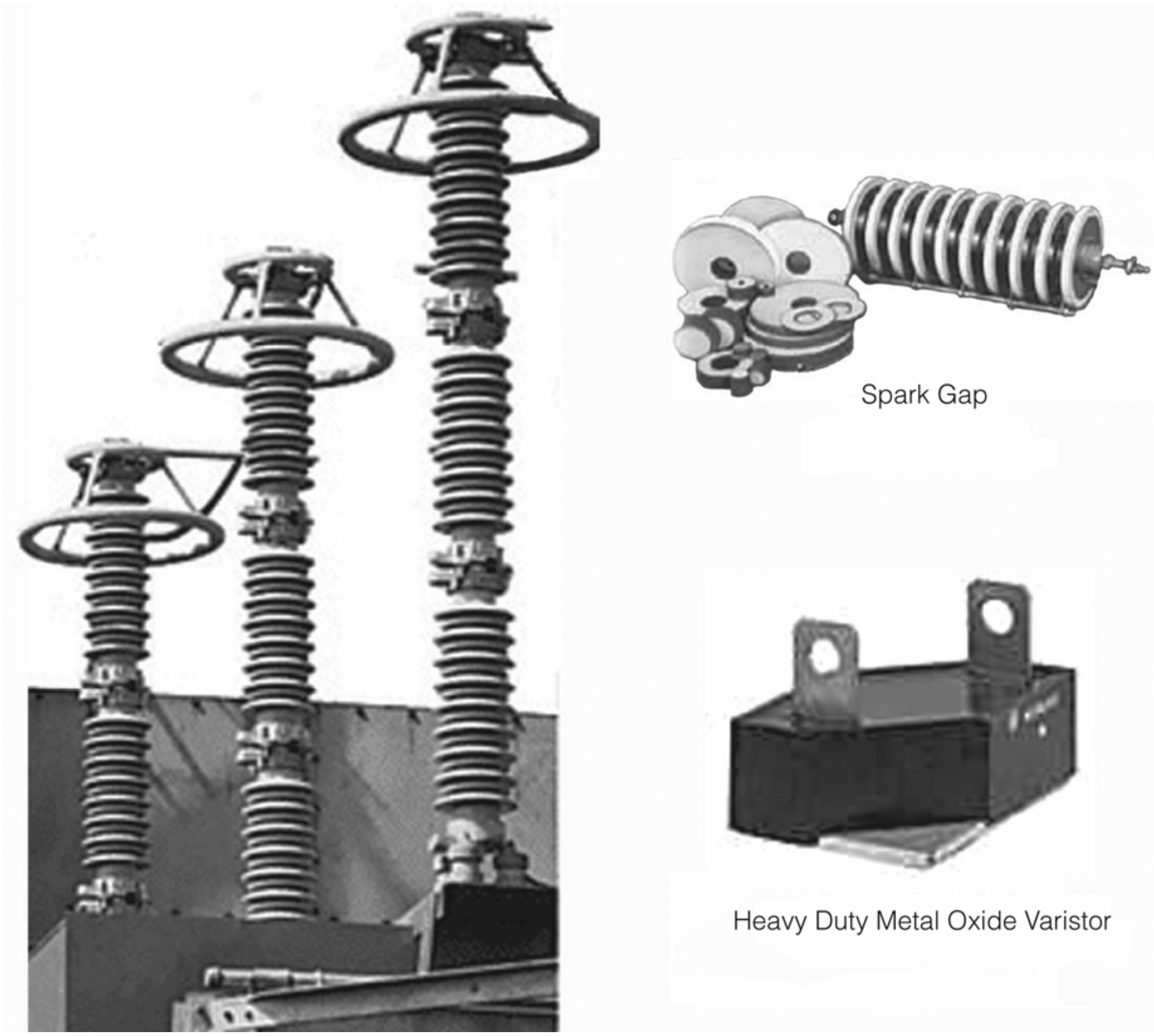


Figure A-20
Typical Surge Arrester and Internals
Source: EPRI Report 1002913 [62]

The metal oxide surge arresters are used under nominal power system frequency of 48–62 Hz. The ambient air temperature in the general vicinity can be between -104°F and +-104°F (-40ºC and +40ºC). Operating characteristics, performance characteristics, design testing, and other pertinent information can be found in IEEE C62.11 [41]. Figure A-21 depicts a typical transformer and lightning arrester installation.

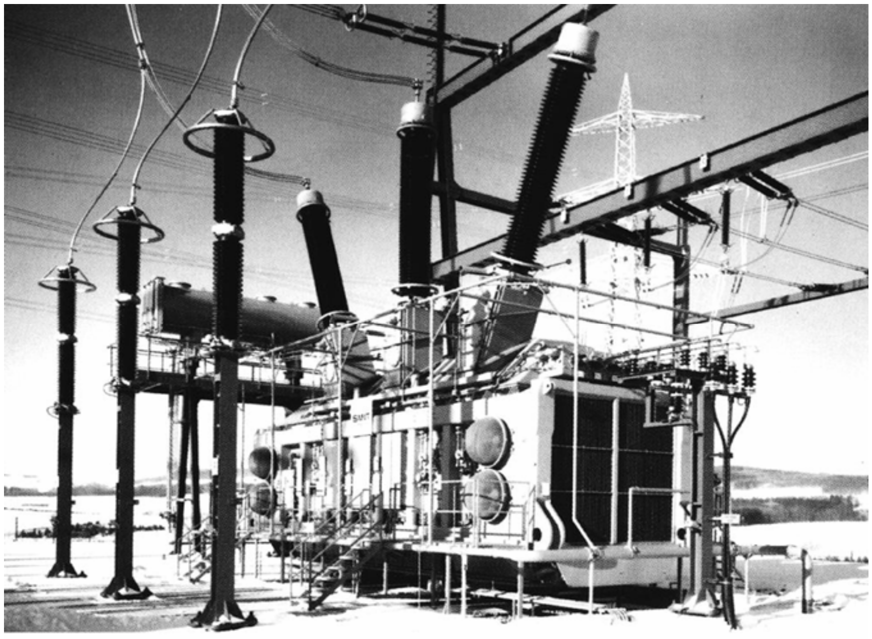


Figure A-21
Typical Surge Arrester Installation
Courtesy of Smit

IEEE C62.22, Guide for the Application of Metal-Oxide Surge Arresters for Alternating Current Systems, and ANSI/IEEE C62.2, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus, describe important considerations for selecting valve-type and metal oxide surge arresters [42, 74].

For optimum surge protection, the surge protection should be as follows:

- The voltage rating of the arrester should be equal to or greater than the normal line-to-ground voltage of the transformer.
- The arrester should be connected as close as possible to the transformer primary bushings.
- The arrester should be grounded to the tank and neutral ground.
- The resistance of the arrester ground connection should be $\leq 5\Omega$.

Use of in-service and out-of-service tests can be useful to assess the condition of arresters. Because arresters are resistive in nature and perform as insulators practically all of their service lives, tests typically performed are those that measure the ability of an arrester to act successfully as an insulator. Only when arresters are removed from service and returned to a service shop might other tests for power-frequency withstand or sparkover be performed.

Field tests that are performed to check the insulating capability of an arrester can, to some degree, also indicate its internal condition. For example, an ac dielectric loss measurement that is significantly higher than measurements on similar units can be indicative of moisture or internal foreign particle contamination. If infrared readings are significantly higher than on similar units, these are usually indicative of excessive losses leading to abnormal heating. These two tests are the most commonly used as screening tests to detect any abnormalities in arrester condition. These tests are also considered to be indicative of conditions that could cause either a malfunction or a failure of an arrester to operate properly under surge conditions. The infrared test is performed with the arrester in service, and the ac dielectric loss test is performed with the arrester out of service.

In specific applications, the arresters can have an arrester discharge counter and grading current instrument installed. The arrester discharge counter records on a cyclometer indicator the number of current discharges through the ground lead of the arrester. The arrester should be examined when the counter registers a discharge.

The arrester grading current instrument provides a continuous reading of the grading current and is typically connected with the discharge counter bypass. The grading current instrument provides information pertaining to degradation of the sealed arrester. Readings are noted on installation of the unit, and the current is trended for variations. The meter will read both surface current and grading current, so the readings should be taken with the arrester clean and dry under similar conditions.

An additional test applicable to those units in a sulfur hexafluoride (SF6) environment is the sparkover gap test. A spark gap is internal to the arrester, and the purpose of the spark gap is to determine whether SF6 gas has leaked inside the arrester housing. SF6 gas in the housing will cause the spark gap to increase. The sparkover of the gap should be monitored by sparking the gap (8 to 10 times) to determine an average gap, with this test performed on a periodic basis through the life of the arrester.

A.1.10 Bushings

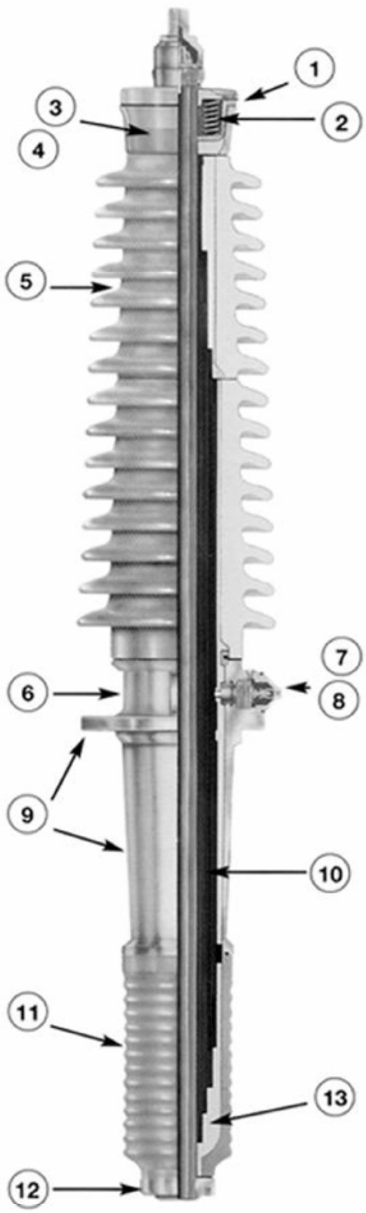
Bushings are insulating devices used on liquid-immersed transformers to insulate and seal the winding terminal connections through the grounded metal cover or sidewall of the tank. Bushings serve to insulate the primary and secondary windings from the tank. The bushing must provide sufficient dielectric strength to withstand the high voltages, and it is skirted to provide a long surface creepage path from the terminal to ground. A skirted, nonconducting porcelain weather shield is used over the upper external portion to provide a long surface path from the terminal to the ground flange and to facilitate moisture run-off from the shield.

There are two primary types of bushings, based on how the bushing is connected to the winding: fixed-conductor type and draw-lead type. For the fixed-conductor type, a central tube or rod conducts current from top of the bushing terminal to the bottom terminal, which in turn is connected to the transformer winding. For the draw-lead type, the winding lead is pulled through the central tube and connected to the top terminal.

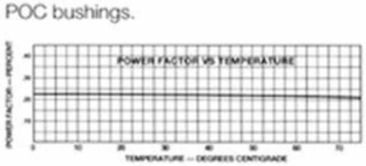
Figure A-22 shows a typical connection between transformer winding and bushings. These flexible connections must remain tightly clamped. If they are allowed to become loose, they could cause a short circuit, thus causing a transformer failure.

Figure A-22
Flexible Connections Between Transformer Winding and Bushings
Courtesy of Exelon

For power transformer high-voltage applications, capacitor-type oil-filled bushings are standard equipment (see Figure A-23). These condenser types of bushings have layers of oil-impregnated kraft paper with aluminum or copper foil layers between them inside the porcelain cylinder. These foil layers form a series of condensers to equalize voltage distribution.



The curve below shows typical power factor versus temperature relationship of Lapp POC bushings.



Lapp capacitor-graded bushings for transformer and oil circuit breaker applications are a proven design based on a capacitor core with aluminum foils and high dielectric paper impregnated with dried, degassed oil. Lapp POC bushings meet all ANSI/IEEE standards for outdoor apparatus bushings, where these standards apply for voltage classes 25 kV through 500 kV. When a transformer application results in overload above ANSI/IEEE standards, a bushing having a higher current rating is recommended. Lapp POC bushings for other applications (e.g., oil-to-oil, oil-to-gas, outdoor-to-indoor air, etc.) are available for various voltage classes and current ratings.

Design Features

1. Gaskets
Cork-nitrile rubber gaskets are designed to provide even loading and oil-tight seals with extended life.

2. High Compression Coil Springs
Multiple heavy-duty coil springs provide uniform, active compressive loading on gaskets to compensate for temperature variations and to assure oil-tight joints and reliable mechanical strength.

3. Clear-View Oil Reservoir (Medium and High Voltage Bushings)
The tinted glass oil reservoir filters damaging ultraviolet rays, preventing oil deterioration. The oil level and condition is clearly visible from any angle.

4. Magnetic Oil Gauge (Extra High Voltage Bushings)
The oil level is indicated by the pointer on the gauge.

5. Porcelain Housing
The outdoor porcelain housing has sturdy sheds to provide the required leakage and strike distance and has ground surfaces on top and bottom ends for oil-tight gasket seals.

6. Name Plate Data
The name plate affixed to the mounting flange identifies the bushing by catalog number, serial number and year of manufacture with electrical ratings and factory measurement data.

7. Power Factor Test Tap (Medium Voltage Bushings)
25 kV through 69 kV bushings have a power factor test tap. The test tap is connected to the ground layer of the capacitor core. An aluminum cap covers the insulated test tap assembly and grounds the tap to the flange when energized.

8. Voltage Tap or Capacitance Tap (High and Extra High Voltage Bushings)
Bushings rated at 115 kV and above have a permanent internal ground. In addition, an insulated tap is connected to a floating capacitor layer. This tap, designated a capacitance tap or a voltage tap, is grounded except when used as a voltage source with a potential device. The voltage tap also serves as a means of measuring power factor and capacitance of the bushing core. The tap is ANSI standard type A, normally grounded.

9. Mounting Flange, Ground Sleeve Assembly
The mounting flange and ground sleeve assembly is made of aluminum and provides nonmagnetic, corrosion-resistant, high-strength service.

10. Paper-Foil Capacitor Core
Conductive layers of aluminum foil with high dielectric paper are wound around the conductor and into the bushing core to produce uniformly valued capacitors in series. This capacitance grading distributes the voltage and the electrical field uniformly throughout the core. The core is vacuum-dried and impregnated with dried, degassed oil.

11. Lower Porcelain Assembly
The lower porcelain has ground gasket surfaces on each end to facilitate alignment and maintain an oil-tight assembly.

12. Bottom Cap Assembly
A confined cork-nitrile rubber gasket provides a leak-proof seal between the porcelain and the cap. The end cap aligns the porcelain with the conductor. For bushings rated 115 kV through 161 kV, the bottom cap is adaptable for use in draw-lead and bottom-connected applications.

13. Dried, Degassed Oil
The internal space in the bushing between its exterior components and the core is filled with dried, degassed insulating oil.

Figure A-23
Apparatus Bushing of the Paper-Oil Capacitor Type
Courtesy of LAPP

Lower-voltage bushings might or might not use the condenser-type design (see Figure A-24).

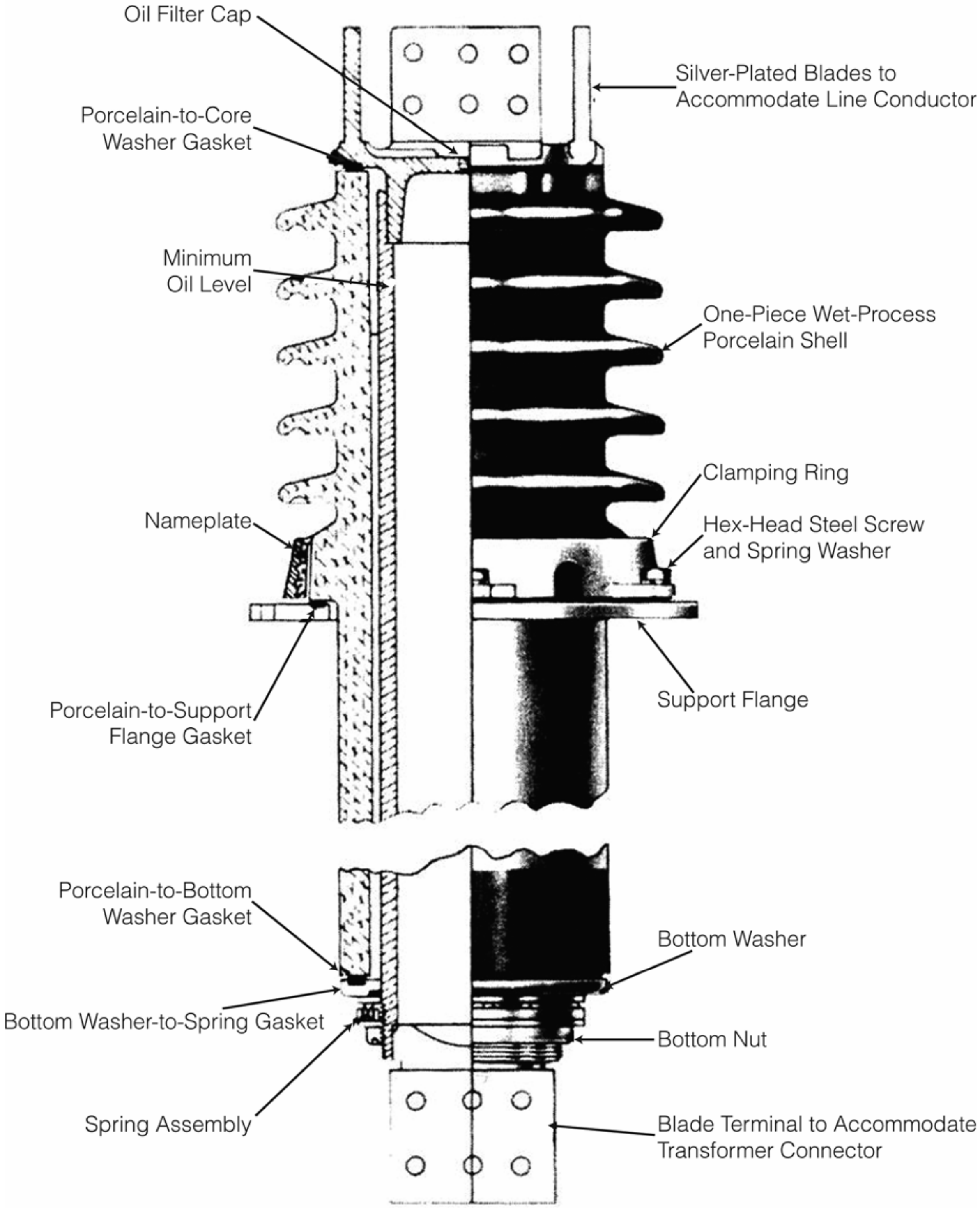


Figure A-24
High-Current Type A Bushing, 25 kV, Class 4500A and Above
Source: EPRI Report 1002913 [62]

Bushings can be equipped with either a test tap or a potential tap, depending on the voltage application. These taps are used during testing and are normally grounded while the transformer is in service.

Bushings can be tested by using the test or potential tap. The capacitance and power factor test results provide information that indicates whether there is a short circuit in the condenser foils. An increase in the power factor is an indication of the presence of moisture or other contaminants. Airborne contaminants (conductive or nonconductive), such as dust and salts, when combined with water, can cause partial discharges and flashovers by providing a conductive coating on the surface of the bushing.

The hot collar test can be used to detect localized defects in bushings. The test is performed by energizing one or more temporary electrodes (a collar of semi-conducting rubber) placed around the outside of the porcelain with the central conductor grounded. This test is useful when the condition of a specified section of the bushing must be investigated for cracks in porcelain, degradation of fluid inside the bushing, or low liquid level.

A.2 Functionality of a Large Power Transformer

A.2.1 Typical Power Plant Transformer Layout

Power transformers are used in generating stations to connect the main generator to the high-voltage transmission system. They also connect the plant and off-site sources of electrical power to distribution subsystems for operation of plant auxiliary electrical equipment at medium and low voltages.

The GSU transformer normally requires no voltage-regulating winding because the field of the generator regulates the voltage. The secondary winding of the GSU is high voltage and requires large internal clearances, which requires the transformer tank to be large. On large generator megavolt ampere output, some utilities choose multiple single-phase transformers.

The UAT is tapped off the isolated phase bus (IPB) duct to feed the plant auxiliary equipment through a segregated or nonsegregated phase bus duct. Its load can vary during startup and shutdown switching operations. The UAT primary and secondary voltages can be in the medium voltage range and the transformer tank is normally smaller than the GSU with small internal clearances.

A second power supply for the plant auxiliary equipment is provided from the preferred power supply (off-site source) through the RAT or SAT. The RAT or SAT provides power to the station equipment when the generating unit is off line, during startup, and during shutdown, and it serves as a backup power supply when the unit is on line. It feeds the plant auxiliary equipment through a segregated or nonsegregated phase bus duct. The primary side of this transformer (off-site source) is high voltage and requires large internal clearances.

Figure A-25 depicts a one-line diagram of a typical generating station. The primary winding of the GSU is connected by flexible links to the IPB duct, which connects to the terminals of the generator, as shown in Figure A-26.

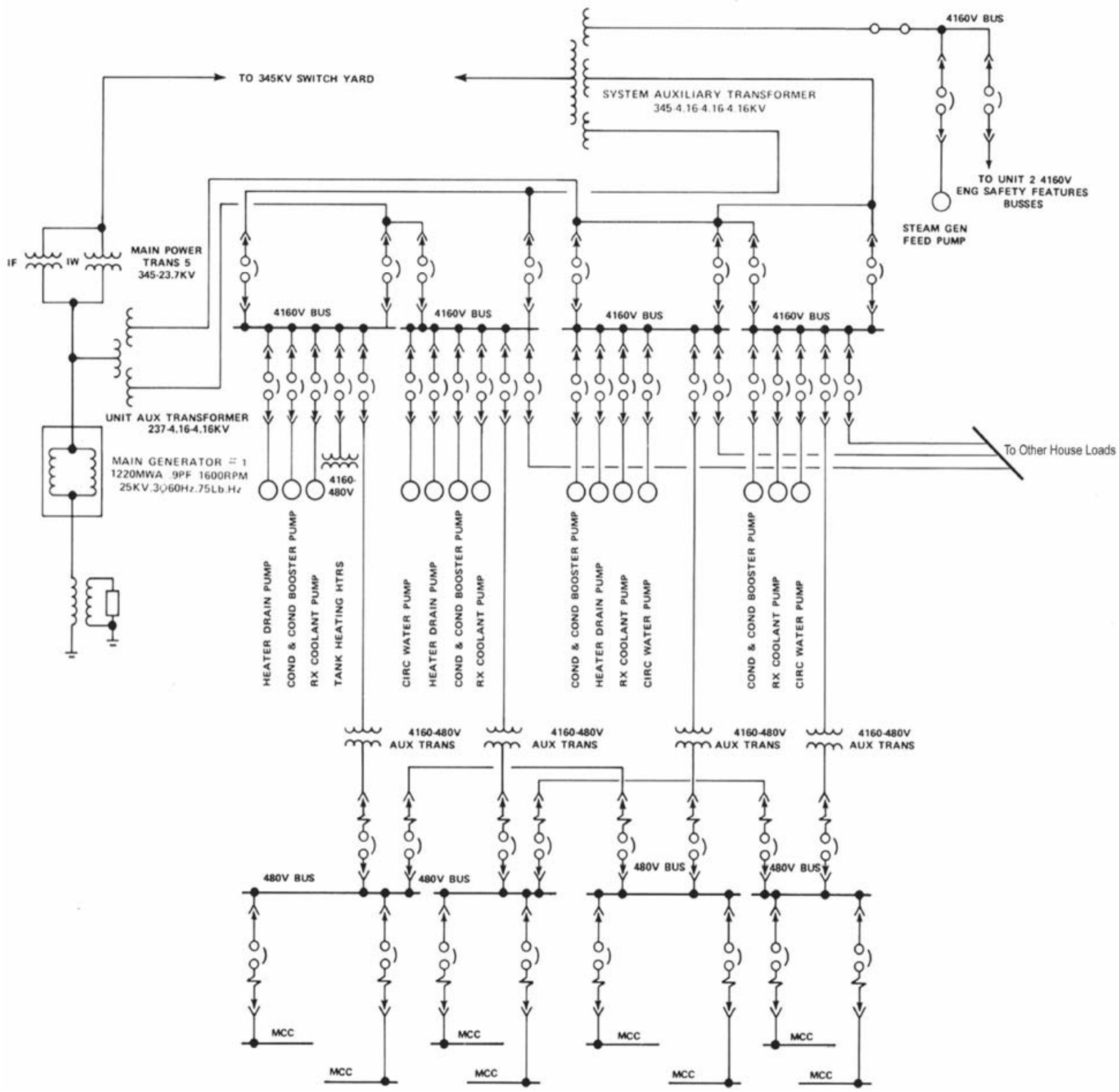


Figure A-25
Typical Generating Station One-Line Diagram
Source: EPRI Report 1002913 [62]

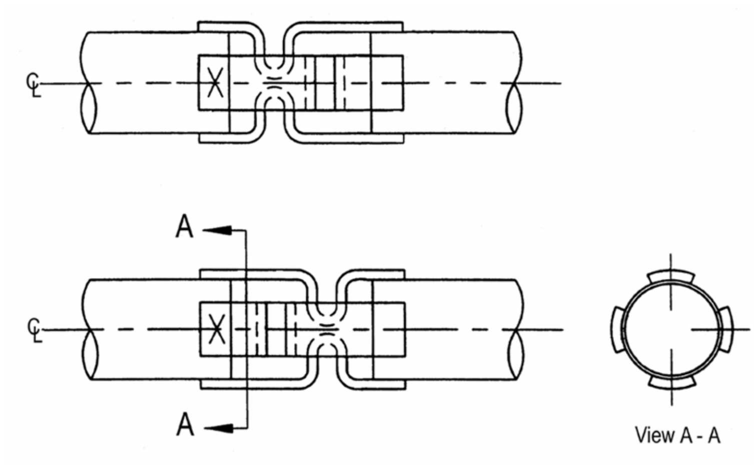


Figure A-26
Laminated Flexible Connections
Source: EPRI Report 1002913 [62]

A.3 Large Power Transformer Failure Mechanisms

The project team should have an understanding of typical failure mechanisms associated with the replacement transformer and should consider lessons learned and how those failures can be mitigated or prevented through the application of various design parameters during the design of the replacement. Transformer failures can be attributed to dielectric breakdown, short circuit, deterioration of insulation properties, bushing failure mechanisms, tap changer failure mechanisms, and transformer manufacturing and design defects. A more detailed description of failure mechanisms for large power transformers is provided in the following subsections.

A.3.1 Dielectric Breakdown

Dielectric breakdown is one significant cause of failure. There are many reasons for such failures, including the following:

- Inadequate vacuum filling of the transformer both when new and when refilled in the field
- Gas bubbles caused by saturation of the oil with nitrogen from the gas cushion oil preservation system
- Gas bubbles caused by excessive water in the insulation when it is heated to high temperatures (≥302°F [≥150ºC]) by overload or by local hot spots
- Inadequate insulation design for the voltages encountered in service
- Static electrification caused by pumping the oil at high flow rates when the oil is cool
- Significant overloading of transformer
- Aging of paper insulation
- High voltage surges from lightning or switching

A.3.2 Short-Circuit Failure

Transformers are designed to more restrictive standards since the IEEE C57.12.00 requirements were initially approved in the mid-1970s [8]. Some transformers designed and manufactured before that time might have questionable strength, and some designed afterward might have design or manufacturing weaknesses. Some of the problems causing short-circuit failures are the following:

- Loose windings caused by inadequate drying, inadequate compression in manufacturing, or improper support for the force in service.
- Inadequate strength in the windings, including a variety of problems depending on the type winding used. Such problem areas are usually the result of poor design practice.
- Inadequate mechanical support for the short-circuit forces.

The actual failure might be dielectric in nature, originating from damage caused during a short circuit, such as shearing of paper or shorting of turns. The failure can occur quite some time after the short circuit.

A.3.3 Deterioration of Insulation Properties from Oxygen and Water

Insulation can degrade more rapidly from exposure to high levels of oxygen (>3000 ppm [>3000 mg/kg]) and water (greater than 0.5% water in paper) at normal operating temperatures. This degradation can occur in older transformers as a result of the following:

- Oil expansion tanks with no rubber bags to prevent oxygen from entering the tank
- Failure to maintain the dehydrating breathers so that water also enters the oil through the expansion tank
- Oil leaks

Smaller transformers with open breathers are also subject to the same problem. If transformers with nitrogen blankets above the oil are not maintained, oxygen and water enter the system and degradation occurs, as follows:

- The paper becomes brittle as if it were thermally aged, even though it has never been overheated.
- The paper in all windings becomes brittle so that they are susceptible to short-circuit failures such as turn-to-turn shorts.
- It is believed that the pressboard also becomes brittle and shrinks in the thickness dimension, producing some looseness. However, the total thickness change might not be significant if the water content is high, because water causes paper to swell.

A.3.4 Corrosive Sulfur Contamination of the Insulating Oil

In the past few years, a number of large transformers, including GSU transformers (of hydro, fossil, and nuclear plants) and transmission shunt reactors have failed abruptly with no external disturbance or alarm. Some of the failures occurred in equipment that is relatively new, sometimes with less than 20,000 hours of operation. These failures have puzzled both owners and manufacturers, who have scrambled to find the root causes of these failures only to reach a dead end in the analysis, in most cases. Some of these failures can now be attributed to corrosive sulfur contamination of the insulating oil and other materials.

The existence of corrosive sulfur in transformer oil is not a new issue. It was been reported many decades ago, was thought to have been eliminated, and was almost forgotten. However, the new stream of failures has shed more light on a problem that could cause serious harm to some power plants and portions of some transmission systems.

Sulfur can be present in different forms in transformers, mostly forms of sulfur that are stable and will have little affect on transformer condition. It is the corrosive sulfur and its compounds that are of concern here. Nevertheless, with the presence of high temperatures, even the stable forms of sulfur can be converted into corrosive sulfur.

Figure A-27 shows the loss of dielectric strength of kraft paper based on the position of the paper relative to the corrosive-attacked conductor and the position of the conductor (Figure A-28). It can be easily concluded from Figure A-27 that the paper close to the conductor surface loses a considerable percentage of its dielectric strength.

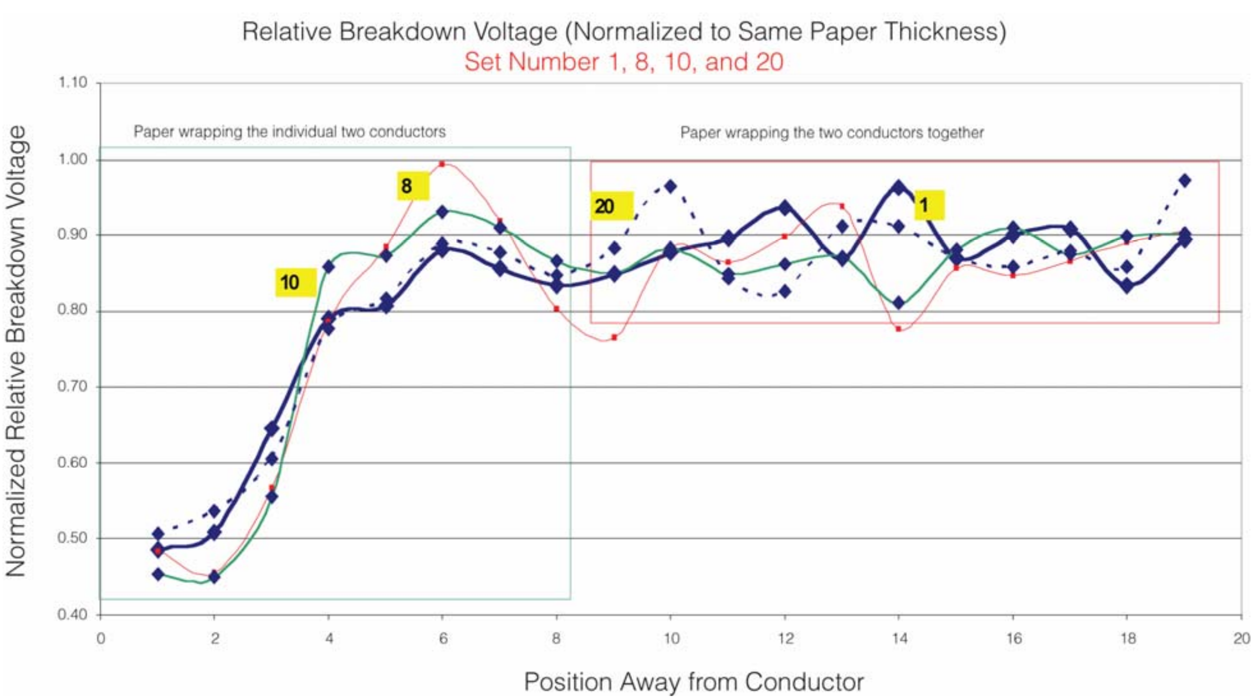


Figure A-27
Effect of Corrosive Sulfur on the Dielectric Strength of Kraft Paper

Figure A-28
Position of Conductors for Figure A-27

A.3.5 Thermal Aging

The thermal rating of a power transformer differs from the thermal rating of other current-carrying elements in a substation. In a power transformer, the cooling system is active. The thermal limits depend on the dielectric and mechanical properties of the cellulose and oil insulation system. With overly conservative loading practices, cellulose insulation life from thermal stress is practically limitless. In practice, deterioration of accessories and non-active parts limits the practical life of the transformer. These elements include the tank, gauges, valves, fans, radiators, bushings, LTCs, and so on. The average, practical life of a transformer is probably 30–50 years; therefore, it is reasonable to allow some thermal aging of the cellulose insulation system. Most of the time, risks other than loss of insulation life are the limiting characteristics.

Paper insulation must have mechanical and dielectric strength. The mechanical strength allows it to withstand forces caused by through faults. When aged, paper loses its mechanical strength, and through faults can cause winding movement sufficient to damage or tear the paper. This physical damage reduces the dielectric withstand of the paper insulation. At this point, the risk of dielectric failure is relatively high.

The normal life of cellulose insulation is the time in years for a transformer operated with a constant 230°F (110ºC) hot-spot winding temperature to reach its defined end-of-life criteria. DP and tensile strength are properties that quantify the aging of cellulose paper insulation. Some things to remember in regard to thermal aging are the following:

- The relationship between life expectancy and temperature is logarithmic, and as the hottest spot conductor temperature moves below (or above) 230°F (110ºC), the life expectancy increases (or decreases) rapidly. An accepted rule of thumb is that the life doubles (or halves) for every 46.4°F (8ºC) decrease (or increase) in operating temperature.
- Cellulose aging is a chemical reaction. As in all reactions, heat, water, and oxygen are required.
- The aging process is minimal if the oil and paper are kept dry, the oxygen content is nominal, and the hot-spot temperatures are not above standard allowances. The expected life of the paper halves when the water content doubles.

A.3.6 Tap Changer Failure Mechanisms

The LTC compartment has current-interrupting contacts and movable taps that are moved frequently for some transformers, depending on the voltage regulation requirements. The frequency of current interruption and tap movement is different from one transformer to another, depending on the voltage regulation requirements of the system. More frequent operation of the LTC will result in accelerated contact wear and higher gas generation in the oil. The LTC requires proper maintenance to avoid failures.

LTC failure can be attributed to the following primary causes:

- Contact coking
- Defective control system components
- Defective mechanical components
- Deteriorated gaskets or seals
- Localized oil overheating or oil contamination
- Partial discharge or tracking

The DETC includes fixed and movable electrical contacts for selecting the optimum transformer turns ratio for operation. Because the DETC typically remains in one position for many years without operating, contact resistance can increase over time and evolve into a coking, arcing and melting failure. Many manufacturers recommend periodic exercising of the DETC (that is, rotating through all positions and back) to wipe the contact surfaces. Recent continuing life tests suggest that the choice of contact surface material (copper or silver) can be critical to the tap changer’s susceptibility to this failure mode.

A.3.7 Bushing Failures

Bushing failures have led to failures of large power transformers. Bushing failures can be attributed to the following causes:

- Aging of equipment
- Design deficiencies
- Formation of gas bubbles and dielectric losses
- Manufacturing deficiencies
- Material quality deficiencies
- Thermal cycling

Power factor and capacitance tests should be performed on the bushings to determine their condition, and the bushings should be replaced when necessary. Thermography and corona inspections should also be performed to identify and correct any defects. Failure to perform such maintenance can lead to transformer failures.

A.3.8 Observations

Several possible service conditions that can produce immediate degradation or aging degradation of a system or component were reviewed. Abnormal conditions and elements such as transients, atmospheric and temperature conditions, vibrations, mechanical and electrical cycling, and contaminants can deteriorate the overall transformer operating condition. When such degrading conditions are allowed to continue without the proper inspection and subsequent corrective steps, the results will be further equipment deterioration that eventually leads to failure.

Electrical tests performed on the windings might include evaluation of the insulation resistance, winding ratio, and insulation power factor. Insulation resistance testing is performed in the field on each winding with the other winding grounded, and from one winding to another. This test indicates the condition of the winding insulation as well as the presence of any moisture. A transformer winding ratio or turns ratio test is used to verify the transformation ratio of the primary to secondary windings at all tap settings. Power factor testing is used to detect degradation in the total transformer insulation system, including the bushing insulation if the bushing has a test tap. New measurement values are compared to previous test results or to test results of identical sister transformers. An increase in power factor readings when taken at similar oil temperatures can be an indication that the insulation system is degrading.

B
SEISMIC DESIGN AND QUALIFICATION REQUIREMENTS

This appendix provides an overview of the requirements described in Annex D of IEEE 693, IEEE Recommended Practice for Seismic Design of Substations, which provides detailed guidance for determining seismic qualification requirements for transformers and liquid-filled reactors [9]. The requirements have been edited as they apply to large power transformers. Project teams should consult the IEEE standard for complete requirements as they apply to the transformer replacement project at their site.

B.1 General

The voltage (kV), as used in this appendix, is the nominal system voltage as defined in IEEE C57.12.00 [8]. The seismic qualification levels are given in Sections B.1.1 through B.1.3. The project team should identify the qualification level applicable to their particular site.

B.1.1 High Seismic Qualification Level

The requirements of IEEE 693, Annex D, with the exception of Sections B.1.2 and B.1.3 of this appendix, apply to transformers and liquid-filled reactors in high seismic qualification level areas [9].

B.1.2 Moderate Seismic Qualification Level

The requirements of IEEE 693, Annex D, with the exception of Sections B.1.1 and B.1.3 of this appendix, apply to all transformers and liquid-filled reactors in moderate seismic qualification level areas [9].

B.1.3 Low Seismic Qualification Level

Only the requirements of IEEE 693, Section A.1.1.4, are applicable to transformers and liquid-filled reactors in low seismic qualification level areas. Project teams should refer to IEEE 693, Clause 1 through Clause 8, for information.

B.2 Operational Requirements

Transformers and liquid-filled reactors shall be designed so there will be neither structural damage nor loss of function immediately after an earthquake when subjected to design seismic loads occurring simultaneously with dead and normal operation loads.

B.3 Seismic Qualification Method

IEEE 693 allows for different qualification methods depending on the size of the transformer [9]. Table B-1 provides the respective seismic withstand capability methods, as well as the sections in both the IEEE standard and this appendix that provide guidance. The information in the table was adapted from IEEE 693 [9].

Table B-1
Summary of Seismic Qualification Methods

Transformer and Liquid-Filled Reactors (The kV Referenced Are the High Side of the Transformer and Liquid-Filled Reactors)			
Size	**Qualification Method**	**Applicable IEEE Section**	**Applicable Guidance in This Appendix**
≥115 kV	Static analysis	D.4.1	B.4.1
35 kV to <115 kV	Load path	D.4.2	N/A
<35 kV	Inherently acceptable	D.4.3	N/A
Bushings			
≥161 kV	Time history shake-table tests	D.4.4	B.4.2
35 kV to <161 kV	Static pull test	D.4.5	N/A
<35 kV	Inherently acceptable	D.4.3	N/A
Surge Arresters			
All kV sizes	Requirements given in Annex K	D.4.6	B.4.5

B.4 Qualification Procedure

The qualification procedure shall be according to the requirements of IEEE 693, Section A.1.1.

B.4.1 Static Analysis

B.4.1.1 Qualification of Tank Components (Excluding Appendages)

The transformer tank, core, coils, anchorage, and other components—other than appendages, bushings, and surge arresters—shall be qualified using static analysis according to the requirements of IEEE 693, Section A.1.3.1.

The static analysis calculations shall include verification of the load path from the core, coils, tank, and base to the anchorage for all three orthogonal axes. All components of the load path shall have sufficient rigidity to restrain the core and coil from shifting. Sketches shall be provided with the analysis that clearly shows a complete load path (or paths) to the anchorage. Load path parts and members shall be clearly labeled and dimensioned. Section properties, calculated stresses, and allowables of all load path parts and members shall be provided.

B.4.1.2 Qualification of Appendages (Such As Radiators, Conservators, and Control Cabinets)

Appendages such as radiators, conservators, and control cabinets shall be qualified by static analysis according to the requirements of IEEE 693, Section A.1.3.1, where the acceleration values are multiplied by 3.

B.4.2 Bushing Time History Shake-Table Tests

Bushings ≥161 kV shall be qualified using a time history test according to the requirements of IEEE 693, Section A.1.2.2. A resonant-frequency search shall be conducted according to IEEE 693, Section A.1.2.1. Because it is impractical to shake-table test the bushings on the transformer or liquid-filled reactor, the bushings shall be mounted on a rigid stand during the test. The stresses that the bushing actually experiences from the ground acceleration are amplified as a result of the influence of the transformer body. Because of the complexity of the flange connection and the criticality of the transformer bushing, it is not acceptable to attempt to project the performance for the required response spectra test. The bushing shall be tested to twice the input level required at the top of the transformer. Therefore, bushings shall be tested to four times for the high seismic level or four times for the moderate seismic level. This testing is to the performance level.

If resistance to lateral load depends on clamping or prestressing of the bushing core, reduction of prestressing force as a result of thermal expansion, relaxation, or material creep effects anticipated at operating temperatures shall be accounted for in qualification tests. As a minimum, specimens used for seismic qualification tests shall be assembled with core clamping forces adjusted for both ambient and operating temperatures above the temperature at assembly.

Rise resulting from ambient temperature in excess of the temperature at assembly shall be based on an operating ambient temperature of +86°F (+30ºC). Operating temperature rise can be conservatively based on the thermal basis of rating requirements given in IEEE C57.19.00 [27]. Thermal analysis or test data applicable to the specific bushing model can be used in place of the values given in IEEE C57.19.00 [27]. Temperature differentials for the bushing shell, core tube, flange, and other affected parts shall be determined from tests, analyses, or other rational methods.

A suggested method for adjustment of the core clamping force because of elevated temperatures is provided in IEEE 693 [9].

B.4.4.1 Monitoring Requirements for Porcelain Bushings

Monitoring requirements shall be in accordance with Section A.2.8 of IEEE 693 and the following [9]:

- Maximum vertical and horizontal accelerations at the top of the bushing, at the end of the bottom of the bushing, at the bushing flange, at the center of gravity of that part of the bushing above the porcelain-flange interface, and at the top of the shake table.
- Maximum relative displacement of the top of the bushing to the flange shall be measured during the test or calculated from the acceleration time histories.
- Maximum porcelain stresses at the base of the bushing near the flange.
- Maximum stresses at the flange metal end fitting and maximum stresses in the flange attachment bolts. The maximum stresses in the bolts can be found by calculations; however, the use of strain bolts is recommended.
- Slippage of bushing relative to the base.

B.4.4.2 Monitoring Requirements for Composite Polymer Bushings

Monitoring requirements shall be in accordance with Section A.2.8 of IEEE 693 and the following [9]:

- Maximum vertical and horizontal accelerations at the top of the bushing, at the end of the bottom of the bushing, at the bushing flange, and at the top of the shake table.
- Maximum relative displacement of the top of the bushing to the flange shall be measured during the test or calculated from the acceleration time histories.
- Maximum stresses at the flange metal end fitting and maximum stresses in the flange attachment bolts. The maximum stresses in the bolts can be found by calculations; however, the use of strain bolts is recommended.

B.4.5 Qualification of Surge Arresters

Surge arresters shall be qualified according to the requirements of Annex K of IEEE 693, except that twice the input acceleration specified by Annex K shall be used [9].

C
EXAMPLE OF A TYPICAL BID SPECIFICATION

This appendix provides an example of a bid specification prepared by one nuclear utility. The specification generally follows the guidance provided in Section 4, Developing Bid Specifications and Requests for Proposals. The example specification is provided solely for illustrative purposes and only represents a specification used by one nuclear utility when procuring a large power transformer.

Note: The example specification should not be used by the licensee without first ensuring that each requirement meets the design parameters for the intended plant-specific application. Under no circumstances should the example be used as-is to specify plant-specific equipment.

When specific manufacturers and models of accessories are specified, the licensee should evaluate the reliability, capability, and plant interface requirements to determine the most appropriate accessory specifications and select the optimal equipment.

This example includes illustrative commercial terms and conditions, schedule requirements, and other administrative requirements that one utility communicated to prospective bidders. Guidance on developing a complete bid specification is provided in Section 4, Developing Bid Specifications and Requests for Proposals.

The term “shall” is used in this example for illustrative purposes only; it does not imply that each requirement is applicable in every procurement scenario.

C.1 Example Table of Contents for a Large Power Transformer Specification

The EPRI report *GPPTS—Guidelines for the Preparation of Power Transformer Specifications* (1011658) provides the following general information regarding the contents of a specification for a large power transformer [55]. The information is provided only as an example; the actual format and contents of the specification prepared by each project team should conform to utility, fleet, and site procedures. Contents can include the following:

- Purpose of the equipment
- Design requirements
- Rating
- Short circuit withstand capabilities
- System operating conditions

- Environmental concerns
- Technical requirements
- Testing
- Technical manual and photographs
- Transformer site
- Transportation
- Furnishing, delivery, erection, and testing
- Warranties
- Bidder’s manufacturing data
- Cancellation schedule
- Transformer loss evaluation

C.2 Example Specification for a Large Power Transformer

TABLE OF CONTENTS

PROPOSAL FORM – PART I FOR
GENERATOR STEP-UP POWER TRANSFORMER

We, __________________, as Contractor, propose in compliance with and in response to your Instructions to Bidders, to fully complete for you as Purchaser, at the prices and on the terms set out below, the work which the Contractor is to perform under bid document listed herein.

NAME OF BIDDER: ____

INSERT ALL INFORMATION WITHIN BRACKETS

1. FIRM PRICES

1.1 Transformers
Price for furnishing one (1) transformers, as specified in Section 105.1, f.o.b. Purchaser's Station, excluding freight, services of manufacturer's qualified representative(s) and all Illinois taxes and based on meeting all conditions of the Bid Documents, unless exceptions are specifically listed, identified in the Proposal .... [$]

1.2 Freight
a. Amount to be added to Price (Item 1.1) for freight, points of shipment to Name of Plant/Site for one (1) transformer............ [$]

1.3 Total Price
a. Total Price, f.o.b., Name of Plant/Site (excluding all Illinois taxes) .... [$]

2. FIELD SERVICES

2.1 Number of working days included in Item 1.3a
TOTAL PRICE for a Service Engineer.. [ ]

2.2 Number of working days included in 1.3b
TOTAL PRICE for a Service Engineer.. [ ]

2.3 Price per working day for the services of the manufacturer's representative (including living expenses but excluding travel expense to be paid at actual cost) to assist in installation, perform the final field inspection after erection and to supervise initial startup if requested by Purchaser... [$]

2.4 Transportation expense for one (1) round trip to the project site
a. Name of Plant/Site.. [$]

3. OPTIONS

3.1 Price for performing Audible Sound Level Test per Section 316.7a (per test).. [$]

3.2 Price for performing optional Dielectric Tests per Section 316.7b (per test) .... [$]

3.3	Price for performing short circuit test (per test)...................................	[$]
3.4	Price for furnishing the entire recommended spare parts inventory (per transformer)	[$]
3.5	Price for expedited delivery (state schedule improvement and cost)	[ ]
	The above options are open for acceptance until time of award of the Generator Step-Up Power Transformers	

4. PRICE ADJUSTMENT

4.1	Firm price will be considered more favorably in the analysis of bids. Is the above price a firm price? (Answer yes or no)	[ ]
4.2	If Bidder cannot quote a firm price, he shall list <u>in detail</u> in his Proposal the exact terms of his price adjustment clause. The price adjustment clause is to be based upon published index (indices) and is to be found on Page _____ of his proposal	[ ]
4.3	The percentage limit of adjustment, expressed as a percentage of the total price...	[%]

5. TAXES

5.1	Bidder shall confirm that no tax has been included in the price column: "No tax included"	[ ]
5.2	Bidder hereby certifies that he has read and accepts the provisions of Article 5.2, Taxes, of Purchaser's Services and Materials Agreement . (answer yes or no; if no, state reason)	[ ]
5.3	Bidder shall list the percentage to be added to the prices quoted f.o.b. Purchaser's stations to cover Illinois Use Tax	[%]

6. BIDDER'S CERTIFICATION

Bidder hereby certifies that he agrees to all provisions of the Bid Documents unless exceptions are specifically and clearly listed in the Proposal and as summarized in Item 20.6 Proposal Form – Part II. Bidder's printed terms and conditions are not considered specific exceptions.

PROPOSAL FORM – PART II FOR

GENERATOR STEP-UP POWER TRANSFORMER

NAME OF BIDDER: ______________________________

DATE OF BID: ______________________________

INSERT ALL INFORMATION WITHIN BRACKETS

1. DELIVERY

1.1 Delivery requested at destination
- Name of Plant/Site (4/1/07) .... [ ]

1.2 Bidder shall state here whether the above delivery dates can be met and, if not, what the earliest possible delivery dates are
- Name of Plant/Site .... [ ]

1.3 Bidder shall state his proposed shipping schedule in order to meet the above required delivery date
- Name of Plant/Site .... [ ]

2 SHIPMENT

2.1 The vendor shall be responsible for the coordination of all transportation issues, including rail capacity and clearances, sea shipment and portal entry requirements, import/export processes, etc. The Vendor shall describe the planned transportation method in detail within the proposal. List proposal page where found. .... [ ]

2.2 Point of Shipment .... [ ]

3. DRAWINGS (CONTRACTOR'S)

3.1 Delivery required after award of contract:

a. Preliminary Outline... (weeks) [4 weeks]

b. Plan of Base, which shall include the following .... (weeks) [4 weeks]

b1. Arrangement and size of the base members. ....

b2. Width and length of each bearing member ....

b3. Load on each bearing member ....

b4. Center of gravity of loads (both shipping and assembled with and without oil)..

b5. Location of jacking points..

c. Final Outline and other information required by Form 1824-K .... (weeks) [16 weeks]

3.2 Bidder shall state here whether the above drawing delivery requirements can be met, and if not, indicate the number of weeks after award of contract that delivery can be made:

a. Preliminary Outline... (weeks) [ ]

b. Plan of Base.. (weeks) [ ]

c. Final Outline and other information required by Form 1824-K .... (weeks) [ ]

4. TRANSFORMER DATA

4.1 Manufacturer .... [ ]

4.2 Class and type of core... [ ]

a. Induction level at nominal voltage.. [ ]
b. Maximum core temperature at nominal voltage.......................... [ ]
c. Induction level at 105% voltage .... [ ]
d. Maximum core temperature at 105% voltage .... [ ]

4.3 Phase .... [ ]

	High Voltage H-Winding	Low Voltage X-Winding
4.4 Conductor material of each winding (only copper is acceptable)...	[ ]	[ ]
4.5 Nominal System Voltage (line-to-line)................(kV)	[ ]	[ ]
4.6 Transformer connections.................... (wye or delta)	[ ]	[ ]
4.7 Is delta connected inside transformer? ...(yes or no)		[ ]
4.8 Rated winding voltage ....(kV)	[ ]	[ ]

	High Voltage H-Winding	Low Voltage X-Winding
4.9 Transformer rating:		
At 55°C rise ....(MVA)	[ ]	[ ]
At 65° rise...(MVA)	[ ]	[ ]

4.10 Tap changer-full capacity taps to be manually changed when transformer is not excited:

a. Above rated voltage at full MVA capacity (number of taps and percent volts each tap) .... [ ]

	b.	Below rated voltage at full MVA capacity (number of taps and percent volts each tap)	[ ]	
	c.	Location of taps on winding	[ ]	
4.11		Insulation Class (nominal system voltage) ....(kV)	[ ]	[ ]
4.12		Neutral insulation class ....(kV)	[ ]	
4.13		Line end basic lightning impulse insulation level (BIL) ....(kV)	[ ]	[ ]
4.14		Neutral end basic lightning impulse insulation level (BIL)...(kV)	[ ]	
4.15		Applied voltage test ....(kV)	[ ]	[ ]
4.16		Induced voltage test (1 hour level):		
			LOW-VOLTAGE Y-WINDING	
	a.	Line to neutral..(kV)	[ ]	
	b.	Line to line ....(kV)	[ ]	
	c.	Connection during test......................... diagram	[ ]	
			High Voltage H-Winding	Low Voltage X-Winding
4.17		Lightning Impulse Test:		
	a.	Full wave..(kV)	[ ]	[ ]
			High Voltage H-Winding	Low Voltage X-Winding
	b.	Chopped Wave:		
	b1.	Crest ....(kV)	[ ]	[ ]
	b2.	Minimum time to flash-over (microsecond)	[ ]	[ ]
4.18		Phase Bushing Ratings:		
	a.	Manufacturer...	[ ]	[ ]
	b.	Type and catalog number.................................	[ ]	[ ]
	c.	Insulation class ....(kV)	[ ]	[ ]
	d.	Rated continuous current .... (A)	[ ]	[ ]
	e.	External basic lightning impulse insulation level (BIL)..(kV)	[ ]	[ ]

f.	Internal basic lightning impulse insulation level (BIL) ....(kV)	[ ]	[ ]
g.	Maximum design voltage to ground ....(kV)	[ ]	[ ]
h.	Minimum creepage ....(in)	[ ]	[ ]
i.	Withstand tests:		
i1.	Dry (1 minute) ....(kV)	[ ]	[ ]
i2.	Wet (10 seconds)....................(kV)	[ ]	[ ]
j.	Wet switching surge value....................(kV)	[ ]	[ ]
k.	List test taps provided....................	[ ]	[ ]
l.	Color of bushing ANSI designation	[ ]	[ ]

4.19 Neutral bushing ratings:

a.	Manufacturer....................	[ ]
b.	Type and catalog number....................	[ ]
c.	Insulation class ....(kV)	[ ]
d.	Rated continuous current .... (A)	[ ]
e.	External basic lightning impulse insulation level (BIL) ....(kV)	[ ]
f.	Internal basic lightning impulse insulation level (BIL) ....(kV)	[ ]
g.	Maximum design voltage to ground ....(kV)	[ ]
h.	Minimum creepage ....(in)	[ ]
i.	Withstand tests:	
i1.	Dry (1 minute) ....(kV)	[ ]
i2.	Wet (10 seconds)....................(kV)	[ ]
j.	List test taps provided....................	[ ]
k.	Color of bushing ANSI designation	[ ]

4.20 Transformer radio influence (RIV):

a.	At 120 percent normal operating voltage ....(microvolt/picocoulomb)	[ ]
b.	At 100 percent of induced test voltage ....(microvolt/picocoulomb)	[ ]

4.21 Efficiency at unity power factor (not including power for cooling):

a. Full load at 55°C rise ....(%) [ ]

b. At 75 percent of full rated load.....................(%) [ ]

c. At 50 percent of full rated load.....................(%) [ ]

d. At 25 percent of full rated load.....................(%) [ ]

4.22 Impedance (guaranteed) based on rated MVA (55°C rise rating) H-Winding

a. Impedance at rated voltage.........................(%) [ ]

b. Impedance at +5% rated tap ....(%) [ ]

c. Impedance at +2-1/2% rated tap.................(%) [ ]

d. Impedance at –2-1/2% rated tap.................(%) [ ]

e. Impedance at –5% rated tap ....(%) [ ]

4.23 Regulation high-voltage winding to low-voltage winding based on rated MVA (55°C rise with second stage cooling) on high-voltage winding:

a. At unity power factor...................................(%) [ ]

b. 0.8 lagging power factor ....(%) [ ]

4.24 Approximate resistance at 75°C (per phase on rated voltage connection):

H Winding ....(ohms) [ ]

X Winding ....(ohms) [ ]

4.25 Losses (warranted):

a. No-Load Loss (Excitation only):

a1. At 100 percent voltage.................... (kW) [ ]

a2. At 110 percent voltage.................... (kW) [ ]

b. Total loss, no-load loss plus load loss, at unity power factor with rated load .... (kW) [ ]

c. Auxiliary Power Losses (total power requirements for cooling:

c1. At rated load, 1st Stage Cooling, (55°C rise)... (kW) [ ]

	c2.	At rated load, 2nd Stage Cooling, (55°C rise) .... (kW)	[ ]
	d.	Percent capacity reduction with one cooler out of service ....(%)	[ ]
	e.	Percent capacity reduction with one fan out of service ....(%)	[ ]
4.26		Temperature Under Continuous Operation (Guaranteed):	
	a.	Temperature rise at full-rated load at 360kV and 0.9pF (55°C rise rating):	
	a1.	Winding temperature rise by resistance ....(°C)	[ ]
	a2.	Hottest-Spot winding temperature rise ....(°C)	[ ]
	a3.	Top oil temperature rise....................(°C)	[ ]
	b.	Performance Reference Temperature to which efficiency, loses, and impedance are corrected ....(°C)	[ ]
4.27		Average sound level at rated load, with all fans and pumps running, scale “A,” slow response, at 5 feet from transformer... (dB)	[ ]
4.28		Exciting current (warranted):	
	a.	At 100 percent voltage................................(%)	[ ]
	b.	At 110 percent voltage................................(%)	[ ]
4.29		Inrush rms magnetizing current on basis of no residual magnetism expressed in multiples of full load current at 982 MVA rating................................	[ ]
4.30		Short circuit capability:	
	a.	60 Hz symmetrical rms short circuit current:	
	a1.	H-winding......................(times normal) +	[ ]
	a2.	X-winding......................(times normal) +	[ ]
	b.	Peak asymmetrical short circuit current:	
	b1.	H-winding......................(times normal) +	[ ]
	b2.	X-winding......................(times normal) +	[ ]

+ The normal value of current is the rms value of winding current when the winding is carrying rated load MVA with second-stage cooling at rated voltage.

4.31 Time that the transformer can carry full load at the 65°C rise rating, without damage, with fans and pumps out of service under the following conditions:

a. Starting cold..(hrs) [ ]

b. After operating continuously at full load ....(hrs) [ ]

Same as above except carrying excitation only:

c. Starting cold..(hrs) [ ]

d. After operating continuously at full load ....(hrs) [ ]

5. TRANSFORMER COOLING EQUIPMENT

5.1 Coolers:

a. Number .... [ ]

b. Manufacturer.. [ ]

c. Type .... [ ]

5.2 Fans:

a. Number first stage .... [ ]

b. Number second stage .... [ ]

c. Horsepower (each) ....(hp) [ ]

d. Voltage and phase....................................... (V) [ ]

e. Locked rotor current (each) .... (A) [ ]

5.3 Pumps:

a. Number first stage .... [ ]

b. Number second stage .... [ ]

c. Horsepower (each) ....(hp) [ ]

d. Voltage and phase....................................... (V) [ ]

e. Locked rotor current (each) .... (A) [ ]

5.4 Molded case circuit breakers:

a. Manufacturer.. [ ]

b.	Catalog number	[ ]
c.	Continuous rating	[ ]
d.	Interrupting rating .... (rms symmetrical A)	[ ]
e.	Interrupting time .... (cycles)	[ ]

5.5 Total auxiliary power requirements at full load (55°C rise forced oil-air cooled rating) .... (kVA) [ ]

6. TRANSFORMER OIL PRESERVATION SYSTEM

6.1 Oil Drain Valves:

a.	Type	[ ]
b.	Size .... (in)	[ ]

6.2 Size of oil sampling valve .... (in) [ ]

6.3 Fault Pressure Device:

a.	Manufacturer	[ ]
b.	Type	[ ]

6.4 Transformer Tank:

a.	Vacuum transformer tank will withstand, measured in inches of mercury (absolute pressure) .... (in)	[ ]

7. BUSHING CURRENT TRANSFORMERS

		High Voltage H-Winding	Low Voltage X-Winding
7.1	For relaying (for each ratio and type):		
a.	Type	[ ]	[ ]
b.	Manufacturer	[ ]	[ ]
c.	Ratio	[ ]	[ ]
d.	Accuracy class	[ ]	[ ]
7.2	For metering (for each ratio and type):		
a.	Type	[ ]	[ ]
b.	Manufacturer	[ ]	[ ]
c.	Ratio	[ ]	[ ]

	d. Accuracy class	[ ]	[ ]
7.3	Neutral Bushing		
	a. Type	[ ]	
	b. Manufacturer	[ ]	
	c. Ratio	[ ]	
	d. Accuracy class	[ ]	

8. LIGHTNING ARRESTERS

8.1	Type		[ ]
8.2	Manufacturer or catalog number		[ ]
8.3	Voltage rating	(kV)	[ ]
8.4	Cantilever force permitted at top of arresters without damage	(lb)	[ ]
8.5	Color – ANSI designation		[ ]

9. CONTROL ENCLOSURE DIMENSIONS

9.1	Height	(in)	[ ]
9.2	Depth	(in)	[ ]
9.3	Length	(in)	[ ]
9.4	Weight	(lb)	[ ]

10. SMALL WIRING INSULATION

10.1	Type of insulation on small wiring	[ ]

(Include description and characteristics with proposal, if insulation other than that described in Standard Specifications is to be supplied.)

11. TRANSFORMER WEIGHT AND DIMENSIONS

11.1	Approximate weights:	(Net)	
	a. Core and coils and shipping tank	(lb)	[ ]
	b. Tank and fittings	(lb)	[ ]
	c. Oil	(lb)	[ ]
	d. Total	(lb)	[ ]
	e. Untanking weight	(lb)	[ ]
	f. Weight of heaviest piece to be handled	(lb)	[ ]

	g.	Coolers ....(lb)	[ ]
	h.	Weight of permanent tank cover removed for shipping ....(lb)	[ ]
	i.	Weight of tank shipping cover ....(lb)	[ ]
11.2	Approximate overall dimensions:		
	a.	Height over lightning arresters.....................(in)	[ ]
	b.	Height over high-voltage bushings ....(in)	[ ]
	c.	Height to center line of low-voltage bushings(in)	[ ]
	d.	Depth ....(in)	[ ]
	e.	Width..(in)	[ ]
	f.	Shipping height...(in)	[ ]
	g.	Shipping width ....(in)	[ ]
	h.	Height, above base, required to remove highest bushing ....(in)	[ ]

12. ISOPHASE BUS DUCT CONNECTION

12.1	Are any special requirements, mechanical or electrical, necessary for Purchasers Isophase bus terminating at the transformer, to prevent excessive heating in the transformer tank................(yes or no)	[ ]
12.2	If answer to the above is yes, Bidder shall explain the requirements below	[ ]

13. SHIPMENT

13.1	List items to be shipped separately from the transformer tank which must be installed in the field. It is understood that items not listed will be shipped installed and connected...	[ ]
13.2	If a special railroad car is to be used for shipment, Bidder shall state the minimum radius of rail curvature the car requires ....(ft)	[ ]

14. MANUFACTURER’S TESTS

The manufacturer shall list all tests to be performed on the transformer and its components during manufacture and after its assembly has been completed..	[ ]

15. INSTALLATION

15.1 Are there any limitations relative to fully assembling, dressing-out and filling the transformer with oil prior to moving it to its permanent installation location? ....(yes or no) [ ]

15.2 If answer is "yes", Bidder shall explain the limitations .... [ ]

15.3 Are there any inspection/witness points required to be performed by Contractor's personnel to maintain the equipment warranty in full effect ....(yes or no) [ ]

15.4 If answer is "yes", Bidder shall explain .... [ ]

16. EXPERIENCE

Bidder shall identify recent experience in supplying Generator Step-Up Power Transformers similar in size and voltage to that being proposed. A listing of this recent experience including buyer, quantity, size, description, date of supply, and name and telephone number of a contact in Buyer's organization familiar with the unit(s) shall be provided. List proposal page where found .... [ ]

17. BID VALIDITY

17.1 Bidder hereby agrees that his proposal will remain valid for acceptance by Purchaser for a period of 120 days from the bid due date.........(Answer yes or no) [ ]

17.2 If answer is "No," Bidder shall indicate the date to which his proposal remains valid for acceptance by Purchaser .... [ ]

18. SUMMARY OF POST-AWARD DOCUMENT SUBMITTAL

18.1 Where not already specified, Bidder shall fill in time, in weeks after award, required to submittal of indicated documents.

a. Schedule for Document Submittal:

1. Acknowledgement of Purchaser Order... [ ]
2. Drawings .... [ ]
3. Data Sheets .... [ ]

4. Quality Assurance:

   a. Program revision and/or Supplement .... [ ]

   b. Approved Program .... [ ]

   c. QC Procedures................................ [ ]

   d. QC Documentation.......................... [ ]

   e. Inspection Point Program................ [ ]

   f. Recommended Witness/Hold schedule .... [ ]

5. Conformed Proposal.............................. [ ]

6. Fabrication or Production Schedule .... [ ]

7. Cost and Schedule Report...................... [ ]

8. Performance Test Report .... [ ]

9. Instruction Books .... [ ]

10. Spare Parts Quotation .... [ ]

b. Names of personnel to contact responsible for:

Engineering/Design .... [ ]

Production.. [ ]

Contract Administration .... [ ]

19. ADDENDA

Bidder represents that this proposal includes provisions for the following addenda (Bidder shall insert Addenda Numbers and dates. If none included, so state)................

[Addendum No.]
[dated]
[Addendum No.]
[dated]
[Addendum No.]
[dated]
[Field Addendum No.]
[dated]

20. BID DOCUMENTS

Bidder hereby certifies that he agrees to all provisions of the Specification Bid Documents listed in this Item 20, unless exceptions are specifically and clearly listed in the Proposal as Exceptions and as summarized in Item 20.6 below. (Bidder's printed terms and conditions are not considered specific exceptions):

20.1 Instructions to Bidders

20.2 Specification (including addenda referred to in Item 19, above, if any).

20.3 Purchaser's Services and Materials Agreement, dated January 1, 2005.

20.4 Proposal Form – Part I;

20.5 Proposal Form – Part II;

20.6 Bidder's exceptions to the foregoing Bid Documents are summarized as follows (if no exceptions are taken by Bidder, so state).

Exception No.	Proposal Page No.	Description	Price Change (Show Add, Deduct or None)

SPECIFICATION FOR
GENERATOR STEP-UP POWER TRANSFORMERS

DIVISION 1 - GENERAL REQUIREMENTS

101. PURCHASER

Utility Name

102. NAME OF PROJECTS

Name of Station/Site

103. LOCATION OF PROJECTS

103.1 Detailed description and address of plant site

104. TRANSPORTATION FACILITIES

Railroad is Chicago and Northwestern RR.

105. SCOPE OF WORK

105.1 Contractor shall design, develop, fabricate, and provide the required analysis and documentation, furnish, test and deliver all required parts f.o.b. Purchaser's station, freight allowed and prepaid, the following:

One 567 MVA, 345 kV Grd. Y- 23.7 kV, type FOA, three-phase, two winding, outdoor, generator step-up power transformer.

105.2 This generator step-up power transformer is being procured as replacement transformer for a failed unit. This unit will be operating in parallel with an existing sister unit to the failed unit. Matching impedances to existing unit is critical.

105.3 Transformer shall be, to the fullest extent possible, a functionally and physically similar transformer to the existing 345-23.7kV generator step-up power transformer currently installed at the nuclear power plant.

105.4 The equipment shall be complete with all accessories as specified hereinafter.

105.5 The equipment covered by this Specification is non-seismic, non-safety related.

105.6 The Contractor shall furnish the services of qualified technical personnel who shall inspect the equipment for shipping damage upon arrival (before unloading) at the site. Additionally, the Contractor shall furnish the services of qualified technical personnel (if requested) to supervise the unloading, erection, testing and placement of the equipment in successful service; and to instruct the Purchaser's cognizant personnel in the correct operational and maintenance and testing procedures, and to witness final inspection and testing of equipment. The Contractor shall identify, in his proposal, any inspection/witness points by his technical personnel required to maintain the equipment warranty in full effect. The fees for service personnel shall be included in the proposal as a per working day cost.

106. MATERIAL AND WORKMANSHIP

All material and workmanship supplied under this Specification shall be the best of its kind. All labor shall be performed by personnel skilled in their particular line of work and it shall be done to the full satisfaction of the Purchaser. All materials shall be the most suitable for the particular purpose for which they are intended.

107. RESPONSIBILITY

It is the Contractor's responsibility to furnish equipment and components as specified and proposed. After award of contract, the Purchaser shall be advised immediately of any deviation in design or components from that specified and/or proposed by the Contractor. The Purchaser retains the right to accept or reject such deviations.

108. WORK BY OTHERS

108.1. Unloading and erection of all equipment.

108.2. Foundations.

108.3. All external connections to Contractor's equipment.

108.4. Erection by Others:

a. Inquiries may be issued by Purchaser to Erection Contractors at a later date. The Contractor furnishing equipment specified herein shall, if requested, furnish the Purchaser necessary drawings and data required to completely indicate the Scope of Work involved in the erection of this equipment, including all accessories furnished therewith.

b. This information shall include a comprehensive outline of field fabrication required and all temporary falsework, connections, bolting, cleaning, checking, inspecting, painting, testing, etc., required to be done by the Erection Contractor.

109. SCHEDULE

Transformer delivery on site is requested for April 1, 2007 if possible. Bidder shall state his best possible delivery date and time included in estimate for the actual transportation to the site.

Contractor shall prepare and submit to the Purchaser within 30 days after award of Contract, a schedule of the work required to accomplish the entire Scope of Work. Contractor shall then submit monthly progress reports to the Purchaser in order to detail adherence to Contractor's submitted schedule.

110. DEFINITIONS

110.1. The term "Purchaser" in this Specification shall be construed to mean "Owner."

110.2 The term "Owner" shall also be construed to mean "Owner's Authorized Representative."

110.3 The term "Vendor" in this Specification shall be construed to mean "Contractor."

110.4 Wherever the term "Project Specification" or "Job Specification" appears in Standard Specifications or Forms, it shall be construed to mean this Specification for Generator Step-Up Power Transformer.

110.5 The term "provide" shall mean "furnish" unless otherwise specifically stated.

110.6 The term "Manufacturer" in this Specification shall be construed to mean "this Contractor."

110.7 Wherever the terms “approved,” “as approved,” “or equal,” or other similar terms are used in this Specification, they shall mean “as reviewed, agreed upon, etc., by the Purchaser,” unless otherwise specifically stated.

111. SPECIFIED PRODUCTS AND SUBSTITUTIONS

Mention of materials or components by name as products of certain manufacturers in this Specification is made to insure that the proper quality and/or type is provided. Products of other manufacturers may be acceptable if Contractor furnishes proof to the Owner (prior to fabrication) and receives concurrence in writing that the proposed substitute products are equal to or better than the specified products in quality, performance, design and suitability for the intended use.

112. QUALITY ASSURANCE/QUALITY CONTROL

112.1 General Requirements

This section describes Quality Assurance Requirements for all activities associated with this specification. The equipment covered by this specification is classified as Commercial Grade and not subject to Nuclear Quality Assurance Requirements for nuclear safety related equipment. It is however, required that all the equipment shall be designed and manufactured under a documented QA program which meets the requirements of this specification in order to obtain components of highest reliability. The Purchaser reserves the right to audit for compliance to the contract and witness any test or inspection at the Contractor’s facility relating to the product procured by this Contract. Purchaser may perform quality assessments of Contractor activities at any time.

112.2 QA Responsibility

The Contractor shall have primary responsibility for Quality Control/Assurance activities for the Work required herein. All technical and quality requirements of this specification shall be met and shall be imposed as applicable by the Contractor on all his Subcontractor’s furnishing hardware or services in accordance with this specification. The Contractor and the Owner shall mutually agree upon resolution of any conflicts between this specification and the Contractor’s QA program.
QA/QC activities by the Purchaser and the Purchaser’s representatives shall not relieve the Contractor and his Subcontractor’s from responsibility to perform all inspections and tests required by the Purchase Order and Governing Codes.

112.3 Contractor’s Quality Assurance

a. The Contractor shall have a documented QA program that shall be submitted, upon request, to the Purchaser for review and acceptance. The program shall be in the form of QA/QC manual/plan or equivalent document and shall address, as a minimum, the following items:

- Design Control
- Control of Purchased Material
- Control of Equipment
- Control of Services
- Identification and Control of Material, Parts and Components
- Control of Special Processes
- Inspection and Testing
- Control of Measuring and Test Equipment
- Control of Nonconformance
- Quality Assurance and Quality Control Records

b. The Contractor's QA organization shall be described in his QA manual.

c. For all on-site work, the Contractor's QA program shall interface with Purchaser's QA program to the extent possible. Within 4 weeks of awarding the contract, the Purchaser and the Contractor shall meet to discuss the details of Contractor and Purchaser QA program interface. Should the need arise to develop a specific QA/QC program to satisfy both the Purchaser's and the Contractor's QA/QC program requirements, the Contractor shall be responsible to develop such program manual with no additional cost to the Purchaser and with no impact on the schedule.

d. Work performed within the scope of this contract, including by Subcontractor's work, shall be controlled by Contractor's Quality Assurance Program or by the Subcontractor's QA/QC program reviewed and approved by the Contractor. The program must comply with the requirements of ANSI Standard ANSI/ASQC-C1-1985 (R1996), Specification of General Requirements for a Quality Program, or equivalent. Supply the basis if not ANSI.

e. Contractor's procurement documents supporting Purchaser's order shall extend to all applicable technical, quality, and administrative requirements of this contract to Subcontractors and lower-tier suppliers.

f. For all non-site activities, the Contractor shall be fully responsible to comply with his own applicable QA/C program. The Contractor shall be fully responsible to assure that his Subcontractor's QA/QC program is fully complied with. The Purchaser reserves the right to witness and audit the execution of Subcontractor's QA/QC program. The Contractor's QA/QC program shall identify how he intends to monitor his Subcontractor's QA/QC program.

g. After award of Contract, Contractor shall make available for review and acceptance the detailed Quality Control Procedures containing those design, manufacturing, testing, inspection, cleaning, etc., procedures necessary to accomplish the Work, and assure its quality.

h. Contractors Procedures shall meet or exceed, as necessary, Code or Standard requirements. These procedures shall detail what equipment is to be used, limiting conditions, acceptance criteria, technique, etc., that will be used.

112.4 Calibration Program

a. A documented calibration program shall be implemented for all work being performed for this specification. The calibration program shall be made available for Purchaser's review and comment. Measuring and test equipment used for acceptance inspection or control of critical processes for the following items shall be included in the Contractor's, and any Subcontractor's program.

a1. Machining and Tooling Operations

a2. Non-Destructive Examinations

a3. Testing (critical parameters and measurements)

a4. Verification and Documentation of Dimensions

a5. Torque Applications

a6. Welding

a7. Heat Treatment

b. Calibration of equipment shall be traceable to the National Bureau of Standards or equivalent which will be subject to Purchaser's approval.

c. All calibration equipment shall be physically serialized and tagged with a unique serial number and its latest calibration date.

d. Documentation shall be available to verify all equipment has been properly calibrated within the specified time period.

e. Any equipment found out of calibration shall be identified and all work performed by that specific device shall be evaluated for impact. The evaluation shall provide justification for accepting the results or identifying measurements that must be performed.

112.5 Purchaser's Surveillance

a. Purchaser shall have unlimited access to the Contractor's (and Subcontractor's) facilities. Supplier shall provide for all reasonable facilities and assistance to Purchaser's representatives in performing their work activities including audits, inspections/surveillances, and expediting.

b. Within 4 weeks after award of contract an inspection point program shall be established by the Contractor and submitted to the Purchaser, and shall include pertinent manufacturing, and inspection operations which will be of concern to the Purchaser relative to Quality Control.

c. The Contractor shall submit a Manufacturing/Procurement Sequence and Schedule providing the following information for all major components, subassemblies, and the total item:
c1. Identification of all items by nomenclature, Contractor's shop order and drawing numbers, and tag number(s) (if provided).

c2. All manufacturing operations (such as welding, heat treatment, assembly, cleaning, surface preparation, coating/painting, etc.).

c3. All in process and final inspections, examinations (including non-destructive) and tests.

d. Preparations for shipment (including application of preservatives, wrapping, crating, attachment of pressure and humidity indicating devices).

e. In addition to those listed below, Purchaser may identify other Witness and Hold Points. All Witness and Hold Points are subject to modification (including additions and deletions) or waiver at Purchaser's option.

f. The Contractor shall notify Purchaser two weeks in advance of each activity that has a specified witness or hold point. Final confirmation of notification particulars shall be transmitted no less than four working days prior to each witness and hold point. If any delay from confirmed notification particulars results in additional Purchaser's costs due to failure of the Contractor to provide timely change information, the Contractor shall be liable for such additional costs.

g. Witness Point/Hold Point: The Purchaser will assign Witness points and Hold points on any schedule or process as necessary to assure quality of any product and compliance with the requirements of specification. They are defined as follows:

g1. Witness Point – Defined as a point in the process where the Purchaser intends to witness the process. Purchaser's failure to witness will be an automatic waiver from the requirements and the Contractor shall continue with the process without impacting the schedule.

g2. Hold Point – Defined as a point in the process where the Purchaser will witness and inspect the process Work shall not proceed beyond established hold points without surveillance by the Purchaser's representative or without a written waiver to proceed. The Purchaser shall notify the Contractor of the intent to witness a test within two working days of the notification of the date of the test. If notification is not received within two working days, the Contractor shall make every reasonable effort to contact the Purchaser to determine if the Purchaser intends to execute the hold point. Failure to respond by the Purchaser will automatically constitute a waiver.

h. Purchaser's Inspector – Authorized inspectors or other representatives of the Purchaser shall be allowed access to the engineering offices, shops, testing/inspection facilities and working areas of the Contractor or his Subcontractor at all reasonable times. These personnel shall have the right to such information as is necessary to demonstrate that the engineering, procurement, production, fabrication, testing, NDE and other necessary activities required to assure that the product per this specification is being delivered with the highest committed quality, with the requirements of this specification and within the prescribed schedule. The inspector shall:

h1. Warn the Contractor at any time that he (the inspector) notices anything that may be contrary to the requirement of the specification and may lead to rejection of the equipment, material or any engineering product when it is presented later for inspection and acceptance. The Contractor shall resolve these issues to the inspector's satisfaction without impacting schedule or cost.

h2. At appropriate time, witness or conduct the various inspection, test and verification, etc. as indicated on the approved Testing, Inspection and Documentation (TID) Record Forms, and indicate each in conformance with the requirements of this specification by signing and dating in the space provided therefore.

h3. Issue properly filled in "Shipping Release Tag."

h4. It is not intended that the Purchaser's inspection shall relieve the Contractor in any way whatsoever of his obligation to maintain an adequate test, inspection and documentation program or of any other obligation under this specification.

112.6 Control and Reporting of Waivers, Deviations and Noncompliance

a. Any anticipated deviation from contract requirements must be brought to Purchaser's attention in advance. The Contractor shall provide, as necessary, additional data and clarifications to permit evaluation and action by Purchaser.

b. Purchaser shall review and approve non-conformances and waivers as noted below. Purchaser shall have at least two (2) working days to review items on the critical path and a minimum five (5) working days review period for non-critical path items unless otherwise agreed upon between Contractor and Purchaser.

b1. Purchaser approval is required for all non-conformances that do not satisfy the properties described in the order specification, affect component safety, maintenance exchangeability, life expectancy or which would require adaptation work by Purchaser.

b2. The Contractor will inform Purchaser of Contractor approved dispositions of non-conformances for component deviations for unstressed components which may remain visible, but do not impair either the function or life duration of the product.

b3. The Contractor will maintain a file of all nonconformance reports which may be reviewed by Purchaser at the Contractor's site of manufacture.

b4. The Contractor will issue quarterly summary reports of all conformances to Purchaser. This report will identify all of the non-conformances and provide the results of the Contractor review of sub-tier supplier non-conformances.

c. If the Contractor has incurred a condition deviation from Contract requirements or from Purchaser approved Contract Documents, the Contractor shall promptly submit a contract Deviation Report.

d. Purchaser action on Contract Waiver requests and Contract Deviation Reports will be taken by responding to the Contract with the disposition indicated. If approved, all affected material and the applicable documentation shall conform with the approved conditions identified on the contract Waiver Request/Deviation Report.

112.7. Non-Conformances

a. The Contractor shall provide to Purchaser a copy of all nonconformance records and of the disposition of the nonconformances for all equipment and components supplied. All nonconformances shall be fully documented in terms of objective, repair/rework method, acceptance test, test results, and disposition as a minimum.

b. Processing of Nonconformances

b1. The Contractor shall be responsible for resolving all non-conforming design deficiencies per the Contractor's approved program.

c. Compliance to Work

c1. In the event the Contractor fails to adequately provide those functions and services defined in this agreement or is found to be in non-compliance with any procedure or safety requirements, Purchaser reserves the right to verbally identify the deficiency to the Contractor and supply a reasonable amount of time for correction. Upon the verbal notification from the Purchaser's representative, the Contractor shall identify and track all cost associated with the non-compliance in a manner that can be identified and separated from the original task. Purchaser's representative shall supply written notification within a reasonable time after the identification of the nonconformance. The Contractor shall not be entitled to any compensation for all time associated with the correction of the non-compliance or any unauthorized work. The craft hours associated with the non-compliance shall not be subject to any performance fee.

d. Final Nonconformance Report

d1. Within one month upon completion of the project, the Contractor shall provide a full nonconformance report to the Purchaser for retention. The report shall contain all nonconformances, approved or disapproved, from beginning to end of the project including those generated at the Contractor or his Sub-supplier's facility.

e. Shipping Release Tag

e1. For each shipment, the Contractor will verify all contract provisions have been met and prepare a Certificate of Conformance attesting to the results of the verification, and present the Certificate (along with contract required records of inspection, examinations, and tests) to Purchaser as instructed when providing notification to Purchaser for final inspection. Shipments shall not commence until authorized by Purchaser.

112.8 Documentation

The following documentation shall be maintained and submitted, if requested, by the Purchaser. Contractor shall store and maintain these records which will be available to the Purchaser. Documentation shall include but not be limited to:

a. Material certification (CMTR)
b. Weld material certification
c. Inspection test reports
d. Non-destructive test records
e. All specified and standard tests
f. Non-conformance and deviation reports

Note: Contractor shall indicate articles and sections of Standards or other applicable codes that are incorporated in his testing program proposed for Purchaser's equipment.

113. COORDINATION/QUALITY CONTROL MEETING

Within 4 weeks after award of Contract, the Purchaser will arrange a meeting with the Contractor to finalize project coordination, QC procedures and QC documentation to be submitted, time frequencies, anticipated problems, schedules, etc.

114. SPARE PARTS

114.1 Contractor shall submit to the Purchaser a Recommended Spare Parts Quotation for inclusion in the final contract. The Recommended Spare Parts Quotation shall:

a. Include recommended spare parts for all equipment, components, auxiliaries, accessories and materials being furnished under the Contract.

b. Include for each recommended spare part, the unit price, expected lead time, quantity, description, catalog number, drawing reference(s), etc., to completely identify the item and the equipment component for which it is recommended.

c. Include shelf life of spare parts.

d. Include short and long term storage requirements.

114.2 All requirements regarding quality assurance and associated documentation that apply to the original parts of the specified equipment shall apply equally to the spare parts of the specified equipment. Contractor shall identify these requirements in detail on the spare parts quotation.

114.3 Contractor shall quote an option price for furnishing the entire recommended spare parts inventory as a part of the shipment.

115. TOOLS

All special tools and instruments required to install, adjust, dismantle, and maintain each type of equipment and not normally furnished by the Purchaser's equipment erector shall be furnished by the Contractor. The tools and instruments shall be new and of first class quality, shall be shipped to the Purchaser in a suitable spare container that is clearly marked with the name of the equipment for which the tools are intended. All tools shall be sent with the equipment shipment.

116. PACKAGING. SHIPPING. STORAGE. ETC.

116.1 Shipping requirements shall be as specified in licensee documents.

116.2 Contractor shall adequately prepare all of the equipment for shipment and all equipment and items shall be packaged for extended outdoor storage. Where required by the nature of the equipment, the Contractor shall furnish and install necessary covers to protect the equipment from rain, hail, wind, dust, etc. Openings, if any, shall be adequately sealed and protected during shipment to prevent corrosion, entrance of foreign matter, and possible damage from rough handling during transit. All exposed machined surfaces shall be protected with a suitable antirust compound before shipment. Packaging shall be such as to prevent tampering or pilfering and to obtain approval and acceptability by transportation companies.

116.3 Any auxiliary equipment not designed for indefinite outdoor storage shall be packaged separately and the container clearly marked "For Indoor Storage." For parts requiring special precautions during storage, the details shall be shown on the outside of each container, or in a durable envelope attached to the container and labeled "Storage Instructions."

116.4 Each transformer shall be shipped upright, filled with dry air under positive pressure. Each transformer tank shall be stenciled to indicate that it is filled with dry air. All valves shall be plugged or covered to prevent tampering while in transit. A gauge shall be provided to indicate the air pressure has been maintained throughout the shipping process. The dry air shall be in accordance with Section 310.5 of this Specification.

116.5 The shipping center of gravity shall be permanently and plainly marked (Shipping Center of Gravity) on four sides of the tank and case to aid riggers and railroad inspectors in handling and shall be dimensioned on the outline drawing.

116.6 All packaging and framing material shall be noncombustible to the maximum extent practicable. Class A fire-retardant pressure-impregnated wood may be used.

116.7 All equipment and separately shipped items shall be clearly identified with a securely fastened, weatherproof tag, labeled with Purchaser's Purchase Order No., Specification No., Name of Station, Unit No., Equipment Number and Service. All shipping containers, packing lists, bills of material, correspondence, etc., shall be identified with the same above information. All boxes, shipping containers, crates, etc., shall have a packing list firmly attached to the exterior and a duplicate packing slip packed internally.

Example: P.O.

Station Name: Name of Plant/Site and Unit Number
Specification No.
Service
Equipment No. .

116.8 Auxiliary equipment such as radiators, bushings, and heat exchangers, must arrive at the destination with the main transformer tank.

116.9 Any items requiring removal for placing the transformer in service, such as pipe plugs, shipping braces, internal shipping wedges, shall be adequately identified.

116.10 Impact Recorder: The Contractor shall attach to each carload shipment an impact recorder which shall be capable of recording shocks in three axes. The recording time of the meter shall be of sufficient duration to monitor the shipment from the factory to the destination, but not less than 30 days. The impact recorder shall remain the property of the Contractor and will be returned by the Purchaser with transportation charges collect. The chart and three copies of it shall be delivered to the Purchaser's Representative at the final destination.

116.11 Test reports shall be as specified herein .

116.12 The Contractor shall coordinate shipping arrangements with the Purchaser to assure that transformers arrive on site with the proper field orientation.

116.13 Contractor shall be responsible for coordination of all transportation issues, including rail capacity and clearances, sea shipment and portal entry requirements, import/export processes, etc.

116.14 Contractor shall describe in detail the planned transportation method with the bid. Contractor shall also provide in the bid the cost savings for shipment of multiple transformers at the same time or an adjusted schedule to meet the Contractor's production schedule.

116.15 Contractor shall, be responsible for his subcontractor(s) adhering to the above shipping preparations on all equipment and items shipped to the Purchaser by the subcontractor.

116.16 Field Assembly

a. The equipment shall be shipped in sections that will minimize erection time in the field, but that can be safely handled by the Purchaser's unloading facilities at the site.

b. In order to determine the extent of the field installation, the Contractor shall list all items which will be shipped separately. It is understood that items not so listed in the Bidder's Response Data Form - Part II (PFII), Article 13, will be shipped installed and connected.

116.17 When the equipment is shipped by truck trailer, the conveyance shall have a removable roof or cover to allow crane lifting of the equipment at the final destination.

116.18 In order to maintain the equipment in a corrosion-free state and the electrical integrity of the equipment covered by this Specification, the Contractor shall furnish the Purchaser with instructions for storage, handling and maintenance for his equipment prior to installation, as well as for the period between the completion of the installation and the time that the equipment is placed in service. These instructions shall also be attached conspicuously to the equipment in a weatherproof container.

117. SHIPPING INSTRUCTIONS

The requirements of paragraph 14.3 (Routing of Shipments; Shipping) of Purchaser' Services and Materials Agreement shall apply.

117.1 Invoices for equipment received on site will not be honored until all documentation has been received and complies with this Specification.

117.2 Name of Plant/Site

a. Delivering carrier for carload shipment shall be Chicago and Northwestern RR. Carload shipment should be consigned to ______________.

b. Truck parcel post or railway express shipments shall be consigned to ______________.

c. Mail to the station shall be addressed in the name of ________________________.

d. Routing instructions will be furnished upon request to Traffic and Expediting Agent, ____________ _______ following receipt of detail information showing points of shipment for all proposed carloads or truck shipments.

118. LIMITS OF POLYCHLORINATED BIPHENYL (PCB) CONTAMINATION

a. The definition of PCB shall be as found in Federal Register 40 CFR Part 761.

b. Certification shall be provided for each transformer indicating that the oil added at the factory and the transformer, together have no detectable PCB.

c. Certification shall also be provided that the transformer, as shipped, was not contaminated with any substance having detectable PCB.

d. A memo or test report identifying the specific transformer, date of manufacture, tests completed, and location of manufacture, including the information indicate above, shall constitute the above certification.

119. SIMILAR SUPPLIED UNITS

The bidder shall provide information on service experience in the manufacturing of generator step-up power transformers. Buyer lists and contact personnel with the quantity and the size of the power transformers supplied shall be provided with the quotation.

DIVISION 2 – SUPPLEMENTS, STANDARDS AND DRAWINGS

201. GENERAL

These codes and standards set forth minimum requirements which may be exceeded by the Contractor if, in his judgment, superior or more economical designs or materials are available for successful operation of the Contractor's equipment and as required by this specification.

In addition to the codes and standards listed below, the Contractor shall comply with the applicable State and local laws, codes and regulations.

In the event of any apparent conflict among standards, codes and this specification, the Contractor shall identify such conflict to Purchaser upon discovery. The Purchaser shall obtain written resolution of such conflict from Purchaser prior to proceeding with work involving the conflict.

Purchaser shall have the option to incorporate requirements resulting from changes in codes, standards and regulations between the date of the purchase order and the date the Contractor initiated fabrication. It is the Contractor responsibility to advise Purchaser of the effects of these changes.

45 days after contract award, the Contractor shall provide for Purchaser's approval a list of major codes and standards (with their effective date) to be used. The minimum applicable codes and standards are listed as follows:

Notes:

1. Unless otherwise noted, the latest code year shall apply.
2. Additional codes listed in the enclosed standards shall also apply to this work.

202 SUPPLEMENTS

The following are attached hereto and form a part hereof:

202.1 Purchaser's Services and Materials Agreement, dated January 1, 2005.

All conditions of Purchaser's Service and Materials Agreement apply except that the first sentence of paragraph 4.2.1 shall be changed to the following:

"Material. If any material does not comply with the foregoing warranties and the licensee gives Contractor notice of such non-compliances within five years…"

203. CODES AND STANDARDS

All materials, equipment, products, accessories and essential services supplied under this Contract shall be designed, fabricated, constructed, or provided in accordance with the latest recommended engineering standards, including the appropriate ANSI C57 standards, and all applicable local, state, and federal laws and codes. The standards, laws, and codes shall include, but not be limited to:

a. American National Standards Institute (ANSI)
b. American Society for Testing and Materials (ASTM)
c. American Society for Quality Control (ASQC)
d. American Welding Society (AWS)
e. Compressed Gas Association (CGA)
f. Electrical Power Research Institute (EPRI)
g. Institute of Electrical and Electronics Engineers (IEEE)
h. Instrument Society of America (ISA)

i. National Electrical Code (NEC)
j. National Electrical Manufacturers Association (NEMA)
k. National Fire Protection Association (NFPA)
l. Uniform Building Code (UBC)
m. Underwriters' Laboratories (UL)

ANSI/IEEE C57.12.00	IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
ANSI/IEEE C57.12.10	Requirements for Transformers
ANSI/IEEE C57.12.70	American National Standard Terminal Markings and Connections for Distribution and Power Transformers
ANSI/IEEE C57.12.80	IEEE Standard Terminology for Power and Distribution Transformers
ANSI/IEEE C57.12.90	IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers
ANSI/IEEE C57.13	IEEE Standard Requirements for Instrument Transformers
ANSI/IEEE C57.19.00	IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings
ANSI/IEEE C57.19.01	IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings
ANSI/IEEE C57.98	IEEE Standard Guide for Transformer Impulse Testing
ANSI/IEEE C57.109	Guide for Liquid Immersed Transformer through Fault Current Duration
ANSI/IEEE C57.115	IEEE Guide for Loading Mineral-Oil Immersed Power Transformers Rated in Excess of 100 MVA
ANSI/IEEE C57.116	IEEE Guide for Transformer Directly Connected to Generators
ANSI/IEEE C62.11	IEEE Standard for Metal Oxide Surge Arresters for AC Power Circuits
ANSI B1.1	Unified Inch Screw Threads
ANSI B1.20.1	Pipe Threads
NEMA Pub TR-1-1993	Transformers, Regulators and Reactors

204. STANDARDS (PURCHASER’S)

The following are attached hereto and form a part hereof:

C-1807	Fall Protection for Major Equipment (10-21-93)
C-2324	Point-to-Point Style of Connections for Vendor’s Wiring Diagrams (08-28-91)
C-2325	Wiring Standards: Switchboard, Switchgear and Miscellaneous Equipment Shop and Field Installation (03-15-97)
C-2326	Termination of CT Secondaries (11-20-95)
EM-14226.l	Transformer Bushing, Draw Lead Type 345 kV, 1600 Amp, 1050 BIL (4-25-73)
EM-14226 .2	Transformer Bushing, Stud Type 345 kV, 1600 Amp, 1050 BIL (04-25-73)
EM-14227	Fall Protection Devices For Transformers with Horizontal Covers (09-15-96)
EM-19620	Terminal Blocks for Control Wiring (10-01-93)
EM- 19621	Multiple Terminal Link (09-01-93)

EM-19622	Terminal Blocks Heavy Duty for Control Wiring (11-01-93)
EM-19624	Terminal Block for Power Distribution 600 Volt (12-15-93)
EM-27001	Inhibited Insulating Oil for Electrical Equipment (03-31-93)
EM-29115	600-Volt Ethylene Propylene Insulated Chlorsulfonated Polyethylene or Neoprene Jacketed Control Wire and Cable for Stations & Substations (01-30-81)
EM-30105	Switchboard Wire for Stations and Substations (01-15-93)
EM-40276	Insulated Copper Lug Connectors (08-01-93)
EM-41112	Standard Stud Connectors for Transformer and Circuit Breaker Bushings (3-21-90)
EM-58204	Dry Air (09-30-94)
EM-59000	Electrical Steel Conduit (10-31-73)

205. REFERENCE SPECIFICATIONS AND STANDARDS

205.1 Intentionally deleted

205.2 Standards

STD-EC-137	Class FOA Transformer Cooling Fan and Pump Control (11-18-76)

206. DRAWINGS (PURCHASER'S)

The following are attached and form a part hereof:

206.1 Drawings (existing transformer vendor drawings)

The existing unit being replaced is a Westinghouse unit manufactured in Muncie, Indiana. Attached please find a copy of connection diagram T-68-137 for this unit.

207. DRAWINGS AND DATA (CONTRACTOR'S)

207.1 All documentation shall be in English.

207.2 All documentation provided in accordance with this Specification shall be legible and of microfilm quality and/or in electronic format compatible with MS Office 97/2000 or AutoCAD Version 14 unless otherwise agreed upon.

207.3 Engineering details shall be completed immediately after award of Contract, regardless of shipping date. Contractor shall hold fabrication until notified in writing by the Purchaser; however, Contractor shall notify Purchaser when equipment must be released for fabrication to maintain delivery schedules.

207.4 Contractor shall prepare a list of interface data required from Purchaser and a schedule for submitting this data. (One copy of the list shall be submitted within thirty (30) days after award of contract.)

207.5 Contractor's Drawings

Contractor's drawings for review shall apply specifically to this Contract.

a. If general "standardized" drawings, using standard symbols defined by the Purchaser, are submitted for review which include devices which Contractor does not intend to supply on this Contract, said drawings shall certify which devices are not to be supplied. Drawing transmittals not meeting this requirement will be immediately returned to the Contractor for correction.
b. It shall be the responsibility of the Contractor to determine the date when drawings for review must be returned for maintenance of the shipping schedule specified in the Contract. The Purchaser shall be advised of said return date at the time drawings for reviews are transmitted.
c. Drawings and documents submitted to the Purchaser are subject to review. The review will be categorized in one of three categories and the category will be noted by the Purchaser by stamping the drawing when it is returned to the Contractor. The three categories are:

Status 1 No exception taken. Contractor may proceed with fabrication or construction.

Status 2 Revise as noted and resubmit. Contractor can proceed with fabrication based on making revisions noted.

Status 3 Results do not meet specification requirements. Hold fabrication. Revise and resubmit.

d. Certain drawings, documents and manufacturer's instruction books will not require review by the Purchaser. Such drawings and documents will be stamped Status 4, "For Identification Only;" or Status 5, "Received for Information Only."

e. When a drawing is submitted to the Purchaser for review for the first time, the Contractor shall state it is the initial transmittal on his transmittal letters or sheet. Subsequent transmittals, if required as a result of the Purchaser's review, shall indicate the revision number or letter in the transmittal letter.

f. After a drawing has been reviewed and a resubmittal by the Contractor is required, the Contractor shall note the revision on the return drawing by the following method:

fl. Show the revised portion by encircling it, or other acceptable notational method, so that it is readily visible and the revision symbol is noted.

f2. In an appropriate space near the drawing title block, indicate the revision number or letter, and the signature of the authorized person who approved the revision.

f3. If the number of revisions is more than three, the Contractor's transmittal letter must also include a description of the changes.

g. It shall be Contractor's responsibility to obtain the Purchaser's review status categorized as either #1 or #2 on drawings eight weeks prior to the shipment. The Contractor shall be liable for the costs of those field changes resulting from failure to adhere to this requirement.

h. Where alternatives are shown on a drawing, the alternative being furnished shall be easily identifiable on that drawing.

i. Drawings, or portions thereof, submitted for review or information will be reproduced and distributed to meet the project requirements. This will include drawings that contain proprietary statements unless the Contractor advises specifically in writing that his drawings are not to be reproduced.

j. All wiring diagrams shall show point to point connection. Drawings not prepared in this manner will not be accepted and will be redrawn at Vendor's expense. Additional information regarding Purchaser's drawing requirements will be provided at Vendor's request.

k. The original contract price shall cover a reasonable amount of changes in drawings incident to rearrangement of equipment to meet Purchaser's requirements.

l. Purchaser shall be advised promptly of changes in equipment requested by them affect the contract price or delivery.

m. The review of drawings shall not in any way relieve the Contractor of his responsibility for correctness, or from the results arising from error or omission. Where variations exist between the approved drawings and this Specification, the Specification requirements shall apply unless specific approval in writing is granted by the Purchaser for each variation.

n. All drawings become the property of the Purchaser and may be used in the future without special permission from the Contractor.

207.6 Contractor's Certified for Construction Drawings

Contractor's drawings certified for construction shall include the following information:

a. Nameplate
b. Connection diagram
c. Transformer outline
d. Transformer base
e. Assembly drawings of all bushings and lightning arresters
f. Schematic diagrams of control and complete wiring diagrams which shall show all terminal blocks being furnished. Manufacturer and model of all devices shall be stated.

g. Curves showing ratio correction factors for each rating of current transformers furnished.

h. L.V. air-filled compartment and/or high-voltage connections.

i. Complete bills of material for all components and parts, including all special appurtenances furnished with the equipment. Bills of material shall include material specifications (i.e. ASTM) and manufacturer's part number.

j. As a minimum, the transformer outline drawings furnished for Purchaser's approval shall show the following:
   - j1. Detailed list of accessories, indicating those removed for shipment.
   - j2. Shipping dimensions and weights.
   - j3. Clearance required for untanking.
   - j4. Current rating of all bushings.
   - j5. Detail of bushing and arrester terminals and transformer ground lugs.
   - j6. All other pertinent dimensions and data necessary to indicate that these specifications and Purchaser's requirements are being adequately fulfilled.
   - j7. Oil preservation system equipment, including piping and filling valves (size, location, and pipe fitting).
   - j8. The completely equipped and oil-filled center of gravity shall be plainly indicated and dimensioned on the outline drawing only for use in foundation design.
   - j9. The height of core and coils.
   - j10. Total weight, weight of tank complete with accessories, weight/gallons of oil, oil fill requirements (U.S. gallons), overall tank dimensions from centerlines and overall dimension with cabinet doors open and closed.
   - j11. Projected floor space, height over tank, overall height.
   - j12. Field welding requirements.
   - j13. Gauge and device locations.
   - j14. Location of control cabinets and location of removable plates for conduit entrance.
   - j15. Location of, number, voltage and rating of fans and pumps
   - j16. Clear area required for and direction of tap changer removal.

k. As a minimum, the transformer plan of base drawing furnished for Purchaser's approval shall show the following:
   - k1. Arrangement and size of the base members.
   - k2. Width and length of each bearing member.
   - k3. Load on each bearing member.
   - k4. Center of gravity of loads as shipped and final assembly with an without oil.
   - k5. Location of jacking points.

l. Manufacturer's internal dimension drawings showing critical dimensions and position/location of components shall be provided for record.

207.7 Instruction Manuals

Contractor shall furnish the Owner with five (5) bound sets and 2 CD-ROMs per transformer of construction/operating books for all equipment furnished by Contractor consisting of manufacturer's instruction books, leaflets and drawings for maintenance, operation and erection of the transformers and associated equipment. Instruction books shall also include reduced drawings of transformer outline, schematic diagrams and wiring diagrams. When epoxy painted units or components are used, a list of compatible or air-dry (touch up) paint and primer shall be furnished in the instruction book. Also, a listing of the dimensions (ID, OD, thickness), material and quantity of all gaskets shall be included. Each instruction/operating book shall have an index listing of all leaflets, etc., in the same order as they appear in the book. (Individual submittal of various manufacturers' instruction books, etc., will not be acceptable). Instruction/operating books shall be issued prior to shipment of transformers.

a. The manual shall include:
   - a1. Maintenance requirements and instructions.
   - a2. Operational troubleshooting guides.
   - a3. Manufacturer's operating and maintenance literature (not sales brochures) with parts lists and with applicable data, including materials clearly indicated.
   - a4. Erection instructions and precautions and installation procedures.
   - a5. Torque values for bolted parts.
   - a6. Complete information for ordering spare parts.
   - a7. All gasket sizes, materials, manufacturers and part numbers.
   - a8. Flange/manway gasket groove designs.

b. Instruction manuals shall cover every item purchased, including materials and setpoints that the Contractor obtained from a sub-supplier. The Contractor shall have the ultimate responsibility for securing the manuals and lists for all items furnished under this requisition and for incorporating them in the manual.

c. One print of each of the photographs noted below in Section 207.9 shall be incorporated in each of the transformer instruction books.

d. The Instruction Manuals, including Spare Parts Bulletins, shall be sent to the Purchaser for review before shipment of the equipment. Final Instruction Manuals, including Spare Parts Bulletins shall be sent to the Purchaser four (4) weeks before shipment of the transformer.

207.8. Contractor shall submit to the Purchaser five (5) copies of certified reports of tests performed on all equipment within two (2) weeks after performance of the tests.

207.9. Photographs

Two (2) sets per transformer of photographs (8-1/2”x11”) and the digital files of these photographs on CD-ROM, showing each of the following views shall be submitted. One (1) set shall be included in the Instruction Manuals:

1. Side of core and coil assembly facing HV leads, taken immediately prior to tanking
2. Side of core and coil assembly facing LV leads taken immediately prior to tanking
3. Side of assembled transformer facing HV bushings
4. Side of assembled transformer facing LV bushings
5. Top of assembled transformer with bushing in place
6. Face of control panel (2) showing operating switches
7. Inside of main tank (empty) but with flux shields in place
8. No load tap changer
9. Any non-linear surge-protecting devices across any of the windings or portion of the windings.

208. <u>DISCREPANCIES</u>

In the event of discrepancies between the Standard Specifications and the Project Specifications, the documents shall apply in the following order:

Project Specifications
Utility Standards
Industry Standards

DIVISION 3 - TECHNICAL SPECIFICATIONS

301. GENERAL

301.1 The transformers shall conform to the attached Standards and Standard Specifications, except as modified on the Drawings and the following specifications.

301.2 The transformers shall be three-phase, 2-winding, 60 Hz, outdoor, step-up, oil immersed type, forced oil and air with two stages of forced cooling.

301.3 These transformers shall conform to the latest version of ANSI/IEEE Standard C57.12.00 and the other standards listed in this specification.

301.4 Reliability shall be of the utmost importance in the design of these transformers.

301.5 Transformer high and low voltage windings shall be of copper.

302. TRANSFORMER RATINGS

			High Voltage H-Winding	Low Voltage X-Winding
302.1	Nominal System Voltage (line-to-line)	(kV)	345	23.7
302.2	Transformer connections	(wye or delta)	Wye	Delta
302.3	Rated winding voltage	(kV)	209.2	25.0
302.4	Transformer Rating at Full Load			
	a. At 55°C rise	(MVA)	567	---
	b. At 65° rise	(MVA)	635	---
	c. There shall be no current restrictions on any load carrying part, as compared to the capacity of the winding, which would impose a limit on emergency loading in accordance with ANSI C57.92.			
302.5	Tap changer-full capacity taps to be manually changed when transformer is not excited:			
	a. Above rated voltage at full MVA capacity (number of taps and percent volts each tap)		(2) 2-1/2%	None
	b. Below rated voltage at full MVA capacity (number of taps and percent volts each tap)		(2) 2-1/2%	None
302.6	System neutral (isolated or type of grounding)....		Solidly Grounded	
302.7	Insulation Class (nominal system voltage)	(kV)	345	25

302.8	Line basic lightning impulse insulation level (BIL)			
		(kV)	1050 (line end)	150
	....(kV)		150 (neutral end)	
302.9	Neutral insulation class........................(kV)		25	---

302.10 Phase Relationship: Phase Relationship, angular displacement, and terminal designations shall be as shown on existing transformer connection diagram T-68-137 attached hereto.

302.11 Impedance: The **test** impedance, based on 567,000 kVA, X-winding to rated tap of H-winding, <u>shall be as close to 10.6 as possible</u>. This unit will be operating in parallel with a sister unit of that impedance, so matching the impedance is critical. The impedance shall be a relatively constant impedance in ohms referred to the low side for all high-voltage tap positions.

302.12 A manually operated tap changer shall be provided for operation when the transformer is not excited. The tap changer shall be manually operated from outside of tank, with operating handle on the side wall of the tank between two and four feet above the transformer base. The handle shall have a tap position indicator and provision for padlocking in any position. The tap changer shall be accessible from either the top of the transformer or through suitably gasketed access covers.

303. <u>TRANSFORMER SERVICE</u>

303.1 Each transformer will be used in step-up service to connect a turbine-generator to a high voltage transmission system. There will be no circuit breaker between the transformer and the generator. Therefore, the transformer may experience periods of over-voltage and over/under frequency following a trip-out (from rated conditions) of the unit, disconnecting the transformer from the high-voltage system.

303.2 Each transformer shall be designed to withstand without injury, backfeeding from the high voltage system with low voltage windings connected only to a unit auxiliary transformer that may or may not be carrying load. The transformer and its controls shall be designed to limit static electrification tendencies. High side windings of auxiliary transformer are delta-connected.

303.3 The voltage regulator for the generator may or may not be in service during and following a trip-out of the turbine-generator from the high-voltage system.

303.4 The Bidder shall state, in his proposal, any limitations with respect to the length of time that the transformer can operate satisfactorily at over-voltage and over/under frequency.

303.5 The transformer shall be designed for cold start temperatures down to -40°C.

303.6 The Bidder shall state the time that the transformer can carry full load at the 65°C rise rating, without damage, with fans and pumps out of service under the following conditions:

a. Starting cold (hours)
b. After operating continuously at full load (hours)

Same as above except carrying excitation only:

a. Starting cold (hours)
b. After operating continuously at full load (hours)

303.7 Each transformer shall be designed to continuously carry the generating unit's full reactive output capability of 480 MVAR.

303.8 Each transformer shall be capable of delivering its full rated output, on any tap, with a voltage input of 95% of the low voltage winding rating.

304. <u>INTERCHANGEABILITY</u>

304.1 Each transformer shall be designed to be physically and electrically interchangeable with the Generator Step-up Power Transformers installed at Name of Plant/Site Units 1 and 2. Bidders may request to visit the station to view the existing transformer installations prior to submitting proposals. Arrangements for station visits can be arranged with the Nuclear Engineering Department, Mr. Kirk Robbins at 630-657-3913.

304.2 The transformer included in this Specification shall be designed and built so it may be substituted for any of the above existing transformers without any modification.

304.3 Each transformer shall operate with the existing isolated phase bus duct equipment without abnormal or injurious heating of the transformer-to-bus duct interface. The vendor shall be responsible to assure that there is no abnormal or injurious heating at this interface including any stray flux heating.

304.4 Transformers and all de-mountable parts of transformers shall be interchangeable both electrically and mechanically with one another. Like parts in the same equipment shall be entirely interchangeable and when so interchanged shall perform their function equally well in every respect.

304.5 Each transformer shall be able to use the existing foundations and match the existing physical electrical connections without modification.

304.6 Each transformer shall be capable of being fully assembled, dressed-out, filled with oil and then moved approximately 1,000 feet to its final installed location. If Contractor has any limitations with respect to this requirement, he shall state them in his proposal.

305. <u>SHORT CIRCUIT CAPABILITY</u>

305.1 Each transformer shall be capable of withstanding, without injury, the mechanical and thermal stresses caused by short circuits on the external system of any winding(s) in accordance with Section 7 of ANSI Standard C57.12.00. Each transformer will be directly connected to the generating unit with no generator circuit breaker. (Note: See Sections 303.1 and 303.3.)

305.2 The Purchaser reserves the option to have a short circuit test performed in accordance with ANSI C57.12.90. If such a test is performed, and the test is not successful, the Contractor shall repair and retest the transformer at Contractor's expense, until a successful test is completed. The cost to perform the optional short circuit test shall be included as a separate item in the Contractor's proposal.

305.3 The Contractor shall submit such supporting evidence as calculations, basic winding material and construction details, bracing and clamping methods, or model prototype test data, or data on full-scale short circuit testing of a particular transformer type to substantiate that the design is satisfactory. Short circuit test data submitted shall include test circuit parameters and procedures, oscillograms of the tests where applicable, comparative test data that will provide the integrity of the design before and after testing, photographs of the windings before and after the tests and any other information that the Contractor feels will substantiate the design.

306. TERMINAL CONNECTIONS AND BUSHINGS

306.1 Transformer leads shall be brought out of the transformer case by means of bushings of the outdoor type. Bushings shall be capable of withstanding the 60 Hz applied potential tests and the lightning impulse tests specified in ANSI Standards. Acceptable bushing manufacturers are LAPP, ABB or equivalent approved by Purchaser prior to award.

.

		High Voltage H-Winding	Low Voltage X-Winding
306.1	Bushing Ratings:		
	a. Insulation Class ....(kV)	345	25
	b. External basic lightning impulse insulation level (BIL) ....(kV)	1300	150
	c. Internal basic lightning impulse insulation level (BIL) ....(kV)	1050	150
	d. Minimum creep distance.................(in)	240	17
	e. Wet switching surge value.............(kV)	825	---
	f. The color of the bushing shall be	Light Grey (ANSI #70)	Light Grey (ANSI #70)

		Neutral Bushing H-Winding
306.3	Neutral bushing ratings:	
	a. Insulation class ....(kV)	25
	b. External basis lightning impulse insulation level (BIL) ....(kV)	150
	c. Internal basic lightning impulse insulation level(BIL) ....(kV)	150
	d. Minimum creepage ....(in)	17
	e. The color of the bushing shall be	Light Grey (ANSI #70)

306.4 Bushings for the high-voltage winding shall be mounted on the top cover of the transformer case. Terminal lugs and copper connections shall be provided between the lightning arresters and the high-voltage bushings. The Contractor must supply any modification materials required for the connections to the overhead conductors and connection details. The connection shall be so arranged that the transformer may be disconnected and removed without disturbing the incoming line span.

306.5 The high-voltage neutral bushing shall be mounted on the top cover and connected with a copper bar to one of the ground pads at the base of the transformer.

306.6 Bushings for the low-voltage winding shall be mounted on the top cover of the transformer case and have flanges suitable for connection to isolated phase bus duct. Enclosures shall be provided with filter drains. The low voltage bushings must line up and match the existing isolated phase bus duct. Ample space and access shall be provided for the connections to the isolated phase bus duct. The Contractor must supply all necessary connections and any modification materials or termination kits required for the bus duct connections and bus duct housing connection details. The box and connections shall be so arranged that the transformers may be disconnected and removed without disturbing the incoming bus connections.

306.7 Oil-filled bushings shall have provision for power factor testing. They shall be tested for power factor at the factory and test values shall be included in test reports to the Purchaser. This information shall be stamped on the bushing name plates.

306.8 All current-carrying parts of power transformer bushings shall be copper or copper alloy material and surfaces shall be plated to inhibit deterioration.

306.9 The transformer bushings shall be provided with nameplates in accordance with IEEE Standard 21 (ANSI C76 .1).

306.10 The core grounding connection shall be accessible without the necessity of entering the transformer. A core ground strap or flexible lead shall be provided for the purpose of grounding the core as well as performing core grounding tests. The grounding strap or lead shall be easily accessible on the cover of the transformer without the removal of transformer oil. The strap or flexible lead shall be connected to a bushing housed in a small compartment on the roof of the transformer. Location shall be marked on the transformer cover and outline drawing. Separate sections of the transformer core shall be electrically connected via copper straps inserted between the sheets of core steel. Only one core ground strap shall be brought to the core ground bushing from the core.

307. <u>BUSHING CURRENT TRANSFORMERS</u>

307.1 Each high voltage bushing shall have the following current transformers stacked in the following order; one 1500 to 5 amperes, one 3000 to 5 amperes, and one 2000 to 5 amperes (closest to transformer winding) relaying accuracy ANSI C-800, with test certificates. These current transformers shall be mounted on each high-voltage bushing for relaying, for a total of 9 current transformers

307.2 One (1) multi-ratio, 2000 to 5 amperes, relaying accuracy ANSI C-800, with test certificates. Current transformer shall be mounted on high-voltage neutral bushing for relaying.

307.3 A total of twelve (12) current transformers shall be installed on the low voltage bushings, relaying accuracy ANSI C-800, with test certificates. Each low-voltage winding bushing (total of 6) shall have a 16000 to 5 amperes and a 14000 to 2 amperes current transformer installed with the 14000 to 2 amperes CT closest to the transformer winding.

307.4 Multi-ratio current transformers shall be of the five-lead distributed winding type with all leads brought out to a shorting type terminal block in the weatherproof cabinet.

307.5 All current transformers shall have a continuous thermal rating factor of 2.0.

307.6 Lead connections to bushing current transformer conductors shall be crimped or brazed. Soft solder (60/40) connections are not acceptable.

308. LIGHTNING ARRESTERS

308.1 The following station type lightning arresters of a type not susceptible to failure because of external contamination shall be furnished mounted on and grounded to the transformer tank: One (1) 264 kV, station type for each 345-kV bushing terminal. Acceptable manufacturers are GE, Ohio Brass, ABB or equivalent approved by Purchaser prior to award.

308.2 Each arrester shall be self-supporting and designed for base mounting.

308.3 A copper ground connection, not less than 1 inch x 1/4 inch copper bar, shall be permanently connected from the base of each lightning arrester to the ground pad on the base of the transformer.

308.4 All ferrous parts exposed to the weather and subject to corrosion shall be zinc coated by the hot-dipped galvanized process.

308.5 Each arrester shall have a pressure relief device which will act positively to vent gas pressures for the prevention of explosion of the porcelain in the event of arrester failure. The arresters shall be mounted with vents pointing away from the transformer bushings.

308.6 Each arrester shall be supplied with an “operations” counter.

308.7 The color of the arresters shall be light grey ANSI #70.

308.8 Corona-free full ampacity connections shall be provided between the lightning arresters and the associated bushings. These connections shall have a flexible arrangement so that the bushings shall not be overstressed during vacuum filling.

308.9 All porcelain used in or with each arrester shall be of the wet porcelain process, free from laminations, cavities, or other flaws affecting its mechanical or dielectric strength, and shall be well vitrified and nonporous. Metal fittings attached to the top and bottom of each porcelain unit shall be provided with necessary gaskets to prevent entrance of moisture into the internals of the arrester even under extreme temperature conditions.

309. COOLING SYSTEM

309.1 Intentionally deleted.

309.2 Two stages of forced cooling shall be provided. The first stage will run continuously, whenever the auxiliary power source is energized. The second stage will be started automatically by a winding-temperature simulator device with adjustable contacts. The temperature simulator device shall be calibrated to the specific transformer supplied. A selector switch shall be provided to interchange the stages of cooling selected for continuous and automatic operation. Selector switches shall have “ON” and “AUTO” positions, but no “OFF” position. Each stage of cooling shall be provided with a separate circuit breaker so as to allow for “online” maintenance of a cooling bank. Additionally, controls shall be provided to shutdown pumps during Winter backfeed operation with minimum load to limit static electrification tendencies. Contractor shall supply two (2) 480-120 volt control transformers. Half of the cooling shall be controlled from each transformer.

309.3 Cooling equipment controls shall be arranged so that no single fault in the control circuitry shall cause loss of more than one half of the cooling system capability.

309.4 Transformer cooling equipment controls shall be arranged so that a single remote contact shall shut down all fans and pumps regardless of the mode selected.

309.5 Purchaser will furnish, for operation of the cooling equipment, two sources of power at 480 volts, 3 phase, 60 Hz. All pump and fan motors shall be rated 460 volts, 3 phase, 60 Hz. Power connections shall be made using adequately sized solid bus bars or cables. Flexible bus bar is not acceptable. An Automatic transfer switch (Automatic Switch Company's Bulletin 930 or approved equal) complete with accessories shall be provided by the vendor to transfer from normal to emergency source of auxiliary power. The transfer switch shall have a continuous current rating at least equal to the full load current of all the transformer auxiliaries and a three cycle withstand rating of 38,000 amperes asymmetrical. The transfer switch shall not use current limiting fuses to limit the momentary current that it will be exposed to under fault conditions.

309.6 The starters for the fan and pump motors shall have NEMA ratings, and be manufactured by one of the following companies:

Cutler-Hammer (Eaton)
Furnas
General Electric
Square D
Westinghouse

309.7 Control circuits shall be designed for operation on 120 volts, 60 Hz, and alarm circuits for 125 volts, dc. Contacts on devices used for alarm functions shall be rated for 250 volts dc. Alarm contacts shall be provided for both normally open and normally closed application.

309.8 Control equipment shall include the necessary circuit breakers, control transformers, temperature control relays, alarm actuating devices, and associated equipment required to provide a complete control system. The interrupting rating of the circuit breakers shall be 25,000 rms symmetrical amperes at 480 volts ac. All auxiliary relays shall be furnished in their own individual enclosure. Each fan shall be provided with a separate circuit breaker.

309.9 All control equipment shall be installed in a NEMA 4 watertight cabinet located on the side of the tank at a height so that its top is not more than 72 inches above the top of the transformer pad. The leads from all alarms and current transformers shall also terminate in this same cabinet. Cabinet shall be equipped with hinged, gasketed, double doors and thermostatically controlled heaters. Necessary lighting fixture(s) complete with switch and duplex receptacle, Hubbell Catalog No. 4792 or Arrow Hart Catalog No. XT-5792, shall also be furnished. Contractor shall supply the source of power (separately fused) for these lights and receptacles.

309.10 Each pump and fan motor shall be totally enclosed and provided with a flexible lead and a weatherproof threaded locking type plug disconnect. Pumps shall be Harley by Cardinal equipped with Techsonic Bearing Wear Monitors. Flow indicators shall be located at eye level. Forced cooling shall be designed to mitigate static electrification tendencies.

309.11 Manual control switches shall be provided in the control cabinet to allow testing and maintenance of fans and pumps.

309.12 Contractor shall provide test switches for all Purchaser’s alarm circuits. Test switches shall be wired between alarms and terminal blocks for Purchaser’s incoming cables, and shall be located inside the watertight cabinet.

310. TRANSFORMER OIL AND OIL PRESERVATION SYSTEM

310.1 Oil will be supplied by Purchaser and will comply with EM-27001.

310.2 Transformer shall have an oil preservation system for protecting the oil against atmospheric moisture and oxygen. Equipment shall be of the conservator tank type.

310.3 When the conservator tank design is used, the oil level in the tank and the top mounted bushings is kept constant by the conservator expansion tank, which is mounted above the transformer. Oil level changes from the thermal expansion of the oil take place only in the conservator tank. A shut-off valve shall be provided between transformer shell and the conservator with a flanged joint between the main transformer casing and the shut-off valve.

310.4 Ambient air shall be prevented from direct contact with the transformer oil through a membrane, bag or manufacturer's design oil trap. A silica gel filled or other acceptable dehydrating breather for the outside air shall be provided.

310.5 The dry air used for filling a transformer shipped without oil in the tank shall conform to the requirements of Standard EM-58204.

311. TRANSFORMER TANK AND BASE

311.1 The transformer tank shall be of welded steel construction. The tank cover shall be welded to the tank with a gasket or shield of inorganic material, permanently located to prevent the entrance of weld spatter.

311.2 The gasketed surfaces around openings in the transformer cover for such items as bushings, manholes, relief devices, etc., shall be raised sufficiently to prevent the accumulation of water around the gasket.

311.3 The main transformer tank and any attached compartment that is subject to operating pressures shall be designed to withstand, without permanent deformation, pressure 25 percent greater than the maximum operating pressures resulting from the system of oil preservation used.

311.4 The maximum operating pressures (positive and negative) which the transformer tank is designed to withstand shall be indicated on the nameplate.

311.5 Tank shall be designed to withstand vacuum filling at full vacuum in the field.

311.6 Contractor shall state his recommendation for backpressure during filling.

311.7 Transformers designed for full vacuum filling shall have two plugged fittings on the cover of the main tank. One fitting for vacuum connection shall be a 3-inch flanged connection located remote from the inert gas inlet connection and the top filter pressure valve; the other fitting shall be a 2-inch fitting for oil filling located in line with the bottom drain valve of the main tank.

311.8 Manholes, not less than 18"x30" or 24" in diameter shall be provided in the cover. The manholes shall have 1-1/2inch IPS, 6-inch nipple, threaded at both ends, welded in the center and protruding an equal distance above and below the plate.

311.9 The bottom of transformer shall have a steel skid base and shall be suitable for installation on a flat concrete pad.

311.10 Unless alternate acceptable provision is made to prevent corrosion of the exterior of the bottom of the tank, the transformer tank design shall be such that ventilation is provided between the concrete supporting slab and the bottom of the transformer tank. Only supporting steel beneath the transformer tank may touch the concrete slab. Design of the steel supporting the transformer tank bottom shall be such that the bottom is accessible for inspection after installation. If Contractor's standard is a flat base, he must provide assurance that it will not be subject o unacceptable amounts of rust or corrosion during its 40-year life.

311.11 Oil-filling connections shall be provided with deflection plates inside the tank to prevent the force of incoming oil from impinging on the core and windings.

311.12 The center lines of tank or case shall be permanently marked near the base on all four sides of the tank or case and also shown on the outline drawing.

311.13 The shipping center of gravity shall be permanently and plainly marked ("<u>Shipping Center of Gravity</u>") on four sides of the tank to aid riggers and railroad inspectors in handling and shall be dimensioned on the outline drawing.

The completely assembled and oil filled transformer center of gravity shall be permanently and plainly marked ("<u>Assembled Center of Gravity</u>") on four sides of the tank and shall be dimensioned on the outline drawing.

311.14 Ground pads shall be furnished on each transformer tank in accordance with the requirements of ANSI/IEEE C57.12.10 at the same relative location as the existing transformer.

311.15 This transformer will replace existing an transformer. CONTRACTOR shall design the base to utilize the existing foundation maintaining existing center lines as much as possible.

a. The transformer base shall be designed and chamfered to permit skidding or rolling in a direction parallel to either center line.

b. The base shall be so designed that the center of gravity of the transformer, as normally prepared for shipment, shall not fall outside the base support members for a tilt of the base of 15 degrees from the horizontal, with or without oil in the transformer.

312. ENCLOSURES

312.1 The control cabinet shall be located such that its location matches the location of the control cabinet on the existing transformer with respect to the plant. The intent is to minimize the amount of conduit and cable rerouting resulting from the transformer replacement project.

312.2 The control cabinet shall have double doors.

312.3 All enclosures shall be weatherproof and designed to prevent the accumulation and freezing of standing water along the panel doors. Gaskets of all removable cover plates and doors shall be recessed and provided with mechanical gasket stops or shielded for adequate protection from the weather. Drain holes, ¼" diameter, shall be provided in low points of all enclosures.

312.4 The control cabinet shall contain all auxiliary devices except those that must be located directly on the transformer. Doors shall be hinged and provided with stops. Auxiliary panels shall be hinged or otherwise designed for ready accessibility to relays, control devices, and associated terminals for testing, adjustment, and maintenance.

312.5 Any other cabinets housing control elements shall be of such dimensions and so located as to provide complete access to a man standing at the transformer base level.

312.6 Cabinets containing indication instruments, such as pressure gauges, etc. shall be provided with windows for viewing these instruments.

312.7 Access doors on all control and auxiliary cabinets shall be furnished with doorstops to hold the doors in the open position until released by the operator.

313. SMALL WIRING

313.1 All small wiring between control cabinet and external equipment shall be Type XHHW. All wiring within the control cabinet shall be in accordance with C-2325 and EM-30105 and terminal blocks per EM-19620, EM-19622, or EM-19624 as applicable.

313.2 All small wiring shall be run in hot dipped galvanized rigid conduit with threaded connections. The low points of all conduit runs and the bottom of vertical cabinets or junction boxes shall have 1/8" weep holes. Conduit shall not enter the top of junction boxes or control cabinet.

313.3 All control and alarm circuits shall be completely wired by the Contractor. Wiring shall be run in rigid steel conduit as specified in EM-59000, except that fan motor connections, gauges, and/or instruments may include liquid tight flexible conduit. Conduit and fittings shall be painted to match the transformer. There shall be no conduit entrances in the top of terminal boxes or control cabinets. Weep-holes shall be provided at the low points on conduits, boxes and control cabinets. Wiring terminations shall be on approved terminal blocks having washer head screw types of connectors and laminated dust covers suitable for engraving. Terminal blocks shall be provided with markings corresponding to those of the Contractor's wiring diagram and shall have space provided on the marking strip for inscription by the Purchaser.

313.4 Terminations shall be segregated and separated as to low voltage power, low voltage control and metering, and low-level signal circuits. Not more than two wires installed by the Contractor shall be connected to one terminal. All terminal blocks for interface connections between the Purchaser's external wiring and Purchaser's equipment wiring shall be located in areas of adequate space and clearances in the control cabinet. These areas shall allow convenient placement and termination of Purchaser's cables in neat and orderly arrays. Future cable removal or addition shall not require temporary removal or disconnection of adjacent unrelated cables. The location and arrangement of terminal blocks for all external wiring shall be subject to approval by the OWNER. 20% spare positions shall be provided on terminal blocks for Purchaser's independent use. Arrangement of spares shall be such that each block or group of blocks shall have its approximate proportion of spares.

313.5 Terminal blocks shall be mounted not less than 12 inches above the floor of the cabinet or less than 6 inches from the top of the cabinet. Contractor shall provide one 12 point terminal block devoid of wiring, with access space either at top or side of the cabinet, for two 1-inch external conduit connections for Purchaser's transformer deluge system. Locknuts or lockwashers shall be applied to all stud-type terminals.

313.6 All Purchaser's cables shall be able to enter the bottom or sides of the control cabinet. Wiring and components shall be arranged so that instruments or devices may be removed and/or serviced without disturbing the wiring. No wire shall be routed across the face or rear of an instrument, junction box, or other device in a manner that will prevent the opening of covers or obstruct access to leads, terminals, devices, or instruments. Cable entry shall be consistent with the existing.

313.7 Control wiring shall not be smaller than #14 AWG. The secondary leads of current transformers shall be #10 AWG. The control wire shall be stranded copper conductor with 600 volt insulation.

313.8 Flexible connections, where required, may be installed in accordance with vendor's standard, subject to Purchaser's approval. Such flexible connections shall be of minimum length and be adequately protected from mechanical damage.

313.9 The insulation or insulation jacket of each insulated conductor in all multi-conductor cables shall be individually identified.

313.10 All exposed wiring in the control cabinet shall be formed with wiring neatly grouped in packs, using wiring cleats or bands, and with groups substantially supported. Only ring tongue, compression-type connectors that firmly grip the conductors shall be used. The crimping tool used shall be approved by the terminal lug manufacturer. Soldered terminals or connection shall not be used.

313.11 Liquid-tight flexible conduit may be provided for all instruments requiring thermocouple or RTD connections and shall be run to the control cabinet enclosure. All thermocouple or RTD connections shall be terminated on terminal blocks in the control cabinet.

313.12 Control and alarm switches shall not be located more than 5 feet, 6 inches or less than 2 feet, 6 inches from the bottom of the transformer base.

313.13 Splices or parallel connections shall not be made in the transformer tank braces or in other non-accessible locations. Such connections shall be made at terminal blocks or readily accessible splice boxes.

314. <u>ACCESSORIES AND FITTINGS</u>

The transformer shall include all standard accessories normally furnished by the Contractor, including but not limited to the following:

314.1 The transformer shall be provided with a stainless steel nameplate which shall contain information in accordance with the latest issue of ANSI/IEEE Standard C57.12.00. In addition, the nameplate shall include the date of manufacture and tables of voltage and currents at kVA ratings (both 55°C and 65°C rise) corresponding to:

a. All fixed taps for the high voltage winding.
b. Ratings of the low voltage winding.

314.2 Fault Pressure Device: One (1) Qualitrol Model 900-1A rapid rise pressure relay, mounted on the side of the tank, suitable for operation on 250 volts dc shall be provided to close a contact for relay operation in case the internal pressure rises suddenly. An auxiliary seal-in relay shall be furnished with the pressure device. The auxiliary relay shall be furnished with one single-pole, double-throw contact. In addition, a GE Co. type SBM control switch or approved equal, shall be mounted in the control housing and wired in between the normally open contact of the pressure relay and the terminal block. This switch will permit opening the pressure relay trip when desired. Contractor shall review the application of the fault pressure device in order that the location chosen ensures proper operation.

314.3 Dissolved Gas and Moisture Monitoring: The dissolved gas monitor shall be a Morgan Schaffer Systems AMS-500 Plus - Calisto. Rubber isolation mounting shall be consistent with the vibration and structural recommendations defined by the Morgan Schaffer. The intent is to isolate the monitor from transformer vibration. The dissolved gas and moisture monitor shall be located with the display approximately 36 inches from the bottom of the transformer. The point of oil exit and entry shall have isolation valves at the transformer capable of isolating the transformer at vacuum. The oil lines between the transformer and the monitor shall be made of flexible braided stainless steel and should be supported every 24 inches. The oil lines should not be of an excessive length and both inlet and outlet oil lines shall be kept as short as reasonable. The intent is to avoid fatigue from movement. The inlet line to the Calisto shall draw oil from the upper portion of the transformer (top oil) and the return line shall be no closer than 24 inches to the inlet. The data communication interface shall be wired with shielded, 18 gauge wire and terminated in the control cabinet. The shield shall be terminated (grounded) only at one end in the control cabinet.

314.4 Self-resetting mechanical trip pressure relief device of approved design with visual trip target and normally closed electrical alarm contacts suitable for operation on 250 Vdc. This pressure relief device shall be furnished on the transformer cover.

314.5 A winding-temperature simulator device with adjustable contacts for control of forced cooling equipment and alarm. The temperature range shall be 0-180°C. The winding-temperature indicator shall be mounted at eye level.

314.6 A magnetic liquid-level indicator shall be furnished and shall be readable from the level of the base. The indicator shall be equipped with two contacts, one to monitor normal liquid level conditions and the other to trip protective equipment when the oil level has reached the minimum oil level for continued operation. Alarm and trip wires shall be enclosed in separate metal conduits and weatherproof fittings.

314.7 Low liquid flow alarm.

314.8 A liquid temperature indicator with adjustable contacts for temperature alarm (100°C maximum setting) Qualitrol 104-253 series, or equivalent. The maximum temperature indication shall be 160°C. The liquid temperature indicator shall be mounted at eye level. Contacts shall be ungrounded and rated 250 Vdc.

314.9 The following additional alarm contacts shall be provided:

a. Control Voltage Failure – Cooling Stage One
b. Control Voltage Failure – Cooling Stage Two
c. Emergency Auxiliary Power Source – No Voltage
d. Transfer Switch Operation

314.10 All alarm devices shall be wired to an alarm terminal board through a test switch, Westinghouse type FT-1 or approved equal, for isolating each trouble source.

314.11 An additional closed well for measuring oil temperature by glass-stem thermometer. The location shall be accessible with the transformer energized.

314.12 The transformer tank shall be equipped with a pressure vacuum gauge.

314.13 Two copper-faced grounding pads located on opposite sides of the base, drilled and tapped with holes for attaching Purchaser's ground cable connector to the tank in accordance with ANSI C57.12 at the same relative locations as the existing transformer.

314.14 A copper bar connection (4"x1/4" minimum size) shall be provided and installed between the high-voltage neutral bushing and the nearest ground pad at the base of the transformer.

314.15 Jacking lugs and lifting lugs.

314.16 Heat exchangers shall be detachable and shall be equipped with shutoff valves, and with vent holes and plugs in the top and with an oil drain valve, with plug, in the bottom. Gate valves for cooler outlet/inlet and main inlet cooler/tank are required (butterfly valves are not acceptable). Valves shall be located so that flow gauge sensors on forced oil type transformers can be removed without draining the main tank.

314.17 A one-inch tapped opening in cover, closed with a pipe plug, for vacuum pump connection.

314.18 A combination drain and lower filter valve of the gate type shall be provided on the main tank. This valve shall be 2 inch, and it shall have 2 inch NPT threads with a pipe plug in the open end. This valve shall provide for complete drainage of the liquid to within one inch of the bottom of the tank and for outlet to oil filtering equipment.

314.19 Oil sampling connection (3/8" minimum) placed on the drain side of the drain valve.

314.20 All gasketed joints shall utilize recessed reusable gaskets and steel stops to prevent over compression.

Only Nitrile gaskets shall be supplied. Nitrile gaskets shall be replaced with Viton gaskets in areas of high temperature.

The manufacturer shall provide drawings in the instruction book with the manufacturer's part number for each gasket, dimensions of each gasket, material composition of each gasket, total quantity required for the transformer, and descriptions of where each gasket is installed.

314.21 All threads on screws, bolts, and nuts used for the Purchaser's external connection shall conform to ANSI B1.1-Unified and American Screw Threads for screws, bolts, nuts and other threaded parts. All internal connection and fastenings, 1/2-inch or larger, shall conform to ANSI B1.1. Metric fasteners are not acceptable.

314.22 Fall protection in accordance with EM-14227 and C-1807 or equivalent. A storage box should be provided to store all Fall Protection equipment with the transformer.

315. IMPEDANCE AT EACH TAP SETTING

The transformer impedance is to be measured at each tap setting and the values obtained from these measurements are to be included in the transformer test reports.

316. TESTS AND INSPECTIONS

316.1 The Purchaser shall have the option of witnessing all tests. Contractor shall advise Owner ten (10) working days in advance of beginning electrical tests so travel arrangements may be made. Additionally, Contractor shall provide a sequence and testing schedule of all tests to be performed.

316.2 Certified test reports covering all tests performed shall be sent to the Purchaser before shipment of the transformer.

316.3 Transformer tests shall be performed in accordance with ANSI/IEEE C57.12.90 where applicable and shall include all routine and design tests included in ANSI/IEEE C57.12.00. Performance characteristics shall be based on 55°C average winding temperature rise and standard reference temperature shall be 75°C. High-voltage nominal system voltage is 345kV. Tests shall be performed with the specified bushings in place and shall include the following:

a. Resistance and voltage ratios of all windings shall be measured on all taps and all windings of each transformer. Resistances on deltas shall be measured bushing to bushing.

b. Losses and impedances shall be measured on all voltage taps of each transformer. The Contractor shall state in the test report the voltage and kVA base on which each impedance is expressed.

c. The no-load loss and exciting current on the rated voltage connection at 100 percent and 110 percent rated voltage shall be determined by test.

d. Tests shall be conducted between windings and between each winding separately and ground.

e. The windings of each transformer shall be given a one minute, 60 Hz applied potential test.

f. All windings of each transformer shall be given induced potential tests.

g. Polarity and phase relation tests shall be performed on the rated voltage connection.

316.4 Full-Load temperature-Rise Tests

An ANSI temperature rise test is required in accordance with IEEE Standard C 57.119. Any additional test information or requirements beyond those stated in the referenced Standard will be furnished by the Purchaser's Thermal Rating Engineer. A Dissolved Gas in Oil Test shall be performed prior to the start of the test and repeated four hours after the conclusion of testing. Results of the oil tests shall be included with the transformer test report. The data listed below shall be obtained with the transformer connections giving the maximum heating.

a. Top oil temperature rise at rated voltage and rated load

b. Average temperature rise by resistance at rated voltage and rated load for all windings

c. Calculated hottest spot temperature rise over average temperature rise for each winding reported in 316.4b above.

d. Thermo-graphic pictures shall be taken after temperatures have stabilized.

316.5 Core Grounding Test

A core grounding test shall be made on all transformers before they leave the factory to determine the resistance between the core and the transformer ground. This test shall be conducted at 2500 volts minimum. A resistance test should be performed by using the ground strap or flexible lead mentioned in Section 306.10. One copy of a test procedure is required to enable the Purchaser to duplicate the data obtained at the factory. The value of the core resistance should be in keeping with good design practice, and a minimum acceptable value should be determined by the Contractor and recorded in the test report.

316.6 Bushings shall be tested in accordance with ANSI/IEEE Standards C57.19.00 and C57.19.01.

316.7 SFRA Analysis Test

316.8 Transformer Tank Vibration Test

316.9 Contractor shall provide cost adder prices in the bid for the following additional tests:

a. Audible Sound Level Test

a1. Audible sound level test in accordance with ANSI/IEEE C57.12.90.

a2. A guaranteed sound level statement for each unit shall be included with each shipment.

b. Dielectric Tests

b1. Switching surge test, phase-to-ground in accordance with ANSI/IEEE C57.12.90.

b2. Radio Influence Voltage (RIV) test in accordance with ANSI/IEEE C57.12.90.

c. Short circuit test in accordance with ANSI/IEEE C57.12.90.

317. TRANSFORMERS LOSSES AND AUXILIARY POWER REOUIREMENTS

317.1 The load losses, efficiency and regulation shall be corrected to a reference temperature according to ANSI C57.12.00. Performance characteristics should be based on 55°C rating with a standard reference temperature of 75°C.

317.2 The losses and auxiliary power will be evaluated for bid comparison as follows:

a. No load (excitation) losses at rated voltage $1541 per kW.

b. Load (copper) losses at 567 MVA load $1455 per kW.

c. Auxiliary power at 567 MVA load $1541 per kW.

318. PAINTING AND COATING

318.1 The transformers shall be cleaned, primed, and finish painted with the Contractor's primer and finish that shall be selected to withstand the conditions of service specified in this Specification.

318.2 A sufficient quantity of touch-up paint shall be provided for field touch-up. Equipment shall be tagged with trade name, designation, and Contractor of primer and finish for reordering.

318.3 Before shipment, all parts of the equipment shall be thoroughly cleaned and painted in the shop in accordance with Contractor's standard practice to give a durable and lasting protective finish. All exposed machined surfaces shall be coated with a suitable grease or antirust compound.

318.4 The transformer tank cover and external accessories shall be thoroughly cleaned and painted with an oil proof paint of ANSI light gray color No. 70 for outdoor service.

____

Signature of Bidder

____

Bidder's Telephone Number

____

Date of Bid

D
EXAMPLE OF A TYPICAL DATA SHEET

This appendix provides an example of a data sheet used by one utility during the specification and procurement of a large power transformer. The example is provided for illustrative purposes only; it might not be appropriate for applications in other plants without appropriate modification. The example shown in Table D-1 has been modified somewhat to make it more relevant to project teams.

Table D-1
Example of Typical Large Transformer Data Sheet
Courtesy of Entergy

Transformer Design Parameter	Manufacturer's Data
Manufacturer	
Construction – Shell or Core	
Electrical Parameters	
• Rated Power (MVA ratings)	
• Cooling Class (as defined in Table 2 of IEEE C57.12.00)	
• Voltage Ratings (kV)	
• No Load Loss at 100%, 105% and 110% of rated voltage	
• Full Load Guaranteed Losses at FOA Ratings of Transformer	
• Efficiency at FOA Ratings of Transformer (See note)	
• Cooling System Losses	
• Impedance	
• Zero Sequence Impedance	
• Impedance at 55º C Rating	
• Reactance at 55º C Rating	
• Resistance at 55º C Rating	
• Estimated Hot Spot Temperature Rise	
• Exciting Current in % of Full Load Current at Rated Current and 60 Hz	

Table D-1 (continued)
Example of Typical Large Transformer Data Sheet
Courtesy of Entergy

Transformer Design Parameter	Manufacturer’s Data
• Three-phase Capacitance to Ground, HV Side	
• Three-phase Capacitance to Ground, LV Side	
• Regulation at 0.8 Power Factor	
Rated Temperature	
1-Phase or 3-Phase	
Rated Frequency	
Cooling System	
• Number of Fans	
• Number of Pumps	
• Horsepower of Each	
• Full Load Current of Each	
• Voltage/Phase	
• Number of Cooling Fans per Stage	
Noise Data	
• Audible Sound Level @ FOA Rating	
• Audible Sound Level with all Cooling Equipment Operating	
Loading Capability	
• With the loss of one-half of the cooling auxiliaries, % load transformer will carry continuously without exceeding hot spot temperature	
Approximate Weights	
• Core and Coils (lbs.)	
• Tank and Fittings (lbs.)	
• Oil (Gal)	
• Total Weight (lbs.)	
• Shipping Weight (lbs.)	

Table D-1 (continued)
Example of Typical Large Transformer Data Sheet
Courtesy of Entergy

Transformer Design Parameter	Manufacturer's Data
Materials	
• Tank	
• HV Winding	
• LV Winding	
Approximate Dimensions	
• Overall Height	
• Width	
• Depth	
• Height Over Cover	
• Untanking (plus slings)	
• Minimum clearance of jacking lugs to base (inches)	
Transformer Oil	
• Manufacturer, Oil Grade	
• Shipping Method	
Fault Pressure Relay Type	
Bushing Data	
• "H" Bushing Vendor	
• "H" Bushing Type/Model	
• "H" Bushing Rated BIL (kV)	
• "H" Bushing Rated Current (Amps)	
• "H" Bushing Creepage Distance (Inches)	
• "X" Bushing Vendor	
• "X" Bushing Type/Model	
• "X" Bushing Rated BIL (kV)	
• "X" Bushing Rated Current (Amps)	
• "X" Bushing Creepage Distance (Inches)	
• "Neutral" Bushing Vendor	

Table D-1 (continued)
Example of Typical Large Transformer Data Sheet
Courtesy of Entergy

Transformer Design Parameter	Manufacturer's Data
• "Neutral" Bushing Type/Model	
• "Neutral" Bushing Rated BIL (kV)	
• "Neutral" Bushing Rated Current (Amps)	
• "Neutral" Bushing Creepage Distance (Inches)	
• Number of CTs per Bushing	
• Ratios for Each CT	
• Accuracy class	
Are Power Factor Test Terminals Included?	
Tap Changer	
• Tap Changer Type: DETC or LTC	
• Vendor	
• Model	
• Range (in percentage)	
• Rated Current	
• Rated Voltage (kV)	
• Rated BIL (kV)	
• Number of Steps	
• Percent Range	
• Capacity Across TC Range	
Windings	
• Surge Arrester for Each Winding	
• Rating for Each Winding	

Notes:
In several instances the terminology FOA is used on this datasheet. In some cases this terminology may no longer be recognized, and OFAF is used instead. Each licensee should ensure FOA is in fact the rating of interest. This is most likely the case for a GSU, but it might not be for SSTs. Thus an alternative may be to ask for the attribute at the (losses, sound, efficiency) at the rating specified by the licensee.

The load losses, efficiency and regulation shall be corrected to a temperature according to ANSI C57.12.00, at FOA ratings of the transformer (55º C and 65º C).

E
VENDOR EVALUATION CHECKLISTS

E.1 Vendor Evaluation and Audit Checklist

This section provides an example of a checklist that one utility used when evaluating the quality controls at the transformer manufacturer's facility. The checklist example is provided for illustrative purposes only.

General Information

Date of Inspection:	**Inspection Performed By:**
Manufacturer Name:	
Factory Location:	
Factory Square Ft:	
Total Number of Employees:	
Number of Years in Business:	Union Labor: Yes ☐ No☐

Key Plant Personnel

Plant General Manager	
Marketing Representative (outside)	
Marketing Representative (inside)	
Manager of Production (shop)	
Manager of Quality Assurance	
Manager of Transformer Design Team (Core)	
Manager of Transformer Design Team (Shell)	
Manager Production Design and Engineering Team	
Manager R&D Engineering	

Number of Employees at this Location:	
Electrical Engineers	
Mechanical Engineers	
Computer Programmers	
Technicians	
Shop Workers	

Other Locations

Factory Location:	**Factory Square Ft:**
Number of Employees:	
Factory Location:	Factory Square Ft:
Number of Employees:	
Factory Location:	Factory Square Ft:
Number of Employees:	
Factory Location:	Factory Square Ft:
Number of Employees:	

Type of Transformers (this location):

☐ **New**	☐ **Repair**
Type construction (check all that apply): ☐ Core Form ☐ Shell Form	
Transformer Types: ☐ Conventional two winding ☐ Conventional three winding ☐ Transformer with OLTC ☐ Generator step-up (GSU) ☐ Reactors ☐ Autotransformers ☐ Portables ☐ Zig-Zag (grounding) ☐ Other Describe:	
Number of transformers shipped per year: Total MVA Shipped per year: MVA	
Minimum - maximum MVA / Voltage range	
Maximum crane capacity / lifting height: /	

GENERAL COMMENTS/INFORMATION THIS PLANT INSPECTION (CUSTOMER):

PRODUCT LINE EXPERIENCE (THIS LOCATION)

What is your experience? How many transformers shipped and what sizes? (provide list – typically the last five years are of most interest)

Provide customer a U.S. users list with contact information:

ENGINEERING CAPABILITIES

Discuss your method for determining short circuit calculations?

Do you calculate forces for all taps and fault types? Describe.

Do you perform field plotting (finite element analysis)? Describe.

Are you capable of determining “free buckling” forces in core form design inner windings? Describe.

Do you calculate forces on radial spacers / hoop stresses on outer windings? Describe.

What is the winding height percent offset do you use to calculate total axial forces?

What are your acceptance criteria for the short circuit design margins and how were they established? (include buckling and other forces):

Has the design been short circuit tested? When? Provide details of the tested transformer(s).

Can you calculate short circuit forces using 110% pre-fault voltage?

What type of computer programs are used for the following: (Same for both core form and shell form?)

For core:

For winding:

For insulation:

For overloading:

For reactor:

For tank:

Others:

Discuss your method of calculating voltage stresses turn-turn, disc-disc, inter-winding, shield to winding.

Discuss the types of shielding used in most common designs.

Are you capable of performing transient analysis calculations beyond initial distribution method (RLC in the model) for our designs?

What is your method of determining leakage field plots, etc? Describe.

What is your method of determining leakage flux heating? Describe.

Which of the following are included in consideration for heating (check all that apply)?

☐ Lock plates

☐ Leads close to windings

☐ Outer core laminations

☐ Tap leads

☐ Connections in windings

☐ Top/bottom end frames

☐ Tank

Other information or discussion:

What is your method of calculating hot spots? Describe.

Which of the following are included in consideration for hot spot (check all that apply)?

☐ Oil flow

☐ Localized losses

☐ Insulation thickness

Where do you calculate hot spots?

☐ Each winding

☐ Tap region

☐ Each lead

☐ Other – describe

Describe core form coil clamping design (rigid, adjustable, dynamic, etc)?

What types of insulation materials used? Discuss each application from insulation of conductors, leads, lead supports, phase barriers, core insulation, etc.

Do you manufacture your own insulation kits from bulk material?

☐ Yes ☐ No

Additional Information about insulation kits:

Do you purchase the insulation “package” from outside supplier?

☐ Yes ☐ No

If yes, who are your supplier(s)?

What types of OLTCs are offered?

☐ Resistance Manufacturer/Models:

☐ Reactance Manufacturer/Model:

☐ Vacuum Manufacturer/Model:

What types of OLTCs do you provide in your standard design if not specified?

☐ Resistance Preferred Manufacturer/Model:

☐ Reactance Preferred Manufacturer/Model:

☐ Vacuum Preferred Manufacturer/Model:

Discuss your in-house experience with OLTCs:

Who is your preferred OLTC controller supplier? (i.e. Beckwith, etc.)

What type of winding designs are used most frequently?

HV:

LV:

TV:

RV in HV:

RV in LV:

Other:

What is your definition of a major failure and minor failure?

What is your percent failure rate of current and past designs?

% shop failure

% require untanking

% field failure in warranty

% field failure out of warranty

General failure information:

Do you provide in-house training for engineers and recurrent training?

☐ Yes ☐ No

If yes, describe process.

How is knowledge passed along?

How will the internal design review be handled inside your engineering organization?

How will the customer design review be handled?

Can you utilize our standard bushings?

☐ Yes without exceptions. ☐ No. Exceptions:

System Voltage (kV)	**Rated Voltage (kV)**	**BIL (kV)**	**Current Rating (A)**	**Manufacturer**	**Model Number**
	List Customer's Standard Bushings				

What is your engineering staff's:

- Average years of experience?
- Maximum years of experience?
- Minimum years of experience?

Engineering standards are well documented / implemented? (customer observation)

CORE CUTTING/STACKING

Do you cut your own cores or buy from outside supplier?

☐ Cut in-house

☐ Cut by outside supplier. Name of supplier(s):

What type of core cutting machine(s) do you operate?

Do you have an "E" stacker?

☐ Yes ☐ No

What is the frequency of maintenance of cutting machine?

What is the frequency of calibration of cutting machine?

How are dull cutting blades identified?

What is the criterion for burrs? (customer prefers less than 0.008 inches)

Documented engineering criteria for core cut / stack tolerances: (customer observation)

Describe core design (step lap, mitered, butt lap, cruciform, square, etc):

How many steps per book in your standard design?

What grades of core steel are used?

- With loss evaluation applied:
- Without loss evaluation applied:

Describe core stacking process:

What is criterion for gaps of stacked core?

Describe method of storing core materials (both uncut / cut):

Describe inspection of uncut core materials before use:

Method of up-ending core after stacking?

Does manufacturer make use of core thru-bolts?

☐ Yes ☐ No

If yes, describe insulation system:

Do you use core leg banding (temporary or permanent)?

☐ Temporary: Material

☐ Permanent: Material

If temporary, describe means for maintaining pressure on core leg steel:

What is the average experience of core cutter operators?

Are there any waves or gaps in core steel? (customer observation)

What is the cleanliness of area? (customer observation)

General observations / comments by customer:

COIL WINDING

Is Winding Room physically separate from other manufacturing areas?

☐ Yes ☐ No

How Is winding room maintained?

☐ Positive pressure?

☐ Climate controlled?

☐ Filtered?

Additional comments:

Do you insulate own conductors or buy pre-wrapped?

Who are your primary conductor supplier(s)?

What types of conductors do you use?

☐ Rectangular/Strap

☐ Magnet Wire

☐ CTC

☐ Epoxy Bonded CTC

☐ Netted CTC

☐ Other. Describe:

Additional information:

Types of insulation used (epoxy bonded, micro-creped, thermally upgraded, Nomex, Formex)?

Average nitrogen content of thermally upgraded paper?

Number of winding machines?

Vertical machines

Horizontal machines

Shell form winding tables

General comments:

Describe dynamic braking or tensioning device(s) used:

Is cross over insulation even? Are there gaps in insulation? (customer observations)

What is the process for burr detection and void detection in insulation? (customer observation)

How are splices made?

Types of coils wound?

- ☐ Circular Disc
- ☐ Helical
- ☐ Layer
- ☐ Pancake
- ☐ Other

Description of coil materials storage (insulation / copper) in shop:

Description of testing performed on partially finished coils in shop:

Description of coils sizing procedure:

What process is used to dry coils?

Are individual coils dried before or after landing coils on core?

How many Vapor Phase and how many Drying ovens?

Vapor Phase

Drying Ovens

General Comments:

Do you marry/land coils before or after loading onto core?

Discuss the method of moving coils in shop?

What type of Degasifying equipment is used?

What percent dryness of paper do you specify?

What criterion and method do you use to determine dryness?

What is the average experience of winders?

What is the cleanliness of area? (customer observation)

General observations / comments:

CORE/COIL ASSEMBLY

What is the method of moving core / coil assemblies?

Observe top yoke stacking procedure (customer observation):

Describe core blocking and methods to support the core (mainly during transport):

What is your standard core and frame grounding location?

☐ Internal ☐ External

Is each ground lead brought out to a separate bushing in your standard design?

☐ Yes ☐ No

How are core/frame ground lead(s) insulated and supported?

Describe coil clamping procedure (differentiate between core and shell if applicable):

LEAD/LEAD SUPPORT ASSEMBLY

What types of lead support materials are used?

What types of hardware are used to hold lead support structure together?

What is the method of attaching leads to coils / tap changers (welded, braised, crimped)?

What precautions are taken to prevent damage / contamination of core / coil during assembly?

Describe final processing / oil fill procedure:

Describe layout of core / coil assembly area:

Does your facility tear-down failed units in the same area as assembly of new units?

Observe the quality of connections? (customer observation)

What is the average experience of assemblers?

Observe the cleanliness of the area? (customer observation)

General observations / comments:

TESTING

Check all tests that you are capable of performing and supply your upper limits for capability of each test:

Capability?	**Test Description**	**Upper Limit of Capability**
☐	Core loss @ 90%, 100%, 110%, 115%, 120%	
☐	Exciting current @ 90%, 100%, 110%, 115%, 120%	
☐	10 kV single phase excitation current	Not Applicable
☐	Winding resistance	Not Applicable
☐	Load loss	MVA (maximum MVA you can test)
☐	Impedance volts	Not Applicable
☐	Regulation @ 1.0%, 0.9%, 0.8%, 0.7% PF	Not Applicable
☐	Efficiencies	Not Applicable
☐	Temperature test (With infrared scans)	MVA (maximum MVA you can test)
☐	Ratio and Polarity	Not Applicable
☐	Zero sequence impedance	Not Applicable
☐	Sound levels (low noise)	dB (lowest sound level in dB that you can test)

☐ Full ☐ Chopped ☐ Switching	Impulse	Impulse Generator rating MV ☐ Digital ☐ Analog Maximum BIL you can test: kV
☐	Power factor of windings and bushings (similar to Doble)	Not Applicable
☐	Insulation resistance of windings and core ground (similar to megger)	Not Applicable
☐	Induced potential with partial discharge measurement	Hz (frequency of generator) kV (maximum kV you can test)
☐	Applied potential	kV Rating: kV mA Rating: mA MVA (maximum MVA rating you can test)
☐	Dissolved gas in oil	Not Applicable

What are your standard DGA limits (increases in key gasses between each test)?

Key Gas	Utility Limit (ppm)	Standard FactoryLimit (ppm)
Acetylene (C_2H_2)	No detection	
Methane (CH_4)	2	
Ethane (C_2H_6)	2	
Ethylene (C_2H_4)	1	
Hydrogen (H_2)	10	
Carbon Monoxide (CO)	20	
Carbon Dioxide (CO_2)	200	

Will you accept our DGA limits without exception?

☐ Yes ☐ No Exceptions:

What are your minimum standards for fluid quality?

Type of Test	ASTM Method	Standard Factory Limits
Aniline Point, Degrees Centigrade	D 611	
Color ASTM	D 1500	
Corrosive Sulfur	D 1275B	
Dielectric Breakdown, kV	D 877	
Dielectric Breakdown, kV	D 1816 (0.04 inch /1 mm gap) - or - D 1816 (0.08 inch /2 mm gap)	
Water Content, ppm	D 1533	
Flash Point, Degrees Centigrade	D 92	
Interfacial Tension, dynes per centimeter	D 971 (Unfiltered)	
Impulse Breakdown Voltage, kV @ 25 Degrees Centigrade	D 3300	
Neutralization Number, milligrams KOH per gram	D 974 (Modified)	
Polychlorinated Biphenyls (PCB)	D 4059	
Pour Points, Degrees Centigrade	D 97	
Power Factor @ 100 Degrees Centigrade, %	D 924	
Power Factor @ 25 Degrees Centigrade, %	D 924	
Specific Gravity, 60/60	D 1298	
Viscosity: Kinematic, cSt, 100 Degrees Centigrade 40 Degrees Centigrade 0 Degrees Centigrade	D 445	
Sludge – Free Life (SFL) Measured at 8-hour periods, hrs, +/- 8 hours	Doble Procedure	
Oxidation Stability (acid sludge) 72 hours: % sludge by weight Total acid number, milligrams KOH/gram 164 hours: % sludge by weight Total acid number, milligrams KOH/gram	D2440	

Oxidation Stability (Rotating Bomb), minutes	D2112	
Particulates	D6786	
Note: Neutralization Number is measured by using 1/100 normal potassium hydroxide standard alcohol solution.		

What equipment is used for infrared scans during temperature rise tests?

What is your maximum factory limit for percent winding insulation power factor?

What are your typical test results for percent winding insulation power factor?

Do you functionally test all alarms, controls, protective relays?

☐ Yes ☐ No Explain:

How do you test programmed accessories such as electronic temperature monitors and PLC Annunciators?

What methods are used to classify, locate and diagnose transformer partial discharge problems that occur during testing?

What is the maximum allowable background noise level for induced voltage, partial discharge measurements?

What measures does your test department take to minimize in-band interference from local radio stations during partial discharge tests?

What precautions does your test department take against external corona at the lead terminals rated 15 kV and below?

What precautions does your test department take against external corona on HV and EHV leads and terminals?

What is your maximum factory limit for partial discharge tests?

pC

What are your typical test results for partial discharge tests?

pC

Review a sample certified test report: (customer observation)

What is the frequency of calibration of test equipment in the test floor? Do you have traceable records?

Is there an oil laboratory at the factory?

☐ Yes If yes, how often is oil laboratory equipment calibrated?

☐ No Who is contracted?

Do you test for PCB in oil in-house or outside lab?

☐ Test in-house

☐ Tested by outside lab. Name of lab(s):

What precautions are you taking to prevent introduction of oil with corrosive sulfur? Have you had any transformers for any customer where you had to introduce a passivator?

What precautions are taken to insure that high quality oil is used for testing the transformer?

What is the average experience of test technicians?

What is the cleanliness of area? (customer observation)

General observations / comments:

MECHANICAL ITEMS (TANK, ENCLOSURES, COOLING)

Are your radiators manufactured in-house or outsourced?

☐ Manufactured in-house

☐ Manufactured by outside supplier. Name of supplier(s):

Who are your supplier(s) of coolers?

Who are your supplier(s) of pumps?

Describe process for testing and inspecting radiators:

Inspections and tests by radiator supplier before reaching your facility:

Inspections and test by your facility prior to installation onto transformer:

Describe process for testing and inspecting coolers:

Inspections and tests by cooler supplier before reaching your facility:

Inspections and test by your facility prior to installation onto transformer:

Describe process for testing and inspecting pumps:

Inspections and tests by pump supplier before reaching your facility:

Inspections and test by your facility prior to installation onto transformer:

Are your tanks manufactured in-house or out-sourced?

☐ In-house

☐ Out-sourced. Name of supplier:

Are conservator tanks built in-house or out-sourced?

☐ In-house

☐ Outsourced. Name of supplier:

Is tank metal cut by hand or by CNC machine?

☐ CNC

☐ Hand

☐ Other Describe:

What is the average experience of welders?

Observe the quality of welds. (customer observation)

How are your tank corners designed?

☐ Butt corner

☐ T joint

☐ “J” corner

☐ Other Describe

Are welds welded inside, outside, or both?

☐ Inside only

☐ Outside only

☐ Both

Describe gas collection system for conservator units:

Are all tanks, radiators, coolers, conservators full vacuum rated (-14.7 PSI)?

☐ Yes

☐ No Which items are not vacuum rated?

Is the OLTC tank vacuum rated?

☐ Yes ☐ No

Describe leak testing of tank:

Describe tie-ins from core/coil assembly to tank:

What type of terminal board is used between main tank and OLTC tank?

How is the tank cover normally secured?

☐ Welded on ☐ Bolted on

Are gasketed flanges machined-grooved, or flush surface?

What types of gasket materials are used?

☐ Rubber

☐ Nitrile

☐ Viton

☐ Cork

☐ Other:

What percent fill for a gasket groove do you design for? %

Observe if the tank shop isolated from other critical areas? (customer observation)

Observe plasma cutting (customer observation)

General observations / comments:

PAINT

Describe the preparation of metal parts for painting:

Describe painting process:

What is the criterion for final paint thickness?

What type of paint and painting system is used for inside of enclosures and tanks?

What type of paint and painting system is used for exterior of enclosures and tanks?

Observe paint system and quality. (customer observation)

CONTROL CABINETS

Do you manufacture your own control cabinets or do you outsource?

☐ In-house ☐ Outsourced Supplier:

Do you wire your own control cabinet or do you outsource?

☐ In-house ☐ Outsourced Supplier:

What type(s) of connectors are used for termination?

Are all wires clearly marked on both ends with permanent labels?

☐ Yes ☐ No Explain:

What type of control wiring is used (insulation and gage – discuss application such as CT circuits or control)?

Are all control devices clearly labeled to match control prints?

☐ Yes ☐ No Explain:

What is the average experience of wiring personnel?

Observe the cleanliness of the area? (customer observation)

General observations / comments:

QUALITY CONTROL

Is the QC Program well documented? (customer observation)

☐ Yes ☐ No

Comments:

Observe if the QC Program is fully implemented. (customer observation)

Engineering

☐ Yes ☐ No

Production

☐ Yes ☐ No

Testing

☐ Yes ☐ No

Comments:

Is the plant ISO 9000/9001 Certified?

☐ Yes ☐ No

Describe the manufacturing and quality control personnel training programs:

Manufacturing training description:

Quality control training description:

Describe nonconformance tracking system from start to finish of problems found during process of manufacturing the transformer:

Observe if the QC inspections are well documented and traceable? (customer observation)

☐ Yes ☐ No

Observations:

To whom do the QC inspectors report?

How is the QC handled for outsourced items?

Provide history of on-time transformer delivery:

SHIPPING

How are transformers shipped to the U.S.?

What means are used in the design to prevent shipping damage?

What checkpoints exist along the way to spot mishandling and shipping damage?

When are impact recorders used?

Are the impact recorders analog or digital type? If digital, how will it be read?

☐ Analog ☐ Digital

If the impact recorder(s) are digital type, is there GPS capability and real time internet access to impacts?

☐ Yes ☐ No

Comments:

Will we have one point of contact for shipping questions and updates?

☐ Yes   Who (name, telephone, email)?

☐ No Explain:

WARRANTY

What is the standard warranty period from shipment and from in-service?

Months ex-factory   Months in-service

What is covered in your standard warranty? (i.e. in-and-out charges, etc.) Provide a copy of your standard warranty.

Where do you repair transformers under warranty?

Are there any special requirements to activate the warranty?

TECHNICAL SUPPORT

Who would we call for technical support?

(name, telephone, email)

Who would we call for field support?

(name, telephone, email)

Where are the technical support personnel located?

Where are the field support crews for U.S. customers based? (city, state)

How soon after contacting you with a question can we expect a response?

Are there any special assembly or oil processing requirements?

CUSTOMER CONCLUSIONS/RECOMMENDATIONS

This supplier is approved for transformer purchases (Range of size in MVA / kV):

☐Yes ☐ No: reasons -

General comments by customer:

Customer to describe areas for improvement and any concerns:

E.2 Inspection and Comparative Evaluation Form

This section provides an example of an evaluation form that one utility used when evaluating the quality controls at the transformer manufacturer's facility. The evaluation form example is provided for illustrative purposes only.

The transformer project team can develop a form similar to this when inspecting potential suppliers to evaluate each supplier's factory based on a weighting system tailored for the particular project.

Transformer Plant Inspection and Weighting Form								
	Weight	**Score**	**Points**			**Weight**	**Score**	**Points**
Insulation					**Assembly**			
Storage of Raw Materials	1.0%		0.0000		Sideframes	3.5%		0.0000
Department Cleanliness	4.5%		0.0000		Terminal Board	1.0%		0.0000
Deburred and Clean	4.5%		0.0000		NLTC	1.5%		0.0000
Consistency	2.0%		0.0000		Cable Support & Layout	2.5%		0.0000
QA of Finished Product	3.0%		0.0000		Braze / Crimps	3.5%		0.0000
					Shielding	1.5%		0.0000
Copper					Cleanliness	4.0%		0.0000
Storage	1.5%		0.0000		Coil Clamping	4.5%		0.0000
QA of Finished Product	1.5%		0.0000		Overall Craftsmanship	3.0%		0.0000
Insulation	2.0%		0.0000					
					Tank and Cover			
Windings					Welding Quality	1.5%		0.0000
Department Cleanliness	5.0%		0.0000		Corners	0.5%		0.0000
Brazes	5.0%		0.0000		Cleanliness	1.5%		0.0000
Crossover Bending	2.5%		0.0000		Paint	0.5%		0.0000
Consistency	2.0%		0.0000		Fittings	0.5%		0.0000
Radial Coil Tightness	2.5%		0.0000		Piping	0.5%		0.0000
Spacer Alignment	2.0%		0.0000		Radiator Welds	1.5%		0.0000
Sizing Practices	3.5%		0.0000		Radiator Cleanliness	3.5%		0.0000
Dryout Practices	2.5%		0.0000					
Storage	2.0%		0.0000		**Wiring**			
Overall Craftsmanship	3.0%		0.0000		Control Cabinet	2.0%		0.0000
					Wiring Neatness	0.5%		0.0000

Transformer Plant Inspection and Weighting Form								
	Weight	**Score**	**Points**			**Weight**	**Score**	**Points**
Core					Conduit	0.5%		0.0000
Material Cleanliness	4.0%		0.0000		Layout	0.5%		0.0000
Burr Control	1.0%		0.0000		CT Blocks	0.5%		0.0000
Stacking / Alignment	1.0%		0.0000		Gauges	1.0%		0.0000
Clamping	4.0%		0.0000					
Overall Scoring								
Category								
Insulation	0.0%	out of	15.0%		Auditor(s):			
Copper	0.0%	out of	5.0%					
Windings	0.0%	out of	30.0%					
Core	0.0%	out of	10.0%		Plant:			
Assembly	0.0%	out of	25.0%					
Tank and Cover	0.0%	out of	10.0%		Date:			
Wiring	0.0%	out of	5.0%					
Total	**0.0%**	out of	100%					

F
MANUFACTURING SURVEILLANCE ACTIVITIES AND EXAMPLES

This appendix provides a list of surveillance attributes that one utility used when evaluating selected quality controls at a large power transformer manufacturer's facility. The list might not include all the tests or inspections required for a given transformer; it is provided for illustrative purposes only and might not be appropriate for other applications without technical review and modification.

F.1 General Information

Transformer MVA,: Voltage: HV LV:

Transformer Serial Number:

Quantity of units on this Order:

Manufacturer:

Manufacturer factory location:

Purchase Order No.:

Date of inspection:

Inspected by:

Manufacturer representatives or project managers present during inspection:

Summary of Inspection/Special Comments

F.2 External Item Inspection

F.2.1 Tank (Refer to Outline Drawing)

Quality of welds:

Quality & color of paint:

Base design:

Braces for conservator tank, control cabinet, arresters, potential devices:

Condition of conservator tank to main tank interconnection piping:

Vacuum bracing (bracing use for gas space or raceway?):

Inside of tank painted, clean and free of debris:

Ground pads (minimum of 2) and pad location:

Pump/radiator flanges (machined gasket surfaces):

Fill/drain valves (quantity & Location):

Type of valves:

Rapid pressure rise relay/valve(s) (quantity & Location):

Quantity/location of temperature gauges or monitor:

Type of WTI and location (RTD accessible online?):

Quantity/location of level gauges:

Location/design of gas accumulator and sampling piping:

CT blocks and tank penetrations:

DETC handle location and design:

Jack pad design/location (check against drawing):

Pulling point design/location (check against drawing):

Lifting hooks (check against drawing):

External wiring in rigid metal conduit (properly attached to tank):

General comments on tank quality/fit/finish, items to be corrected:

F.2.2 Tank Cover (Refer to Outline Drawing)

HV bus duct flange design/location/dimensions:

LV bus duct flange design/location/dimensions:

Bushing locations:

Gas accumulation relay/gas collection system design & location:

Manholes (access ports) size & location:

CT wiring routed and secured to underside of lid or emerges from each turret:

Quantity/location and mounting of bushing CTs:

Pressure relief device design & location:

Adequate lift points (eyes, hooks, etc.):

General comments on tank cover quality/items to be corrected:

F.2.3 Control Cabinet (Refer to Wiring and Schematic Diagrams)

Breather/drain in bottom of control box:

Latch/hinge design:

Rigid conduit for all wiring entering or leaving control cabinet:

All terminal blocks & wires clearly marked:

Wire labels durable and cannot easily fall off during maintenance activities:

All control cabinet relays, terminals, devices included on layout, and are they accurate per connection diagram:

Transformer nameplate mounted on door:

Heaters (with thermostat) & lights (with door operated switch):

All compression ring terminals secure (pull test):

General comments on control box quality/items to be corrected:

F.3 Active Part Inspection

This section provides examples of a core and coil pre-tanking inspection form that one utility used when evaluating the quality controls at the transformer manufacturer's facility. The evaluation form examples are provided for illustrative purposes only.

F.3.1 Core and Coil Pre-Tanking Inspection (Shell Form)

F.3.1.1 Core

☐ Unit is core form so this section is not applicable.

Quality of core stack (gaps in mitered joints):

T beam insulation in place:

Condition of core (edge damage, rust, dirt, burrs):

Insulation from tank (top and bottom):

Core ground placement:

Type of core shielding used:

Top laminations protected from clamping wedges adequately:

General comments about core quality/items to be corrected:

F.3.1.2 Bridge Structure

☐ Unit is core form so this section is not applicable.

Condition and type of wood used for interphase blocking:

Partitions in place:

Bolts/nuts for partitions and lead supports tight and secured:

All leads taped at bends:

Quality of lead brazing:

Bolted conductor terminations clean and smooth:

Coil support wedges in place and locked in:

Insulated bus/lead abrasion protection at all points supported:

Adequate of all bus/leads:

Condition of DETC mounting and drive shaft:

Condition of DETC contacts (silver plated):

DETC drive shaft clean and smooth:

Condition of coil end support panels:

Coils covered with clean cloths to protect while assembly is completed:

All lead/bus support structure bolts tight and secured in place:

General comments of quality of core/coil assembly, items to be corrected:

F.3.2 Core and Coil Pre-Tanking Inspection (Core Form)

F.3.2.1 Oil Box and Barriers (Forced Air Cooled or Forced Oil and Air Cooled Design)

☐ Unit does not have directed flow oil box/pumps.

Condition of material used to build oil box:

Bolts holding box together tight and secured in place:

Inside of oil box clean and free of debris:

Condition of FOA tubes:

General comments on quality of oil box/barriers, items to be corrected:

F.3.2.2 Core and Coil Clamps

☐ Unit is shell form so this section is not applicable.

Material/design of coil clamps (i.e., steel ring, screw jacks, Wiedmann T-4 pressure rings, etc):

Condition of coil bracing under yoke (core window coil blocks):

Condition of coil clamps (top and bottom):

Condition of blocks/rings (top & bottom, splitting/cracking):

Tie (lock plate) between top & bottom core clamps (solid or stripped):

Core clamp bolts (through bolts) insulated from core:

Shielding of core clamping parts in high flux areas:

Step support blocks correctly fitted (captured in place) to core steps:

General comments, items to be corrected:

F.3.2.3 Bus and Leads

☐ Unit is shell form so this section is not applicable.

Ensure that the routing of leads and lead supports do not preclude the full use of manholes

Condition of brazed joints:

Bolted conductor terminations clean and smooth:

Insulated leads protected from abrasion at all support points:

Flexible leads properly secured:

Condition of wooden lead/bus support structure:

Connections at DETC tap changers:

Condition of DETC mounting and drive shaft:

Condition of DETC contacts (silver plated):

DETC drive shaft clean and smooth:

Condition of hand wrapped insulation over brazed connections:

General comments on quality of lead / bus, items to be corrected:

F.3.2.4 Coils

☐ Unit is shell form so this section is not applicable.

Radial spacers vertically aligned from top to bottom of coils:

Radial spacers tight (test tap with small hammer or block):

Main radial clamping blocks in line with radial spacers:

Condition of insulation on leads exiting coils:

Condition of insulation on coils (nicks, cuts, scrapes, particularly at disk crossovers):

Screw jacks tight and locked in position:

Top coil blocks tight and in proper positions:

Top and bottom oil ducts clean and free of debris:

General comments on quality of coils, items to be corrected:

F.3.2.5 Core

☐ Unit is shell form so this section is not applicable.

Condition of core insulation (in place and tight):

Condition of top yoke stack (miter joint fits, edge damage, gaps in between “books”, dings, warping of laminations):

Core damage/rust:

Core ground lead in place and tight:

General comments on quality of core, items to be corrected:

F.3.2.6 General

All nuts bolts tight and secured in place:

Splitting / cracking of wooden materials / blocking:

Overall cleanliness:

Shielding in high flux areas:

General items to be corrected:

G
EXAMPLE OF FINAL PRODUCT TESTS

This appendix provides an example list of tests that were conducted before releasing a new transformer for shipment and witnessed by one utility. Table 19 of IEEE C57.12.00 provides a basis for establishing appropriate final product testing for large power transformers [8]. These tests might also be referred to as factory acceptance tests; they should typically be witnessed by the licensee or their approved agent. Working 8- to 10-hour days, a team can typically complete the final product testing in approximately 10 days.

Table G-1
Example List of Final Product Tests for Large Transformers

Item No.	Type of Test	Factory Test Schedule (See Note)	IEEE Standard Or Purchase Specification
1	Measurement of winding resistance	1st day	IEEE C57.12.90
2	Measurement of voltage ratio	1st day	IEEE C57.12.90
3	Check of polarity	1st day	IEEE C57.12.90
4	Measurement of insulation resistance	2nd day	IEEE C57.12.90
5	Measurement of insulation power factor and capacitance	2nd day	IEEE C57.12.90
6	Measurement of no-load loss and excitation current (plus harmonic analysis of no-load current)	3rd day	IEEE C57.12.90
7	24 hours core loss test	8th day	Purchase Specification
8	Measurement of impedance voltage and load loss	4th day	IEEE C57.12.90
9	Efficiency and voltage regulation calculation	4th day	IEEE C57.12.90
10	Temperature rise test	4th day	IEEE C57.12.90
11	Overload test	5th day	Purchase Specification
12	Lightning impulse test	6th day	IEEE C57.12.90
13	Switching impulse test	7th day	IEEE C57.12.90
14	Applied voltage test	7th day	IEEE C57.12.90

Table G-1 (continued)
Example List of Final Product Tests for Large Transformers

Item No.	Type of Test	Factory Test Schedule (See Note)	IEEE Standard Or Purchase Specification
15	Induced voltage test and partial discharge test	8th day	IEEE C57.12.90
16	Measurement of audible sound level	8th day	IEEE C57.12.90
17	Measurement of 10kV excitation current	8th day	Purchase Specification
18	Measurement of power taken by cooling equipment	1st day	Purchase Specification
19	Measurement of core insulation resistance	1st day	Purchase Specification
20	Measurement of leakage current	8th day	Purchase Specification
21	Sweep frequency response analysis	9th day	Purchase Specification
22	Dissolved gas check	In associate with heat rise	IEEE PC 57.130
23	Construction check	6th day	Manufacturing Standard
24	Gas injection test	10th day	Manufacturing Standard
25	Pressure test	9th day	Manufacturing Standard
26	Vacuum test	9th day	Manufacturing Standard
27	Test cooler control panel a) Inspect construction b) Visually inspect wiring c) Perform Insulation resistance test d) Verify CTs installation/termination e) Verify RTDs installation/termination f) Verify Digital inputs g) Perform operational sequence test	On-going complete by 8th day	Manufacturing Standard

Table G-1 (continued)
Example List of Final Product Tests for Large Transformers

Item No.	Type of Test	Factory Test Schedule (See Note)	IEEE Standard Or Purchase Specification
28	Verify on-line DGA device a) Configure communications b) Configure analog outputs c) Configure heater plate alarms d) Verify firmware e) Verify oil sampling and temperature setup f) Verify alarms g) Perform sensor test	On-going complete by 8^{th} day	Purchase Specification
29	Test Transformer monitoring a) Perform configuration firmware verification b) Verify application software is installed c) Verify Hydran configuration d) Verify configuration of analog and digital inputs and outputs e) Verify data descriptions f) Perform configuration download and verification g) Test all digital inputs and outputs h) Test all analog inputs i) Perform operational sequence test	On-going complete by 8^{th} day	Purchase Specification
30	Test of (other) parts and accessories (Records should be checked to verify manufacturer's inspection and testing of items tested before mounting)	On-going complete by 8^{th} day	Manufacturing Standard

Note: Most manufacturers do not work just one shift on the test floor, and the duration of the test schedule may be shortened to 5-6 days when the manufacturer employs multiple shifts.

H

EXAMPLE OF A TRANSFORMER INSTALLATION AND STARTUP CHECKLIST

This appendix provides an example of a checklist of various installation and startup inspections and tests that one utility used to prepare a large power transformer for reliable service. The list of items is provided for illustrative purposes only; it might not include all of the activities required for each particular installation or type of transformer.

Table H-1
Example of Installation and Startup Checklist
Courtesy of TVA

Step	Task to be Verified	OK	Verified By	Date
1	Complete vacuum oil filling per requirements			
2	Oil analysis performed and meets criterea in Attachment G			
3	Conservator			
	All valves to main tank in open position			
	Oil level gauge reading proper level			
	Silica gel breather properly filled			
	Oil cup on silica gel breather filled to proper level			
	No oil leakage observed			
4	Bushings			
	All bushings clean and free from contaminates			
	Bushing oil levels at proper level			
	All electrical connections torqued			
	No oil leakage observed			

Table H-1 (continued)
Example of Installation and Startup Checklist
Courtesy of TVA

Step	Task to be Verified	OK	Verified By	Date
5	Coolers or Radiators			
	All valves to main tank in open position and secured			
	Correct rotation and operation of all fans			
	Drain holes in fan motor housing open (if equipped)			
	Correct rotation and operation of all pumps			
	Oil flow indicators provided correct indication			
	No oil leakage observed			
6	De-energized Tap Changer (DETC)			
	Tap changer moves properly through all taps			
	Position indicator properly aligned and visible			
	Locking mechanism properly engages and secures			
	Secured padlock prevents operation			
7	Load Tap Changer (LTC)			
	Tap changer moves properly through all taps			
	Position indicator properly aligned and visible			
	Oil level gauge reading proper level			
	Silica gel breather properly filled			
	Oil cup on silica gel breather filled to proper level			
	All functional checks performed on LTC per OEM instructions			
	All safety checks performed on LTC per OEM instructions			
	No oil leakage observed			

Table H-1 (continued)
Example of Installation and Startup Checklist
Courtesy of TVA

Step	Task to be Verified	OK	Verified By	Date
8	Control Cabinet			
	All connections checked for proper connections			
	All connections checked for tightness			
	All controls checked for proper operation			
	Transfer switch operates properly on loss of voltage (if equipped)			
	Weather tight connections and seals secured			
	Strip heaters checked for operation			
9	Lightning Arresters			
	Arresters clean and free from contaminates			
	All electrical connections torqued			
	Ground cables connected properly			
10	Main Tank			
	Tank grounds properly connected			
	All conduit fittings secured and weather tight			
	Paint system touched up as required			
	No oil leakage observed			
11	Protective and Indicating Devices			
	Oil temperature device indicating properly			
	Winding temperature device(s) indicating properly			
	Fiber optics device indicating properly			
	Sudden (fault) pressure relay valve open and relay vented			
	Bucholtz (gas operated) relay valves open and relay vented			

Table H-1 (continued)
Example of Installation and Startup Checklist
Courtesy of TVA

Step	Task to be Verified	OK	Verified By	Date
12	Electrical and Functional Tests			
	Insulation resistance - 1 megohm or greater per kV rating			
	Insulation power factor			
	Core-to-ground resistance - 50 megohms or greater			
	Polarity - in accordance with nameplate			
	Ratio - +/- 2 percent of nameplate			
	Exciting current			
	Winding resistance - all taps - +/- 5 percent of factory tests			
	DETC in locked position on set tap - final winding resistance			
	BTCT's - ratio, polarity, insulation resistance, winding resistance, excitation current			
	Oil temp indicator - calibration / alarms			
	Winding temp indicator - calibration / cooling control / alarm / trip			
	RTD's - calibration / alarm			
	Sudden (fault) pressure relay - calibration / trip			
	Bucholtz (gas operated) relay - calibration / alarm / trip			
	Pressure relay (LTC) - calibration / trip			
	Pressure relief device - semaphore in correct position			
	LTC controls operating properly			
13	Final Check			
	All protective relays connected for operation			
	All alarms connected for operations			
	All loose objects removed from top of tank			
	All temporary grounds have been removed			

Table H-1 (continued)
Example of Installation and Startup Checklist
Courtesy of TVA

Step	Task to be Verified	OK	Verified By	Date
14	After Energizing			
	Listen for any unusual sounds or noises			
	Check temperature indicators for proper readings			
	Recheck for any oil leaks			
	Obtain oil samples per sample schedule			
	Perform infrared per schedule			

I

EXAMPLE OF FIRST-YEAR OIL SAMPLING AND THERMOGRAPHY INTERVALS

This appendix provides a list of tests and inspections that one utility conducted during the first year of operation of a new large power transformer. The example is provided for illustrative purposes only; it might not be appropriate for other plant applications without technical review and modification.

Table I-1
Recommended Oil Sampling and Thermography Intervals for New Transformer Installations
Courtesy of TVA

Sample/Inspection Interval	DGA Main Tank	DGA LTC	Quality Main Tank	Quality LTC	Thermography
Prior to energizing	X	X	X	X	
24 hours after energizing (Transport to Lab immediately)	X				
Immediately after loading					X
1 hour after loading					X
24 hours after loading (Transport to Lab immediately)	X	X			X
48 hours after loading (Transport to Lab immediately)	X				X
72 hours after loading (Transport to Lab immediately)	X				
1 week after loading	X				
2 weeks after loading	X				
3 weeks after loading	X				
1 month after loading	X	X			
2 months after loading	X				
3 months after loading	X				

Table I-1 (continued)
Recommended Oil Sampling and Thermography Intervals for New Transformer Installations
Courtesy of TVA

Sample/Inspection Interval	DGA Main Tank	DGA LTC	Quality Main Tank	Quality LTC	Thermography
6 months after loading	X	X	X	X	X
9 months after loading	X				
12 months after loading	X	X	X	X	X

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

Programs:

Nuclear Power

Plant Support Engineering

Printed on recycled paper in the United States of America

1015077

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com