Reliability Centered Maintenance (RCM) Technical Reference for Power Delivery

TR-108068

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ORDERING INFORMATION

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REPORT SUMMARY

The overall goal of Reliability Centered Maintenance (RCM) is to improve the economic posture of a utility by promoting cost-effective application of maintenance resources. EPRI's RCM Technical Reference for Power Delivery provides utilities with essential technical data and guidance for conducting RCM studies of power delivery equipment and systems. It serves as the "handbook" of RCM for the utility power delivery sector.

Background
Preventive maintenance is perhaps the single largest controllable cost of a utility operation. Careful planning and good management are essential to achieve an optimal balance between cost of maintenance and service reliability. Traditional maintenance programs rely heavily on time-directed maintenance and manufacturer recommendations to preserve equipment operation. RCM addresses problems of traditional maintenance programs by focusing resources on preservation of function as opposed to individual equipment operation. RCM also promotes use of predictive techniques and recognizes that some failure can be more cost-effectively handled through corrective maintenance. This project used results of a previous substation effort to expand and refine the material in developing appropriate guidance and references for all of power delivery.

Objectives
To provide utilities with essential technical guidance and data for performance of RCM studies.

Approach
Working with the transmission substation version of existing technical materials, investigators enhanced each portion to improve clarity and suitability based on feedback from utility users. They expanded the scope of the generic data set to include transmission and distribution equipment (both overhead and underground), and they added terminology and maintenance technology overviews that were specific to transmission and distribution equipment. Technical examples of RCM studies for transmission and distribution equipment also were added, and a new approach to addressing inspection programs was developed and incorporated into the guide. In completing this effort, investigators worked with scores of utilities to ensure that data, techniques, and guidance were suitable for use in utility environments.

Results

This technical reference presents a compendium of resources that are indispensable for those engaged in RCM studies of power delivery equipment and systems. The technical reference is a valuable tool for individuals involved in optimizing maintenance resources—it contains both guidance in applying RCM methods and appropriate data references suitable for use with or without RCM analysis software.

The technical reference materials also are available in a software version, the RCM Technical Reference for Power Delivery. A companion software product, the RCM Workstation for Power Delivery, provides a computerized environment for conducting and documenting RCM studies. The workstation product allows users to conduct RCM studies using methods and generic data in the technical reference. Thus, the two software products are compatible from the standpoints of philosophy, process, and technology. Minimum system requirements are a 486/50 PC with 8 megabytes RAM and 15 megabytes free hard disk space.

EPRI Perspective

This technical reference and its companion software products are a response to industry needs for guidance in performing maintenance optimization studies using RCM methodology. Several trial applications of RCM have shown potential for substantial savings in maintenance costs (averaging 5% - 20%) while providing quantifiable improvement in service reliability. Related EPRI products under development include an RCM-based model of a Living Preventive Maintenance (PM) Program, an approach to vegetation management based on RCM philosophies, a comprehensive maintenance management tool called Maintenance Management Workstation (MMW), and a transmission field inspection and maintenance tool called Transmission Inspection & Maintenance System (TIMS).

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Interest Categories

Distribution o&m
Substation o&m
Overhead construction, o&m
Underground construction, o&m

Keywords

Reliability-centered maintenance
Maintenance management
Maintenance optimization
Maintenance database
Maintenance cost reduction

ABSTRACT

This product is a compilation of guidance and technical reference material for use by individuals conducting Reliability Centered Maintenance (RCM) studies of power delivery equipment and systems. It contains helpful hints and insights, data references, technical guidance, definition of common terminology, and an introduction to maintenance technologies. It is designed to be useful for both experienced RCM analysts and beginners.

To help ensure successful use of the reference, a section is provided to explain how to use the guide. This section contains abbreviated examples of completed RCM studies in the three main technical areas of substations, transmission and distribution.

A major portion of the reference material is dedicated to the presentation of generic data used in RCM studies. This data shows equipment failure modes, causes and routine maintenance tasks for a wide range of equipment types. The maintenance tasks address those of a predictive, preventive and failure finding nature. The equipment types encompass the most common maintainable items in power delivery. For convenience, the data is categorized by the general areas of substations, transmission and distribution.

ACKNOWLEDGMENTS

This technical reference was developed from the efforts of two separate EPRI Reliability Centered Maintenance (RCM) projects conducted back-to-back over a three year period: RCM for Substations; and, RCM for Transmission and Distribution. The combined result is a reference for the conduct of RCM studies associated with any discipline of power delivery. Throughout the three year effort, the projects relied on the technical advice of numerous utility participants, and the expertise of industry RCM consultants from SCIENTECH. Gratitude is expressed to all contributors for their time and technical expertise.

Participating Utilities

B. C. Hydro

Baltimore Gas and Electric Company

Bonneville Power Administration

Consolidated Edison of New York

Duke Power Company

Entergy Services, Inc.

Nevada Power

New York State Electric and Gas

Northern Indiana Public Service Company

Ohio Edison

Pacific Gas & Electric

PECO Energy

Pennsylvania Power and Light

Public Service Electric & Gas

Puget Sound Power and Light

Rural Electric Cooperative, Inc.

San Diego Gas and Electric

Seattle City Light

Sonomish County PUD

South Carolina Electric and Gas

Tennessee Valley Authority

TU Electric

United Illuminating

CONTENTS

INTRODUCTION

The Reliability Centered Maintenance (RCM) Technical Reference for Power Delivery is a response to industry need for a guidance document to support RCM evaluations of electric utility power delivery preventive maintenance (PM) programs. Through the application of RCM, several improvements can be expected in the PM program for power delivery equipment. These include: more cost-effective tasks; a documented technical basis for tasks; a reduction in the number of PM induced corrective maintenance actions; and enhanced service reliability. The benefits should be observable through a variety of indicators including: overall reduction in the cost of PM tasks; improved use of man-power; a reduction in the frequency and severity of catastrophic equipment failures; and reduced equipment and customer outages.

It should be noted that the overall goal of RCM is to improve the economic posture of the business operation by improving the cost-effective application of maintenance resources. In some cases, this will mean adding PM tasks to eliminate or reduce costly service outages. In other cases, this will mean eliminating unnecessary tasks that add cost and introduce opportunities for maintenance error. Some of the benefits of RCM will be easily measurable, such as reduction in maintenance expenditures, while others will be less tangible in nature. For example, avoided revenue losses and replacement power costs are difficult to measure yet may provide a greater cost savings than that associated with reductions in maintenance resource expenditures.

The purpose of this document is to provide appropriate reference material and limited technical guidance for the accomplishment of RCM. It is intended to provide useful technical information, insights to the RCM process and helpful hints in support of RCM studies. It should be compatible with any specific RCM instruction that is designed around the basic principles of RCM. The Technical Reference is also intended to be a companion for the RCM Workstation for Power Delivery, a software tool for the conduct of RCM studies.

The Technical Reference is not intended to be a step-by-step guide explaining how to perform RCM evaluations. It is also not intended to provide programmatic guidance. This type of information should be contained in technical instructions and administrative procedures.

HOW TO USE THIS TECHNICAL REFERENCE

RCM presents many opportunities to exercise discretion in completing the technical process. This level of program management discretion is reflected in the guidance contained herein, and may present some uncertainty to the user. For example, the guidance notes that the criticality of a failure mode can be characterized in many ways, and provides three examples, each with a discussion about its value. The user can decide to follow a specific example or create their own manner of characterizing criticality. The decision depends on the specific objectives of each utility maintenance program and how the results of RCM are expected to be used. It is left up to the developers of specific RCM instructions at each utility to establish conventions such as this so that the work is completed with consistency.

The RCM Technical Reference for Power Delivery is written in such a manner as to be useful for individuals performing RCM using a range of "dialects," however, the central focus of the technical advice is in the application of a function-based approach to RCM, closely related to the traditional RCM methodology of the air transport industry. This function-based approach reflects lessons learned by EPRI in applying RCM in the utility industry in general, and specifically within the power delivery arena. The basic difference between the RCM method for power delivery and that of the air transport industry is the level of detail and rigor, and the amount of documentation required. In the power delivery environment, a high level of detail and extensive documentation is not necessary, nor desirable. Despite these differences, all the basic concepts and philosophies of RCM from the air transport industry remain unaltered to ensure that the value of the RCM methodology is retained.

The organization and presentation of materials in this document is intended to provide guidance and references to support several technical approaches to RCM that are suggested. The text provides helpful hints and insights as well as data references. Data tables provide information necessary for technical accuracy and consistency of RCM studies as well as an overview of pertinent maintenance technologies.

It is assumed that individuals using this technical reference are familiar with the RCM process. Although the guidance is intended to help the evaluator avoid common pitfalls and other difficulties, it cannot be a substitute for detailed training or on-the-job experience in performing RCM evaluations. In many cases, this training and experience is essential to understanding the context in which the guidance is offered.

The material in this reference is organized in the approximate order that RCM evaluations are completed. Detailed discussion of technical approaches, helpful suggestions, lessons learned and insights are provided in text format and supplemented by figures and tables where appropriate. To obtain data and insights quickly, data tables, example formats and flow diagrams are provided. A summary and review section is provided, as a convenience, at the end of each section.

In developing each section of the RCM Technical Reference for Power Delivery, there were a number of objectives that EPRI desired to achieve. The following highlights the objectives for each section of the document.

- Main Body of Text - The primary objective of the main body of the reference is to provide useful insights and guidance in support of RCM studies. There are a number of variations of RCM practiced, so the guidance is focused at a general level. Making the materials useful for all potential users was a primary objective of the work.

  The guidance is not intended to address all conceivable needs but rather focuses on the most common questions and opportunities for misunderstanding regarding the technical aspects of performing RCM.

- Definition of Key Terms - To achieve a complete and consistent understanding of the issues, a set of definitions for key terms is provided. The definitions are intended to encompass both the common and less commonly used (and understood) terminology of RCM. It is EPRI's intention that the terminology be consistent with related technical data in the industry. Therefore the definitions have been reviewed for consistency against terminology standards in the industry.

- Equipment Reference Data - This portion of the guidance provides advice as to applicable maintenance tasks for common combinations of equipment types, failure modes and causes. The maintenance tasks presented include predictive, preventive, and failure finding tasks. In some cases, it may not be practical for a specific maintenance task to be cost-effectively applied. For this reason, the information in this section is intended to serve only as a selection reference. The user must review each of the task options, in accordance with the RCM methodology, to identify those that would cost-effectively address failures of concern.

- Maintenance Technologies Overview - The Maintenance Technologies Overview section provides detailed descriptions and example applications for selected maintenance techniques and technologies addressed in the Equipment Reference Data section. It is intended to provide a level of familiarity for a wide range of maintenance tasks.

- The remaining information in this section is offered to provide a clear understanding of how to apply the data, guidance and equipment reference materials contained herein. The exact method for using the reference will depend upon the specific manner in which RCM is applied. The design of the Technical Reference takes into consideration the many commonalties between various "dialects" of RCM, thus making the reference information more globally applicable. A flow diagram depicting the typical function-based RCM process is provided as Figure A. This will help the user associate portions of the Technical Reference with specific steps of this EPRI preferred RCM "dialect."

What follows is a discussion of how each section of the Technical Reference is used to support RCM studies. Following portions of the discussion are abbreviated technical examples for equipment from the disciplines of: Substation (161kV air blast breaker); Transmission (100kV line and steel lattice tower); and, Distribution (underground switch - submersible oil insulated). The examples show what might be done and documented for each of the three disciplines and their example equipment items. The technical examples are indented and italicized to separate them from the discussion of the text.

Step 1 of the function-based RCM process involves the definition of boundaries. Simply stated, boundaries provide an convenient means of defining the extent of the study, and providing organization to the work. Without them, the scope of a study could quickly become unmanageable. Boundaries are defined for a particular equipment item or multiple items of the same equipment type, or for a system containing multiple equipment items of different types. A system boundary can be further divided into subsystems (each containing multiple equipment items of different types) or equipment sets (each containing multiple equipment items of the same type). Section 1.0 provides guidance in the determination of equipment and system boundaries, and the usefulness of subsystems and equipment subgroups within a system boundary.

Substation Example:

The equipment item under study is a Delle Type PK 161kV Air Blast Breaker, ID number 440468WK from the XYZ Substation in the Western Region of ABC Electric Company. The equipment boundary encompasses the breaker, electrical controls, mechanical linkages and air storage facilities. The equipment boundary does not encompass the high pressure air plant. This study is of a single equipment item.

Transmission Example:

The system under study is a 100kV circuit line that begins at the WWW Tie Station's black and white circuit outrigger connections through the ZZZ Switching Station ending at the customer substation outrigger connections. The boundary includes all structures/towers 1 through 129, conductors, non-foreign equipment attached to the towers, grounding system, shield wire, and associated right of way (ROW) for the line.

Distribution Example:

The equipment group to be studied is composed of all underground, submersible, oil insulated switches of the TYDY Electric Company that serve in the load/duty class 44B, and serve commercial and light industrial customers. The equipment item representative of this equipment group is ID number SWT7701349. The results of this equipment item will be applied to other members of the group to eliminate the need for further analysis. The boundary of this equipment group begins at the underground termination connections of the incoming lines to the high voltage bushings continuing through the switch contacts and internal bus, and ending at the outgoing high voltage bushing underground termination connections. The boundary includes all connecting hardware, bushings, insulating medium, switch assembly, moving and stationary blades/contacts, switch operating mechanism, monitoring devices and tank.

STEPS	RCM PROCESS ELEMENTS	APPLICABLE PORTIONS OF TECHNICAL REFERENCE
	SELECT EQUIPMENT/SYSTEM FOR RCM EVALUATION	N/A
1	DEFINE EQUIPMENT/SYSTEM BOUNDARIES	Section 1
2	COLLECT AND REVIEW PERTINENT DATA, AND DOCUMENT INSIGHTS	Section 2
3	IDENTIFY EQUIPMENT/SYSTEM FUNCTIONS	Section 3
4	IDENTIFY CRITICAL EQUIPMENT FAILURE MODES	Section 5, 6, and 7
5	DATA REVIEW, ASSESSMENT, AND DOCUMENT INSIGHTS	Section 2
6	IDENTIFY CAUSES OF CRITICAL EQUIPMENT FAILURE MODES	Section 8
7	SELECT APPROPRIATE AND COST-EFFECTIVE MAINTENANCE TASKS	Section 9
8	PERFORM TASK COMPARISON, DELETE INEFFECTIVE PM TASKS, MODIFY CURRENT PM PROGRAM TO REFLECT RCM RESULTS, ADD NEW PM TASKS WHERE WARRANTED, AND RETAIN TASKS THAT ARE COST-EFFECTIVE	Section 10
	PREPARE RCM EVALUATION RESULTS DOCUMENTATION	N/A

Figure A

Step 2 of the RCM process encompasses the collection, review and documentation of maintenance insights and failure data for the equipment within the previously defined boundaries. The collection and review of the data is addressed in Section 2.0 of the guidance. The documentation of data is not addressed since this is a programmatic issue.

Substation Example:

A review was conducted of failure history records for the past 7 years. Information pertaining to failures occurring greater than 7 years ago was not considered as pertinent to the study. Data for this review was collected from all 12 Air Blast Breakers at the XYZ Substation because of limited data available for equipment item 440468WK. Data from the other 11 breakers of the same type is believed to be appropriate to review since the design, operation and maintenance of the other 11 breakers is identical. The following summarizes the highlights of this review.

- *Failure of micro switch contacts caused a pressure switch failure in November, 1988*
- *A rupture disc failed in January, 1989*
- *Rod coupling failure resulted in a horizontal rod failure in February, 1989*
- *A resistor switch failed in September, 1990*
- *A capacitor failed in January, 1993*
- *Loose lock nuts on a vertical rod caused a failure of that rod in February, 1993*
- *A capacitor failed in August, 1993*
- *After a trip of the breaker, the main contact broke. Upon closing, the breaker failed to carry load. This occurred in April, 1994*
- *A rupture disc failed in April, 1995*

Transmission Example:

A review of circuit line problems and discrepancies was performed for the 100kV XYZ circuit. The data collected included all documented discrepancy reports from aerial inspections for the past 15 years. Only those discrepancies documented for the past 7 years were deemed current for evaluation purposes. The review indicated only minor discrepancies such as chipped insulators and surface rust on the lattice *structures. No major failures or items of concern were documented for the XYZ 100kV line.*

Distribution Example:

A review of the underground switch maintenance history database was conducted. Approximately 70 records from the 1991-1993 time period were reviewed with 15% indicating some type of corrective maintenance required as a follow-up from routine visual inspections. The as-found condition of the equipment was generally not noted, leading the reviewer to believe that 85% of the inspection activities had no problems noted.

Step 3 of the RCM study involves the identification of functions for the equipment or system within the boundaries previously defined. This step is essential to a "function-based RCM" process. The functions must be so important that they warrant the application of preventive maintenance resources to ensure that they are preserved. The development of functions is addressed in Section 3.0 of the guidance. Example functions for equipment items and systems are offered for review.

Substation Example:

Equipment Item Functions *(partial listing)*

1.0 Trip on demand

2.0 Provide adequate path for current flow

3.0 Provide various status signals

Transmission Example:

System Functions *(partial listing)*

1.0 Transport three-phase 100KV power at rated voltage and current.

2.0 Provide mechanical support to conductors and overhead shield wires.

3.0 Provide lightning protection and proper grounding for the line.

Distribution Example:

Equipment Group Functions (partial listing)

1.0 Provide automatic and manual connection tie and switching point from line to line and line to load during normal operation.

2.0 Provide protection for overload and fault conditions.

Step 4 involves performing a criticality analysis. The analysis is performed for each dominant failure mode of equipment items within the boundaries that would result in failing the function previously defined. Tools such as Failure Modes and Effects Analysis, Criticality Checklist, or Criticality Pre-Selection can be utilized. The relative criticality of each failure mode is determined based on the consequences of the failure. Section 4.0 provides guidance and examples to assist in the selection and utilization of a criticality analysis tool.

The first portion of **Step 4** involves the selection of equipment failure modes that fail the important functions previously defined. Section 5.0 provides detailed guidance regarding the selection of equipment failure modes. Appendix B provides a listing of common equipment failure modes to consider. It should be noted that only dominant failure modes should be considered.

The final actions of **Step 4** are the review of consequences of each dominant equipment failure mode in order to determine its relative criticality based on the expected consequences of failure. Section 6.0 provides guidance for determining the effects (consequences) of a failure mode. For convenience, the effects are presented in the form of a "pick list" organized by proximity to the equipment for which a failure mode is considered: <u>local effects</u>, at the equipment; effects that occur within the defined boundaries of the study; and <u>external effects</u>, outside of the defined boundaries of the study. Section 7.0 of the technical reference materials provides guidance for determining critical equipment failure modes using a standard qualitative method for system evaluations.

A determination of "critical" means that a preventive maintenance task will be sought for the causes of this failure mode. A determination of "non-critical" means that no preventive maintenance task will be sought to address the causes of this failure mode.

Substation Example:

Function	***Equipment Failure Mode***	***Consequences of Failure***	***Criticality Determination***
Provide adequate path for current flow	*Breaker loss of conduction path*	*Damage to equipment, long outage time to repair, personnel safety hazard.*	*Critical*
Provide adequate path for current flow	*Breaker high resistance load path*	*Damage to equipment, long outage time to repair, personnel safety hazard.*	*Critical*
Provide various status signals	*Breaker status signals fail to operate*	*Maintenance inconvenience*	*Non-critical*
Provide various status signals	*Breaker status signals fail high or low*	*Maintenance inconvenience*	*Non-critical*

Transmission Example:

Function	***Equipment Failure Mode***	***Consequences of Failure***	***Criticality Determination***
Provide mechanical support to conductors and overhead shield wires	*Tower fails to maintain conductor position*	*Customer economic loss; Customer outage; Reduced revenues; Adverse publicity; Grid transient or instability; High repair costs; Endangerment to public/environment*	*Critical*

Distribution Example:

Function	***Equipment Failure Mode***	***Consequences of Failure***	***Criticality Determination***
Provide an automatic and manual connection tie and switching point from line to line and line to load during normal operation	*Switch fails to operate*	*Customer economic loss; Customer outage; Reduced revenues; Adverse publicity*	*Critical*

Step 5 of the process involves data gathering through the use of personnel interviews. The purpose of the interview process is to gather pertinent information about the failure history of the equipment and to determine appropriate failure causes, and the relative effectiveness of PM tasks in addressing the causes of equipment failures. Guidance for interviews is offered in Section 2.0 along with advice for data collection and review from other sources.

Substation Example:

Personnel interviews provided insights regarding problems experienced on the Delle PK 161kV Air Blast Breakers. Problem areas were identified as:

- *Air transfer valves*
- *Closing valves*
- *Trip valves*
- *Interrupters*
- *Mechanical linkages*
- *Pressure leaks*

Additional insights from the interview were:

- *Overhauls need to be more frequent, the O-rings tend to get a compression "set" if left to operate without replacement over a long period of time*
- *Spurious signals to the trip coils, from operation of other breakers, eliminated through previous design change*

Transmission Example:

Interviews with transmission maintenance personnel indicate that the XYZ 100kV circuit line is a significant revenue generator. The line was designed with redundancy (double bundled) to reduce the possibility of line faults or failure to the customer. Interviewees corroborated the written record by stating that the line has experienced only a few minor discrepancies and no major problems over the review period. It was suggested that better documentation of "as-found" conditions would significantly contribute to future PM changes.

Distribution Example:

Interviews with distribution maintenance personnel showed that the most frequent problem experienced with underground switches involves inadequate cabling/connections caused by corrosion and poor installation. Interviews results also indicate that there is low confidence in oil dielectric testing due to non-repeatable or erratic test results experienced in the past with both new and used insulating oil.

In **Step 6** of an RCM evaluation, dominant causes of "critical" equipment failure modes are identified. Section 8.0 offers guidance in the selection of appropriate causes for critical equipment failure modes, and discusses how these causes relate to the selection of appropriate PM tasks. Appendix B provides a listing of common equipment failure modes, and the causes to consider during the performance of failure cause selection.

Substation Example:

Critical Equipment Failure Mode	***Dominant Failure Mode Cause(s)***
Breaker fails to trip	*Failed trip coil* * *Failure of trip or blast valves* *Failure of mechanical linkage* *Sticking or binding linkage* *Out of calibration pressure switches and relays*
Breaker loss of conduction path	*Main contact failure*
Breaker high resistance load path	*High resistance connections*

** Failed trip coil would normally be considered a non-dominant cause of failure since there are redundant trip coils, but in this case it is prudent to proceed with cause identification and task selection because the coils are in a stand-by mode.*

Transmission Example:

Critical Equipment Failure Mode	***Dominant Failure Mode Cause(s)***
Tower fails to maintain conductor position	*Lattice/brace failure*

Distribution Example:

Critical Equipment Failure Mode	***Failure Mode Cause(s)***
Switch fails to operate	*Mechanism linkage binds or jams; Stored energy failure*

In **Step 7** of the process, the RCM evaluator selects appropriate maintenance tasks using a structured decision logic. The decision to select a task is based on the technical feasibility of the task and its cost-effectiveness when compared with other alternatives. Section 9.0 describes the maintenance tasks available to address the causes of critical equipment failure modes, and provides guidance on the selection of tasks using a commonly accepted task selection logic. The type of tasks available for selection include predictive, preventive, and failure finding techniques as well as options for corrective maintenance (run-to-failure) and design changes. Appendix B provides a listing of common equipment failure modes, failure causes, and related PM tasks to consider during the selection of maintenance tasks.

A discussion of the application of basic maintenance is also provided in addition to the maintenance task selection for addressing the causes of critical equipment failure modes. The selection of basic maintenance tasks is applicable to equipment determined non-critical due to the presence of redundant/backup equipment. Although a comprehensive listing of basic maintenance tasks is not offered for consideration, a discussion is provided regarding how these type of tasks can be identified and when they should be applied.

Substation Example:

Equipment Failure Mode and Cause	***PM Task Selected***	***Task Type***
Breaker fails to trip due to failed trip coil	*Functional breaker trip test*	*Failure-finding*
Breaker fails to trip due to failure of trip or blast valves	*Breaker timing test*	*Condition monitoring*
Breaker fails to trip due to failure of mechanical linkage	*Functional test of linkage*	*Failure-finding*

Equipment Failure Mode and Cause	***PM Task Selected***	***Task Type***
Breaker fails to trip due to sticking or binding linkage	*Clean, lubricate and exercise linkage*	*Time-directed*
Breaker fails to trip due to out of calibration pressure switches and relays	*Calibration check of pressure switches and relays*	*Time-directed*
Breaker loss of conduction path due to main contact failure	*Internal inspection for signs of contact degradation*	*Time-directed*
Breaker high resistance load path due to high resistance connections	*Infrared test of connection points in the load path*	*Condition monitoring*

Transmission Example:

Equipment Failure Mode and Cause	***PM Task Selected***	***Task Type***
Tower fails to maintain conductor position due to lattice/brace failure	*Visual inspection using binoculars and infrared during aerial flyby*	*Condition monitoring*

Distribution Example:

Equipment Failure Mode and Cause	***PM Task Selected***	***Task Type***
Switch fails to operate due to mechanism linkage binding or jamming	*Operate/exercise switch to full close and open position*	*Failure finding*

Step 8 of the RCM process involves the comparison of the RCM recommendations with the current preventive maintenance program, and reconciling the differences to develop a final PM program for implementing. The process of task comparison is addressed in Section 10.0.

Substation Example:

RCM Recommendation	***Corresponding PM Task Activity***	***Final PM Task Action***
Functional breaker trip test	*Breaker performance test each 48 months*	*Retain breaker performance test each 48 months*
Breaker timing test	*NA*	*Add breaker timing test each 48 months in conjunction with the breaker performance test*
Functional test of linkage	*Breaker performance test each 48 months*	*Retain breaker performance test each 48 months*
Clean, lubricate and exercise linkage	*Clean, inspect and lubricate linkages and other bearing surfaces each 144 months*	*Retain linkage cleaning, inspection and lubrication each 144 months*
Calibration check of pressure switches and relays	*Breaker performance test each 48 months*	*Retain breaker performance test each 48 months*
Internal inspection for signs of contact degradation	*Internal inspection for signs of contact degradation each 120 months*	*Modify internal inspection for signs of contact degradation to 144 months to match the internal inspection frequency*
Infrared test of connection points in the load path	*Visual inspection of connection points in the load path each 12 months*	*Modify inspection to include use of infrared technology to enhance the effectiveness of the task. Retain the frequency at 12 months*

Transmission Example:

RCM Recommendation	***Corresponding PM Task Activity***	***Final PM Task Action***
Visual inspection using binoculars and infrared during aerial flyby	*Visual inspection using aerial flyby every 6 months*	*Modify task frequency to extend aerial flyby inspections from 6 months to 12 months.*

Distribution Example:

RCM Recommendation	***Corresponding PM Task Activity***	***Final PM Task Action***
Operate/exercise switch to full close and open position	*Visual inspection every 6 years*	*No Action Required: Underground switching operations occur twice a year. Retain current visual inspection at 6 years.*

1

SETTING BOUNDARIES FOR RCM STUDIES

The first step of an RCM study involves the definition of boundaries. Boundaries can be defined as an equipment item or type (e.g., Oil Circuit Breaker 681134G, or all 138kV Oil Circuit Breakers), or as a system with or without subsystems (e.g., Substation ABC, or Substation ABC composed of 3 subsystems: circuits X, Y and Z). Boundaries serve to define the extent of the study and promote organization of work. For greatest efficiency, the boundaries of an RCM study should be consistent with the organization of the PM program.

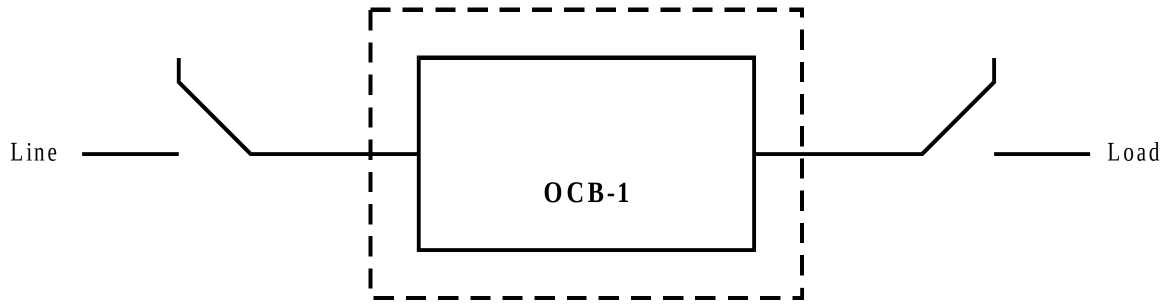
A set of conventions for establishing boundaries should be adopted so that they can be applied with consistency for almost any system or equipment type. The following provides guidance for establishing these conventions.

1.1 Equipment, System and Subsystem Boundaries

Equipment Boundaries. When establishing equipment boundaries, the RCM evaluator is defining the scope of a specific equipment item or type that will be studied using RCM. This is the lowest level at which a boundary should be assigned. The level of detail required to adequately describe equipment type boundaries is largely dependent on the type of equipment being studied. For instance, a substation oil circuit breaker will be different from those of a transmission steel tower, or a three phased ganged overhead distribution switch.

Figure 1-1 shows an example equipment boundary for a typical oil circuit breaker (OCB). For clarity, the equipment boundary is shown in two formats: a one line drawing; and, a field sketch. On the one line drawing, the OCB boundary is shown within the dashed line and includes the breaker and its connection points from both the line and load sides, but does not include the disconnect switches. The field sketch shows more detail regarding the boundary. Here it is clear that the boundary includes the connection points at the: bushings; ground grid; station service AC; DC control; and SCADA. When a drawing or other graphic depiction of a boundary is not clear, it is advisable to add text statements to provide the necessary clarification.

ONE-LINE DRAWING



FIELD SKETCH

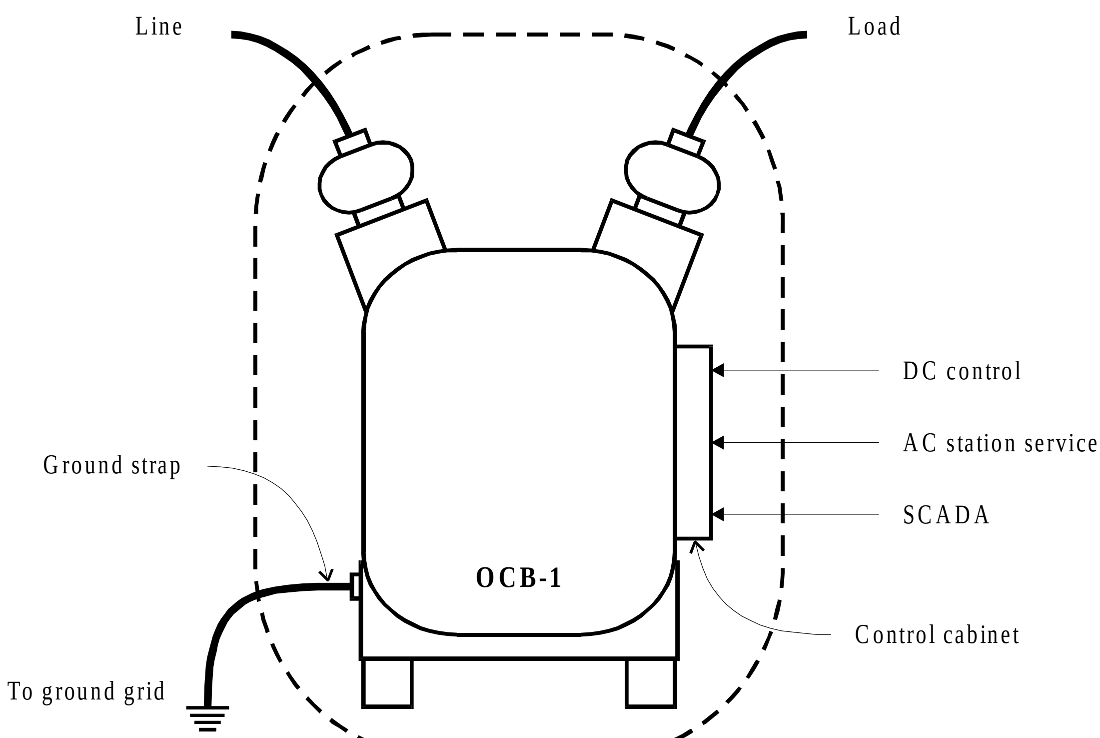


Figure 1-1

In setting equipment boundaries, particular attention should be paid to how the PM program is organized, and how work is divided among the technical disciplines. In many cases, defining a clear equipment boundary should be relatively simple to do since most work is planned and performed by equipment type. The extent of the equipment encompassed by an equipment item should be common knowledge. The establishment of boundaries for the RCM study is meant to formalize the "common knowledge" definition of equipment boundaries, and provide an appropriate level of organization for the work.

Unnecessarily detailed boundaries or boundaries that are too narrowly defined can be self defeating since they create unnecessary administrative burden. A boundary should go to a level of detail that would be appropriate for the proper management of preventive resources applied to the equipment.

System Boundaries - A system boundary is a collection of equipment having a functional relationship. The system boundary defines the scope of equipment that will be subject to the RCM study. The identification of equipment can be accomplished by listing equipment, circling groups of equipment on drawings or any other method that defines the extent of the evaluation. A short text description detailing the system's beginning and ending points should also accompany the drawing. Figure 1-2 provides an example system boundary. Equipment that is excluded from the RCM study is simply not included within the boundary drawing, but may be described or listed in the text description for clarity.

Subsystem Boundaries - Subsystems can be thought of as smaller systems within a system. Subsystems are advisable when the level of complexity of a system is too great to easily handle as a single piece. The creation of a subsystem requires the same level of attention as does the creation of a system. If an entire substation is defined as a system, then a particular circuit within the substation can be defined as a subsystem. The purpose of defining subsystems is to break the system into smaller pieces for ease of completion. The need to define subsystem boundaries is not essential to the performance of RCM, and does not affect technical accuracy of a study. In the case of relatively simple systems, there is no need to segregate the whole into smaller pieces. Creating unnecessary subsystems can cause additional administrative burden, while providing no additional technical benefit.

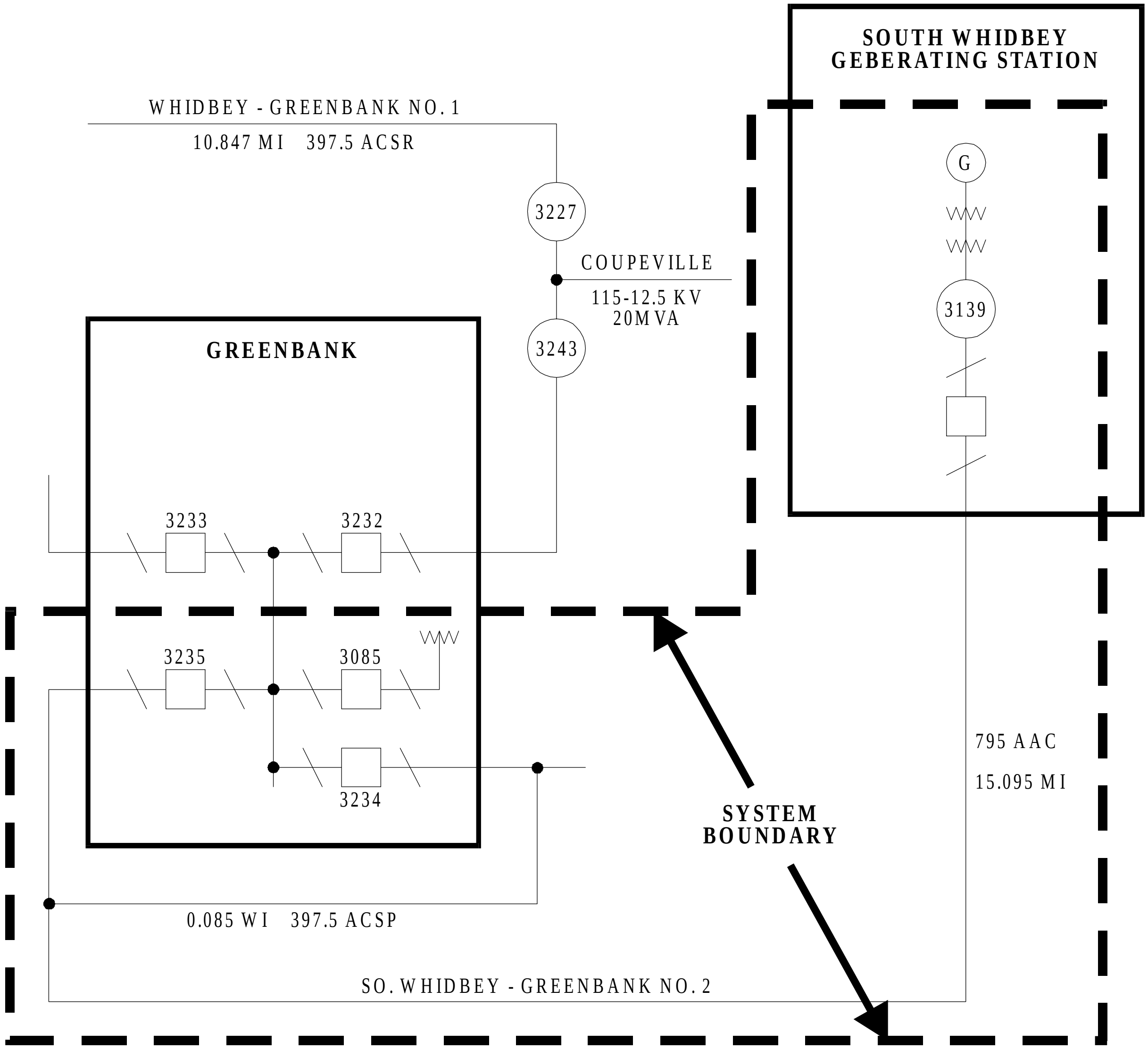

SOUTH WHIDBEY
GEBERATING STATION
WHIDBEY - GREENBANK NO. 1
10.847 MI 397.5 ACSR
G
3227
COUPEVILLE
115-12.5 KV
20MVA
3243
3139
GREENBANK
3233
3232
3235
3085
3234
795 AAC
15.095 MI
SYSTEM
BOUNDARY
0.085 WI 397.5 ACSP
SO. WHIDBEY - GREENBANK NO. 2

Figure 1-2

1.2 Data Sources and References for Setting Boundaries

The following discusses items that should be considered for use when identifying equipment, system and subsystem boundaries.

System Descriptions & Design/Technical Manuals - Design manuals, vendor technical manuals and system descriptions may provide hints about how boundaries could be established. These documents often provide detailed information regarding the function and organization of equipment, two key factors in associating groups of equipment items or establishing a system of equipment. Conforming to the equipment and system boundaries in system descriptions or technical manuals allows the RCM evaluator to take advantage of the established organization of information about equipment operation and maintenance, thus improving efficiency of the study.

Equipment/System Function or Purpose - The RCM evaluator can define equipment and system boundaries, to a large extent, based primarily on function. It makes sense to associate similar equipment that are performing a similar mission into an equipment grouping. An example of such an equipment grouping is wood poles. It also makes sense to associate functionally related equipment into a system. An example of functionally related equipment is a battery charger, battery and associated instrumentation. Typically, protection and control equipment are included within the equipment/system boundary.

It also makes sense to exclude equipment from a system that provides only indirect support or has no relationship to the equipment performing the primary function. For example, circuit breakers that serve as motor controllers are commonly included within the boundary, whereas circuit breakers that provide power but no controlling function are generally left within another system boundary or studied as part of a separate equipment group.

Maintenance Data Collection - It is common that operational data for monitoring and trending is collected from key equipment, substations and circuits as part of the routine business of maintenance. This information may include corrective maintenance activities, system performance parameter monitoring, and results of inspection and testing. Equipment and system boundaries that are organized similar to maintenance related data will help streamline the acquisition and utilization of this information. Boundaries that are inconsistent with maintenance related data collection may present complications when performance data is sought as an input to portions of the RCM study process. The organization of maintenance related data should be carefully considered during the establishment of equipment and system boundaries.

Preventive Maintenance Program - The organization of the preventive maintenance program is important to consider when developing equipment and system boundaries.

The issues in this area are similar to the those associated with maintenance data collection. It will be much more difficult to perform some portions of the RCM process, and to implement the results, when the study and its results are organized substantially different from the current preventive maintenance program.

1.3 Equipment Exclusion

There will be occasions when excluding certain equipment from the RCM study will make sense. In the boundary text description, and separately if needed, the equipment excluded from a study can be listed. This listing may also include a brief explanation of why the equipment was excluded. Equipment should be excluded from an RCM study if it: (1) has no significant function; (2) is essentially not maintainable, (3) is deemed to be inherently reliable, (4) will undergo a significant design change in the near future, or (5) is not cost-effective to include in the study.

1.4 Equipment/System Interfaces

A list of interfaces should be generated for each equipment/system boundary. The purpose of the interface listing is to document resources and inputs to the equipment/system that the RCM study will not be immediately concerned with. Interfaces are those resources or outputs from equipment/systems outside the scope of the RCM study. They are assumed to be fully operational and available to the equipment/system under study. Interfaces exist between and among boundaries established for equipment, systems and subsystems. Interfaces are never made part of the RCM study of equipment/systems to which they are associated. Instead, they are studied as a separate equipment/system, (if they are analyzed at all).

Typically, interfaces consist of electrical power, control signals, cooling and insulating mediums, and other supporting elements that often traverse the boundaries of the equipment or system. Table 1 lists a generic set of common interfaces. When reviewing this list, it should become apparent that the functions (outputs) of one equipment/system can become the interfaces of another.

Table 1-1

Typical Interfaces

Alarm Signals
Atmospheric Air
Closed Cooling Water
Computer Control Signals
Control Signals from Manual Switches
Control / Input Signals from / to Protective Relays
Monitoring / Control Signals to / from SCADA
Distribution Lines
Electrical Power, AC
Electrical Power, DC
Interlock Signals
Override Signals
Status Signals (e.g. Temperature, Position and Pressure)
Transmission Lines
Trip Signals

1.5 Summary and Review

In selecting boundaries, the following should be considered:

- The organization of tasks within the PM program
- The equipment/system definition as presented in system descriptions, design documentation and vendor manuals
- The overall function or purpose of the equipment or system
- The structure of maintenance data collection

In establishing subsystem boundaries, the following should be considered:

- Grouping like equipment with similar or related functions
- Minimize the number of subsystems

Boundaries of equipment/systems are defined by the hardware and equipment items within, and some items can (and should) be excluded from the boundary if they are not appropriate to be included. A list of items excluded, and the reason for exclusion, should be prepared.

When identifying interfaces, the following should be considered:

- Interfaces are outputs or functions of another equipment/system or subsystem
- Interfaces are always assumed to be available and are not considered during the study of the equipment/system that they support
- Listing interfaces can be useful in supporting the documentation of items excluded from an RCM study.

2

MAINTENANCE DATA REVIEW AND ASSESSMENT

Collecting, reviewing and analyzing maintenance data and equipment performance history is an important part of the RCM process. The results of these activities support both a determination of criticality and the development of maintenance tasks. There are two basic techniques for reviewing and evaluating maintenance data and performance history. These techniques encompass the general areas of quantitative and qualitative data assessment.

In the area of quantitative data assessment, efforts are focused on identifying insights from the maintenance history based in part on statistical review techniques. In the area of qualitative data assessment, the efforts are focused on identifying failure trends and insights from the data based largely on professional experience and engineering judgment. It should be noted that the single largest source of qualitative information is the personnel interview process. In some cases, data is only available through an interview. In other cases, the interview serves to corroborate information obtained in data files and hard copy records. Nearly all of the data needs identified below can be obtained from or augmented by personnel interviews, and the interview of knowledgeable maintenance personnel is a required element of RCM.

The following highlights the principal elements of quantitative and qualitative data assessment.

2.1 Quantitative Data Assessment

The RCM process is designed to identify critical equipment failure modes and assign appropriate preventive maintenance resources to address the causes of failure. Critical equipment failure modes are those that are desirable to avoid in light of the foreseeable consequences and estimated frequency of occurrence. Recognizing and understanding what is meant by the concept of “dominant” when referring to equipment failure modes and causes is important in applying quantitative data in RCM evaluations. The following discusses several aspects of using quantitative data to assist in failure mode criticality determinations.

Dominant Failure Modes - Proper focus in RCM requires that only the most likely (dominant) failure modes of equipment are studied. The term dominant implies that the failure mode is reasonably likely to occur one or more times during the useful life of the equipment. If it is not reasonably likely that a failure mode will be seen within the life of the equipment, then it is not dominant and should not be considered further. Failure modes are a general description of how equipment fails, but not why.

Dominant failure modes can be determined in part through review of corrective maintenance work orders associated with the equipment or system under study. This data is useful in identifying failure modes that have been experienced, suggesting that they may be dominant. In addition, a review of industry operating experience can also help to identify dominant failure modes for a particular type of equipment. It should not be assumed that a single occurrence of a failure mode makes that failure mode dominant for a particular type of equipment. By the same token, failure modes that have not been experienced, should not be discounted as non-dominant. Section 5.2 provides additional guidance in determining dominant failure modes.

For failure modes not experienced, the RCM evaluator should postulate the dominant failure modes based on general industry experience and engineering judgment. Interviews with personnel familiar with the equipment being studied can provide qualitative information in support of identifying dominant failure modes. The data obtained through interview techniques are discussed in more detail in Section 2.2 of the guidance. In any event, when engineering judgment is used, the assumptions, methods and reasons should be documented for future reference.

Mean Time Between Failures (MTBF) - The mean time between failures for equipment can be useful in determining appropriate task frequencies. The MTBF represents the average time between any modes of failure, or the average time between the same mode of failure for a specific type of equipment. The mean time between the same modes of failure for specific equipment and equipment types can help identify appropriate frequencies for preventive maintenance tasks. If review of corrective maintenance history shows a pattern of failures that appear at a regular frequency, then the application of certain preventive maintenance activities at a similar time interval may be appropriate. The effects of existing preventive maintenance activities must be taken into consideration with respect to the MTBF or any recognized failure patterns, since maintenance activities may in part be responsible for the failure pattern.

The MTBF can be obtained by reviewing the record of failure history noting the date of initial operation of the equipment, and failure dates for each failure occurrence. In order for the MTBF to be most meaningful, an average value must be established based on a number of similar failure occurrences. The greater the number of occurrences involved in the data set, the more valid the resultant value will be.

The MTBF for specific equipment and its associated failure modes can be converted to a specific failure rate by taking the inverse of the MTBF (1/MTBF). This information can be used to support the determination of the criticality of equipment failure modes. When using the MTBF as an aid to criticality determination, caution should be used to ensure that equipment with high MTBF are not automatically deemed non-critical since a high MTBF may be attributable, in part, to the application of appropriate maintenance tasks. It should also be noted that equipment with a high MTBF may still be deemed critical because of the seriousness of the consequences.

Mean Time to Repair (MTTR) - The mean time to repair equipment is an average value for the duration of repairs to equipment. The MTTR is calculated in a similar manner as MTBF except that the data of interest to the evaluator are the dates of failure and return to service. In addition, a review of maintenance work orders, tagging system records and operations logs can also support the identification of average times to repair equipment. The MTTR can be calculated based on like equipment failure modes and causes to provide the most useful data in determining the average out of service time for specific equipment failures. This information can help assess the relative impact of equipment failures in terms of the duration of power outages.

Frequent and Recurring Failures - Looking at the number, frequency and severity of corrective and preventive maintenance tasks from data obtained through review of maintenance work orders, industry shared failure information, and other data sources can influence the determination of critical equipment failure modes. Failure patterns can be identified and prove useful in developing maintenance program recommendations. By noting the time of equipment failure modes for specific equipment or equipment types and examining activities such as changes in equipment operation, the review may identify operations-related causes of equipment failures and degradation for which operating policies can be modified and/or maintenance program recommendations can be developed.

Of particular interest are frequent failures and failures that occur or recur (for the same cause) despite the performance of routine preventive maintenance. Much of this data is obtained through the review of maintenance history. It is important that maintenance history is reviewed to a sufficient level of detail where failure modes can be distinguished from failure causes, and the impact (or relative severity) of each failure is understood. The results of the data review may be useful as input to the prioritization of equipment types or systems for RCM evaluation.

It may be noted that some equipment exhibits high reliability due in part to the assigned maintenance program tasks and frequencies. Information inferred through evaluation of this type of data should be used only as a guide in determining appropriate tasks and frequencies since many factors, such as equipment design and operating environment, can also influence equipment reliability.

Dominant Causes of Equipment Failure Modes - In determining the most appropriate maintenance task recommendations for system equipment, data obtained through the review of maintenance work orders and interviews with maintenance personnel can be used to identify the primary causes of failure modes. These causes become the focal point for developing a cost-effective maintenance strategy intended to predict, prevent or eliminate the causes. As with dominant failure modes, the dominant causes of equipment failure are the focus of concern. A dominant cause is one that is reasonably likely to be the immediate cause of a dominant failure mode of the equipment.

Cost-Effectiveness of Tasks - Repair costs for a particular equipment failure mode are also used to identify equipment that warrant PM program application. This information can help identify equipment that has extremely high repair costs. These costs alone can be compelling in the determination of criticality.

Assessment of repair and preventive maintenance costs associated with maintenance task options can aid in the selection of the most cost-effective approach to maintenance. Alternatives for consideration include predictive, preventive and corrective maintenance. By calculating the approximate costs associated with predictive and preventive maintenance and comparing those costs with the cost of repair of failed equipment, a cost-benefit decision can be made. When considering the relative cost and value associated with each alternative, consideration should be given to the cost of parts, materials, labor, equipment replacement, outage time, potential equipment damage, and the cost of new testing and monitoring equipment. The cost of preventive maintenance should also be considered for all predictive maintenance (monitoring) alternatives. This is necessary since the equipment monitoring only helps to predict, it does not prevent, equipment failures. For each activity, including corrective maintenance, a frequency will need to be assumed so that a comparison of the relative cost-effectiveness of each alternative can be made.

To assess the net savings attributable to adopting a set of RCM recommendations, a comparison will need to be made between the total “before” and “after” maintenance costs associated with the scope of the study. The total costs of maintenance can be determined by adding all costs for preventive and corrective activities, including testing and inspection. In determining the total cost of maintenance, cost details such as cost of labor, spare parts and materials will need to be addressed in each before and after scenario. Finally, the total maintenance costs must also factor in those costs not directly associated with maintenance. Such indirect costs include: replacement power; lost revenue; customer interruption penalties; adverse publicity; and loss of customer base. Subtracting one total from the other will provide a net savings or cost increase associated with the adoption of the RCM-based maintenance tasks.

Estimating cost savings in terms of increased service reliability is less easily determined than for man-hours, parts and materials. Calculating the mean-time between outages for an equipment failure mode and comparing this information with historical records can identify where RCM recommendations have made improvements in this area. The mean-time between outages represents the average time between failures (MTBF) that result in a disruption in service. In order to obtain a valid “time average” picture of increases in service reliability attributable to RCM, the recommendations from an RCM study will need to be in place for several years.

2.2 Qualitative Data Assessment

In addition to quantitative assessment of data, qualitative assessments of data can also be made in support of RCM studies. This data often takes the form of engineering judgment and opinion of individuals that are involved on a day-to-day basis with the equipment subject to study. The individuals involved include work leaders, planner/schedulers as well as technicians and engineers in operations, maintenance and engineering. The following discusses the types of qualitative information that can be obtained from a survey or interview process involving knowledgeable individuals.

Problem Equipment - Often specific equipment problems can be investigated further through the interview process. The purpose of the interview is to obtain more detailed information concerning why the equipment is presenting problems and what sort of maintenance tasks should be considered for application. Problem equipment can be viewed as equipment that is exceptionally expensive or difficult to repair. Such equipment may warrant extra attention during the task selection process.

Clarifying Work Orders and Failure Data - One of the principal objectives of examining the qualitative side of data is to obtain a perspective that may not be obtainable through review of records alone. Often times written records of maintenance and operations lack detail, and this can effectively mask important information. Interviews of knowledgeable personnel can provide details that the written records often lack.

Design Changes - Discussions with knowledgeable individuals can be useful in identifying equipment where a design change is the appropriate option to eliminate the cause of failure. Design changes should be strongly considered when the application of maintenance resources has proven to be ineffective, and any time the risk associated with failure of equipment is unacceptable. They are also appropriate when the cause of failure can be directly attributed to design, incorrect installation or application of equipment.

Task Sequencing - During the interview process, it is likely that situations will be identified where multiple tasks can be combined into a single concurrent activity for a specific equipment item or group, to reduce unnecessary maintenance, preparation and travel time. In some cases, routine and/or special testing/inspection tasks can be used to support condition-monitoring and failure-finding tasks. This task sequencing information is of value in task selection, task comparison and implementation planning activities.

Validating Maintenance Tasks - Results from interviews with knowledgeable personnel provide an opportunity to validate the feasibility of maintenance tasks. Potentially effective tasks can be identified in preparation for the maintenance task selection portion of the RCM process. An effective task is one that directly addresses the immediate cause of failure. Ineffective tasks that do not directly address the cause of failure can also be identified. These tasks may be deemed invalid based on equipment design, equipment operation, operating environment, unavailability of appropriate maintenance technology or an inability to correctly apply maintenance techniques.

Note: Current maintenance program tasks should not influence the task selection process of RCM. Consideration of current maintenance tasks should only occur during reconciliation of RCM recommended tasks with current maintenance program tasks during the task comparison portion of RCM.

New Approaches to Preventive Maintenance - The interview process also helps uncover new ideas regarding the application of preventive maintenance resources to more effectively address the causes of equipment failure. New ideas are best uncovered in an open discussion environment where the creation of a maintenance strategy is done with a "clean slate," without regard to current practices. Taking advantage of the wealth of knowledge of technical personnel can add considerable efficiency as well as validity to the RCM results.

New Maintenance Technologies - Some causes of equipment failure can be solved with the application of new maintenance technologies. Often maintenance personnel have insight as to what new technologies are available in the industry and may work effectively for the equipment under study. The possibility of applying new or different technologies to achieve increased cost-effectiveness should be explored during the personnel interviews. One hazard inherent in investigating the application of new technologies is that some participants may not fully understand or accept the technology. There may be a natural resistance to change. Another hazard is that personnel may believe that new technologies will be a panacea for a range of failure causes that are outside the scope of the technology.

2.3 Summary and Review

When reviewing quantitative and qualitative maintenance information, the following sources should be considered:

- Maintenance work orders
- Problem reports
- Interviews with operations, maintenance and engineering personnel

The following information is useful in supporting the RCM process and can be obtained through a review of quantitative data sources:

- Dominant failure modes
- Dominant failure causes
- Mean time between failures
- Mean time to repair
- Frequent equipment failures
- Recurring equipment failures for the same cause
- Cost of maintenance

The following information is useful in supporting RCM and can be obtained through personnel interviews as a primary source of qualitative data:

- Problem equipment
- Frequent equipment failures
- Recurring equipment failures for the same cause
- Potential design improvements
- Desirable task sequencing
- Appropriate maintenance tasks
- Inappropriate maintenance tasks
- Severity of equipment failures
- New maintenance technologies

3

IDENTIFYING FUNCTIONS

The core of any function-based approach to RCM is founded on the initial activities involved in identifying appropriate functions for the equipment or system subject to study. The purpose of performing this step is to create a deliberate focus on what the RCM study will attempt to preserve using preventive maintenance resources. It also minimizes or eliminates focus on functions that are deemed not worthy of preserving through the use of preventive maintenance resources. The number of functions and level of detail will largely depend on the technical approach selected and the extent of the boundaries established. As a general rule, the more focused the function definition portion of the evaluation is, the more focused the RCM study will be.

3.1 Functions

RCM strives to focus maintenance resources to preserve functions, not necessarily equipment operation. This is the main difference between RCM and traditional maintenance approaches. With RCM, only the equipment that supports important functions will receive consideration for the application of maintenance, whereas a traditional approach to maintenance would apply resources to preserve equipment operation, regardless of its role in supporting important functions. The guidance provided below identifies some of the key issues and activities associated with identifying functions for RCM studies.

Identifying Functions - Functions can be identified by reviewing the intended purpose of the equipment through equipment walk downs and review of the general layout and configuration on drawings and in technical manuals. The focus of the effort should be on identifying the primary mission of the equipment/system, and not every conceivable function that it could perform. For example, an equipment item such as a transformer has a primary mission of <u>transform and regulate voltage</u>. The transformer also retains insulating oil, provides cooling for the oil, and maintains itself in an upright position, however, these are not primary functions and therefore should not be listed.

In a system example, a portion of a distribution grid typically has numerous disconnect switches intended to <u>provide manual and automatic isolation/interruption of the line during both normal and abnormal conditions</u>. It is possible to identify numerous configurations of the system that could be isolated, but only the anticipated isolation/interruption scenarios should be considered when developing the list of system functions.

When defining system functions, it is not always necessary to review the function of each piece of equipment in the system since many systems have redundant equipment that serves the same function. Although the functions of the system are ultimately based on the functions of the equipment assigned to it, system functions should be identified based on the general design purposes of equipment configuration and operation.

Functional statements should be at a general performance level, and should not include the identification of specific equipment items or measurable performance standards. Equipment associated with each function is identified later in the RCM process, and specific performance standards provide no additional benefit in the RCM study. The following provides examples of appropriate and inappropriate functions.

Appropriate functional statements:

- Provide adequate DC power during normal and abnormal conditions
- Support overhead conductor in proper position
- Interrupt circuit during abnormal conditions
- Provide local and remote indications of level, temperature and pressure

Inappropriate functional statements:

- Provide adequate connections to battery terminals and maintain electrolyte level within the “safe” zone indicated on the battery cell (too specific)
- Provide support for overhead conductor capable of withstanding 100mph winds (unnecessary performance standard details)
- Interrupt circuit upon contact with vegetation (too specific)
- Provide local indications of breaker tank oil level with the float indicator, remote indication of temperature on panel C26, and remote indications of pressure at the station house (too specific)

Important Functions - After all functions are identified, a review should be made to identify which functions are so important that they must be preserved. Important functions may encompass those that would be suggested by the name of the equipment or system, or found in a brief mission statement for the equipment or system. RCM strives to preserve the operation of equipment that supports those functions deemed important. Therefore, the scope and focus of the preventive maintenance program will largely be influenced by the identification of important functions.

3.2 Summary and Review

When identifying functions the following should be considered:

- Identify functions based on the primary mission of the equipment or system
- Create functions using general, not detailed, performance statements
- Avoid including unnecessary specifics such as equipment identification and detailed performance standards
- Identify functions that are so important that they deserve to be preserved through the application of preventive maintenance resources

4

SELECTING AMONG CRITICALITY ANALYSIS METHODOLOGIES

For each equipment type or system under study, a methodology must be identified for determining criticality of equipment failure modes. The level of detail of the results, and the type of results obtained, will be directly attributable to the type of criticality analysis method employed. The following summarizes three basic methods of performing a criticality analysis: Failure Modes and Effects Analysis (FMEA), Criticality Checklist, and Programs. It should be noted that the basic principles and concepts of RCM are embodied in each of the three basic methods. The choice among the methods is one of preference and desired level of detail in the results. Since the basic principles of RCM are embodied in each, the results produced by using the methods should be relatively consistent, with differences attributable mainly to the skill of the analyst and the information on which the study is based.

For each method, a discussion is provided regarding the basic process, optional steps or process variations, and the advantages and disadvantages of the method. No attempt has been made to provide detailed instructions regarding use of the methods since that is not the intention of this guidance. For each criticality method, it is assumed that the user has already established boundaries, identified important functions to preserve and has collected basic information regarding equipment failure history.

A fourth method called Criticality Pre-Selection is also discussed. This is a streamlined approach to criticality determinations that should only be used by experienced individuals. This fourth approach follows the same basic process as the other three, but with less rigor in the documentation of the analysis results. It is for this reason that it should be used only be an RCM experienced individual.

4.1 Failure Modes and Effects Analysis (FMEA)

The terms Failure Modes and Effects Analysis implies an analysis of the effects, or consequences, of a failure mode. The process begins by selecting a function and identifying equipment failure modes that result in a loss of the function. The equipment must be from within the boundary. For example, a function of provide local indications of level could have the following equipment failure modes associated with it:

- Indicator fails to operate
- Indicator fails low
- Indicator fails high
- Indicator fails as-is

The next step of the process is to identify the effects, or consequences of the failure modes. In this case, the equipment would continue to operate with no significant effect other than to repair the faulty indicator, a minor maintenance item. Such information is noted for future reference.

Based on the consequences of failure, a relative criticality is determined. Typically, criticality is determined using one of the following scales:

- Critical; Non-critical
- Critical High, Low; and Non-critical
- Critical High, Medium, Low; and Non-critical

Additional comments are made as necessary to fully explain the criticality determination or other assumptions associated with the analysis records.

If desired, probabilities of failure for specific equipment failure modes can be documented to support the determination of criticality. Higher probabilities of failure can be considered influential in determining a failure mode to be more critical than a failure mode with a lower probability of failure.

4.2 FMEA Advantages and Disadvantages

The FMEA is the closest to the traditional methods used for criticality determinations. This method allows the user to provide more documentation regarding the consequences of failure than do other methods. Although the FMEA provides greater opportunity for documentation, the exact level of documentation is largely determined by the user.

One of the advantages of the FMEA is that the consequences of failure are qualitative and readily understandable by engineering and technical personnel. This is due, in part, to its emphasis on plain text descriptions of the consequences of failure and the ability of the analyst to include remarks for each record. Another advantage is that the documentation is sufficient to allow someone to perform a review of the analysis results with little, if any, assistance from the original evaluator.

A disadvantage of the process is that the level of documentation can be labor intensive, especially if there are a number of equipment failure modes to analyze, and description of consequences is lengthy.

4.3 The Criticality Checklist

The term Criticality Checklist implies the use of a checklist format to determine the relative criticality of equipment failure modes. The process begins by selecting a function and identifying equipment failure modes that result in a loss of the function. The equipment must be from within the boundary. For example, a function of <u>interrupt power during abnormal conditions and restore power after fault clearance</u> could have the following equipment failure modes associated with it:

- Recloser fails on interrupt
- Recloser fails to close
- Recloser fails to operate

The next step in the process is to use the checklist of statements / questions pertaining to failure consequences and to make a determination of criticality based on the applicability of the statements / questions to the consequences of each failure mode. Examples of typical statements and questions include:

<u>Example checklist questions</u>

- Is the failure expensive to repair
- Does the failure result in risk to personal safety
- Are important customers adversely affected by this failure
- Does this failure result in an extended outage

<u>Example checklist statements</u>

- Failure of this nature is intolerable
- Corrective maintenance for this failure will exceed $30,000
- More than 10,000 customers will be adversely affected by this failure
- One or more of our top 200 customers will be adversely affected by this failure

Typically, only questions or statements are used, not a mixture of both. In response to each question or statement, the user enters either a Yes / No response or a numerical response. A “yes” response is used to answer the question or indicate agreement with the statement. A “no” response is used to answer the question or disagree with the statement. Numerical responses could, for example, number between 1 and 10, with 1 indicating a strong negative response to the question or no agreement with the statement, and 10 indicating a strong positive response to the question or full agreement with the statement. If the “yes” response is given a value of 1 and a “no” response is given a value of zero, then a total score for each failure mode can be determined by adding the scores for each question/statement. In the following example, it is assumed that only three questions/statements are used.

Example failure mode studied using Yes/No responses to questions

Question 1: Does this failure…?	Answer: Yes	Score 1
Question 2: Is it likely that…?	Answer: No	Score 0
Question 3: Will high repair…?	Answer: Yes	Score 1
	Total Score: 2	

Example failure mode studied using numerical responses to statements

Statement 1: This failure creates….	Value 1	Score 1
Statement 2: The results of this….	Value 6	Score 6
Statement 3: High repair will be….	Value 4	Score 4
	Total Score: 11	

In addition to the Yes/No or numerical responses, the checklist can also be set up so that individual questions/statements have a weighted value. This weighted value can then be used to adjust the responses to each question/statement accordingly. The following illustrates how the above example would change with the addition of weighted values for each statement/question, and how this could be used to influence the total score for a failure mode.

Example failure mode studied using Yes / No responses to questions having weighted value

Question 1: Does this failure…?	Answer: Yes	Score 1	Weight Factor 3	Weighted Score 3
Question 2: Is it likely that…?	Answer: No	Score 0	Weight Factor 5	Weighted Score 0
Question 3: Will high repair…?	Answer: Yes	Score 1	Weight Factor 2	Weighted Score 2
	Total Weighted Score: 5			

Example failure mode studied using numerical responses to statements having weighted value

Statement 1: This failure creates…	Response / Score 1	Weight Factor 3	Weighted Score 3
Statement 2: The results of this….	Response / Score 6	Weight Factor 5	Weighted Score 30
Statement 3: High repair will be…	Response / Score 4	Weight Factor 2	Weighted Score 8
	Total Weighted Score: 41		

As can be seen in this example, the use of weighting factors can significantly increase the scores assigned to failure modes, thus showing more clearly the relative criticality of failure modes when a comparison is made. With the use of additional questions, a wider range of numerical response values, and a wider range of weighted values for each statement / question, the range of total scores for a failure mode can be very large. An increase in the range of total scores can be used to help differentiate between the criticality levels of equipment failure modes.

Depending on the total possible score, the user will pre-establish ranges of scores corresponding to the criticality scale previously selected. For example, assuming that there are only four statements / questions used in the checklist, a numerical scoring approach is selected with ten as the highest possible score, each question is weighted by a factor of one, and the criticality scale is Critical High, Low, and Non-critical, a set of ranges for each criticality level might look like the following:

4 statements / questions x 10 points maximum per statement / question x a weighting factor of 1 for each statement / question = 40 points possible.

00-10: Non-critical

11-25: Critical Low

26-40: Critical High

4.4 Criticality Checklist Advantages and Disadvantages

The Criticality Checklist is a variation of the FMEA with the use of checklist statements or questions instead of a narrative explanation of the failure consequences. Whereas the FMEA lists all the significant consequences of failure, the Criticality Checklist simply records, in a checklist manner, the consequences of a failure mode that match a pre-defined set of statements or questions.

One of the advantages of the Criticality Checklist is that it tends to require less time to complete than the FMEA. The checklist format allows the user to quickly annotate the applicability of a question or statement and make a criticality determination. Another advantage is that the statements and questions of the checklist are user defined. This allows the user to control their number and complexity.

Another advantage is that the checklist can be used to quantitatively rank the relative criticality of each failure mode through the use of numerical responses and weighting factors for each statement or question. The resulting quantitative criticality values can further guide the focus of maintenance resource application by showing that some equipment failure modes have higher relative significance based on the potential consequences of failure. If so desired, the application of maintenance resources can be made based on the relative criticality of an equipment item as demonstrated by the aggregate of its failure mode criticality rankings.

One of disadvantages of the Criticality Checklist is that it may be difficult to make a match in every case with the pre-defined criticality statements or questions. This could require lengthy remarks to be added by the evaluator to fully explain the consequences for a given failure mode. Another disadvantage is that the statements or questions must be sufficiently generic so that they can be used for all equipment and systems. If the statements or questions are not identical, then consistency in criticality rankings between and among equipment and systems will erode.

4.5 Programs

The term "Programs," implies an analysis of maintenance activities organized to promote the efficient conduct of tests, inspections and other routine activities associated with: 1) equipment of multiple types serving a common purpose; 2) equipment of similar types requiring the same general type of maintenance; and, 3) utility rights of way. Typical examples of maintenance programs include: infrared monitoring; vegetation management; wood pole inspections; and, cable/conductor inspections.

The RCM approach for Programs is very similar to the FMEA described above, except that it is intended to involve representative equipment sets, instead of unique equipment items. This is true because: 1) a program of maintenance is applied to a general area or set of equipment items, and 2) a maintenance program is rarely tracked and accounted for against a specific equipment listing. Since an inspection program such as infrared may include examination of multiple equipment types within a geographical area, the approach also allows the analysis of these multiple equipment types.

As with the FMEA, a function statement serves as the guide for identifying equipment failure modes that result in a loss of the function. The equipment sets selected for failure mode evaluation must be from within the program boundary. For each failure mode associated with failing a function, the consequences of failure are determined. Based on the consequences of failure, a relative criticality is determined. Typically, criticality is determined using one of the following scales:

- Critical; Non-critical
- Critical High, Low; and Non-critical
- Critical High, Medium, Low; and Non-critical

Additional comments are made as necessary to fully explain the criticality determination or other assumptions associated with the analysis records.

4.6 Advantages and Disadvantages of Programs

The Programs approach to criticality determination closely resembles traditional methods used for criticality determinations. This method allows the user to provide more documentation regarding the consequences of failure than do other methods. Although greater opportunity exits for documentation, the exact level of documentation is largely determined by the user.

One of the advantages of Programs is that the consequences of failure are qualitative and readily understandable by engineering and technical personnel. This is due, in part, to its emphasis on plain text descriptions of the consequences of failure and the ability of the analyst to include remarks for each record. Another advantage is that the documentation is sufficient to allow someone to perform a review of the analysis results with little, if any, assistance from the original evaluator.

A disadvantage of the process is that the level of documentation can be labor intensive, especially if there are a number of equipment failure modes to analyze, and description of consequences are lengthy.

4.7 Criticality Pre-Selection

The last method of criticality determination is Pre-Selection. This is a streamlined approach that allows the user to provide less documentation of the criticality determinations. The term Criticality Pre-Selection implies that the criticality determination is made ahead of the normal course of criticality determinations. The process is intended to be used in situations where the relative criticality of particular failure modes for certain equipment can be determined without question.

The process involves simply selecting an equipment failure mode, making a determination of criticality and providing a justification for the “pre-selection” of criticality. The justification need not be elaborate, but should be suitable for defending the level of criticality selected. Once a failure mode for an equipment item has been “pre-selected”, it is not processed again using the other criticality analysis methods.

4.8 Advantages and Disadvantages of Criticality Pre-Selection

One of the advantages of the Criticality Pre-Selection method is the speed with which portions of an analysis can be completed. The purpose of the streamlined method is to avoid time spent in analysis and documentation for equipment items that should be “no brainers.” It is especially useful for “pre-selecting” non-critical items.

Another advantage is that it is intended to be complementary to both the FMEA and Criticality Checklist methods. It can serves as a means to lighten the analysis load where there is not question regarding the relative criticality of certain equipment failure modes.

One of the major disadvantages of the method is that there are many opportunities for error if used by inexperienced personnel. Another disadvantage is that the results will not have a corresponding level of consistency with the FMEA and Criticality Checklist methods.

4.9 Summary and Review

In selecting a criticality evaluation method, the following should be considered:

- The two basic methods available are the FMEA and the Criticality Checklist
- The FMEA is similar to the original method employed in the airline industry, while the Criticality Checklist is a variation on the FMEA intended to add efficiency to the process
- The Criticality Checklist offers the opportunity to “quantify” the relative criticality of each failure mode
- In selecting an evaluation method, the advantages and disadvantages must be reviewed to determine which method will be most appropriate to apply
- Criticality Pre-Selection is a method that is compatible with the FMEA and Criticality Checklist that can be applied, by experienced users, in cases where the relative criticality of an equipment failure mode is not in question

5

UNDERSTANDING EQUIPMENT FAILURE MODES

The initial step in any criticality analysis is the identification of failure modes associated with loss of equipment or system function. Failure modes describe in general terms how equipment fails. It is important to understand equipment failure modes since this is one of the key foundations of the RCM process. The following discusses important issues associated with equipment failure modes.

5.1 Failure Modes

Failure modes describe, in a general way, the manner of equipment failure. Failure modes describe how equipment fails without offering a reason. Failure modes are characterized at a level so general that it is impossible to prescribe an appropriate maintenance task without additional information regarding the cause of failure. For example, a switch may have several failure modes including: fails to open; and, fails to close. These are general descriptions of how the switch fails, but are so general that a maintenance task cannot be prescribed to address the failure.

It is important to note that a general failure mode can represent many specific examples of the failure, yet be characterized in a general manner. For example, the failure mode of fails to close can represent many specific failure scenarios. Starting with the switch in the open position, and given a signal to close, the switch can exhibit fails to close in the following ways:

- Fails to close at all
- Starts to close but stops in a partly closed position
- Fails to fully close
- Closes but makes inadequate contact
- Closes, but won't stay closed

In the RCM process, it isn't important that the exact manner of failure be captured in the failure mode description. Regardless of the exact manner of failure, in each of the above examples, the switch fails to close. Therefore in the mind of the RCM analyst, the failure mode of fails to close means: fails to close in a manner as designed, intended or expected.

5.2 Dominant Failure Modes

In the RCM process, the only concern is with dominant failure modes. The term "dominant" means reasonably likely. It does not mean the single most likely, rather it means all failure modes that are reasonably likely to occur. RCM is only concerned about dominant modes of failure because it is intended to build a defense against only those modes of failure that are likely to be experienced. If maintenance resources are used to defend against modes of failure that are not likely, then resources are being wasted.

A good technique for identifying dominant failure modes involves imagining that no preventive maintenance is performed on the equipment and then postulating all the ways that it would be likely to fail. In order to develop a complete set of dominant failure modes, the analyst must "set aside" each identified mode of failure so that others can be postulated. For example, after assuming no preventive maintenance on the equipment and identifying the first dominant mode of failure, the analyst must imagine that the first mode of failure didn't occur and then consider what might happen next. The same thought process is followed for each additional failure mode identified until no additional reasonable modes of failure can be postulated.

Examples of failure modes for a battery include:

- No output
- Low output
- External leak
- Reduced capacity

It is possible to see that all of these failure modes could be dominant. If there is a non-dominant failure mode in the listing, it is most likely the external leak. Unless there is a manufacturing defect, improper handling, poor installation, or other external source of trauma to the battery case, it is not likely that it will leak during its useful life. The determination of dominant failure modes is left up to the judgment of the analyst.

5.3 Equipment Failure Modes Data Reference

To support the completion of RCM studies, the user is provided with a failure mode data reference. A suggested listing of failure modes is located in Appendix B, Equipment Failure Modes, Failure Causes and PM Task References. The failure modes provided are associated with power delivery equipment types.

5.4 Summary and Review

When identifying equipment failure modes, the following should be considered:

- Failure modes are general descriptions of how the equipment fails and not why
- Dominant failure modes are the only failure modes of concern
- Dominant failure modes should be credible and reasonably likely

6

FAILURE EFFECTS/CONSEQUENCES

To determine the criticality of an equipment failure mode, the effects of failure must be understood. Both the FMEA and the Criticality Checklist document the effects of failure and use this information in making criticality determinations. Essentially, the analyst is making a judgment regarding the criticality of a failure mode based on the severity of its consequences. In making these determinations, the analyst must consider various general categories of effects and determine the severity of each. These general categories can include:

- Cost of labor to repair or replace
- Cost of replacement equipment
- Potential personnel hazard
- Interruption to customers
- Loss of revenue
- Replacement power costs
- Adverse publicity
- Environment impact
- Fines and penalties

Regardless of the specific RCM method, knowledge of the effects of failure is essential to making determinations of equipment failure mode criticality. This knowledge comes from many sources including the analyst's own specific experience, interviews with knowledgeable personnel, equipment walk downs, and information such as technical diagrams and system descriptions.

It is important for the analyst to consider all aspects of equipment failure consequences and severity to ensure that a proper determination of criticality is made. Typically, failure consequences are viewed locally, within the boundary of the study, and external to the boundary of the study. For example, leaking oil is a <u>local</u> effect since its impact is experienced at the equipment; a loss of station service is an effect <u>within the boundary</u>, if the boundary is defined as a substation; and, a loss of service to customers is an effect <u>external to the boundary</u>. The three categories of effects serve only to remind the analyst that the consequences of failure may be found locally at the equipment, within the boundaries of the study, or external to the boundaries of the equipment or system under study.

6.1 Equipment Redundancy Influences Failure Effects

When considering the broader operational effects of an equipment failure mode, the presence of redundant or backup equipment warrants special attention. In some cases, credit can be taken for redundancy in determining failure effects, in other cases it is not advisable. Refer to Sections 7.3 and 9.7 for a discussion of how the issue of redundancy should be considered when determining consequences of failure and making criticality determinations.

6.2 Failure Effects Data Reference

Although the determination of failure effects is dependent upon the failure mode and application of the equipment, some general failure consequences can be suggested for consideration. Table 6-1 provides a suggested "pick list" of failure effects and provides a starting point for specifying the consequences of failure. For organizational purposes, the table is divided into local, within the boundary, and external to the boundary categories. Some intentional overlapping of consequences exist between the categories since the scope of study can vary widely.

Table 6-1

Distinguishing Categories of Failure Effects

Local Effects	Within the Boundary Effects	External to the Boundary Effects
Air/Gas Leak	Backup System/Equipment Initiates	Adverse Publicity/Regulatory Interest
Alarm or Annunciation	Damage to Equipment	Brown/Black Out
Contaminated Insulation	Extended Equipment/System Outage	Customer Economic Loss
Damage to Nearby Equipment	High Repair Costs	Customer Outage
Environmental Contamination	Loss of Backup Capacity	Economic Dispatch
Fire/Explosion	Loss of Cooling/Heat Removal	Endangerment of the Public/Environment
Loss of Alarm/Annunciation	Loss of Intertie	Fire/Explosion

Local Effects	Within the Boundary Effects	External to the Boundary Effects
Loss or Incorrect Indication	Loss of Material / Equipment	Grid Transient / Instability
None	Loss of Protection	High Repair Costs
Oil Leak	Loss of Station Control	Loss of Data Analysis Capability
Personnel Hazard	Loss of Switching Capability / Flexibility	Loss of Generation
Reduced Equipment Life	Loss of System Output / Function	Loss of Generation Control
Vacuum Leak	Loss of Test Capability	Loss of Intertie
	Loss or Incorrect Alarm / Indication	Loss of Protection
	Maintenance Inconvenience	Loss of Station Control
	None	Maintenance Inconvenience
	Operational Inconvenience	None
	Reduced Equipment Life	Operational Inconvenience
	Reduced Power Quality	Reduced Power Quality
	System Fails to Initiate	Reduced Power Scheduling
	System / Equipment Fails to Trip	Reduced Revenues
		Reduced System Integrity / Stability

6.3 Summary and Review

When identifying failure effects, the following should be considered:

- The effects / consequences of failure modes determine the relative criticality of the failure modes
- All consequences of a failure mode, regardless of location or nature, should be considered in determining its criticality

7

IDENTIFICATION OF CRITICAL EQUIPMENT FAILURE MODES

The final part of the criticality analysis is determining the relative criticality of equipment failure modes. As a general rule, critical failure modes are carried further in the RCM process. The intention is to attempt to find cost-effective preventive tasks so that the consequences of the critical failure modes can be avoided. Non-critical failure modes are not processed any further since their consequences are so minor that the application of preventive maintenance is not warranted.

The term critical refers to failure modes of an equipment item, and <u>not</u> the equipment item itself. The reason for this distinction is to help focus maintenance resources on the failure mode(s) of concern and not on the equipment item in general. The other reason for this distinction is that equipment typically has both critical and non-critical failure modes. For example, a switch failing to reclose may create a maintenance inconvenience and be deemed non-critical. The same switch failing to interrupt will likely cause extensive damage to itself or other items in the power delivery system, and therefore be deemed critical. Since the switch cannot be critical and non-critical at the same time, the criticality determination is associated with the failure mode.

7.1 Failure Consequences

Equipment criticality can be based on failure consequences alone. In making this determination, particular attention is focused on failure effects associated with safety, damage to equipment, high cost of repair or replacement, and extended outages for a circuit. Essentially, the analyst is determining the criticality of the failure based on the severity of the consequences. A good rule to use when determining equipment criticality is: any consequence of a single equipment failure mode, that is considered unacceptable, should be viewed as a critical failure mode.

7.2 Other Factors for Criticality Determinations

In addition to qualitative engineering judgment and management discretion, the use of reliability data can play a role in determining critical equipment failure modes. In the case of management discretion, certain types of equipment failures could be pre-designated as critical to ensure that they will receive consideration for the application of maintenance. It can be expected that equipment failure modes that cause forced outages, high replacement costs or high repair costs would be pre-designated as critical.

In some cases, frequency of failure can influence the determination of criticality. Failure frequency can be identified through the review of failure history reporting and trending. This information can be used to show frequent or recurring failures. Regardless of the consequences of failure, the frequency of corrective maintenance actions for an equipment item or type may be severe enough to warrant the equipment failures as critical. In this way, the equipment failure mode will be processed in an attempt to identify cost-effective tasks to address the failures of concern. The following table suggests a method of reconciling the severity of failure consequences with the frequency of failure.

Failure Severity	Failure Frequency	Criticality
High	High	Very High
High	Medium	High
High	Low	Medium
High	None (Non-Dominant)	N/A
Medium	High	High
Medium	Medium	Medium
Medium	Low	Low
Medium	None (Non-Dominant)	N/A

Failure Severity	Failure Frequency	Criticality
Low	High	Medium
Low	Medium	Low
Low	Low	Non-Critical
Low	None (Non-Dominant)	N / A
None	High	Non-Critical
None	Medium	Non-Critical
None	Low	Non-Critical
None	None (Non-Dominant)	N / A

Although the table represents a qualitative approach to determining criticality, it is possible that a quantitative approach could also be used. In this case, all failure consequences might be expressed in dollars and the frequency of failure might be expressed in a failure rate. The difficulties involved with this type of a quantitative approach are two fold: 1) quantifying failure effects and failure rates is time consuming; and, 2) there is a high level of uncertainty as to the validity of any numerical value. For these reasons, the use of quantitative data is not strongly suggested.

7.3 Determining Criticality of Redundant Equipment

Equipment redundancy is typically built into various equipment, circuits and systems to ensure that important functions will not be compromised as a result of single equipment failure. Efforts associated with optimizing the preventive maintenance program should not undermine the benefits of redundancy in equipment configuration. The objective of RCM is not to challenge redundant features but rather to take credit for them when it can be technically justified.

Up to this point, the guidance regarding identification of critical equipment failure modes assumes that equipment is examined one at a time without consideration of redundant or back-up features supporting the same function. With redundancy, there is an opportunity to identify equipment failure modes as non-critical because of the presence of redundant or backup features that mitigate the consequences of failure.

There are several issues that must be explored to determine whether redundancy in equipment configuration can be used advantageously in making criticality determinations.

Without careful consideration in this area, equipment in a redundant or back-up configuration could easily be deemed non-critical because of its single failure tolerance. Following this logic, and the standard approach to RCM, all redundant equipment could be deemed non-critical and consequently receive no consideration in the maintenance task selection process. This equipment would ultimately fail due to the lack of preventive maintenance attention, and the reliability of the equipment configuration suffers because of the elimination of redundancy created by the failures.

The issue facing the analyst is how to appropriately take advantage of the presence of redundant and back-up equipment without unnecessarily jeopardizing the reliability of the equipment configuration from which the advantage is obtained. There are two keys to addressing this issue: 1) awareness of the loss of redundancy; and, 2) timely reinstatement of redundancy after failure. Both issues are simple to understand and address in the RCM process.

It is essential that personnel be aware of a failure of a redundant configuration so that appropriate action can be taken to restore it. Second, it is essential that the failed redundancy can be quickly addressed so that the period of time without redundancy is brief, thus reducing risk to an acceptable level. Figure 7-1 depicts a method that can be followed in addressing this issue.

Regarding the issue of awareness, credit should be taken for normal checks and observations made by personnel at the equipment locations to find apparent failures as well as alarms and other indications of equipment failure that would be evident to the operating crew. It is important that personnel in a position to correct the problem be made aware of the problem in a timely manner.

Regarding the issue of restoration of redundancy, it is important that the failure mode in question be one that can be addressed quickly so that the period of time vulnerable to a single failure is small. A determination must be made regarding the acceptable time period for repair. In establishing this time period, consideration must be given to the availability of spare parts, availability of technical expertise to repair failed equipment, the nature of the repair or replacement activity.

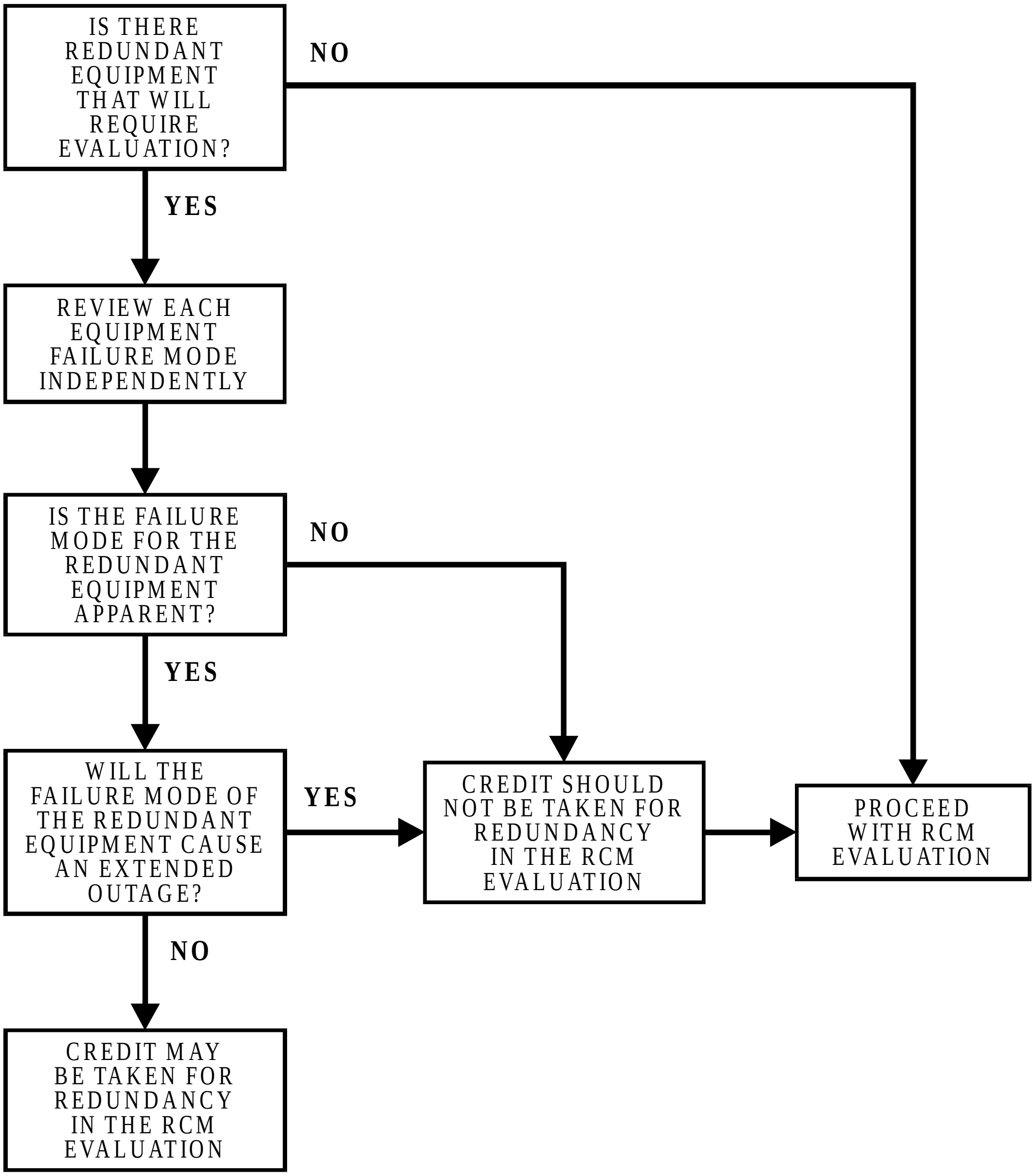

IS THERE REDUNDANT EQUIPMENT THAT WILL REQUIRE EVALUATION?
NO
YES
REVIEW EACH EQUIPMENT FAILURE MODE INDEPENDENTLY
IS THE FAILURE MODE FOR THE REDUNDANT EQUIPMENT APPARENT?
NO
YES
WILL THE FAILURE MODE OF THE REDUNDANT EQUIPMENT CAUSE AN EXTENDED OUTAGE?
YES
CREDIT SHOULD NOT BE TAKEN FOR REDUNDANCY IN THE RCM EVALUATION
PROCEED WITH RCM EVALUATION
NO
CREDIT MAY BE TAKEN FOR REDUNDANCY IN THE RCM EVALUATION

Figure 7-1

7.4 Summary and Review

When determining the criticality of an equipment failure mode, the following must be considered:

- Criticality is assigned to an equipment failure mode, and <u>not</u> to the equipment item alone
- Consequences of failure can be used alone to identify critical equipment failure modes, especially when external effects are severe
- Failure consequences and frequency of failure can be used in combination to determine criticality based on the relative impact of the failure in view of its likelihood of occurrence
- Management discretion can play a role in determining equipment criticality
- Credit can be taken for redundancy in the process of identifying critical equipment failure modes, only if the equipment failure is apparent and not likely to create extended repair or outage time

8

UNDERSTANDING EQUIPMENT FAILURE CAUSES

The initial step in any maintenance task selection process is the identification of failure causes associated with critical equipment failure modes. Failure causes describe in general terms <u>why</u> equipment fails. It is important to understand equipment failure causes since they are the key foundation to the development of cost-effective maintenance tasks. The following discusses important issues associated with equipment failure causes.

8.1 Failure Causes

Failure causes describe, in a general way, the reason for equipment failure modes. Failure causes describe <u>why</u> equipment fails. Failure causes are characterized at a level specific enough to allow an appropriate maintenance task to be prescribed for performance by an operations or maintenance technician. For example, a breaker failing to interrupt may have several failure causes including: linkage binding, degraded lubrication, trip coil failure, and low insulation level. These are specific reasons <u>why</u> the breaker failed to interrupt. The specific nature of the failure cause descriptions allow maintenance tasks to be prescribed to address these situations.

It is important to note that a failure cause can represent several specific reasons for an equipment failure mode. For example, the failure cause of <u>degraded lubricant</u> can represent:

- Worn out lubricant
- Coagulated lubricant
- Dirty lubricant
- Hardened lubricant

In the RCM process, it is important that the detailed reason for failure be captured to the extent that it influences the task that would be performed. Regardless of the exact nature of the lubricant degradation, a task of <u>clean and replace lubricant</u> would be appropriate to address any of the variations of degraded lubricant noted above. In the event that a specific failure cause could lead to the selection of a different task, or a different task frequency, then the specific cause should be further broken down into more descriptive detail.

8.2 Dominant Failure Causes

In the RCM process, the only concern is with dominant failure causes. The term "dominant" means reasonably likely. It does not mean the single most likely, rather it means all failure causes that are reasonably likely to occur. RCM is only concerned about dominant causes of failure because it is intended to build a defense against only those causes of failure that are likely to be experienced. If maintenance resources are used to defend against causes of failure that are not likely, then resources are being wasted.

A good technique for identifying dominant failure causes involves imagining that no preventive maintenance is performed on the equipment and then postulating all the reasons that the failure mode would occur. In order to develop a complete set of dominant failure causes, the analyst must "set aside" each identified cause of failure so that others can be postulated. For example, for each critical failure mode, the analyst would assume no preventive maintenance is being performed and postulate the first dominant cause of failure. Then analyst must then imagine that the first cause of failure didn't occur and then consider what might happen next. The same thought process is followed for each additional failure cause until no additional reasonable causes of failure can be postulated.

Examples of failure causes for a battery with a critical failure mode of low output include:

- Corrosion
- Internal fault
- Internal component failure
- Loose connection
- Low electrolyte level

It is possible to see that all of these failure causes could be dominant. If there is a non-dominant failure mode in the listing, it is most likely the internal component failure. Unless there is a manufacturing defect, improper handling, poor installation, or other external source of trauma to the battery, it is not likely that it will experience an internal component failure during its useful life. The determination of dominant failure causes is left up to the judgment of the analyst.

8.3 Failure Cause Contributors

There are a number of contributors to failure that should not be overlooked when identifying dominant causes of equipment failure. Using the degraded lubricant failure cause example above when analyzing a "Fails to interrupt" failure mode for a

138kV oil circuit breaker, it is possible that a breaker cabinet heater failure could result in a hardened or coagulated lubricant. In this case, the heater failure is an indirect contributor of “Fails to interrupt,” but nevertheless should be considered as a dominant failure cause of the equipment failure mode. A separate heater operability test would be required to address this separate cause of failure.

8.4 Root Causes of Equipment Failure

RCM is generally not concerned about the root cause of equipment failures, but rather the immediate or proximate cause of equipment failure. This is because it is usually not possible to perform PM on a root cause of failure. Root causes are typically at a level that is much more detailed than that at which the maintenance technician works. For example, an aeronautical warning sphere may lose its appearance due to the effects of exposure to the environment. The root cause of failure is exposure to the sun’s ultraviolet rays. The maintenance technician cannot perform a maintenance task to reduce the exposure of the device to the sun, however, a task can be performed to repaint or replace the sphere to provide the proper appearance to aircraft pilots. When identifying causes, the evaluator must identify causes at a level that the maintenance program can address.

8.5 Inappropriate Failure Causes

As a general rule, the only failure causes that are appropriate for consideration by RCM are those that can be effectively addressed by the application of maintenance program resources. Design deficiencies, errors in maintenance practices, inadequate training, poor installation and improper operation are all inappropriate for analysis consideration in an RCM study since no technical change to a preventive maintenance procedure can be effective in addressing these problem areas. Design deficiencies need redesign action, errors in maintenance is a human factors concern, inadequate training is a training department issue, poor installation needs to be addressed through reinstallation or modification efforts, and improper operation of equipment needs to be addressed through changes in operation.

Figure 8-1 provides a process by which the failure mode and cause description can be reviewed to determine whether it is appropriate to proceed with maintenance task selection.

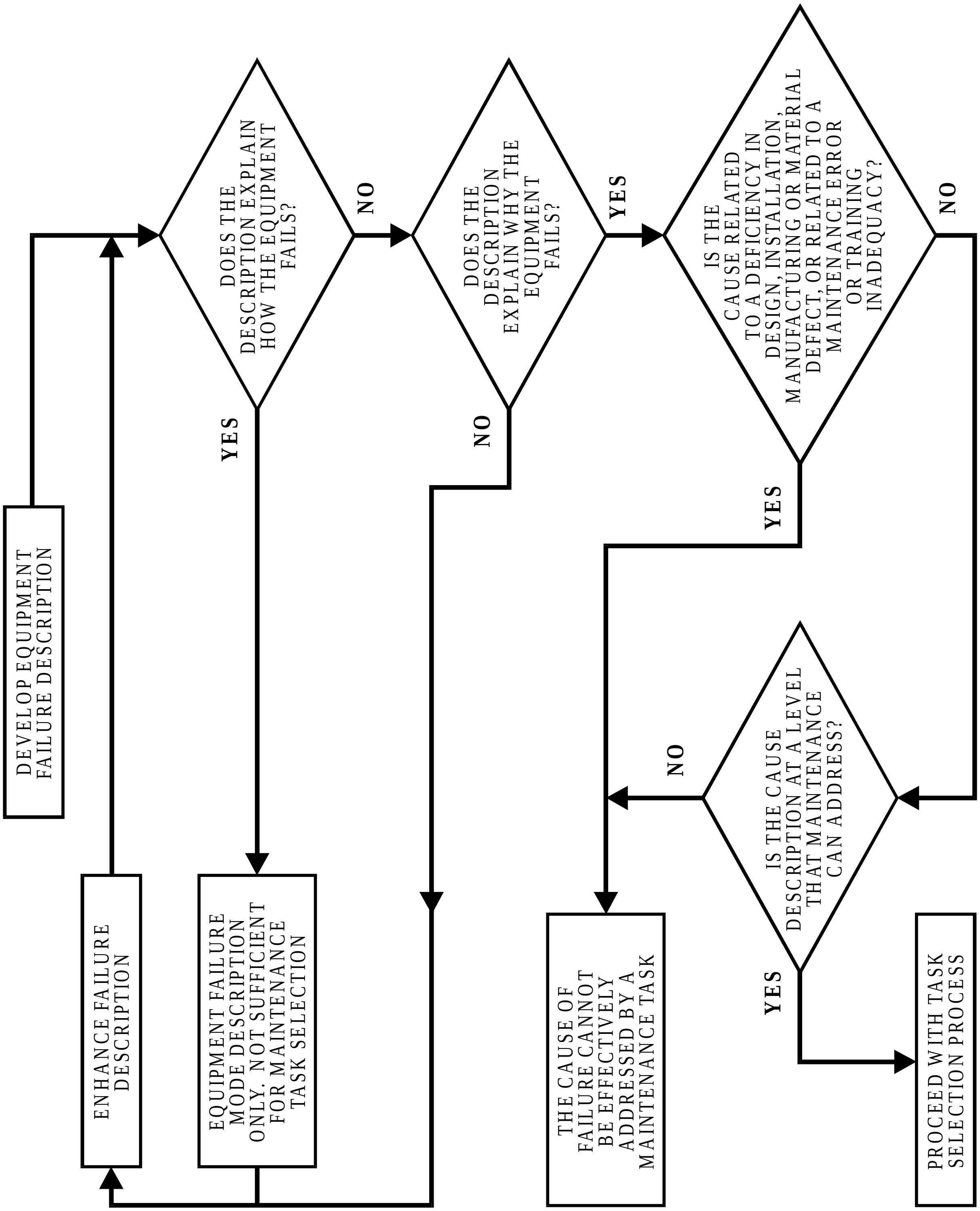

DEVELOP EQUIPMENT FAILURE DESCRIPTION
DOES THE DESCRIPTION EXPLAIN HOW THE EQUIPMENT FAILS?
YES
NO
EQUIPMENT FAILURE MODE DESCRIPTION ONLY. NOT SUFFICIENT FOR MAINTENANCE TASK SELECTION
ENHANCE FAILURE DESCRIPTION
DOES THE DESCRIPTION EXPLAIN WHY THE EQUIPMENT FAILS?
NO
YES
IS THE CAUSE RELATED TO A DEFICIENCY IN DESIGN, INSTALLATION, MANUFACTURING OR MATERIAL DEFECT, OR RELATED TO A MAINTENANCE ERROR OR TRAINING INADEQUACY?
YES
NO
IS THE CAUSE DESCRIPTION AT A LEVEL THAT MAINTENANCE CAN ADDRESS?
NO
YES
THE CAUSE OF FAILURE CANNOT BE EFFECTIVELY ADDRESSED BY A MAINTENANCE TASK
PROCEED WITH TASK SELECTION PROCESS

Figure 8-1

8.6 Equipment Failure Causes Data Reference

To support the completion of RCM studies, the user is provided with a failure cause data reference. A suggested listing of failure causes is located in Appendix B, Equipment Failure Modes, Failure Causes and PM Task References. The failure causes provided are associated with specific failure modes of power delivery equipment types.

8.7 Summary and Review

The following should be considered when developing failure causes:

- Causes of failure are why a failure mode occurs, characterized at a level that can be addressed by an operator or maintenance technician
- Indirect causes of failure must be carefully considered to avoid overlooking subtle, yet possible contributors to equipment failure
- RCM is only concerned with failure causes that are considered to be dominant
- It is inappropriate to identify a root cause of equipment failure or other causes that are not properly addressed by a maintenance technician

9

MAINTENANCE TASK SELECTION

Maintenance task selection involves identification of appropriate and cost-effective maintenance tasks to address causes of equipment failure. For each task selected, a frequency or other triggers for task performance is also identified. The process involves a structured decision logic intended to promote consistent selection of maintenance tasks to eliminate or greatly reduce the likelihood of failure. During the process, the analyst gives consideration to a wide range of task options including condition monitoring (predictive / diagnostic), time-directed (routine preventive), design changes (to eliminate unpreventable failures with consequences that cannot be tolerated), failure finding (tests and inspections), and run-to-failure (corrective maintenance). The process also allows the analyst to suggest minor changes in design to make maintenance tasks possible or more cost-effective than they would be absent of the design change.

During the task selection process, each cause of failure is addressed independently, without concern for the tasks or frequencies selected for other causes of equipment failure. The process is not intended to be a task scheduling and planning tool, but simply a means of selecting the most cost-effective task and frequency. Coordination between tasks is accomplished as part of the task comparison and implementation planning step of the overall evaluation process.

Figure 9-1 presents a method for distinguishing between maintenance task options. Each option represents a different task type. Although it is important for an analyst to recognize the difference between task types, it is far more important that the most cost-effective task be selected, regardless of the type.

Figure 9-2a and 9-2b presents the simplified decision logic for selecting between maintenance task options and design change alternatives. This is the preferred method of task selection for application to power delivery equipment. Circled letter designators on the diagram help tie in the discussion in the remaining part of this section with specific elements of the simplified decision logic. As shown in the decision logic, for each cause the analyst first attempts to identify a condition monitoring (predictive / diagnostic) task that is cost-effective. If none can be identified, then an attempt is made to select a time-directed (routine preventive) task. If neither a condition monitoring or time-directed task is cost-effective, then the analyst must assume that the failure will occur. Therefore the consequences of the associated failure mode will be experienced.

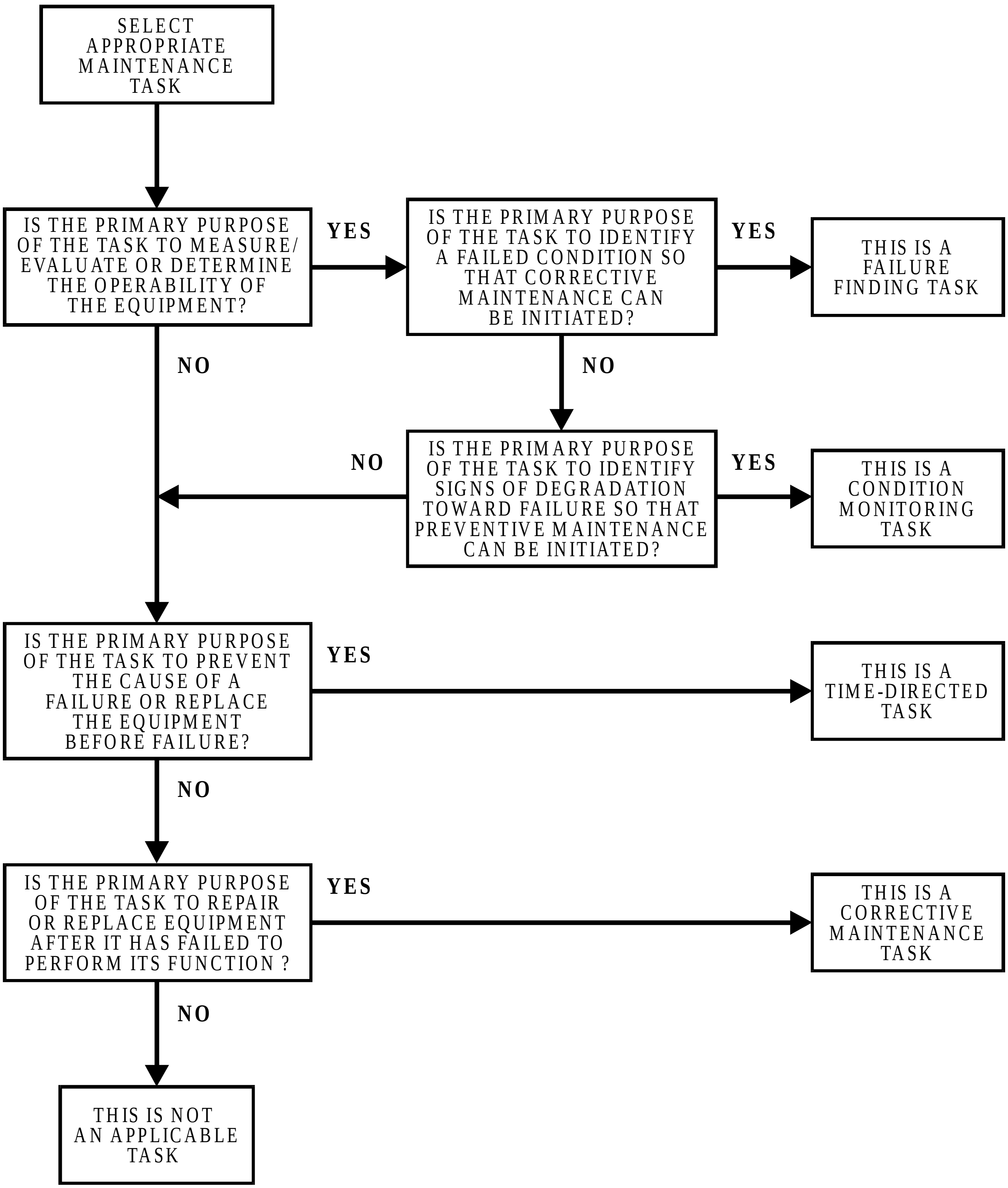

SELECT APPROPRIATE MAINTENANCE TASK
IS THE PRIMARY PURPOSE OF THE TASK TO MEASURE/ EVALUATE OR DETERMINE THE OPERABILITY OF THE EQUIPMENT?
YES
IS THE PRIMARY PURPOSE OF THE TASK TO IDENTIFY A FAILED CONDITION SO THAT CORRECTIVE MAINTENANCE CAN BE INITIATED?
YES
THIS IS A FAILURE FINDING TASK
NO
NO
NO
IS THE PRIMARY PURPOSE OF THE TASK TO IDENTIFY SIGNS OF DEGRADATION TOWARD FAILURE SO THAT PREVENTIVE MAINTENANCE CAN BE INITIATED?
YES
THIS IS A CONDITION MONITORING TASK
IS THE PRIMARY PURPOSE OF THE TASK TO PREVENT THE CAUSE OF A FAILURE OR REPLACE THE EQUIPMENT BEFORE FAILURE?
YES
THIS IS A TIME-DIRECTED TASK
NO
IS THE PRIMARY PURPOSE OF THE TASK TO REPAIR OR REPLACE EQUIPMENT AFTER IT HAS FAILED TO PERFORM ITS FUNCTION ?
YES
THIS IS A CORRECTIVE MAINTENANCE TASK
NO
THIS IS NOT AN APPLICABLE TASK

Figure 9-1

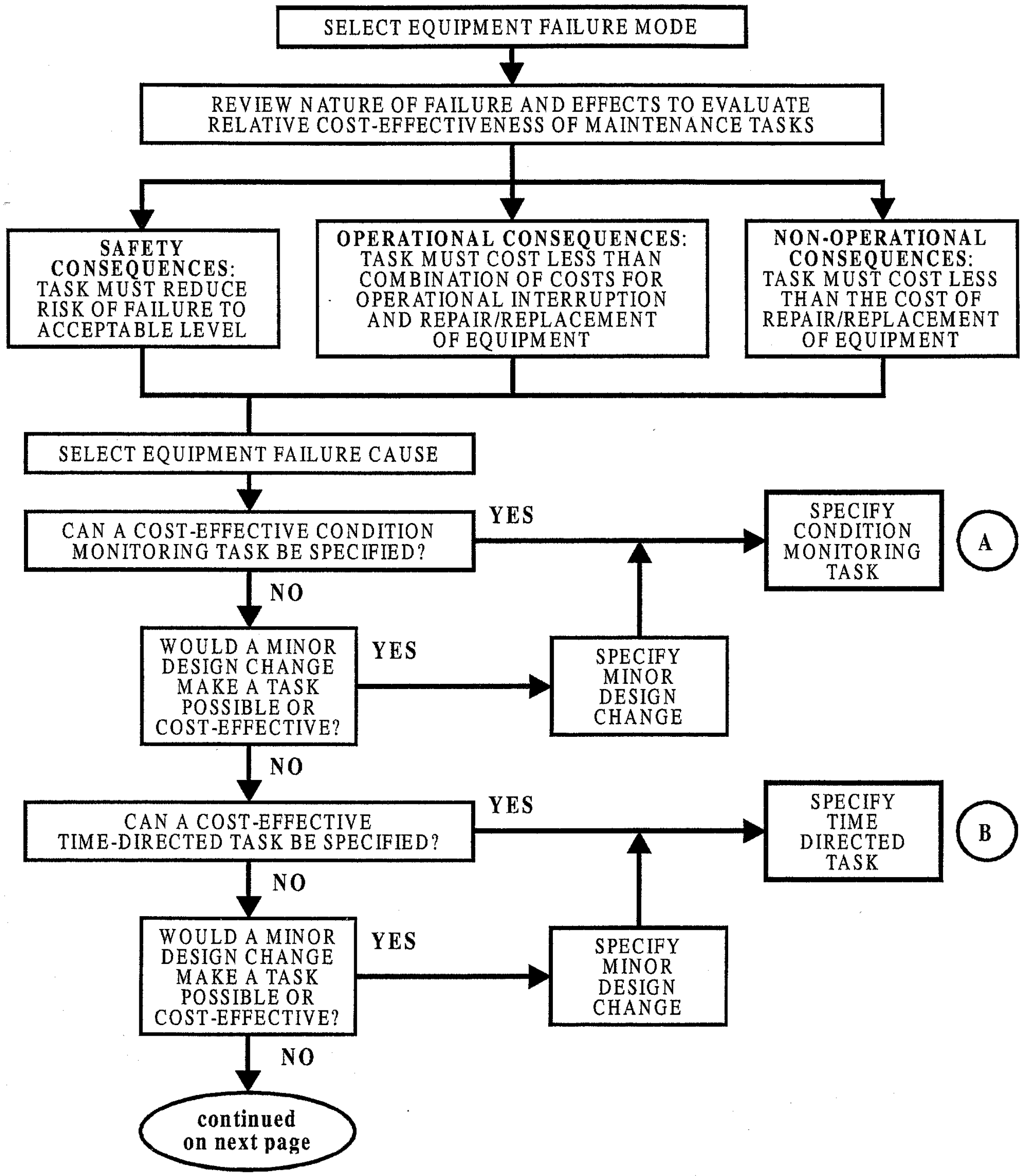

SELECT EQUIPMENT FAILURE MODE
REVIEW NATURE OF FAILURE AND EFFECTS TO EVALUATE RELATIVE COST-EFFECTIVENESS OF MAINTENANCE TASKS
SAFETY CONSEQUENCES: TASK MUST REDUCE RISK OF FAILURE TO ACCEPTABLE LEVEL
OPERATIONAL CONSEQUENCES: TASK MUST COST LESS THAN COMBINATION OF COSTS FOR OPERATIONAL INTERRUPTION AND REPAIR/REPLACEMENT OF EQUIPMENT
NON-OPERATIONAL CONSEQUENCES: TASK MUST COST LESS THAN THE COST OF REPAIR/REPLACEMENT OF EQUIPMENT
SELECT EQUIPMENT FAILURE CAUSE
CAN A COST-EFFECTIVE CONDITION MONITORING TASK BE SPECIFIED?
YES
SPECIFY CONDITION MONITORING TASK
A
NO
WOULD A MINOR DESIGN CHANGE MAKE A TASK POSSIBLE OR COST-EFFECTIVE?
YES
SPECIFY MINOR DESIGN CHANGE
NO
CAN A COST-EFFECTIVE TIME-DIRECTED TASK BE SPECIFIED?
YES
SPECIFY TIME DIRECTED TASK
B
NO
WOULD A MINOR DESIGN CHANGE MAKE A TASK POSSIBLE OR COST-EFFECTIVE?
YES
SPECIFY MINOR DESIGN CHANGE
NO
continued on next page

Figure 9-2a

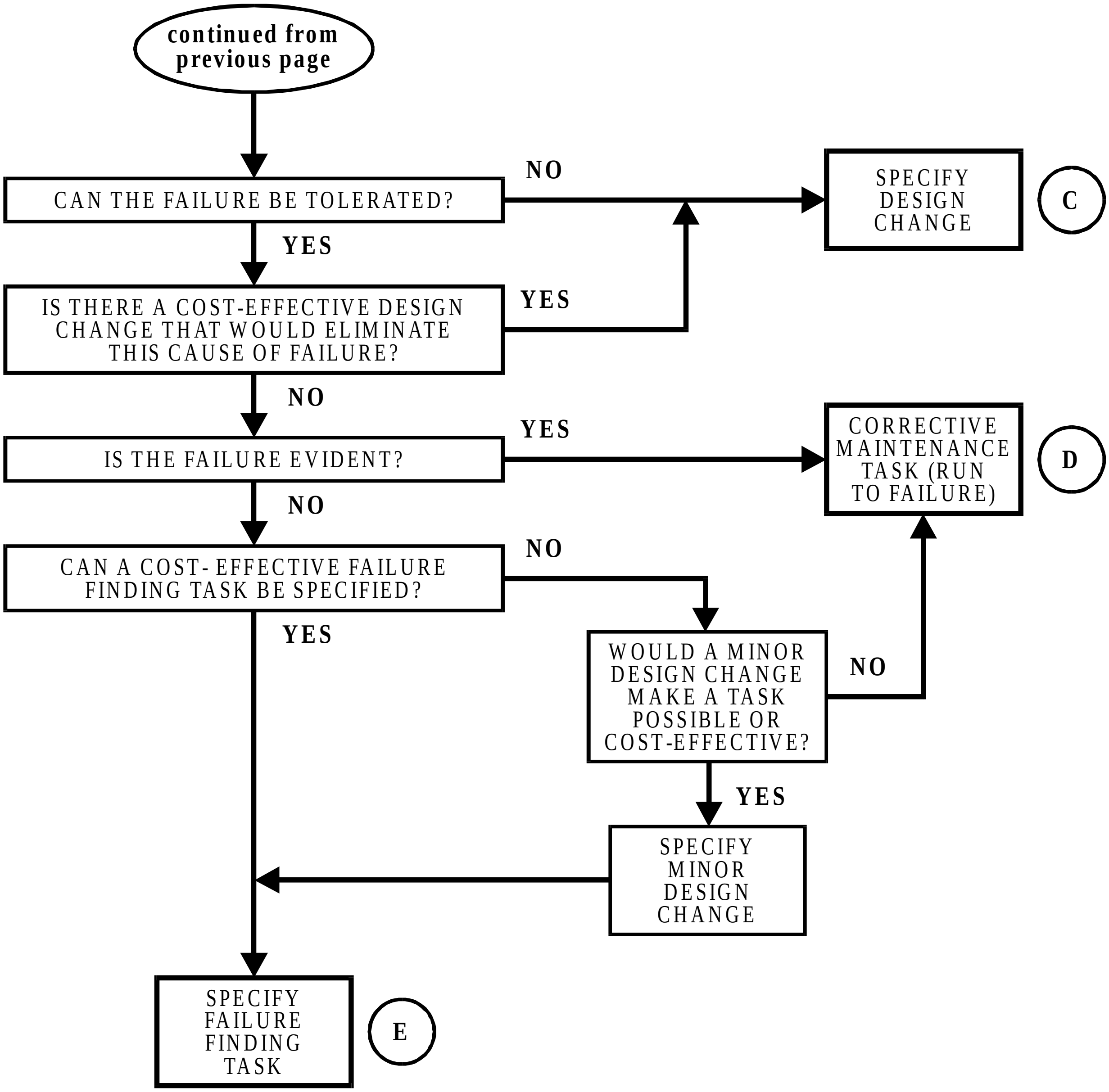

continued from previous page
CAN THE FAILURE BE TOLERATED?
NO
SPECIFY DESIGN CHANGE
C
YES
IS THERE A COST-EFFECTIVE DESIGN CHANGE THAT WOULD ELIMINATE THIS CAUSE OF FAILURE?
YES
NO
IS THE FAILURE EVIDENT?
YES
CORRECTIVE MAINTENANCE TASK (RUN TO FAILURE)
D
NO
CAN A COST- EFFECTIVE FAILURE FINDING TASK BE SPECIFIED?
NO
YES
WOULD A MINOR DESIGN CHANGE MAKE A TASK POSSIBLE OR COST-EFFECTIVE?
NO
YES
SPECIFY MINOR DESIGN CHANGE
SPECIFY FAILURE FINDING TASK
E

Figure 9-2b

If the consequences are not tolerable, a design change must be made. If the consequences are tolerable, then the equipment is allowed to fail (corrective maintenance) if the failure is evident to the operating crew. If the failure is not evident to the operating crew, a failure finding (test or inspection) task is selected to find the failure.

Figures 9-3a - 9-3c shows the traditional task selection logic that originated in the air transport industry. The traditional task selection logic is included here for completeness, but is not the preferred method because it is not specifically suited for power delivery applications, and it has added complexity that provides no additional value. It should be noted that both methods provide the user with essentially the same results.

9.1 Applicable and Cost-effective Tasks

In this step of the RCM process, the analyst is striving to select the most cost-effective maintenance task(s) to address each cause of an equipment critical failure mode. A cost-effective task is one that addresses the cause of failure, in a technically correct manner, at the lowest cost. Both the technical applicability and cost of the task must be considered together. One way to think of cost-effectiveness is the overall value of the task in preventing the cause of failure relative to other task options. Another way to think about cost-effectiveness is in terms of return on investment, where resources are expended to gain improvement in equipment reliability.

For example, causes of failure such as corrosion or linkage binding could be addressed by tasks such as: equipment replacement; overhaul; timing and travel measurement; and, clean, lubricate and exercise. Each task is applicable because it addresses the causes of failure, but typically the replacement or overhaul of equipment is far more costly than a simple clean, lubricate and exercise task. Therefore, it is likely that the overhaul and replacement tasks would not be considered cost-effective. Figure 9-4 presents an overview of the thought process that should be considered when determining the applicability and cost-effectiveness of maintenance tasks.

9.2 Condition Monitoring Tasks

In keeping with the simplified task selection logic, the RCM evaluator should first look to establish <u>condition monitoring</u> tasks to measure conditions that allow for the prediction of failure. The term "condition monitoring” is related but not synonymous to the term condition-directed. Condition monitoring refers to the monitoring or diagnostic activity that is used to <u>predict</u> or foresee equipment failures. The “condition- directed” task is performed to <u>prevent</u> the failures that the condition monitoring task is foretelling. The task that is directed (based on the condition

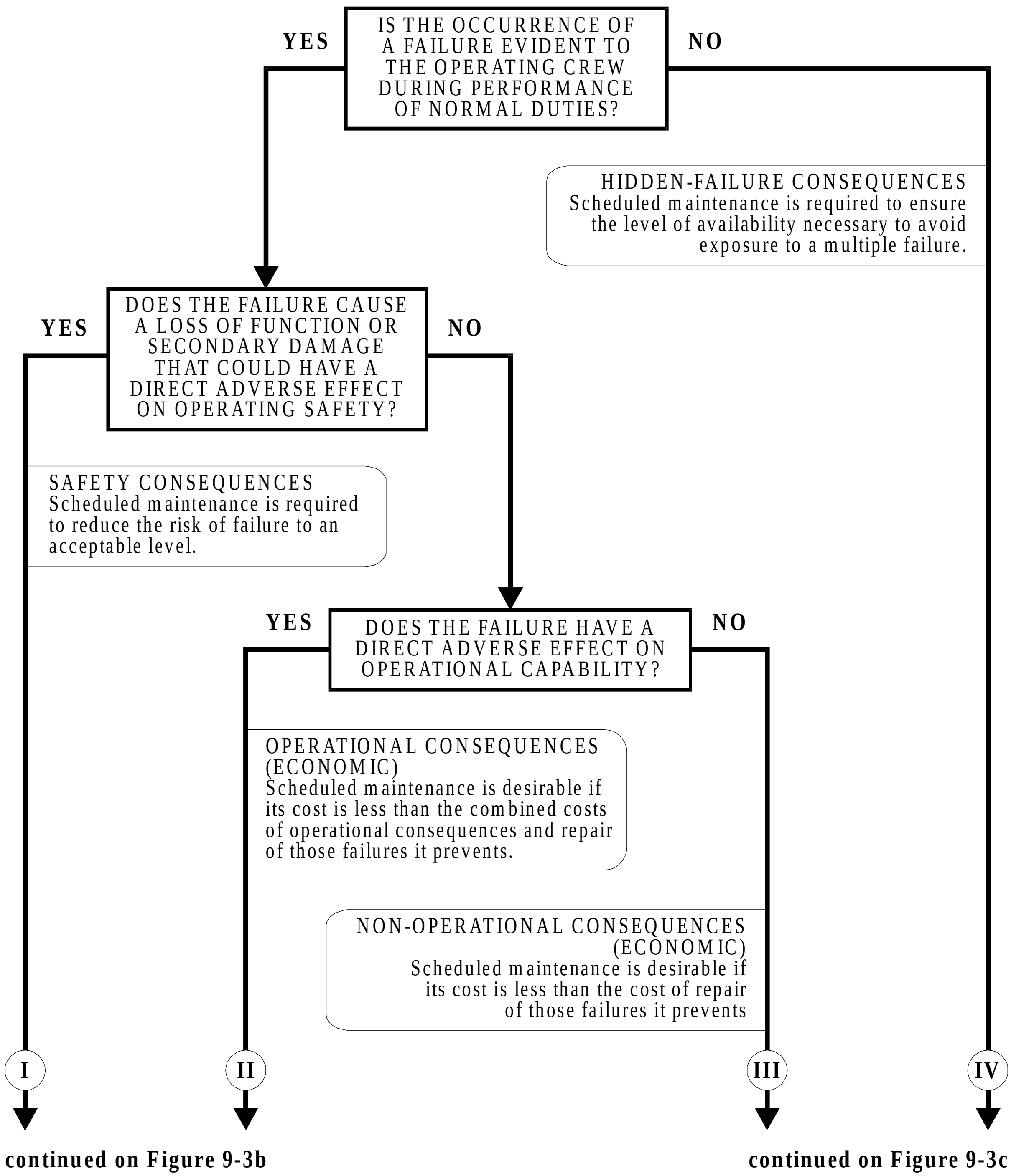

IS THE OCCURRENCE OF A FAILURE EVIDENT TO THE OPERATING CREW DURING PERFORMANCE OF NORMAL DUTIES?
YES
NO
HIDDEN-FAILURE CONSEQUENCES
Scheduled maintenance is required to ensure the level of availability necessary to avoid exposure to a multiple failure.
DOES THE FAILURE CAUSE A LOSS OF FUNCTION OR SECONDARY DAMAGE THAT COULD HAVE A DIRECT ADVERSE EFFECT ON OPERATING SAFETY?
YES
NO
SAFETY CONSEQUENCES
Scheduled maintenance is required to reduce the risk of failure to an acceptable level.
DOES THE FAILURE HAVE A DIRECT ADVERSE EFFECT ON OPERATIONAL CAPABILITY?
YES
NO
OPERATIONAL CONSEQUENCES (ECONOMIC)
Scheduled maintenance is desirable if its cost is less than the combined costs of operational consequences and repair of those failures it prevents.
NON-OPERATIONAL CONSEQUENCES (ECONOMIC)
Scheduled maintenance is desirable if its cost is less than the cost of repair of those failures it prevents
I
II
III
IV
continued on Figure 9-3b
continued on Figure 9-3c

Figure 9-3a

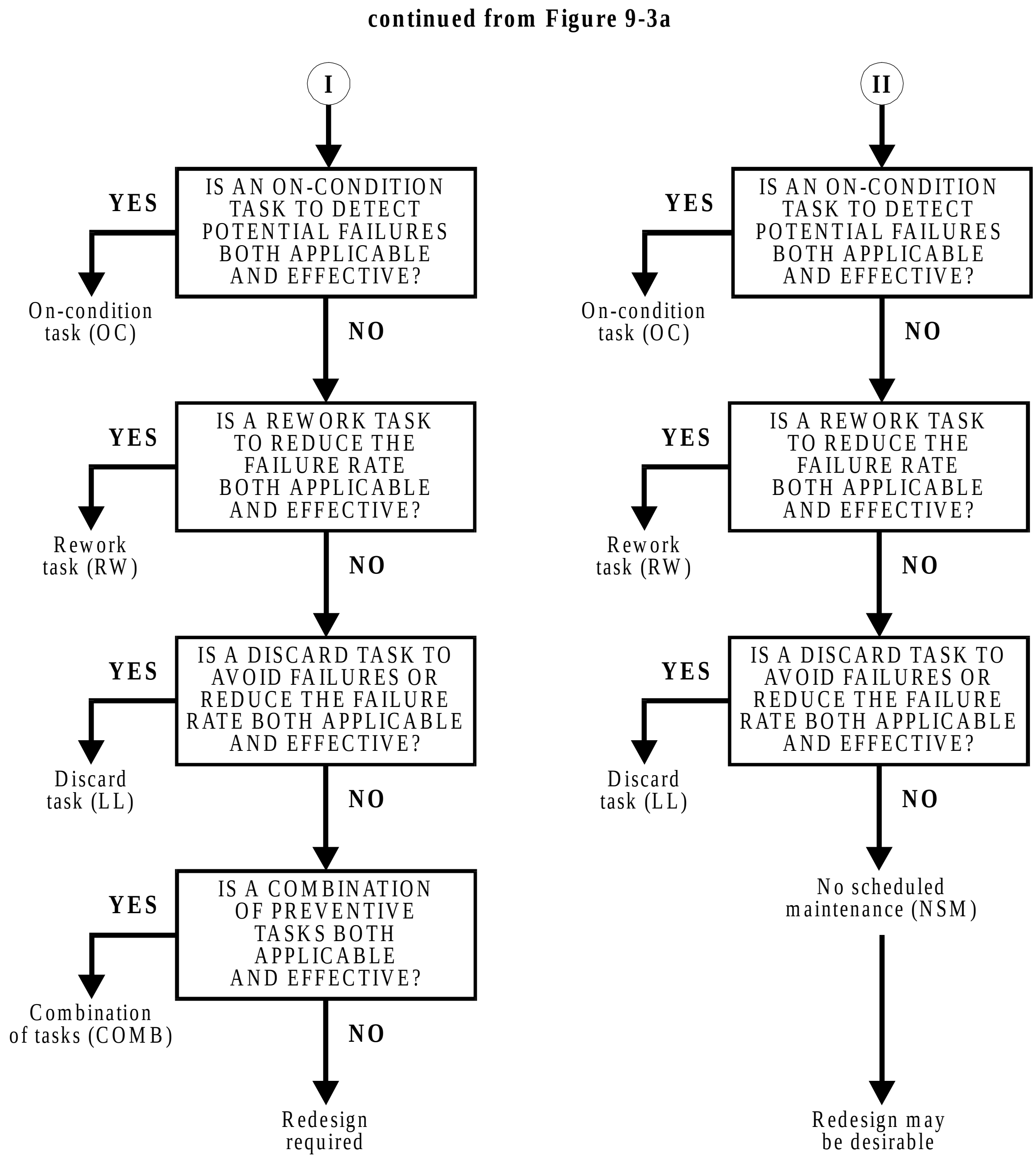

continued from Figure 9-3a
I
II
IS AN ON-CONDITION TASK TO DETECT POTENTIAL FAILURES BOTH APPLICABLE AND EFFECTIVE?
YES
On-condition task (OC)
NO
IS A REWORK TASK TO REDUCE THE FAILURE RATE BOTH APPLICABLE AND EFFECTIVE?
YES
Rework task (RW)
NO
IS A DISCARD TASK TO AVOID FAILURES OR REDUCE THE FAILURE RATE BOTH APPLICABLE AND EFFECTIVE?
YES
Discard task (LL)
NO
IS A COMBINATION OF PREVENTIVE TASKS BOTH APPLICABLE AND EFFECTIVE?
YES
Combination of tasks (COMB)
NO
Redesign required
IS AN ON-CONDITION TASK TO DETECT POTENTIAL FAILURES BOTH APPLICABLE AND EFFECTIVE?
YES
On-condition task (OC)
NO
IS A REWORK TASK TO REDUCE THE FAILURE RATE BOTH APPLICABLE AND EFFECTIVE?
YES
Rework task (RW)
NO
IS A DISCARD TASK TO AVOID FAILURES OR REDUCE THE FAILURE RATE BOTH APPLICABLE AND EFFECTIVE?
YES
Discard task (LL)
NO
No scheduled maintenance (NSM)
Redesign may be desirable

Figure 9-3b

continued from Figure 9-3a

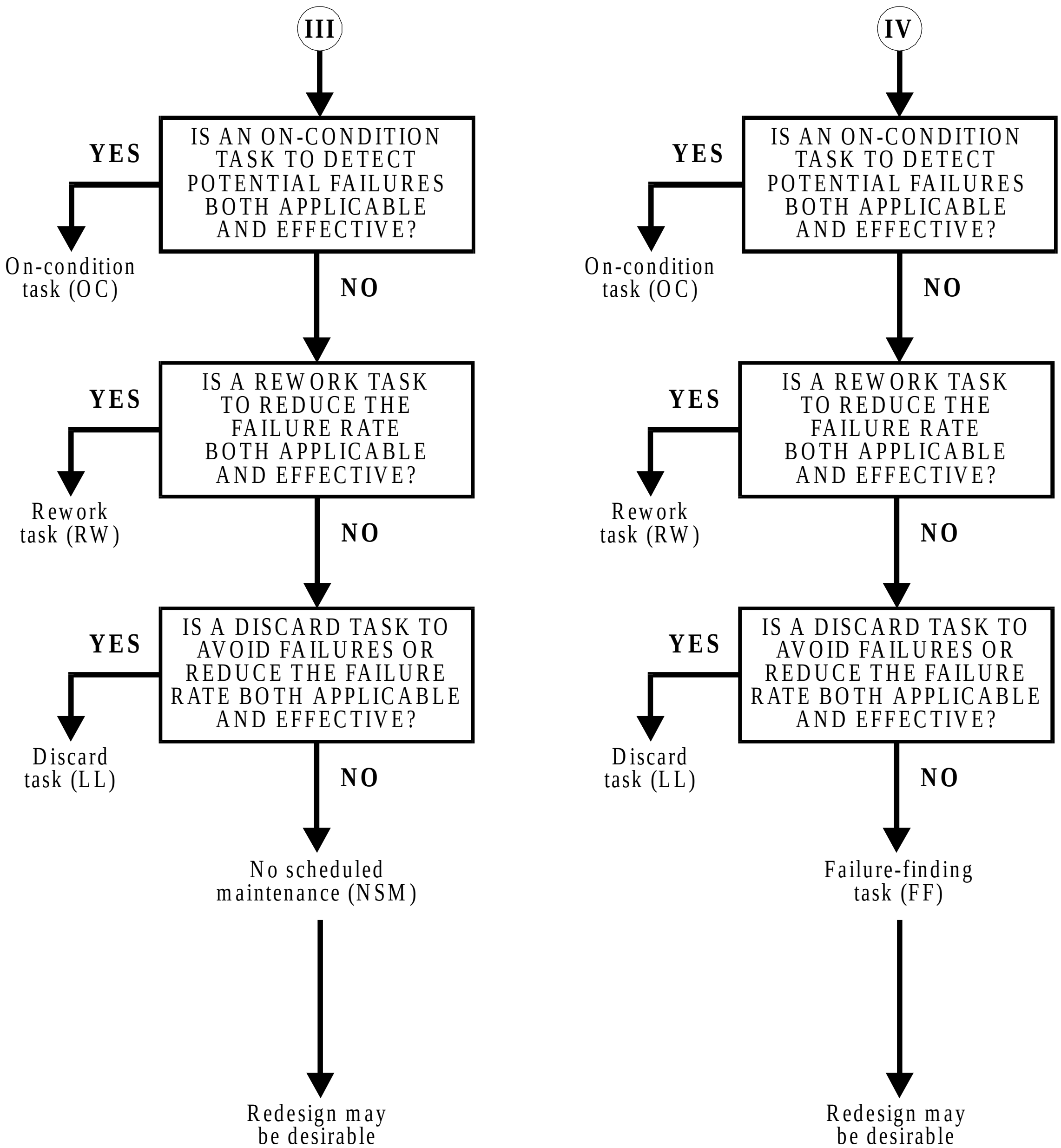


Figure 9-3c

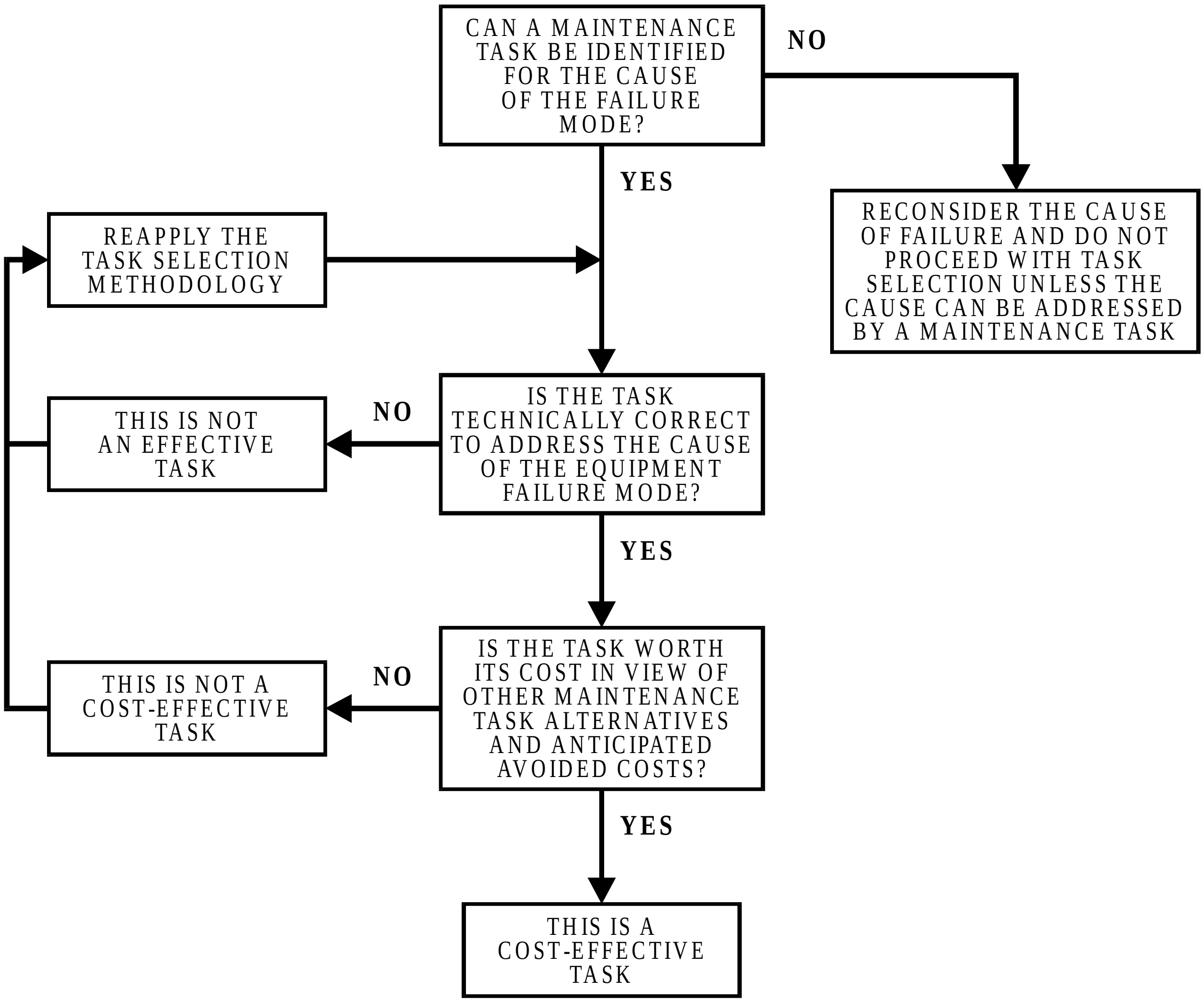

CAN A MAINTENANCE TASK BE IDENTIFIED FOR THE CAUSE OF THE FAILURE MODE?
NO
RECONSIDER THE CAUSE OF FAILURE AND DO NOT PROCEED WITH TASK SELECTION UNLESS THE CAUSE CAN BE ADDRESSED BY A MAINTENANCE TASK
YES
REAPPLY THE TASK SELECTION METHODOLOGY
IS THE TASK TECHNICALLY CORRECT TO ADDRESS THE CAUSE OF THE EQUIPMENT FAILURE MODE?
NO
THIS IS NOT AN EFFECTIVE TASK
YES
IS THE TASK WORTH ITS COST IN VIEW OF OTHER MAINTENANCE TASK ALTERNATIVES AND ANTICIPATED AVOIDED COSTS?
NO
THIS IS NOT A COST-EFFECTIVE TASK
YES
THIS IS A COST-EFFECTIVE TASK

Figure 9-4

monitored) is largely unknown until the condition of the equipment is ascertained.

Condition monitoring tasks (element A of Figure 9-2a) can take the form of simple qualitative and quantitative monitoring of equipment such as: visual inspection of fluid level and color, listening for patterns of sound; and, feeling patterns of vibration. Condition monitoring tasks can also take the form of sophisticated predictive technologies such as thermography and dissolved gas analysis. These type of tasks are intended to help identify how and when equipment is likely to fail. One of the simplest techniques that can be employed to condition-direct tasks is to monitor and trend equipment status that is available through installed instrumentation. The results of system testing is also a simple source of data that can show equipment status useful in forecasting maintenance needs.

In order for a condition monitoring task to be applicable for a given cause, it must provide sufficient advanced notice to allow appropriate actions (condition-directed tasks) to address the degradation and prevent catastrophic failure of the equipment. If the task merely identifies when the equipment is in a failed condition, then it is a failure-finding task.

It should be noted that condition monitoring tasks need to be performed on a frequency or event basis to be conducive to scheduling. The regularly scheduled performance of the monitoring does <u>not</u> mean that the task is time-directed. As long as the application of preventive resources is based on the <u>condition</u> of the equipment, and <u>not</u> the passage of time or occurrence of events, then the task is condition monitoring. The scheduled application of condition monitoring tasks should be such that incipient failures are detected far enough ahead to apply preventive maintenance actions to avoid failure.

Monitoring the output of redundant instruments is an example of a simple condition monitoring technique that can be utilized for station instrumentation. The staff can use it to identify when routine maintenance such as calibration is required. This activity involves monitoring the same parameter via multiple instruments and determining the need for maintenance based on the noted differences between instrument readings.

In the area of high technology predictive maintenance techniques, the evaluator has a wide range of techniques from which to choose. See the maintenance technologies presented in Appendix C. Each of these techniques has a variety of applications, and the evaluator must determine which of these techniques, or combination of techniques, is most appropriate to predict the relative health of the equipment.

9.3 Time-Directed Tasks

According to the task selection logic, if no condition monitoring task is selected, then an attempt is made to identify a cost-effective time-directed task (element B of Figure 9-2a). Time-directed tasks are routine preventive actions performed based on a presumed condition of the equipment as suggested by factors such as the passage of time, number of operations, operating hours, or seasonal changes of the year. Tasks of a time-directed nature are performed irrespective of the condition of the equipment. Like condition monitoring tasks, time-directed tasks can be simple maintenance activities such as cleaning and lubricating, or relatively complex equipment rebuilds. In addition, they can include other activities that require an extensive outlay of resources in terms of labor, specialized equipment, and replacement parts and supplies.

Time-directed tasks can be identical to condition-directed tasks that result from condition monitoring activities. For example, recalibration of an instrument can be both a time-directed and a condition-directed task, depending on what “triggered” the performance of the task. A condition-directed recalibration is performed based on the results of condition monitoring which suggest that a recalibration is required. A time-directed recalibration is performed based on a routine maintenance schedule, regardless of the condition of the equipment. This is why condition monitoring tasks are generally thought to be more cost-effective than time-directed tasks.

9.4 Run-to-Failure

Run-to-failure (element D of Figure 9-2b) is an option that is selected only in the event that a technically correct and cost-effective task cannot be identified among condition monitoring and time-directed tasks. In selecting run-to-failure, the analyst is making a decision to use corrective maintenance as the most cost-effective of available maintenance task alternatives.

To make a decision to run-to-failure, two items of information must be reviewed. The first item is the effects of the associated failure mode. This information is obtained through review of the criticality analysis. If the failure effects are deemed tolerable (although undesirable), run-to-failure may be appropriate. If the failure effects are deemed not tolerable, then a design change must be initiated.

The second item is the awareness of the operating crew. If the operating crew will be immediately aware of a general condition of failure, then run-to-failure is appropriate to select. The operating crew must be aware of the failure through alarms or other prominent failure indications that cannot be ignored, but they do not need to know the exact nature of the failure. The nature of the failure can be determined later through investigation. If the operating crew will not be immediately aware of the failure, then a failure finding task must be specified.

Simply stated, the selection of run-to-failure means that the application of maintenance resources before equipment failure was determined to be less cost-effective, than application of maintenance resources after equipment failure. The application of corrective maintenance is not a neglect of the equipment, it is simply a decision regarding the cost-effective application of maintenance resources.

9.5 Design Changes

Design changes (element C of Figure 9-2b) are not in the pure sense a maintenance recommendation. They are, however, a viable alternative when maintenance tasks are deemed not cost-effective in addressing equipment failures that have intolerable consequences. Following the task selection logic, the analyst determines whether predictive/preventive techniques are cost-effective. If not, then a recommendation to run-to-failure is considered in light of the failure consequences. In cases where consequences of failure are intolerable, a design change must be selected.

The reasoning behind this logic is simple to follow: 1) a determination is made that the cause of failure cannot be cost-effectively addressed by condition monitoring or time-directed tasks; 2) this means that no preventive resources will be applied; 3) therefore the equipment will eventually fail; and, 4) if the failure consequences are intolerable, then a design change must be made to avoid the eventual failure.

Design changes are also encouraged in cases where condition monitoring and time-directed tasks are not cost-effective, yet a change in design could be cost-effective in eliminating the cause of failure. The idea here is that the prevention of maintenance may be more cost-effective in the long term than recurring maintenance of a preventive or corrective nature. This is equivalent to “an ounce of prevention” where the “preventive” measure is a permanent change in design.

In addition to addressing non-preventable intolerable failures and failure causes that can be cost-effectively eliminated, a design change can be used to make a maintenance task possible or cost-effective. This is only advisable if the design change is inexpensive in nature. For example, oil sampling (a condition monitoring task) may be impossible, or not cost-effective in the absence of an oil sampling valve. Without a design change, the analyst may select oil reconditioning on a regular schedule (time-directed task). If a valve could be installed to allow sampling, then the condition monitoring task would be possible and perhaps more cost-effective than routine oil reconditioning. At each point in the task selection logic where a preventive maintenance task can be selected, the analyst is provided with the opportunity to select a minor design change to facilitate enhanced cost-effectiveness of the task.

9.6 Failure-Finding Tasks

One of the last preventive maintenance options is the failure-finding task (element E of Figure 9-2b). In accordance with the task selection logic, a failure-finding task is selected when: 1) failure cannot be predicted or prevented; 2) a design change is not warranted; and, 3) the occurrence of the failure will not be evident to the operating crew. Failure-finding tasks are simple tests and inspections designed to confirm operability of equipment at a general level. They are typically performed on a pass/fail basis for equipment that is in a stand-by condition. Self tests, functional tests, exercising the equipment and verification of circuit continuity through observation of indicating lights are all examples of failure finding tasks.

One of the basic differences between failure finding tasks and the other preventive tasks is that the failure finding task is focused on identifying equipment failure modes, whereas the other tasks are focused on the failure cause. For example, a predictive task might measure dielectric strength of oil to determine when it should be replaced or reconditioned so that it does not <u>cause</u> a failure. A preventive task might clean and relubricate bearing surfaces to prevent a lubricant related <u>cause</u> of failure. The failure-finding task might test to see if the equipment will open, close, trip or start. Detecting these <u>failure modes</u> is the intention of the task. The cause of the failure is sought as part of the investigation and corrective measures that ensue.

9.7 Basic Maintenance for Non-Critical Equipment

The guidance provided thus far focuses on applying maintenance tasks to address the causes of <u>critical</u> failure modes of equipment. As previously noted, equipment failure modes can be deemed non-critical based on the limited consequences as shown in the criticality analysis. In particular, the analyst is interested in identifying non-critical failure modes that are attributable to the presence of redundant or backup equipment. In these cases, <u>basic</u> maintenance must be applied to maintain the intrinsic reliability of the equipment. This will allow for the minimal expenditure of maintenance resources necessary to preserve the defense in depth that the redundancy or backup configuration was originally designed to provide.

The following illustrates the thought process behind this concept. Consider several equipment items in a redundant configuration. Assuming that the criticality analysis deemed this equipment to have no critical failure modes due to redundancy, then we can imagine that one or more failure modes of each item of equipment would otherwise be deemed critical. Therefore, under non-redundant conditions, it is expected that tasks of a preventive nature would be prescribed for each equipment item. This expectation hinges on the reasonable assumption that dominant causes of failure and cost-effective tasks can be identified. In this non-redundant example, a failure to apply maintenance would constitute neglect.

Now when considering the same configuration, deemed non-critical due to redundancy, it seems reasonable that applying some level of maintenance would be desirable because of two reasons. First, except for the recognition of redundancy, the equipment would not be neglected, but would receive maintenance of a preventive nature. Second, the advance of redundancy requires that redundant equipment perform its function on demand so that the system enjoys the benefits of redundancy.

Therefore, the issue to resolve is the appropriate level of maintenance for non-critical equipment in a redundant configuration. It is understandable that the expected level of maintenance should be less than that resulting from the application of a formal task selection process, for if that were not the case, then there would be no advantage in special recognition for equipment in a redundant configuration. The answer is founded in the second reason, noted above, for applying maintenance for equipment deemed non-critical due to redundancy; equipment must provide an <u>acceptable assurance of reliability</u> in order for the advantages of redundancy to be realized.

A formal task selection process should results in a maintenance strategy that provides <u>high assurance of reliability</u>. No maintenance should result in <u>low assurance of reliability</u>, and the lack of maintenance will eventually erode the intrinsic reliability of the equipment design to the point where we would have <u>no assurance of reliability</u>. Therefore, an appropriate balance can be made between the desire to maintain an <u>acceptable assurance of reliability</u> with reduced expenditures in maintenance by applying a <u>basic maintenance</u> program intended to preserve the intrinsic reliability of the equipment design.

Although there are no specific recommendations regarding <u>basic maintenance</u> tasks, the analyst can develop basic maintenance tasks by imagining the level of maintenance that a system designer would assume to be performed on the equipment to maintain its integrity. Information in Appendix B can be used as a reference for selecting appropriate tasks. Some general examples are provided in Table 9-1.

Note: For equipment failure modes deemed non-critical, irrespective of the issue of redundancy, the application of routine maintenance tasks is discretionary. Unless compelling reasons are identified, non-critical equipment failure modes should receive no routine maintenance.

Table 9-1

Example Basic Maintenance Tasks

Equipment Type	Basic Maintenance Tasks
Compressor	Lubricate, Inspect for Leaks
Breaker	Clean and Inspect Mechanism, Functionally Test
Indicator	None
Annunciator	None
Manual Disconnect Switch	None
Transformer	Check Oil Level, Inspect for Leaks
Cables / Transmission Lines	None
Lead Acid Batteries	Inspect for Leaks and Corrosion, Check Electrolyte Level

9.8 PM Task Frequencies

It is difficult to provide guidance for the determination of appropriate frequencies of maintenance tasks due in part to the number of factors that influence the frequency of tasks. For example, the following factors influence the frequency of maintenance:

- Purpose of task (task type)
- Failure cause
- Operating hours
- Duty cycles
- Equipment age
- Environment
- Criticality of failure modes

In light of the number of factors that need to be considered, the guidance offered in this section is limited to general guidelines for task frequencies according to the type of task selected. The task type is perhaps the single most influential factor in establishing an appropriate frequency. The following guidance should be considered first when establishing a frequency for a routine maintenance activity.

Condition Monitoring Tasks - The frequency of tasks should promote the collection of data that can be trended over time to provide a picture of the relative healthiness of the equipment. The main idea behind condition monitoring is that equipment often has no known life or point of wear out, and monitoring key parameters is intended to identify incipient failures so that appropriate preventive measures can be taken to avoid failure. It is appropriate to have relatively frequent monitoring since monitoring is usually not expensive, and a large population of data provides the ability to trend results over the life of the equipment. Trending allows forecasting failure, thus supporting the planned application of preventive resources.

It is inappropriate to strive to establish large periods of time between condition monitoring activities because this reduces the predictive value of the results. In other words, with longer intervals between tasks, it is more likely that a failure trend would appear and reach a point of failure in between data gathering. The key to establishing a frequency for condition monitoring is to understand the mechanisms of failure, and their telltale signs, and then to establish a frequency that provides high assurance that the telltale signs will be identified in time to take preventive measures.

Time-Directed Tasks - The frequency of tasks should promote the prevention of failure causes that have an expected pattern of occurrence influenced by passage of time, season of the year, number of operations, hours of operations or combinations thereof. The time-directed task applies the preventive measure regardless of the condition of the equipment, but with the expectation that the frequency will be modified based on feedback of “as-found” conditions.

The key to proper frequency for time-directed tasks is to identify failure cause patterns and match the frequency of preventive measures with the patterns to avoid catastrophic failure. It is also important that the frequency of task performance be soon enough to avoid unnecessary wear, stress or damage to the equipment that could contribute to critical failures in the future. It is inappropriate to strive to establish small periods of time between time-directed tasks when the application of the preventive resources is excessive.

One technique for refining frequencies of time-directed tasks is called “age exploration.” The idea is to establish a frequency that appears reasonable and adjust the frequency based on feedback from preventive and corrective activities. When feedback shows no need for maintenance, the frequency can be extended to some value until signs of incipient failure are detected. When feedback shows that maintenance was not applied soon enough, then the frequency can be reduced until signs of incipient failure are detected. This will allow for “just in time” application of maintenance. This technique works well for time dependent failures, if other factors such as use, load and environment are relatively constant.

Failure Finding Tasks - The frequency of tasks should promote the discovery of “hidden” failure modes before the equipment is called upon to operate in those modes. Failure finding tasks are intended to provide some level of confidence in the ability of the equipment to perform its function, based on test or inspection results showing that the equipment did, or would, successfully operate. The key to a proper frequency for failure finding tasks is to ensure that tests or inspections are frequent enough to detect failures in time to allow for restoration of the equipment before it is needed for service. It is also appropriate for the frequency of the tasks to take into consideration successful exercise of the equipment, during normal operations, that shows the equipment did operate successfully on demand.

It is inappropriate, especially for demanding tests on equipment, to establish frequencies that would promote “test-to-failure.” In other words, if the testing activity constitutes a frequent challenge that becomes a significant contributor to wear out, then the frequency of the test is not advisable.

9.9 Maintenance Templates

A Maintenance Template is a pre-engineered set of maintenance tasks and frequencies for a specific equipment type or group having the same application. The template is designed to address the causes of dominant failure modes while considering factors of maintenance that can influence task content and frequency. These factors are known as “drivers,” and include items such as equipment age, duty cycle, load, environment, and criticality. Once constructed, the analyst can apply the maintenance template to an equipment item of the same type, in lieu of using the RCM task selection logic process. The major advantages of a template are: 1) avoiding duplication of effort in task selection for equipment items of the same type and application; 2) enhancing task selection consistency among analysts; and 3) developing templates as a separate activity from other portions of the RCM study.

A maintenance template cross-references dominant failure modes and causes of an equipment type and their applicable drivers to appropriate and cost-effective maintenance tasks and frequencies. As part of the template construction, the analyst uses an RCM task selection logic. The completed template is then stored as a reference for application to like equipment items. The application to like equipment items is performed by simply matching certain aspects of the equipment item under study with those of the template of the same type or group as follows: 1) critical failure modes; 2) dominant causes; and, 3) maintenance drivers.

Steps in developing templates include:

- Identify groups of similar equipment that are likely to have significant differences in maintenance due to design or application
- Categorize the groups by type, application, make and model
- Select one group for analysis
- Identify and list all dominant failure modes
- Identify all dominant failure causes for each failure mode
- Identify appropriate maintenance drivers and their applicability (e.g., environment - harsh / mild, age - young / old)
- Use the RCM simplified task selection logic to select cost-effective tasks for each failure mode / cause combination and each driver variation
- Assign frequencies for each task with consideration of equipment criticality combined with other driver variations
- Use completed templates for an equipment type to create additional templates for similar equipment types

Table 9-2 shows an abbreviated example of a Maintenance Template for an SF6 breaker. In this example, the maintenance drivers and their variations are Load (normal / heavy) and Usage (normal / heavy). In addition, the failure mode and cause combination evaluated is “Fails to close / high contact resistance.” It is assumed that the SF6 breaker is critical. Note that there are only two “drivers” of maintenance addressed in this abbreviated template. As the number of specific failure modes, causes and “drivers” increase, the complexity of the template also increases. Using the example in Table 9-2, the following guidance is offered in constructing a template.

> SF6 breakers are first organized into homogeneous groupings according to type and application. For example, tie breakers vs. feeder breakers, single chamber vs. double chamber. This organization will assist in efficient targeting of maintenance strategies contained in the templates. In this example, the SF6 breaker template is for a single chamber tie breaker. Once constructed, the analyst would modify the template to suit the needs of the remaining breaker types, giving consideration to the dominant failure modes and causes and maintenance drivers.
>
> Using the RCM task selection logic to select a cost-effective task for high contact resistance, and considering one set or combination of maintenance driver variations noted in the first column as Usage-Normal and Load-Normal, the maintenance task “Ductor test” was selected. If more failure

causes were to be analyzed, this step is repeated for all dominant failure causes for the driver combination.

The task selection process is repeated for the next combination set of drivers, such as Usage-Normal and Load-Heavy and so forth, until all combination sets of drivers are considered for the failure cause.

When more than one failure mode / cause combination is being analyzed, some duplication of maintenance tasks should be expected. Tasks that duplicate one another in both content and frequency can be eliminated.

When assigning task frequencies, the analyst must bear in mind that the drivers set forth in the maintenance template have an influence on task frequency as well as content. For example, it may be advisable to perform a cleaning task more often if the equipment is exposed to a harsh environment, however, the equipment criticality, load and age will probably not have any influence on frequency of the cleaning task. The idea is that the guidance on task frequency, noted in Section 9.8 above, is fully applicable, but should be tempered by the drivers of maintenance as documented in the template.

Once completed, the maintenance template serves as a “source” maintenance strategy or standard. Information from this “source” can be applied to “target” equipment that is of the same type and application. To apply the template to a “target” equipment group or item, the following steps must be taken: 1) identify an SF6 breaker of the same type and application as the “source” template: 2) match the failure modes criticality determinations of the “target” equipment item with the dominant failure modes addressed in the template; 3) match the dominant failure causes of each critical failure modes from the “target” equipment item with the dominant failure causes of the template; and, 4) match the maintenance “drivers” of the “target” SF6 breaker with those of the template to determine the appropriate maintenance tasks and frequencies.

In the above example, the maintenance program for hundreds of SF6 circuit breakers is determined quickly through the use of equipment groupings and templates that match those groupings. Without the use of these tools, the conduct of hundreds of individual analyses would be very time consuming. This same approach can be used for any other equipment type or equipment grouping.

9.10 PM Task Data Reference

To support the completion of RCM studies, the user is provided with data references for preventive maintenance tasks. A suggested listing of tasks is provided in Appendix B. The tasks provided are associated with appropriate equipment types, failure modes, and causes so that the information is organized in a manner that is conducive to completing RCM studies.

Table 9-2

Abbreviated Example Maintenance Template

Equipment Type: SF6 Breaker **Make/Model:** ABC, Inc. / 6897-XXC

Failure Modes: Fails to Close **Causes:** High Contact Resistance

Usage:	Normal	X	X		
	Heavy			X	X
Load:	Normal	X		X	
	Heavy		X		X

Prescribed PM Tasks	**PM Task Frequencies**			
Condition Monitoring Tasks:				
Ductor test	5 I.O.F.	5 I.O.F.	1K Op or 5 I.O.F.	500 Op or 5 I.O.F.
Breaker timing test	5 I.O.F.	5 I.O.F.	1K Op or 5 I.O.F.	1K Op or 5 I.O.F.
Time-Directed Tasks:				
Clean, inspect, lubricate and exercise	5Y	5Y	1K Op	1K Op
Heater check	1Y	1Y	1Y	1Y

Prescribed PM Tasks	PM Task Frequencies			
Condition Monitoring Tasks:				
Calibration check of SF6 density instrumentation	3Y	3Y	3Y	3Y
Failure-Finding Tasks:				
None	NA	NA	NA	NA
Design/Operational Changes:				
Remote breaker position verification	Each Op	Each Op	Each Op	Each Op

I.O.F. = Interruption of Fault; Op = Operation / Operations; Y = Year; K = 1000

9.11 Summary and Review

When selecting appropriate maintenance tasks, the analyst should consider the following:

- Knowledge of the equipment failure cause is essential for the identification of appropriate maintenance tasks
- Maintenance tasks must be technically correct and worth the investment of resources
- Condition monitoring (predictive / diagnostic maintenance techniques) is the first preferred option to address the causes of equipment failure
- Time-directed tasks are the second preferred option when condition monitoring (predictive maintenance) techniques are not appropriate
- Run-to-failure (corrective maintenance) is a viable option for tolerable failures that cannot be cost-effectively monitored or prevented
- Design changes must be proposed for failures that cannot be tolerated and cannot be cost-effectively predicted or prevented

- Failure finding tasks are appropriate for identifying equipment failures that are not evident to the operating crew
- Basic maintenance should be considered for equipment determined to be non-critical because of equipment redundancy
- Maintenance task frequencies are difficult to establish with any certainty, and are subject to change based on feedback from preventive and corrective maintenance activities
- Basic task-type oriented rules can be successfully applied to establishing frequencies that are reasonable
- Maintenance templates are an efficient means of applying maintenance tasks to a large number of equipment items

10

TASK COMPARISON AND IMPLEMENTATION PLANNING

The last steps of an RCM study are the comparison of RCM recommended tasks with current PM task requirements, and planning for implementation of the results. These actions are completed independently for each equipment item studied. The purpose of task comparison is to provide a means of reconciling the differences between the preventive maintenance program built as a result of the RCM study, and the current PM tasks and associated requirements, in order to create a final PM strategy. The purpose of implementation planning is to plan for effective incorporation of the final PM strategy into daily maintenance activities.

10.1 Task Comparison

Task comparison simply compares the PM tasks recommended by an RCM study with the current PM tasks associated with the equipment. The idea is to merge both sets of tasks into a final PM strategy. In doing so, the analyst assumes that the RCM recommended tasks have a clear technical basis, as documented in the RCM study, and both task content and frequency have been carefully considered. The analyst also assumes that the current PM related activities have a questionable technical bases. Up to this point in the RCM study, the current PM tasks for the equipment have been given little if any consideration. This is done so that the results of the RCM study will not be unduly influenced by the current PM program. The task comparison is the first time that the current PM tasks will be fully exposed for review by the analyst, side-by-side with the results of the RCM study.

The comparison can be performed using a three column format. The first column on the left is composed of tasks recommended as a result of the RCM study. The second column in the middle contains the current PM related activities. The third column on the right is the final PM strategy. When completed, the third column will contain action statements and references to a task from the first or second column. Since the main idea of task comparison is to communicate a change to the current PM program, it is most advisable to make statements in the third column that refer to actions involving the current PM program. Only in cases where the RCM recommended task is new, should an action statement refer to the RCM recommended task.

RCM recommended tasks should include every recommendation for PM or a design change. It is not appropriate to list run-to-failure (corrective maintenance) as a task result from the study. PM tasks must include a general frequency, situation or condition that "triggers" the task.

Current PM related tasks must include every "preventive" action associated with the task including operator rounds, vendor recommended activities and regulatory requirements. Tasks must include a general frequency, situation or condition that "triggers" the task, even if it is simply "as needed." The analyst must be careful not to list actions or tasks that are corrective in nature and performed as a result of finding an equipment problem. During the comparison process, corrective maintenance should not be considered routine PM.

The process begins by identifying task content that is the same or similar between the first and second columns of information. Current activities that match an RCM recommendation in both content and frequency, should have an action statement that indicates that the task will be retained and no further action is required. In the event that matching tasks have different frequencies, the technical basis for the frequencies must be examined to determine which frequency is most valid and should be used. In some cases, an alternate frequency may be established for the task based on a careful review of the bases for each frequency and the perceived effectiveness of the current task frequency. If any change is made to the frequency of a current task, the action statement for the task should indicate that the task will be modified.

Likewise, if changes to the current PM task content are influenced by the recommended tasks from the RCM study, then the action statement should also indicate that the current task will be modified.

In cases where RCM recommendations do not have a corresponding task in the current PM program, the action statement is associated with the RCM recommendation, and it should note that a new task will be added.

In cases where current PM tasks have no corresponding RCM recommendation, the task is tentatively identified for deletion. Before making a final decision to delete the task, the consequences of failure that might result, if the task is not conducted, must be carefully examined and clearly understood. Failure consequences are determined by identifying the causes of failure that the PM task is preventing, then identifying the mode(s) of failure associated with the failure causes. For each mode of failure identified, the consequences associated with the failure are determined. For those consequences that are minor, the task can be safely deleted. For those consequences that are major, the task should be retained. In performing this examination, the analyst should assume that other PM tasks of the program are being conducted. In this way, a task can be deleted if another task of the final program will effectively address the same cause(s) of failure.

Required tasks include regulatory requirements and management commitments. These type of tasks should not be changed or eliminated unless appropriate authorization is obtained. It should be safe to add an RCM recommended tasks to a required task activity where necessary to enhance technical depth and to meet the intent of the RCM recommended tasks. In this way, new tasks need not be developed to implement RCM recommendations where a current required task can be used as a means to facilitate implementation.

Design changes that result from the RCM study should be added to the PM program as a one-time change to the equipment design and/or configuration. In the event that a design change eliminates the need for a PM task, the PM task should be identified for deletion only after the design change is fully implemented.

10.2 RCM Results Implementation Planning

After completion of task comparison activities, the final PM program is implemented by way of an implementation plan. Development of the implementation plan involves an examination of each element of the final PM strategy, and a determination of the required actions, resources and prerequisites necessary to achieve satisfactory implementation of the program. Only those portions of the strategy that require an action need be considered in the development of the implementation plan. If no action is required for a particular aspect of the final PM program, then it need not be addressed in the implementation plan. Simply stated, the implementation plan consists of the following.

A listing of each element of the final PM strategy that requires action. For example:

- Addition of PM task
- Modification of PM task
- Modification of PM task frequency
- Design change
- Modification of required inspection activity

For each element, brief statements of the steps needed to implement the element of the strategy. The statements should also consider pre-requisites. For example:

- Develop a procedure
- Acquire new equipment
- Train personnel in new equipment use
- Change a procedure
- Obtain approval
- Investigate application of a new technology

For each element, a listing of the involved organizations. For example:

- Operations
- Maintenance
- Design

For each element, a schedule for implementation. For example:

- Start date
- Estimated completion
- Milestones

In addition to the information noted above, the plan for implementation should contain pertinent remarks, as necessary to describe other considerations associated with fully implementing each element of the final PM strategy.

A

DEFINITION OF KEY TERMS

The following terms are defined for use in power delivery RCM applications. Definitions derived from IEEE Standard 100-1992, are noted as (IEEE100). These definitions were used to the extent practicable.

Applicable and Effective Tasks - Recommendations regarding maintenance program activities that represent both technically correct and cost-effective strategies for eliminating, preventing, mitigating, predicting, detecting and correcting equipment degradation and failure. These tasks encompass:

- Condition Monitoring (Predictive Maintenance)
- Time-Directed (Preventive Maintenance)
- Run-to-Failure (Corrective Maintenance)
- Failure Finding (Tests and Inspections)
- Design Changes (One time only, non-routine)

Boundary - A specified interface between equipment types, equipment and system, or two systems or subsystems.

Condition Monitoring - The monitoring or diagnostic activity that is used to predict or foresee equipment failures.

Critical Failure Mode - An equipment failure mode having serious operational, safety or maintenance effects and therefore warranting the selection of maintenance tasks, using a task selection logic, to prevent the failure mode from occurring.

Design Change - A modification or redesign of an item or system.

Discard Task - A time-directed replacement of an equipment item.

Dominant - Credible and likely. Used in reference to both failure modes and failure causes.

Duty - A statement of the operating conditions to which the machine or apparatus is subjected, their respective duration, and their sequence in time (IEEE100).

Effect - The consequence of a failure mode that describes the physical, operational, safety, maintenance or financial impact of the event. Related terms include:

- **Local (Effect)** - The consequence of failure observable at the failed equipment
- **Within the Boundary (Effect)** - The effect within the boundary of the RCM defined equipment or system, other than local effects, resulting from the failure of the equipment
- **External to the Boundary (Effects)** - Consequences remote to the RCM defined equipment or system boundary, due to failure of the equipment

Equipment Group - The organization of like equipment types having similar characteristics (e.g., identical vendor and model number, application, etc.) into a group for RCM analysis.

Failure - The termination of the ability of an item to perform a required function (IEEE100). Related terms include:

- **Apparent (Failure)** - A non-evident failure that will be recognized during routine duties
- **Evident (Failure)** - A failure that will be immediately recognized by the operating crew
- **Failure Cause** - The circumstances during design, manufacture or use which have led to failure (IEEE100). Failure causes describe why, but not how equipment fails. Failure causes are rarely the root cause of failure, and are defined at the level at which maintenance is performed
- **Failure Mechanism** - The physical, chemical or other process that results in failure. Note: The circumstance that induces or activates the process is termed the root cause of the failure (IEEE100)
- **Failure Mode** - The effect by which a failure is observed to occur (IEEE100). A failure mode describes how, but not why equipment fails
- **(Hidden) Failure** - A non-evident and non-apparent equipment failure mode that is not normally detectable without performing a failure finding task
- **Failure Rate** - The actual or expected number of failures in a specified time period or specified number of operations

Failure Modes and Effects Analysis (FMEA) - The identification of significant failures, irrespective of cause, and their consequences. This includes electrical and mechanical failures that could conceivably occur under specified service conditions and their effect, if any, on adjoining circuitry or mechanical interfaces displayed in a table, chart, fault tree or other format (IEEE100).

Function - The purpose or output of equipment or a system often expressed in general terms of performance. Functions can be active or passive. Active functions include transforming voltage and load switching. Passive functions include preservation of pressure boundary or structural integrity. A function almost never refers directly to a specific equipment or component.

Failure-Finding Task - A task performed to discover a hidden (non-evident and non-apparent) failure so that corrective maintenance can be initiated.

Interfaces - Signals, outputs and resources entering into an equipment or system boundary that are required for the equipment or system to perform its functions. These items typically include AC and DC supply and signals. They are assumed to be available when required for equipment or system function.

Intrinsic Reliability - The level of reliability achieved through a combination of design and the performance of basic preventive maintenance that is assumed to take place when the equipment is offered for installation.

Item - A general term referring to an assembly (such as a component or equipment) that includes piece parts or components.

Logic Tree Analysis (LTA) - The RCM task selection process used to ensure that only applicable and cost-effective tasks are selected to address the causes of critical equipment failure modes.

Maintenance - The combination of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function. Note: The required function may be defined as a stated condition (IEEE100). Related terms include:

- **Basic (Maintenance)** - A fundamental level of preventive maintenance intended to ensure the intrinsic reliability of equipment
- **Corrective (Maintenance)** - The maintenance carried out, after a failure has occurred, that is intended to restore an item to a state in which it can perform its required function (IEEE100)
- **Predictive (Maintenance)** -Any monitoring or diagnostic task performed to determine whether the condition of equipment is such that maintenance should be performed to preclude failure
- **Preventive (Maintenance)** - Tasks, intended to prevent equipment failure, that are performed on the basis of a fixed time schedule or corresponding to particular activities

Maintenance Template - A pre-engineered set of maintenance tasks for an equipment type, environment, application, etc., developed using a logic tree analysis. Maintenance templates improve the efficiency of task selection.

Non-critical Equipment - Equipment that does not have a critical failure mode.

Non-critical Failure Mode - An equipment failure mode that has limited physical, operational, safety, maintenance, or financial effects such that the selection of maintenance tasks using a task selection logic is not warranted.

Non-dominant - Not credible and / or not likely. Used in reference to both failure modes and failure causes.

On-Condition - A descriptive term referring to activities that take place based on the condition of the equipment.

RCM Defined Equipment Item, Group, System or Subsystem - An equipment item, group, system or subsystem created or recognized for the convenience of an RCM study.

Root Cause - The circumstance that induces or activates the process of failure (IEEE100).

Run-to-Failure - A decision not to perform preventive maintenance.

Subsystem - A portion of a system containing a collection of interrelated equipment (IEEE100).

System - A collection of equipment arranged to provide a desired function (IEEE100).

Task Selection Logic - A structured decision process for selecting applicable and effective tasks to address the causes of critical equipment failure modes.

B

EQUIPMENT REFERENCE DATA

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared test.	Check / re-torque connections. Overhaul. Exercise. Visual inspection.	
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Close coil - open / shorted / failed	Measure coil resistance. Voltage close test. Check heaters for control valve coil assembly. Travel / timing test. Breaker monitor.	Visual inspection.	Functional test.
Control circuit failure	Fault recorder data analysis. Timing / travel test. Control wire insulation resistance test. Breaker monitor. Monitor AC & DC voltage.		Functional test. Visual-indicating light lit, connections, insulation, etc.
Degraded lubrication	Timing / travel test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High pressure air plant	Monitor air pressure. Monitor compressor run time. Monitor temperature. Monitor oil consumption. Monitor piston blowby. Monitor interstage pressure. Breaker monitor.	Check oil level / lockout. Replace / overhaul air compressor components. Service air / oil separator. Calibrate pressure switches. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test. Test heater circuit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stored energy failure	Monitor operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Test pressure switch. Monitor AC voltage. Timing / travel test. Monitor pump up time. Breaker monitor.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Replace / overhaul air compressor components. Verify mechanical tolerances. Visual inspection for leaks.	Functional test.

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Blast valve failure	Timing / travel test. Monitor pressure gauge(s). Monitor compressor run time. Record and trend air consumption during operation. Breaker monitor. Fault recorder data review. Ultrasonic test.	Overhaul / replace blast valve.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated air	Moisture test.	Overhaul dryer. Bleed air tanks / check for moisture (visual).	Functional test dryer / controls. Hi-pot test.
Degraded lubrication	Timing / travel test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
High pressure air plant	Monitor pressure. Monitor compressor run time. Monitor temperature. Monitor oil consumption. Monitor piston blowby. Monitor interstage pressure. Monitor air dew point. Breaker monitor.	Check oil level / lockout. Replace / overhaul air compressor components. Service air / oil separator. Calibrate pressure switches. Replace / overhaul dry air system. Inspect piping for leaks.	Functional test. Test heater circuit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanism / linkage failure	Timing / travel test.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test. Test heater circuit.
Resistor / grading capacitor failure	Timing / travel test. Measure resistance / capacitance. Breaker monitor. Power factor test.		
Stored energy failure	Monitor operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor AC control voltage. Timing / travel test. Monitor pump up time. Test pressure switch. Breaker monitor.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Replace / overhaul air compressor components. Verify mechanical tolerances. Replace / overhaul dry air system. Visual inspection for leaks.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

<table>
<tr><th colspan="4"><u>Failure Mode: Fails to open</u></th></tr>
<tr><th>FAILURE CAUSE</th><th colspan="3">ROUTINE MAINTENANCE TASKS</th></tr>
<tr><td></td><td>Condition Monitoring</td><td>Time Directed</td><td>Failure Finding</td></tr>
<tr><td>Control circuit failure</td><td>Fault recorder data analysis.
Timing / travel test.
Control wire insulation resistance test.
Breaker monitor.
Monitor AC & DC voltage.</td><td></td><td>Functional test.
Visual-indicating light lit, connections, insulation, etc.</td></tr>
<tr><td>Degraded lubrication</td><td>Timing / travel test.
Fault recorder data review.
Breaker monitor.</td><td>Clean and relubricate.
Exercise.
Visual inspection.</td><td>Functional test.</td></tr>
<tr><td>High pressure air plant</td><td>Monitor / air pressure.
Monitor compressor run time.
Monitor temperature.
Monitor oil consumption.
Monitor piston blowby.
Monitor interstage pressure.
Breaker monitor.</td><td>Check oil level / lockout.
Replace / overhaul air compressor components.
Service air / oil separator.
Calibrate pressure switches.
Replace oil.
Visual inspection.</td><td>Functional test.</td></tr>
</table>

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanism / linkage failure	Timing / travel test.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection.	Functional test. Test heater circuit.
Stored energy failure	Monitor operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Test pressure switch. Monitor AC control voltage. Timing / travel test. Monitor pump up time. Breaker monitor.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Replace / overhaul air compressor components. Verify mechanical tolerances. Visual inspection for leaks.	Functional test.
Trip coil - open / shorted / failed	Measure coil resistance. Voltage trip test. Check heaters for control valve coil assembly. Timing / travel test. Breaker monitor.	Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR BLAST BREAKER

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated gas / air	Moisture test. SF6 quality test-lab. SF6 quality test-field.	Reclaim / replace gas. Bleed air tanks / check for moisture. Overhaul dryer.	Hi-pot test. Functional test - dryer / controls.
Solid dielectric failure	Insulation power factor test. Insulation resistance test.	Clean solid insulation.	Visual inspection for cracks and tracking.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR INSULATED BUS SYSTEM

Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulator failure	Audio indication of insulator failure Partial discharge.		Hi-pot test.
Moisture / particle contamination of gas	Gas analysis (quality test). Dew point (moisture analysis).		Hi-pot test.
Moisture / particle contamination of solid insulation	Gas analysis (quality test). Dew point (moisture analysis).		Hi-pot test.
Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
External contamination	Measure leakage current. Ultrasonic test.	Cleaning. Visual inspection.	
Insulator mechanical failure		Cleaning.	Visual inspection.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR MAGNETIC BREAKER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared test. Timing / travel test.	Check / re-torque connections. Overhaul. Exercise. Visual inspection.	
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test.
Racking mechanism failure		Adjust and lubricate mechanism.	Functional test - remove and install.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR MAGNETIC BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Close coil - open / shorted / failed	Measure coil resistance. Voltage test. Breaker monitor.	Visual inspection.	Functional test.
Control circuit failure	Timing / travel test. Insulation resistance test on control wires. Breaker monitor. Monitor loss of AC or DC voltage.		Functional test. Visual inspection.
Degraded lubrication	Timing / travel test. Breaker monitor. Fault recorder data review.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test. Voltage close test. Breaker monitor.	Overhaul. Verify mechanical tolerances. Exercise. Visual inspection.	Functional test.
Stored energy failure	Record and trend operations to lockout. Timing / travel test. Breaker monitor.	Clean and relubricate. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR MAGNETIC BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated arc chutes		Clean arc chutes. Visual inspection.	
Degraded lubrication	Timing / travel test. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test.
Stored energy failure	Operations to lockout. Timing / travel test. Breaker monitor.	Clean and relubricate.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR MAGNETIC BREAKER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Monitor AC & DC voltage. Timing / travel test. Control wire insulation resistance test.	Visual inspection.	Functional test. Visual-indicating light lit.
Degraded lubrication	Timing / travel test. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical clearances. Visual inspection.	Functional test.
Stored energy failure	Operations to lockout. Timing / travel test. Breaker monitor.	Clean and relubricate. Visual inspection.	Functional test.
Trip coil - open / shorted / failed	Trip coil monitoring check (red light). Timing / travel test. Measure coil resistance. Voltage close test. Breaker monitor.		Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: AIR MAGNETIC BREAKER

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Solid dielectric failure	Insulation power factor test. Insulation resistance test. Hi-pot test.	Dry solid insulation. Clean solid insulation. Clean and wipe bushings and support insulators.	Visual inspection.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: BATTERY

Failure Mode: Loss of capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance connection	Resistance test. Infrared inspection.	Clean connections & coat w / oxidation inhibitor. Re-torque connections. Visual inspection.	Capacity test. Impedance test.
Internal component degradation	Capacity test. Impedance test.	Replace battery cells. Visual inspection.	
Internal / external contamination		Clean jars (battery case). Clean straps and coat with oxidation inhibitor. Visual inspection.	Capacity test.
Leaks		Reseal with RTV or other similar product. Visual inspection for cracked jars, post seal leakage, plate growth, over filling and overcharging (check charger output).	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: BATTERY

Failure Mode: Loss of capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of electrolyte		Visual inspection.	Specific gravity.
Over temperature			Capacity test. Impedance test.
Under / over charge		Visual inspection (boil over).	Specific gravity. Cell voltage.
Failure Mode: Loss of conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Resistance test - (Micro-Ohm).	Clean. Coat with oxidation inhibitor.	Capacity test.
Grounds			Alarm / indicator lights / ground detector. Measure voltage from + & - terminals to ground.
Loose connection	Resistance test - (Micro-Ohm).	Re-torque. Replace straps and fasteners.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: BATTERY CHARGER

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Connection	Measure resistance. Record and trend battery charger output.	Visual inspection.	
Loss of regulation	Capacity test. Impedance test.	Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CAPACITOR BANKS

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
Animal intrusion / vegetation growth	Condition Monitoring	Time Directed	Failure Finding
		Bare ground herbilization. Fence / animal barrier maintenance. Inspect fence and enclosures.	
Failure Mode: voltage unbalance			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
Loss of individual can	Condition Monitoring	Time Directed	Failure Finding
	Record and trend voltage and neutral current.	Visual inspection of cans and fuses.	Capacitance test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to Carry Load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared test. Travel / timing test.	Check / re-torque connections. Visual internal inspection. Exercise.	
Mechanism / linkage failure	Timing / travel test.	Calibrate / check measurement. Exercise. Verify mechanical tolerances. Visual inspection of linkage.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contactor failure	Record and trend coil resistance. Voltage close test.		Functional test (close).
Control circuit failure	Monitor AC / DC control voltage. Fault recorder data analysis. Timing / travel test. Control wire insulation resistance test.	Visual inspection.	Functional test (close). Visual-indicating light lit.
Degraded lubrication	Travel / timing test. Fault recorder data review.	Clean and relubricate. Exercise. Visual inspection.	Functional test (close).
Mechanism / linkage failure	Timing / travel test.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection of linkage.	Functional test (close).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated gas	Moisture test. SF6 quality test-lab. SF6 quality test-field.		
Degraded lubrication	Timing test. Fault recorder data review.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Low gas pressure	Monitor / record gas pressure.		Visual inspection of pressure gauge and targets.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanism / linkage failure	Timing / travel test.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection of linkage.	Functional test.
SF6 puffer failure	Timing / travel test. Monitor high pressure gauge.		Functional test (open).
Stored energy failure			Functional test (open).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to open			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Brake fails to release	Timing / travel test.	Adjust / replace brake. Clean and lubricate.	Functional test (open).
Contactor failure	Timing / travel test. Record and trend coil resistance. Voltage close test. Monitor trip circuit current.		Functional test (open).
Control circuit failure	Monitor AC / DC control voltage. Fault recorder data analysis. Timing / travel test. Insulation resistance - control wires.	Visual inspection.	Functional test (open). Visual-indicating light lit.
Degraded lubrication	Travel / timing test. Fault recorder data review.	Clean and relubricate. Exercise. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CIRCUIT SWITCHER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanism / linkage failure	Timing / travel test.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection of linkage.	Functional test.
Shunt trip failure	Timing / travel test.		Functional test (open).
Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated gas	Moisture test. SF6 quality test-lab. SF6 quality test-field.		
Low gas pressure	Record and trend gas pressure.		Visual inspection of gas pressure gauge / target.
Solid dielectric failure	Insulation power factor test. Insulation resistance test.	Clean porcelain.	Visual inspection of porcelain.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CURRENT TRANSFORMER (STAND ALONE)

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Measure / trend paint thickness. Measure / trend tank plate thickness. Dye penetration test. Sample and analyze corrosion / contamination.	Paint. Wash / clean. Check heaters. Visual inspection.	Measure paint thickness.
Porcelain failure	Dye penetration test. Hot collar test.	Visual inspection.	
Seal failure	Dye penetration test.	Replace seals. Visual inspection.	
Valve leak	Dye penetration test. Trend insulating medium level.	Replace valve. Tighten packing nut. Tighten valve. Replace valve packing. Visual inspection.	
Weld failure	Ultrasound. Magna flux. X-ray. Dye penetration.	Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CURRENT TRANSFORMER (STAND ALONE)

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing failure	Insulation power factor test. Equivalent salt deposit density. Ultrasonic detection (partial discharge). Measure leakage current.	Clean bushings. Visual inspection.	Insulation resistance test. Radio frequency interference measurement. Equivalent salt deposit density.
Insulation failure	Insulation power factor test. Dissolved gas analysis. Partial discharge test.	Clean molded housing. Visual inspection.	Insulation resistance test. Infrared inspection. Winding ratio test. Radio frequency interference measurement.
Low oil	Monitor oil level.	Re-fill oil. Calibrate oil gauge.	Visual inspection. Infrared inspection.
Oil dielectric failure	Insulation power factor test. Oil quality test. Dissolved gas analysis.	Process / replace oil.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: CURRENT TRANSFORMER (STAND ALONE)

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Dissolved gas analysis. Infrared inspection. Measure / trend voltage. Insulation power factor test.	Clean / tighten connections. Visual inspection.	Inspect fuses. Measure voltage. Monitor / alarm. Continuity check of windings. Infrared inspection.
Out of calibration	Measure / plot drift. Insulation power factor test.	Calibrate. Replace aged components.	
Shorted turns	Dissolved gas analysis. Capacitance test. Insulation power factor test.		Winding ratio test. Measure voltage. Record and trend current.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ELECTROMECHANICAL RELAY

Failure Mode: Fails to target			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal connection failure		Tighten / re-torque connections. Visual inspection.	Functional test.
Out of adjustment		Calibrate / adjust.	
Failure Mode: Improper operation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Calibration. Visual inspection.	Fault simulation. Functional test.
Contact assembly failure		Clean / adjust. Visual inspection.	Functional test.
Internal connection failure		Re-torque / tighten connections. Visual inspection.	Functional test.
Mechanical restriction		Calibration test. Clean. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ELECTROMECHANICAL RELAY

Failure Mode: Improper operation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Out of calibration / adjustment	Measure / plot drift.	Check calibration. Change out aged components (capacitors) (e.g. change capacitors out of a KD relay).	Fault simulation. Analyze fault records for proper operation.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ENCLOSED BUS SYSTEM (METAL CLAD)

Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connections		Contact resistance test. Visual inspection.	Infrared.
Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
Particle/ contamination	Condition Monitoring	Time Directed	Failure Finding
		Clean and re-torque. Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: FAULT RECORDERS

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Visual inspection (display). Functional test. Periodic polling.
Modem failure			Visual inspection (display). Functional test. Periodic polling.
Power supply failure			Visual inspection (display). Functional test. Periodic polling.

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test.	Visual inspection (display). Monitor alarm.
Out of calibration		Calibrate.	Function test.
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: FAULT RECORDERS

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test.	Visual inspection (display). Monitor alarm.
Out of calibration		Calibrate.	Functional test.
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: FOUNDATION AND SUPPORT

Failure Mode: Loss of structural integrity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bolted structures, welds, and connection failures	Dye penetrant. X-ray. Magna flux. Ultrasonic.	Clean, prime, and paint. Visual inspection.	
Corrosion		Clean, prime, and paint. Visual inspection.	
Setting, aging of concrete		Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: GAS ISOLATED BUS

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Leaks (gaskets, welds, piping, fittings, and valves)	Monitor temperature compensated pressure (density). Ultrasonic leak detection. Track and trend SF6 usage.	Visual inspection.	

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulator failure	Audio indication of insulator failure. Partial discharge.		Hi-pot test.
Loose connections (switches, bus joints, etc.)	Gas analysis (quality test). Infrared. Resistance test. Micro-Ohm test.		
Moisture / particle contamination of gas	Gas analysis (quality test). Dew point (moisture analysis).		Hi-pot test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: GAS ISOLATED BUS

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Moisture / particle contamination of solid insulation	Gas analysis (quality test). Dew point (moisture analysis).		Hi-pot test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: GROUNDING

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bad propellant (fault initiating switch - explosive charge)			Functional test (close).
Control circuit failure	Control wire insulation resistance test. Visual inspection of terminal connections.		Functional test (close).
Low gas pressure (fault initiating switch - compressed gas)	Monitor / record pressure. Moisture test.	Lubricate, adjust and exercise. Visual inspection for leaks.	Functional test (close).
Mechanism / linkage failure		Lubricate, adjust and exercise.	Functional test (close).
Operator failure		Lubricate, adjust and exercise.	Functional test (close).
Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Low gas pressure (fault initiating switch - compressed gas)	Monitor / record pressure. Moisture test.	Lubricate, adjust and exercise. Visual inspection for leaks.	Functional test (close).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: INDICATING/RECORDING METERS

Failure Mode: Fails to store peak readings			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Calibration test. Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: INVERTER

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanical failure			Functional test.
Open circuit			Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ISOLATING

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bus connections	Infrared inspection for hot spots, loose connections, etc. Contact resistance test.	Clean. Coat with oxidation inhibitor. Re-torque loose bolted connections. Visual inspection for loose and / or corroded connections.	
High contact resistance	Contact resistance test. Infrared inspection for hot spots, loose connections, etc.	Clean and lubricate. Coat with oxidation inhibitor. Check / adjust contact pressure. Replace contacts. Linkage adjustment.	

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corroded hinge pin and / or mechanism linkage corrosion	Infrared hot spots due to corrosion. Visual inspection.	Clean, lubricate and adjust.	Functional test (open / close).
Improper alignment / adjustment of blade or stationary contact	Infrared monitoring of blade contacts.	Clean, lubricate and adjust. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ISOLATING

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Latch fails to close	Visual inspection for proper operation of latch.	Clean, lubricate and adjust latch.	Functional test (close).
Motor control circuit failure (contactors, fuses, wiring)	Visual inspection of control wiring and connections. Check contactor resistance.	Check heater. Adjust brakes. Lubricate. Adjust cams.	Functional test (open / close).
Motor failure		Clean, lubricate and adjust.	Functional test (open / close). Coupled / decoupled.
Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corroded hinge pin and / or mechanism linkage corrosion	Infrared hot spots due to corrosion. Visual inspection.	Clean, lubricate and adjust.	Functional test (open / close).
Improper alignment / adjustment of blade or stationary contact		Visual inspection.	Functional test.
Interrupter failure (load break)		Inspect, clean and adjust.	High voltage DC test. Vacuum bottle (hi-pot).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ISOLATING

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Latch fails to close	Visual inspection for proper operation of latch.	Clean, lubricate and adjust latch.	Functional test (close).
Motor control circuit failure (contactors, fuses, wiring)	Visual inspection of control wiring and connections. Check contactor resistance.	Check heater. Adjust brakes. Lubricate. Adjust cams.	Functional test (open / close).
Motor failure		Clean, lubricate and adjust.	Functional test (open / close). Coupled / decoupled.
Whip failure (load break)		Inspect, clean, and adjust. Visual inspection for burning and seating.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ISOLATING

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contact welding		Visual inspection.	Functional test (open).
Corroded hinge pin	Infrared for signs of hot spots due to corrosion. Visual inspection.	Clean, lubricate and adjust.	Functional test (open / close). Infrared for signs of hot spots due to corrosion.
Latch fails to release		Clean, lubricate, adjust latch. Visual inspection for corroded or stuck latch.	Functional test (open).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: ISOLATING

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Defective insulator (broken, cracked, or chipped)	Visual inspection for broken, chipped, or cracked insulators. Insulation resistance test. High voltage DC test (hi-pot).		Ring out insulators.
External contamination (insulator)	Visual inspection for surface contamination. Insulation resistance test. High voltage DC test (hi-pot).	Clean / wash.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: MICROPROCESSOR RELAY

Failure Mode: Fails to target			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal component failure			Functional test.
Failure Mode: Improper operation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure (this is external to the relay)		Calibration. Measure signal levels.	Functional test.
Internal component failure	Analyze fault records for proper operation. Self diagnostics.	Calibration. Visual inspection.	Fault simulation. Analyze fault records for proper operation. Functional test.
Trip output failure			Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to Carry Load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared test. Travel / timing test. Micro-Ohm test (bushing to bushing).	Check / re-torque connections. Visual internal inspection. Overhaul. Exercise.	
Mechanism / linkage failure	Timing / travel test. Calibrate / check measurement. Breaker monitor.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection.	Functional test. Test heater circuit.
Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Close coil - open / shorted / failed	Voltage close test. Measure coil resistance. Check heaters for control valve coil assembly. Breaker monitor. Timing / travel test.	Visual inspection.	Functional test. Close coil monitoring.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Monitor AC & DC voltage. Fault recorder data analysis. Timing / travel test. Control wire insulation resistance test. Breaker monitor.		Functional test. Visual inspection.
Degraded lubrication	Timing / travel test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Interrupter failure	Timing / travel test. Contact resistance test. Fault recorder data analysis. Monitoring phase currents (SCADA).	Overhaul / replace. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test. Test heater circuit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stored energy failure	Operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor accumulator precharge pressure. Monitor pump up time. Monitor AC voltage. Breaker monitor. Timing / travel test.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Verify mechanical tolerances. Overhaul compressor. Overhaul hydraulic system. Visual inspection.	Functional test.

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Monitor AC / DC voltage. Fault recorder data analysis. Timing / travel test. Control wire insulation resistance test. Breaker monitor.		Functional test (open & close). Visual-indicating light lit, connections, insulation, etc.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Degraded lubrication	Timing test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Interrupter contact failure	Insulation power factor test. Timing / travel test. Monitor test of pre-insertion resistors. Monitor test of grading capacitors. Infrared inspection.	Overhaul interrupter. Visual inspection of interrupter.	
Loss of oil		Replace gaskets and seals.	Visual inspection of gauge / surroundings.
Mechanism / linkage failure	Timing / travel test.	Overhaul / replace. Exercise. Verify mechanical tolerances. Visual inspection of linkage.	Functional test (open). Test heater circuit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Poor oil quality	Dielectric test. Oil color (visual or colorimeter).	Filter / replace oil.	
Resistor failure	Timing / travel test. Measure resistance. Breaker monitor. Power factor test.		

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stored energy failure	Timing / travel test. Monitor AC voltage. Operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor accumulator precharge pressure. Monitor pump up time. Breaker monitor.	Change oil. Change belts. Change filter. Change / filter hydraulic oil. Cycle / force hydraulic oil flow. Bleed air tank. Verify mechanical tolerances. Visual inspection.	Functional test (open).

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Timing / travel test. Control wire insulation test. Monitor AC & DC voltage. Fault recorder data analysis. Breaker monitor.	Visual inspection.	Functional test (open). Visual-indicating light lit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Degraded lubrication	Timing / travel test. Fault recorder data review (speed of breaker). Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection.	Functional test (open). Test heater circuit.
Stored energy failure	Operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor accumulator precharge pressure. Monitor pump up time. Monitor AC voltage. Breaker monitor. Timing / travel test.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Verify mechanical tolerances. Overhaul compressor. Overhaul hydraulic system. Visual inspection.	Functional test.
Trip coil - open / shorted / failed	Timing / travel test. Measure coil resistance. Voltage test. Monitor trip coil current. Breaker monitor.	Visual inspection.	Functional test (open). Trip coil monitoring check (red light) - visual.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL CIRCUIT BREAKERS

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
External and / or internal contamination	Dielectric test. Insulation power factor test. Insulation resistance test.	Filter or replace oil. Clean / wash bushings.	Visual inspection.
Loss of oil			Visual inspection of oil level sight gauge.
Oil related failure	Oil dielectric test. Insulation power factor test. Insulation resistance test.	Filter or replace oil. Visual inspection.	Visual inspection of oil level sight gauge.
Solid dielectric failure	Insulation power factor test. Insulation resistance test.	Clean bushings and supports. Replace liner (oil reclosers).	Visual inspection for cracks and tracking.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL INSULATED CABLE BUS SYSTEM

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Check system oil level. Monitor cathodic protection system.	Maintain cathodic protection system. Visual inspection.	

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of pressure	Trend system pressure.	Periodic pump inspection.	
Oil contamination	Oil analysis (particle analysis, acidity, DGA, pH, etc.).	Reclaim oil. Replace oil.	Hi-pot test. Insulation resistance test.
Solid insulation degradation	Oil analysis (particle analysis, acidity, DGA, pH, etc.).		Hi-pot test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: OIL INSULATED CABLE BUS SYSTEM

Failure Mode: Reduced/no capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of circulation	Monitor oil flow. Track and trend differential pressure. Monitor pressure.	Maintain pump / motor. Maintain auxiliary controls (e.g. inspect contacts). Visual inspection.	
Loss of cooling	Trend temperature / water flow coolant.	Maintain heat exchangers (i.e. cleaning, lubricate system, etc.). Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Periodic painting. Periodic washing/cleaning. Visual inspection for signs of rust or leaks.	
Gasket failure	Record and trend inert gas usage rate. Monitor inert gas pressure. Monitor oil level. Oil quality test.	Re-torque bolts, capscrews, couplings, and fittings. Regasket. Visual inspection for oil leaks.	Ultra sound test for leaks. Halogen leak test. Acoustic monitoring.
Loose bolts, connections, fatigue failure of piping	Monitor oil level. Measure/trend gas usage rate. Monitor gas pressure.	Re-torque bolts, capscrews, couplings, and fittings. Visual inspection of connections and piping/vibration.	Acoustic monitoring for leaks.
Overpressurization	Monitor inert gas pressure. Monitor oil level.	Adjust inert gas regulator. Replace pressure relief device/rupture disk. Visual inspection of pressure relief device targets. Visual inspection for bulging tank.	Functional test of pressure relief device.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Valve leakage	Measure / trend gas usage rate. Monitor gas pressure. Monitor oil level.	Rebuild / pack valves tighten packing. Visual inspection of connections and piping.	
Weld failure	Record and trend inert gas usage rate. Monitor inert gas pressure. Monitor oil level. Oil quality test.	Visual inspection for oil leaks.	Ultra sound test for leaks. Halogen leak test. Acoustic monitoring.
Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing failure	Infrared inspection of bushing for hot spots. Monitor bushing tap potential. Bushing power factor test. Dissolved gas analysis (DGA) on bushing oil.	Clean bushings. Replace suspect type bushings. Visual inspection of bushings for cracks / chips. Visual inspection of bushing oil level.	
Insulation oil contamination / degradation	Oil quality test. Dissolved gas analysis (DGA). Oil analysis for metals.	Filter / degas oil. Add oxidation inhibitors.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Low oil	Record and trend oil temperature versus load. Infrared inspection for oil level Monitor oil level.	Calibrate oil level gauge. Visual inspection of oil gauge for low oil level.	
Solid insulation failure	Oil quality test. Dissolved gas analysis (DGA). Short circuit impedance test. Winding excitation test.	Check / tighten blocking (one time occurrence at commissioning).	Insulation resistance test. Insulation resistance test - core ground.
Winding insulation failure	Dissolved gas analysis (DGA). Oil quality test. Short circuit impedance test. Partial discharge test. Insulation power factor test.		Winding ratio test. Insulation resistance test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Fails to regulate voltage (LTC transformers and regulators)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Failed drive train (motor/controls/linkage)	Record motor vibration monitor. Record and trend operating current/torque. Monitor transformer output voltage. Record and trend number of operations. Monitor for out of step condition (three single phase transformers).	Lubricate drive mechanism. Replace or adjust brakes. Drive motor brush inspection. Internal inspection of LTC drive mechanism.	Functional test of LTC controls. Visual inspection of linkage and position indicators.
Failed preventive auto transformer	Monitor transformer output voltage. Dissolved gas analysis (DGA). Insulation power factor test. Excitation test.	Internal inspection of windings.	Winding ratio test. Insulation resistance test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Fails to regulate voltage (LTC transformers and regulators)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Interrupter contact failure	DGA of LTC compartment oil. Infrared inspection. Temperature monitoring. Oil quality test (oil quality includes dielectric). Contact resistance test (bridge test).	Internal inspection of LTC. Contact - replacement / exercise. Visual inspection (contact wear index, vacuum bottle). Hi-pot vacuum bottle.	Winding ratio test. Insulation resistance test.
Loss of sensing voltage		Visual inspection of control wiring and connections.	Measure input voltage.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Fails to regulate voltage (LTC transformers and regulators)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Reversing contact failure	Dissolved gas analysis of oil in LTC compartment. Infrared inspection. Temperature monitoring. Oil quality test.	Internal inspection. Reversing switch contact - replace / exercise.	Winding ratio test.
Selector switch contact failure	Dissolved gas analysis - LTC compartment. Infrared inspection. Temperature monitoring. Oil quality test.	Internal inspection of LTC. Stationary contact - replace / exercise.	Functional test of change taps. Winding ratio test.
Voltage control regulating relay failed / out of adjustment	Monitor transformer output voltage. Record and trend voltage. Record and trend the range / number of operations. Monitor for out of step condition (three single phase transformers). Monitor relay operation and time sequences.	Calibrate voltage regulating relay.	Functional test of voltage controls - bandwidth, time delay.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Reduced/no capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Auxiliary control failure	Monitor for loss of cooling or overtemperature.	Calibrate temperature switches. Inspection of control cabinet - visually for dirt, water, smell for burnt components, audio for control noise (relay chatter), overloads (breaker thrown).	Functional test including visual inspection of proper operation of fans and pumps. Insulation resistance test of control circuitry. Monitor relay operating time (sequence of operations).
Bushing CT failure	Insulation resistance test. DC resistance test. Ratio test.		CT excitation test. Saturation test. Burden test (admittance test). Winding ratio test. Continuity test.
Clogged / corroded cooler / radiator	Infrared inspection for cold spot. Record and trend oil temperature. Monitor for loss of cooling or high temperature.	Periodic cleaning. Visual inspection for clogs and debris. Touch, to assess the general temperature profile.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Reduced/no capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Fan failure	Vibration analysis of fan motor. Record and trend motor speed. Record and trend motor current. Infrared inspection of fan motor. Ultrasonic analysis of fan motor. Monitor on loss of cooling or high temperature.	Periodic lubrication of bearings. Overhaul motor (replace bearings). Visual inspection for proper operation and motor control wiring. Check for motor overload trip / alarm.	Functional test fan banks (manual & automatic operation; start & stop operation). Audio for proper operation. Insulation resistance test of fan motors.
High resistance load path	Infrared inspection of bus connections for hotspots. Record / trend top oil, winding, or hot spot temperature. Dissolved gas analysis on LTC. Record and trend load current Oil quality test. DC resistance (bridge) of winding, connections, and bus.	Clean and re-torque connections. Internal inspection and repair of tap changer. Internal inspection of transformer for bad connections.	Winding ratio test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Reduced/no capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path (continued)	Contact resistance test on tap changer. Winding excitation test. Particle analysis of oil in LTC. Temperature differential between main tank and LTC tank.		
Low oil	Infrared inspection for low oil level. Monitor oil level. Record and trend oil temperature and load.	Calibrate oil level gauge. Visual inspection of low oil gauge.	
Pump failure	Vibration analysis of pump and motor. Infrared inspection of pump and motor. Monitor bearings for wear. Monitor overtemp and oil flow. Record and trend motor current. Trace metal analysis of oil for bearing damage. Ultrasonic analysis of pump motor.	Replace pumps with new/rebuilt units. Overhaul pumps. Visual inspection for motor control wiring and connections.	Functional test pumps for oil flow. Insulation resistance test of pump motors.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: POWER TRANSFORMERS, REGULATORS, REACTOR (OIL FILLED)

Failure Mode: Reduced/no capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Restricted oil flow	Monitor and record oil flow rates. Infrared inspection for cold spots. Record and trend over temperature. Record and trend pump motor current. Record and measure differential oil pressure - measure across pump.	Visual inspection of valve position indicator for open.	Functional test of pumps (both manual and automatic modes, and for start and stop). X-ray of valves for open or close.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REMOTE TERMINAL UNIT

Failure Mode: Fails to alarm			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Self diagnostic test.		Functional test - status point.
Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Self diagnostic test.		Functional test - status point.
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Battery failure			Functional test.
Component failure			Functional test.
Power supply failure			Functional test.
Timing adjustment			Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REMOTE TERMINAL UNIT

Failure Mode: Fails to indicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Self diagnostic test.		Functional test - status point.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (DIGITAL/MICRO)

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test. Replace components. Visual inspection.	Functional test.
Modem failure			Periodic polling. Visual inspection (modem display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (DIGITAL/MICRO)

Failure Mode: Fails to display output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test.	Visual inspection (display). Functional test. Monitor alarm.
Internal connection failure	Trend / monitor output or display.	Function test.	Monitor alarm. Visual inspection. (display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test. Monitor alarm.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (DIGITAL/MICRO)

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Replace components.	Visual inspection (display). Functional test.
Internal connection failure	Trend / monitor output or display.	Tighten connections.	Monitor alarm. Visual inspection (display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (DIGITAL/MICRO)

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Trend / monitor output or display.	Replace battery. Replace components. Visual inspection.	Monitor alarm. Functional test.
Out of calibration		Calibrate.	Functional test.
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (ELECTRO/MICRO)

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test. Replace components. Visual inspection.	Functional test.
Modem failure			Periodic polling. Visual inspection (modem display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.

Failure Mode: Fails to display output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test.	Visual inspection (display). Functional test. Monitor alarm.
Internal connection failure	Trend / monitor output or display.	Function test.	Monitor alarm. Visual inspection (display). Functional test (modem).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (ELECTRO/MICRO)

Failure Mode: Fails to display output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure			Visual inspection (display). Functional test. Monitor alarm.

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Replace components.	Visual inspection (display). Functional test.
Internal connection failure	Trend / monitor output or display.	Tighten connections.	Monitor alarm. Visual inspection (display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (ELECTRO/MICRO)

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Trend / monitor output or display.	Replace battery. Replace components. Visual inspection.	Monitor alarm. Functional test.
Out of calibration		Calibrate.	Functional test.
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (SOLID STATE)

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test. Replace components. Visual inspection.	Functional test.
Modem failure			Periodic polling. Visual inspection (modem display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.
Failure Mode: Fails to display output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Functional test.	Visual inspection (display). Functional test. Monitor alarm.
Internal connection failure	Trend / monitor output or display.	Function test.	Monitor alarm. Visual inspection (display). Functional test (modem).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (SOLID STATE)

Failure Mode: Fails to display output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure			Visual inspection (display). Functional test. Monitor alarm.

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Replace components.	Visual inspection (display). Functional test.
Internal connection failure	Trend / monitor output or display.	Tighten connections.	Monitor alarm. Visual inspection (display). Functional test (modem).
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: REVENUE METERS/RECORDERS (SOLID STATE)

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure	Trend / monitor output or display.	Replace battery. Replace components. Visual inspection.	Monitor alarm. Functional test.
Out of calibration		Calibrate.	Functional test.
Power supply failure			Visual inspection (display). Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SEQUENCE OF EVENTS RECORDERS

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Calibration test.	Visual inspection. Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared. Travel / timing test. Micro Ohm test.	Check / re-torque connections. Visual inspection. Overhaul. Exercise.	
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Visual inspection (heaters, etc.). Overhaul. Exercise. Verify mechanical tolerances.	Functional test. Test heater circuit.

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Close coil - open / shorted / failed	Measure coil resistance. Voltage close test. Timing / travel test. Breaker monitor.	Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Monitor loss of AC or DC voltage. Fault recorder data analysis. Timing / travel test. Breaker monitor. Control wire insulation resistance test.		Functional test. Visual inspection.
Degraded lubrication	Timing / travel test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Interrupter failure	Timing / travel test. Contact resistance test. Fault recorder data analysis. Monitor phase currents. Breaker monitor.	Overhaul / replace. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Low gas pressure	Check / test density monitor. Monitor pressure. Check low pressure lockout / trip. Trend gas leak rate. Breaker monitor.		Functional test. Test heater circuit.
Mechanism / linkage failure	Timing / travel test.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test. Test heater circuit.
Stored energy failure	Operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor accumulator precharge pressure. Monitor pump up time. Test pressure switch. Monitor AC voltage. Timing / travel test. Breaker monitor.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Verify mechanical tolerances. Overhaul compressor. Overhaul hydraulic system. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contaminated gas	Moisture test. SF6 quality test-lab. SF6 quality test-field.	Reclaim / replace gas.	
Degraded lubrication	Timing / travel test. Fault recorder data review (speed of breaker). Breaker monitor.	Clean and relubricate. Exercise. Visual inspection of lubricant.	Functional test.
Interrupter failure	Insulation power factor test. Timing / travel test. Fault recorder data analysis. Monitor test of pre-insertion registors. Monitor test of grading capacitors.	Overhaul / replace. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Low gas pressure	Test heater circuit. Check / test density monitor. Monitor pressure. Check low pressure lockout / trip. Monitor lockout (SCADA). Gas quality test. Breaker monitor.	Calibrate temperature compensated pressure switches. Replace / overhaul. SF6 compressor components.	Functional test. Test heater circuit.
Mechanism / linkage failure	Timing / travel test. Verify mechanical tolerances.	Visual inspection. Overhaul / replace. Exercise.	Functional test. Test heater circuit.

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Resistor / grading capacitor failure	Timing / travel test. Measure resistance / capacitance. Breaker monitor. Power factor test.		

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
SF6 blast valve failure	Timing / travel test. Monitor pressure gauge (high / low). Monitor compressor run time. Measure gas consumption during operation. Breaker monitor. Fault recorder data review.	Overhaul / replace blast valve. Internal inspection.	
SF6 puffer failure	Timing / travel test. Power factor test. Fault recorder data review. Breaker monitor.	Overhaul interrupters. Replace sealed interrupter.	
Stored energy failure	Operations to lockout. Monitor pressure. Monitor motor run time. Monitor leak rate. Monitor accumulator precharge pressure. Record pump up time. Test pressure switch. Monitor AC voltage. Timing / travel test. Breaker monitor.	Bleed air tank. Verify mechanical tolerances. Visual inspection (spring integrity, etc.). Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Fault recorder data analysis. Timing / travel test. Control wire insulation resistance test. Breaker monitor. Monitor loss of AC and DC voltage.		Functional test. Visual inspection.
Degraded lubrication	Timing / travel test. Fault recorder data review (speed of breaker). Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test (open).
Interrupter failure	Timing / travel test. Contact resistance test. Fault recorder data analysis. Monitor phase currents. Breaker monitor.	Overhaul / replace. Visual inspection.	Functional test.
Low gas pressure	Check / test density monitor. Monitor pressure Check low pressure lockout / trip. Trend gas leak rate. Breaker monitor.		Functional test. Test heater circuit.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Mechanism / linkage failure	Timing / travel test.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test (open). Test heater circuit.
Stored energy failure	Operations to lockout. Monitor pressure. Monitor motor runtime. Monitor leak rate. Monitor accumulator precharge pressure. Record pump up time. Test pressure switch. Monitor AC voltage. Timing / travel test. Breaker monitor.	Change oil. Change belts. Change filters. Change / filter hydraulic oil. Cycle / force hydraulic fluid flow. Bleed air tank. Verify mechanical tolerances. Visual inspection (spring integrity, etc.). Visual inspection.	Functional test (open).
Trip coil - open / shorted / failed	Trip coil monitoring check (red light). Timing / travel test. Measure coil resistance. Reduced voltage trip test. Breaker monitor.	Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing failure	Insulation power factor test. Insulation resistance test.	Clean / wash bushings. Internal inspection for leaks.	Visual inspection.
Contaminated gas	Moisture test. SF6 quality test-lab. SF6 quality test-field.	Reclaim / replace gas.	Hi-pot test (puffer bottle).

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SF6 GAS CIRCUIT BREAKER

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Low gas pressure	Record pressure gauge readings. Test heater circuit. Check / test density monitor. Monitor pressure (on line). Check low pressure lockout / trip. Monitor lockout (SCADA). Gas quality test. Trend gas leak rate. Breaker monitor.	Calibrate temperature compensated pressure switches. Replace / overhaul. SF6 compressor components.	Functional test.
Solid dielectric failure	Insulation power factor test. Insulation resistance test.	Clean / replace.	Visual inspection.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SOLID STATE RELAY

Failure Mode: Fails to target			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal component failure		Replace lamp.	Functional test.
Failure Mode: Improper operation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contact assembly failure		Clean / adjust. Visual inspection.	Functional test.
Internal component failure		Calibration. Visual inspection.	Fault simulation. Analyze fault records for proper operation. Functional test.
Internal connection failure		Re-torque / tighten connections. Visual inspection.	Functional test.
Out of calibration		Calibration.	Fault simulation. Analyze fault records for proper operation.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: STATION GROUND SYSTEM

Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Smart ground meter.	Re-torque. Ground resistance test. Visual inspection.	
Loose connections		Resistance check. Continuity check. Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: SURGE ARRESTOR

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
External contamination	Monitor / trend leakage current. Watts loss test.	Clean / wash. Visual inspection.	
Failure Mode: Improper operation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High or low internal resistance	Track and / or trend leakage current. Watts loss test.	Replace.	Measure voltage at which conduction takes place.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: UNINTERRUPTABLE POWER SUPPLY

Failure Mode: Loss of capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance connection	Resistance test. Visual inspection. Infrared inspection.	Clean connections. Re-torque connections.	Capacity test.
Internal component degradation	Impedance test.	Change battery / cell. Visual inspection.	Capacity test.
Internal / external contamination	Visual inspection. Water quality (distilled water) - lab test.	Clean jars (battery case). Clean straps. Coat with no-oxide grease.	Capacity test.
Leaks		Reseal with RTV, etc. Visual inspection for cracked jars, post seal leakage, plate growth, over filling, and overcharging (check charge output).	
Loss of electrolyte	Visual inspection. Specific gravity.		
Temperature	Monitor cell environment / temperature.		

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: UNINTERRUPTABLE POWER SUPPLY

Failure Mode: Loss of capacity			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Under / over charge	Specific gravity. Cell voltage. Alarm low / high voltage. Visual inspection (boil over).		

Failure Mode: Loss of conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Visual inspection. Contact resistance test (Micro-Ohm).	Clean. Coat with an oxidation inhibitor. Replace straps and fasteners.	
Grounds	Alarm / indicator lights / ground detector. Measure voltage from + & - terminals to ground.		
Loose connection	Contact resistance test (Micro-Ohm). Visual inspection.	Re-torque. Replace straps and fasteners.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VACUUM CIRCUIT BREAKER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Contact resistance test. Infrared inspection. Travel / timing test.	Check / re-torque connections. Visual inspection. Overhaul. Exercise.	
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Verify mechanical tolerances. Overhaul. Exercise. Visual inspection.	
Racking mechanism failure		Adjust and lubricate mechanism.	Functional test - remove and install.

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Close coil - open / shorted / failed	Record and trend coil resistance. Voltage close test. Timing / travel test. Breaker monitor.	Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VACUUM CIRCUIT BREAKER

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Monitor loss of AC or DC voltage. Timing / travel test. Control wire insulation resistance test. Breaker monitor.		Functional test. Visual inspection.
Degraded lubrication	Travel / timing test. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection of lubricated surfaces.	Functional test.
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test.
Stored energy failure	Record operations to lockout. Breaker monitor.	Clean and relubricate. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VACUUM CIRCUIT BREAKER

Failure Mode: Fails to interrupt			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Degraded lubrication	Timing / travel test. Fault recorder data review. Breaker monitor.	Clean and relubricate. Exercise. Visual inspection.	Functional test (open).
Loss of vacuum			Hi-pot test.
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances. Visual inspection.	Functional test.
Stored energy failure	Timing / travel test. Operations to lockout. Breaker monitor.	Clean and relubricate. Visual inspection.	Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VACUUM CIRCUIT BREAKER

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure	Timing / travel test. Control wire insulation resistance test. Monitor AC & DC voltage. Breaker monitor.	Visual inspection.	Functional test. Visual-indicating light lit.
Degraded lubrication	Travel / timing test.	Clean and relubricate. Exercise. Visual inspection.	Functional test.
Mechanism / linkage failure	Timing / travel test. Breaker monitor.	Overhaul. Exercise. Verify mechanical tolerances.	Functional test. Visual inspection.
Stored energy failure	Timing / travel test. Operations to lockout. Breaker monitor.	Clean and relubricate. Visual inspection.	Functional test.
Trip coil - open / shorted / failed	Monitor trip coil. Monitoring check (red light). Timing / travel test. Record and trend coil resistance. Voltage close test. Breaker monitor.		Functional test.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VACUUM CIRCUIT BREAKER

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of vacuum			Hi-pot test.
Solid dielectric failure	Insulation power factor test. Insulation resistance test. Hi-pot test.	Clean and wipe bushings and support insulators. Dry solid insulation. Clean solid insulation.	Visual inspection.

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VOLTAGE TRANSFORMER, CCVT, AND POTENTIAL DEVICE

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Measure/trend paint thickness. Measure/trend tank plate thickness. Dye penetration test. Sample and analyze corrosion/contamination.	Paint. Wash/clean. Check heaters. Visual inspection.	Measure paint thickness.
Porcelain failure	Dye penetration test. Hot collar test.		Visual inspection.
Seal failure	Dye penetration test.	Replace seals. Visual inspection.	
Valve leak	Dye penetration test. Trend insulating medium level.	Replace valve. Tighten packing nut. Tighten valve. Replace valve packing. Visual inspection.	
Weld failure	Ultrasound. Magna flux. X-ray. Dye penetration.	Visual inspection.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VOLTAGE TRANSFORMER, CCVT, AND POTENTIAL DEVICE

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing failure	Insulation power factor test. Equivalent salt deposit density. Ultrasonic detection (partial discharge). Measure leakage current.	Clean bushings.	Insulation resistance test. Visual inspection. Radio frequency interference measurement. Equivalent salt deposit density.
Insulation failure	Insulation power factor test. Dissolved gas analysis. Partial discharge test.	Clean molded housing.	Insulation resistance test. Visual inspection. Infrared inspection. Winding ratio test. Radio frequency interference measurement.
Low oil	Monitor oil level.	Re-fill oil. Calibrate oil gauge.	Visual inspection. Infrared inspection.
Oil dielectric failure	Insulation power factor test. Oil quality test. Dissolved gas analysis.	Process / replace oil.	

REFERENCE DATA FOR SUBSTATION

EQUIPMENT TYPE: VOLTAGE TRANSFORMER, CCVT, AND POTENTIAL DEVICE

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High resistance load path	Dissolved gas analysis. Infrared inspection Measure / trend voltage. Insulation power factor test.	Clean / tighten connections.	Inspect fuses. Measure voltage. Monitor / alarm. Continuity check of windings. Infrared inspection.
Open circuit CCVT- (dry type)			Inspect fuses. Measure voltage. Monitor / alarm. Continuity check of windings.
Out of calibration	Measure / plot drift. Insulation power factor test.	Calibrate. Replace aged components.	
Shorted turns	Dissolved gas analysis. Capacitance test. Insulation power factor test.		Winding ratio test. Measure voltage. Record and trend current.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: CONDUCTOR - OVERHEAD

Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	
Spacer failure		Visual inspection.	
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure	Thermography / infrared inspection. Historisis test (core corrosion detector).	Visual inspection.	
Splice / connector failure	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: High resistance path			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure	Thermography / infrared inspection. Historisis test (core corrosion detector).	Visual inspection.	Line resistance test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection. Check , clean and re-torque connections.	
Subconductor failure	Thermography / infrared inspection.	Visual inspection.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: CONDUCTOR - OVERHEAD

Failure Mode: Radio/TV interference			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection		Visual inspection.	Radio/TV interference test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: FIBER OPTIC CABLE

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	
Failure Mode: Fails to transmit			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Fiber damage	Performance test.	Visual inspection.	Functional test.
Loose connection / splice	Performance test.		Functional test.
Failure Mode: High attenuation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Faulty connection	Performance test.		Functional test.
Fiber damage	Performance test.	Visual inspection.	Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: FOREIGN EQUIPMENT

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: GROUNDING

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure		Visual inspection.	
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Splice / connector failure	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure		Visual inspection.	
High soil resistivity			Ground rod to soil resistance test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection. Check, clean and re-torque connections	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: INSULATORS

Failure Mode: Fails to insulate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Broken / cracked / weathered	Insulation test.	Visual inspection.	
Contamination / corrosion	Insulation test.	Clean and inspect.	
Corona discharge / arching	Acoustic monitoring.		Night vision detection.

Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: POLE

Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion (woodpecker)		Visual inspection of pole and animal guards.	
Cross arm / brace failure		Visual inspection.	Sounding test. Core boring. Inspection / sampling.
Guy wire / anchor failure		Visual inspection.	Pull / shake test.
Pole / brace failure	Check coating thickness. Check steel thickness.	Visual inspection. Excavate and inspect.	Sounding test. Core boring. Inspection / sampling.
Soil foundation failure			Visual inspection.
Wood rot / decay / insect infestation		Visual inspection above and below grade. Periodic treatment program.	Core boring. Inspection / sampling. Sounding test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: RIGHT OF WAY/EASEMENT

Failure Mode: Fails to provide access			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Erosion		Visual inspection.	
Foreign encroachment		Visual inspection.	
Vegetation growth	Growth rate projection. Monitor tree outage rate.	Visual inspection. Herbicide application. Trim / cut / mow.	
Failure Mode: Fails to provide clearance			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Foreign encroachment		Visual inspection.	
Vegetation growth	Growth rate projection.	Visual inspection. Herbicide application. Trim / cut / mow.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SURGE ARRESTOR

Failure Mode: Fails to insulate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Moisture contamination (internal)	Power factor test.		
Surface contamination		Clean and inspect.	
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection	Thermography/ infrared inspection.	Check, clean and re-torque connections. Visual inspection.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SWITCH - MANUAL AND MOTOR OPERATED

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Component failure			Functional test.
Internal connection failure			Functional test.
Operator circuit failure			Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SWITCH - MANUAL AND MOTOR OPERATED

Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Check for proper output voltage. Clean battery terminals / check water level / specific gravity. Battery load test. Periodic battery replacement.	Functional test. Periodic polling.
Sensor failure			Functional test.
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Contact welding			Functional test (open).
Contamination / degradation of arc extinguishing medium	SF6 lab quality test (gas medium).	Reclaim / replace gas bottle.	Moisture test (gas medium). SF6 field quality test (gas medium).

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SWITCH - MANUAL AND MOTOR OPERATED

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corroded contact	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Corroded hinge pin and / or mechanism linkage corrosion		Visual inspection.	Functional test.
Degraded lubrication		Clean and lubricate.	Functional test.
Improper alignment / adjustment of blade		Clean, lubricate and adjust. Visual inspection.	Functional test.
Interrupter failure (load break)		Inspect, clean, lubricate and adjust.	
Latch failure		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SWITCH - MANUAL AND MOTOR OPERATED

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of arc extinguishing medium		Periodic gas bottle replacement. Visual inspection for signs of rust or leaks. Re-torque bolts and cap screws . Visual inspection of bushings for cracks and chips. Visual inspection of pressure relief targets.	
Mechanism linkage binds or jams		Clean, lubricate and adjust.	Functional test.
Motor / control circuit failure		Clean and adjust contacts. Clean and lubricate motor. Visual inspection of control wiring and connections.	Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: SWITCH - MANUAL AND MOTOR OPERATED

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Check for proper output voltage. Battery load test. Clean battery terminals / check water level / specific gravity. Periodic battery replacement.	Functional test. Periodic polling.
Stored energy failure		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: TOWERS - LATTICE

Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Guy wire / anchor failure		Visual inspection.	Pull / shake test.
Lattice / brace failure		Visual inspection. Clean and paint.	Pull / shake test. Check coating thickness. Check steel thickness.
Soil foundation failure		Visual inspection.	

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: WARNING DEVICE

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection		Visual inspection. Check, clean, re-torque and reseal connections.	
Structural failure		Visual inspection.	
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Lamp failure		Periodic lamp replacement. Visual inspection.	Functional test.
Loose/corroded connection		Check, clean, re-torque and reseal connections. Visual inspection.	
Power supply failure		Solar array cleaning. Periodic battery replacement. Check, clean, re-torque and reseal connections. Grease connections.	Functional test.
Strobe circuit/motor failure		Periodic unit assembly replacement. Visual inspection.	Functional test.

REFERENCE DATA FOR TRANSMISSION

EQUIPMENT TYPE: WARNING DEVICE

Failure Mode: Loss of visibility			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contamination		Visual inspection.	
Ultra violet fading / weather		Visual inspection.	
Failure Mode: Structural integrity failure			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Ultra violet aging / cracking		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CABLE (INCLUDES UNDERGROUND)

Failure Mode: Connection/termination failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection	Thermography/ infrared inspection.	Visual inspection.	Line resistance test.
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor failure			Line resistance test.
Gas insulation degradation	Lab gas quality test. Monitor and trend gas bottle reservoir pressure.	Reclaim/replace gas. Visual inspection for external leak/ corrosion.	Field gas quality test.
Oil insulation degradation	Oil dielectric test. Dissolved gas in oil analysis.	Visually inspect oil for contaminants. Filter or replace oil. Visual inspection for external leak/corrosion.	Oil power factor test.
Solid insulation degradation	Insulation resistance test. High potential testing.		Visual inspection DC jacket test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CABLE (INCLUDES UNDERGROUND)

Failure Mode: Loss of concentric neutral			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion	Ground potential rise test.		Visual inspection.

Failure Mode: Radio/TV interference			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection			Radio/TV interference test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CAPACITOR BANK - CONTROLLED

Failure Mode: Voltage unbalance			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of individual can	Record and trend voltage / neutral current.	Visual inspection for damaged cans and blown fuses.	
Failure Mode: Fails to change state			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Failed controls			Functional test. Periodic polling.
Failed operator			Functional test.
Failed switch		Visual inspection of linkage and switch / position indicators.	Functional test.
Power supply failure		Clean battery terminals / check water level / specific gravity. Battery load test. Periodic battery replacement.	Functional test. Periodic polling.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CAPACITOR BANK - CONTROLLED

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contamination		Clean and inspect.	
Loss of fluid		Visual inspection.	
Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CAPACITOR BANK - FIXED

Failure Mode: Voltage unbalance			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loss of individual can	Record and trend voltage / neutral current.	Visual inspection for damaged cans and blown fuses.	
Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contamination		Clean and inspect.	
Loss of fluid		Visual inspection.	
Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CONDUCTOR - OVERHEAD

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	
Spacer failure		Visual inspection.	
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure	Thermography / infrared inspection. Historisis test (core corrosion detector).	Visual inspection.	
Splice / connector failure	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure	Thermography / infrared inspection. Historisis test (core corrosion detector).	Visual inspection.	Line resistance test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection. Check, clean, and re-torque connections.	
Subconductor failure	Thermography / infrared inspection.	Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CONDUCTOR - OVERHEAD

Failure Mode: Radio/TV interference			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection			Radio/TV interference test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: CONVERTER - PHASE

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Check for proper output voltage.	Functional test.
Internal connection failure		Check for proper output voltage.	Functional test.
Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing contamination		Clean and inspect.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: GROUNDING

Failure Mode: Fails to maintain position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Hardware / attachment failure		Visual inspection.	
Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure		Visual inspection.	
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Splice / connector failure	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor / strand failure		Visual inspection.	
High soil resistivity			Ground rod to soil resistance test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection. Check, clean, and re-torque connections.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: LIGHTING - OUTDOOR

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion		Visual inspection of animal guards.	
Ballast failure		Visual inspection.	
Lamp failure		Periodic lamp replacement.	Visual inspection.
Loose/corroded connection		Visual inspection.	
Power supply failure		Check for proper output voltage.	Functional test.
Sensor/switch failure		Visual inspection.	
Starter board failure		Visual inspection.	

Failure Mode: Illumination level low			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection		Visual inspection.	
Power supply voltage low		Check for proper output voltage.	Functional test.
Reflector corroded		Visual inspection.	
Reflector loose/out of alignment		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: LIGHTING - OUTDOOR

Failure Mode: Illumination level low			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Refractor / lens dirty / discolored		Visual inspection.	
Vegetation intrusion		Visual inspection.	
Failure Mode: Radio/TV interference			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Ballast failure			Radio / TV interference test.
Starter board failure			Radio / TV interference test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: METERING - REVENUE - AND MONITORING DEVICE

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Visual inspection.	Functional test. Periodic polling.
Loose / corroded connection		Visual inspection.	
Modem failure			Functional test. Periodic polling.
Power supply failure		Check for proper output voltage.	Functional test.
Radio failure			Functional test. Periodic polling.
Sensor / RTU / SCADA failure			Functional test. Periodic polling.

Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Check for expected recorded data.	Periodic polling.
Internal connection failure		Visual inspection.	Functional test.
Loose / corroded connection		Visual inspection.	
Power supply failure		Check for proper output voltage.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: METERING - REVENUE - AND MONITORING DEVICE

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Visual inspection. Periodic polling.
Internal connection failure		Visual inspection.	Functional test.
Loose / corroded connection		Visual inspection.	
Out of calibration	Calibration check.	Calibration / adjustment.	Periodic polling.
Power supply failure		Check for proper output voltage.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: METERING - REVENUE - AND MONITORING DEVICE

Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: NAVIGATIONAL WARNING LIGHT - AERONAUTICAL/ NAUTICAL

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Circuit failure			Visual inspection. Functional test.
Lamp failure		Periodic lamp replacement.	Visual inspection.
Loose/corroded connection		Check, clean, re-torque and reseal connections. Visual inspection.	
Power supply failure		Check for proper output voltage. Clean battery terminals/check water level/specific gravity. Battery load test. Periodic battery replacement.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: NAVIGATIONAL WARNING LIGHT - AERONAUTICAL/ NAUTICAL

Failure Mode: Illumination level low			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection		Check, clean, re-torque and reseal connections. Visual inspection.	
Power supply voltage low		Check for proper output voltage.	
Refractor/lens dirty/discolored			Visual inspection.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: POLE - OVERHEAD STRUCTURE

Failure Mode: Warning signs illegible			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Physical damage		Visual inspection.	
UV / aging		Visual inspection.	
Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Cross arm / brace failure		Visual inspection.	Sounding test. Core boring. Inspection / sampling.
Insulator structural failure			Visual inspection.
Loose / corroded connection			Visual inspection.
Tie wire failure			Visual inspection. Radio / TV interference test.
Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion		Visual inspection of animal guards.	
Insulator contamination		Visual inspection. Clean / grease insulators.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: POLE - OVERHEAD STRUCTURE

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulator mechanical failure		Visual inspection for chipped, cracked or broken insulator.	Radio/TV interference test.
Surge arrestor contamination		Clean and inspect.	
Failure Mode: Fails to provide lightning protection			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Static lines out of position		Visual inspection.	
Surge arrestor failure			Visual inspection. Radio/TV interference test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: POLE - OVERHEAD STRUCTURE

Failure Mode: Radio/TV interference			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	Radio / TV interference test.

Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion (woodpecker)		Visual inspection of animal guards.	
Bolted structures		Check / re-torque connections. Visual inspection.	
Change grade / soil erosion / excavation		Visual inspection and grade confirmation.	
Corrosion		Visual inspection. Periodic painting.	Sounding test. Hammer pick test.
Foundation settling		Visual inspection.	
Leaning / out of alignment		Visual inspection.	
Loose / broken guy wire / anchor		Visual inspection.	Pull / shake test.
Structural fatigue		Visual inspection.	
Wood rot / decay / insect infestation		Visual inspection above and below grade. Periodic treatment program.	Core boring. Inspection / sampling. Sounding test .

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTION - CATHODIC

Failure Mode: Fails to provide conduction path			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Conductor failure			Visual inspection. Continuity check.
Insulation degradation			Visual inspection.
Failure Mode: Fails to provide protection			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Anode depletion		Visual inspection.	
Interference / material degradation from foreign system			Polarization survey.
Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTION - CATHODIC

Failure Mode: Rectifier circuit failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Functional test.
Internal connection failure			Functional test.
Power supply failure		Visual inspection.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTOR - NETWORK

Failure Mode: Fails to alarm			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Auxiliary relay failure	Calibration check.	Calibrate and / or adjust relay / circuit.	Functional test.
Communication link failure			Functional test. Periodic polling.
Power supply failure		Visual inspection.	Functional test. Periodic polling.
Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance		Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Loose / corroded connection		Visual inspection.	
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Component failure			Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTOR - NETWORK

Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal connection failure			Functional test.
Power supply failure		Visual inspection.	Functional test. Periodic polling.
Protective relay failed / out of adjustment	Calibration check.	Calibrate and / or adjust relay / circuit.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTOR - NETWORK

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Contact welding			Functional test (open).
Corroded contact		Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Degraded lubrication		Clean and lubricate.	Functional test.
Improper alignment / adjustment of contacts		Clean, lubricate and adjust.	Functional test.
Latch failure		Clean, lubricate and adjust.	Functional test (close).
Mechanism linkage binds or jams		Clean, lubricate and adjust.	Functional test.
Mechanism linkage corrosion		Visual inspection.	Functional test.
Motor / control circuit failure			Functional test.
Power supply failure		Check for proper output voltage.	Functional test. Periodic polling.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTOR - NETWORK

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stored energy failure		Clean, lubricate and adjust.	Functional test (close).
Trip coil / circuit failure			Functional test (open). Visual inspection of trip coil light.

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing contamination		Clean and inspect.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: PROTECTOR - NETWORK

Failure Mode: Structural integrity failure (pad mounted enclosure only)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	Low pressure air test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: RECLOSER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance			Functional test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Component failure			Functional test.
High ground resistance	Measure ground impedance.		
Internal connection failure			Functional test.
Power supply failure		Clean battery terminals / check water level / specific gravity. Battery load test. Periodic battery replacement. Check for proper output voltage.	Functional test. Periodic polling.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: RECLOSER

Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Protective relay failed / out of adjustment	Calibration check.	Calibrate / adjust relay / circuit.	Functional test.
Recloser logic circuit failure	Calibration check.	Calibrate / adjust circuit.	Functional test.

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal component failure		Overhaul / replace recloser.	Functional test.
Internal connection failure			Functional test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Loss of arc extinguishing medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: RECLOSER

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Battery load test. Clean battery terminals / check water level / specific gravity. Periodic battery replacement. Check for proper output voltage.	Functional test. Periodic polling.
Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing contamination		Clean and inspect.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Loss of insulation medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	
Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: RECTIFIER

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing contamination		Clean and inspect.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Failure Mode: Fails to regulate DC voltage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Check for proper output voltage.	Functional test.
Failure Mode: Reduced capacity/No output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure		Check for proper output voltage.	Functional test.
Internal connection failure		Check for proper output voltage.	Functional test.
Loose/corroded connection	Thermography/ infrared inspection.		

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: REGULATOR

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion		Visual inspection of animal guards.	
Bushing contamination		Visual inspection.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Low oil	Monitor oil level.		Visual inspection for leakage.
Oil dielectric contamination / degradation	Oil quality test. Oil dielectric test.	Filter or replace oil.	
Winding insulation failure	Oil quality test.		

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: REGULATOR

Failure Mode: Fails to regulate voltage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Failed auto transformer		Check for proper output voltage.	Functional test.
Failed drive train (motor/controls/linkage)		Visual inspection.	Functional test.
Interrupter contact failure		Visual inspection.	Functional test.
Power supply failure		Check for proper output voltage.	Functional test.
Reversing contact failure		Visual inspection.	Functional test.
Selector switch contact failure		Visual inspection.	Functional test (change taps).
Sensor failure		Visual inspection of control wiring and connections.	Functional test.
Voltage control regulating relay failed/out of adjustment	Calibration check.	Calibrate/adjust voltage regulating relay.	Functional test (bandwidth; time delay).

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: REGULATOR

Failure Mode: Reduced capacity/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection	Thermography/ infrared inspection.	Visual inspection.	
Failure Mode: Structural integrity failure (pad mounted enclosure only)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical/ structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: RIGHT OF WAY/EASEMENT

Failure Mode: Fails to provide access			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Erosion		Visual inspection.	
Foreign encroachment		Visual inspection.	
Vegetation growth	Growth rate projection. Monitor tree outage rate.	Visual inspection. Herbicide application. Trim / cut / mow.	

Failure Mode: Fails to provide clearance			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Foreign encroachment		Visual inspection.	
Vegetation growth	Growth rate projection.	Visual inspection. Herbicide application. Trim / cut / mow.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SECTIONIZER

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance			Functional test (open / close).
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Internal component failure			Functional test.
Internal connection failure			Functional test.
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Power supply failure		Battery load test. Clean battery terminals / check water level / specific gravity. Periodic battery replacement.	Functional test. Periodic polling.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SECTIONIZER

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bushing contamination		Visual inspection.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Loss of insulation medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	
Failure Mode: Structural integrity failure (pad mounted enclosure only)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - OVERHEAD

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Component failure			Functional test.
Internal connection failure			Functional test.
Operator circuit failure			Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - OVERHEAD

Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Clean battery terminals / check water level / specific gravity. Battery load test. Periodic battery replacement. Check for proper output voltage.	Functional test. Periodic polling.
Sensor failure			Functional test.
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Contact welding			Functional test (open).

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - OVERHEAD

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Contamination / degradation of arc extinguishing medium	Oil dielectric test (oil medium). Oil quality test (oil medium). Visually inspect oil for contaminants (oil medium).		
Corroded contact	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Corroded hinge pin and / or mechanism linkage corrosion		Visual inspection.	Functional test.
Degraded lubrication		Clean and lubricate.	Functional test.
Improper alignment / adjustment of blade		Clean, lubricate and adjust. Visual inspection.	Functional test.
Interrupter failure (load break)		Inspect, clean, lubricate and adjust.	
Latch failure		Clean, lubricate and adjust.	Functional test.
Loss of arc extinguishing medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	
Mechanism linkage binds or jams		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - OVERHEAD

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Motor / control circuit failure		Clean and adjust contacts. Clean and lubricate motor. Visual inspection of control wiring and connections.	Functional test.
Power supply failure		Check for proper output voltage. Battery load test. Clean battery terminals / check water level / specific gravity. Periodic battery replacement.	Functional test. Periodic polling.
Stored energy failure		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - OVERHEAD

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Fails to provide insulation			
Insulator contamination		Visual inspection.	Radio/TV interference test.
Insulator mechanical failure		Visual inspection for chipped or broken insulator.	
Loss of insulating medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Fails to carry load			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High contact resistance	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Loose / corroded connection	Thermography / infrared inspection.	Visual inspection.	
Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Component failure			Functional test.
Internal connection failure			Functional test.
Operator circuit failure			Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Fails to control			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Clean battery terminals / check water level / specific gravity. Battery load test. Periodic battery replacement. Check for proper output voltage.	Functional test. Periodic polling.
Sensor failure			Functional test.
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Communication link failure			Functional test. Periodic polling.
Contact welding			Functional test (open).
Contamination / degradation of arc extinguishing medium	Oil dielectric test (oil medium). Oil quality test (oil medium). Visually inspect oil for contaminants (oil medium).		

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corroded contact	Thermography / infrared inspection.	Check / adjust contact pressure. Clean and lubricate. Apply oxidation inhibitor. Linkage adjustment.	
Corroded hinge pin and / or mechanism linkage corrosion	Visual inspection.	Clean, lubricate and adjust.	Functional test.
Degraded lubrication		Clean, lubricate and adjust.	Functional test.
Improper alignment / adjustment of blade		Clean, lubricate and adjust. Visual inspection.	Functional test.
Interrupter failure (load break)		Inspect, clean and adjust.	Clean and lubricate.
Latch failure		Clean, lubricate and adjust.	Functional test.
Loss of arc extinguishing medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	
Mechanism linkage binds or jams		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Motor / control circuit failure		Clean and adjust contacts. Clean and lubricate motor. Visual inspection of control wiring and connections.	Functional test.
Power supply failure		Battery load test. Clean battery terminals / check water level / specific gravity. Periodic battery replacement. Check for proper output voltage.	Functional test (open / close). Periodic polling.
Stored energy failure		Clean, lubricate and adjust.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	ROUTINE MAINTENANCE TASKS		
	Condition Monitoring	Time Directed	Failure Finding
Insulator contamination		Visual inspection.	Radio / TV interference test.
Insulator mechanical failure (broken or chipped)		Visual inspection.	
Loss of insulating medium	Monitor oil level (oil medium).	Visual inspection for leakage (oil medium).	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: SWITCH/SWITCHGEAR - UNDERGROUND

Failure Mode: Structural integrity failure (pad mounted enclosure only)			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical / structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: TRANSFORMER/REACTOR

Failure Mode: Fails to provide insulation			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Animal intrusion		Visual inspection of animal guards.	
Bushing contamination		Clean and inspect.	
Bushing mechanical failure		Visual inspection of bushings for cracks and chips.	
Insulation oil contamination / degradation	Oil quality test. Oil analysis for metals. Visually inspect oil for contaminants.	Filter or replace oil.	
Low oil	Monitor oil level.	Visual inspection for signs of rust or leaks.	
Oil dielectric failure	Oil quality test. Oil dielectric test.	Filter or replace oil.	
Winding insulation failure	Oil quality test.		

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: TRANSFORMER/REACTOR

Failure Mode: Reduced capacity/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded connection	Thermography/ infrared inspection.	Visual inspection.	
Overload	Thermography/ infrared inspection. Trend load management data.		

Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Visual inspection.	
Mechanical/ structural damage		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: VAULT/MANHOLE/UNDERGROUND STRUCTURE

Failure Mode: Fails to maintain conductor position			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Cable rack structural failure		Visual inspection.	
Conduit support structural failure		Visual inspection.	
Termination panel / rack structural failure		Visual inspection.	

Failure Mode: Flooding			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Floor drain blocked		Visual inspection.	
Floor drain plugged		Visual inspection. Periodically clean drain line.	Functional test.
Level switch failure		Level switch test and calibration.	Functional test.
Power source failure			Functional test.
Sump pump discharge line blocked or restricted		Visual inspection.	Functional test.
Sump pump failure			Functional test.
Sump pump intake blocked or restricted		Visual inspection.	Functional test.

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: VAULT/MANHOLE/UNDERGROUND STRUCTURE

Failure Mode: Structural integrity failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bolted structures		Visual inspection.	
Corrosion		Visual inspection. Periodic painting.	
Cracked or spalled concrete / brick / block / mortar joints		Visual inspection.	
Foundation settling		Visual inspection.	
Unsecured entry		Visual inspection.	

REFERENCE DATA FOR DISTRIBUTION

EQUIPMENT TYPE: VAULT/MANHOLE/UNDERGROUND STRUCTURE

Failure Mode: Ventilation failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Fan discharge restricted / blocked		Visual inspection.	Functional test.
Fan failure		Visual inspection.	Functional test.
Fan intake restricted / blocked		Visual inspection.	Functional test.
Natural circulation flow paths restricted / blocked		Visual inspection.	
Power supply failure			Functional test.
Failure Mode: Volatile/Foreign fluid contamination			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gas generation due to overheating	Air quality monitoring. Air temperature monitoring.		
Intrusion of explosive or corrosive material	Air quality monitoring.	Visual inspection.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: ALARM/ANNUNCIATOR

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Subcomponent failure			Functional test by simulating input, observing operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: CABLE JACKET (EXTRUDED CABLE)

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure			Functional test - megger insulation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: CATHODIC PROTECTION

Failure Mode: Anode depletion			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
High depletion rate		Cathodic protection survey - verification of proper current to sections of protected equipment against half cell reference current.	
Failure Mode: Failure to provide conduction path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor structural failure			Functional test to verify proper operation.
Failure Mode: Pipe short to ground			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Conductor structural failure		Cathodic protection survey - verification of proper current to sections of protected equipment against half cell reference current.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: CATHODIC PROTECTION

Failure Mode: High resistance path			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose/corroded external electrical connection		Visual inspection for loose and/or corroded connections.	

Failure Mode: Rectifier circuit failure			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Power supply failure		Visual inspection of rectifier circuit ammeter.	Functional test to verify proper operation.
Subcomponent failure			Functional test to verify proper operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: EXTRUDED CABLE SYSTEM

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure	AC breakdown test. Insulation power factor test.		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: HEAT EXCHANGERS/COOLERS

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gaskets			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Failure Mode: Fails to transfer heat			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Fouling		Chemically clean to remove corrosion, scaling, or fouling.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: HEAT EXCHANGERS/COOLERS

Failure Mode: Internal leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Plugging		Chemically clean to remove corrosion, scaling, or fouling.	
Tube rupture		Internal inspection for corrosion, erosion, or fouling.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: HIGH PRESSURE FLUID CABLE SYSTEM

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			
Fluid leaks (gaskets - welds - piping - fittings - and valves)	Monitor tank low level indication / alarm. Pressurizing station pump leak detection. Track and trend pressurizing pump operations.	Visual inspection.	

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure	AC breakdown test. Audio indication of insulator failure. DC proof test. Insulation power factor test.		
Loss of pressure	Dissolved gas analysis (quality test). Monitor and track cable pressure / pump operations.		
Contamination of fluid / paper insulation	AC breakdown test. Dissolved gas analysis (quality test). Insulation power factor test.		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: HIGH PRESSURE GAS CABLE SYSTEM

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gas leaks (gaskets - welds - piping - fittings - and valves)	Monitor temperature compensated pressure (density).		

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure	AC breakdown test. DC proof test. Insulation power factor test.		
Loose connection	Dissolved gas analysis (quality test). Infrared.		
Moisture / particle contamination of gas	AC breakdown test. Dew point (moisture analysis). Dissolved gas analysis (quality test). Insulation power factor test.		
Moisture / particle contamination of paper insulation	AC breakdown test. Insulation power factor test.		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: INDICATOR - LEVEL - SIGHT GLASS

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gasket / O-ring failure		Overhaul replacing gaskets and seals.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection	Bolt torque / tightness check of bolt or fastener, torque to manufacturer's specifications.	Bolt torque / tightness check to manufacturer's specifications, or in the absence of specifications, securely tighten.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Ruptured line / tube			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: INDICATOR - LEVEL - SIGHT GLASS

Failure Mode: Incorrect indication			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Surface fouling	Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Clean and inspect.	
Plugged / obstructed sensing line	Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Backflush sensing line.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: INDICATOR - PRESSURE/VACUUM

Failure Mode: Fails high			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Electronic card failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.
Out of calibration / adjustment	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.
Subcomponent failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: INDICATOR - PRESSURE/VACUUM

Failure Mode: Fails low			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Electronic card failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.
Out of calibration / adjustment	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: INDICATOR PRESSURE/VACUUM

Failure Mode: Fails low			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Subcomponent failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Electronic card failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.
Subcomponent failure	Calibration check. Visual inspection of instrumentation for correct indications when compared with expected, calculated, or secondary indications.	Calibration.	Functional test by simulating input, observing operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: JOINT

Failure Mode: External leakage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Visual inspection for signs of corrosion on and around electrical connections and loose connections.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: MOTOR - AC INDUCTION

Failure Mode: Fails to run / fails to continue running			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bearing wear			Functional test to verify starting on appropriate signal.
Grounding		Clean and inspect removing dust, dirt, moisture, corrosion, and contamination.	Functional test to verify starting on appropriate signal.
Insulation failure		Clean and inspect removing dust, dirt, moisture, corrosion, and contamination.	Functional test to verify starting on appropriate signal.
Loose connection			Functional test to verify starting on appropriate signal.
Open / shorted windings			Functional test to verify starting on appropriate signal.
Failure Mode: Fails to start			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stem / shaft binding			Functional test to verify starting on appropriate signal.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: NITROGEN BLANKET SYSTEM

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gas bottle leakage		Visual inspection of gas pressure gauge/target.	
Cracked housing / body / tube		Visual inspection of gas pressure gauge/target.	
Loose bolts / threaded connection		Visual inspection of gas pressure gauge/target.	
Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gas bottle supply depletion		Visual inspection of gas pressure gauge/target.	
Regulating valve failure		Visual inspection of gas pressure gauge/target.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PIPE - CABLE

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Cathodic protection survey - verification of proper current to sections of protected equipment against half cell reference current.	
Cracked housing / body / tube			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gasket / O-ring failure			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PIPE - SUPPLY

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion		Cathodic protection survey - verification of proper current to sections of protected equipment against half cell reference current.	
Cracked housing / body / tube			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gasket / O-ring failure			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: POLARIZATION CELLS

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Cell degradation		Replace electrolyte.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: POWER TRANSFER SWITCH

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Control circuit failure		Overhaul / replace.	Functional test (close).
Mechanism binding			Functional test (close).

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PRESSURE RECORDERS

Failure Mode: Fails to communicate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Functional test. Periodic polling. Visual inspection (display).
Modem failure			Functional test. Periodic polling. Visual inspection (display).
Power supply failure			Functional test. Periodic polling. Visual inspection (display).
Failure Mode: Fails to record/archive data			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Functional test. Monitor alarm. Visual inspection (display).
Out of calibration		Calibrate.	Function test.
Power supply failure			Functional test. Visual inspection (display).

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PRESSURE RECORDERS

Failure Mode: Incorrect/no output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Component failure			Functional test. Monitor alarm. Visual inspection (display).
Out of calibration		Calibrate.	Functional test.
Power supply failure			Functional test. Visual inspection (display).

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PUMP - POSITIVE DISPLACEMENT

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Cracked housing / body / tube			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gasket / O-ring failure			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PUMP - POSITIVE DISPLACEMENT

Failure Mode: Fails to run / fails to continue running			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bearing seizure			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.
Broken shaft / stem			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.
Seizure of subcomponent			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: PUMP - POSITIVE DISPLACEMENT

Failure Mode: Fails to start			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seizure of subcomponent			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.

Failure Mode: Low output			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Bearing wear			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.
Subcomponent failure			Functional test by operating under full load to determine if it is able to maintain normal head pressure and / or flow.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: RUPTURE DISK

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gasket / O-ring failure		Replace component.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seizure of subcomponent		Replace component.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: RUPTURE DISK

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Loose bolts / threaded connection		Bolt torque / tightness check to manufacturer's specifications or in the absence of specifications, securely tighten.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

Failure Mode: Fails to filter			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal damage - puncture	Monitor differential pressure (low readings/alarms).		

Failure Mode: Plugged			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Clogged strainer / filter	Monitor differential pressure (high readings/alarms).	Clean and inspect.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: SOLENOID OPERATED BALL VALVE

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gaskets			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

Failure Mode: Fails to operate			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Open / shorted windings		Overhaul/replace.	Functional test by verify operation at setpoint and / or operate manually.
Stem / shaft binding		Overhaul/replace.	Functional test by verify operation at setpoint and / or operate manually.
Subcomponent failure		Overhaul/replace.	Functional test by verify operation at setpoint and / or operate manually.
Seizure of subcomponent		Overhaul/replace.	Functional test by verify operation at setpoint and / or operate manually.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: SOLENOID OPERATED BALL VALVE

Failure Mode: Internal leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seat leakage		Overhaul / replace.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: STRAINER

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Cracked housing / body / tube	Visual inspection of housing, casing, or piping for signs of mechanical shock, stress, cracking, pitting, or corrosion.		Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gasket / O-ring failure			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection		Bolt torque / tightness check to manufacturer's specifications or in the absence of specifications, securely tightened.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Failure Mode: Fails to filter			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Internal damage - puncture	Monitor differential pressure low readings/alarms).		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: STRAINER

Failure Mode: Plugged			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Clogged strainer / filter	Monitor differential pressure (high readings / alarms).		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: SURGE DIVERTERS

Failure Mode: Fails closed			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Short circuit	Measure resistance.		

Failure Mode: Fails open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Open circuit	Measure resistance.		

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: SWITCH - PRESSURE

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Functional test.
Out of calibration / adjustment		Calibration by simulating switch input and adjusting switch actuation set point.	
Ruptured bellows / diaphragm	Performance test to determine performance within manufacturer's or design parameters under the range of operating conditions.	Internal inspection of subcomponents for signs of wear or deformation including disassembly and tolerance checks where required.	Functional test.
Subcomponent failure	Performance test to determine performance within manufacturer's or design parameters under the range of operating conditions.	Visual inspection of subcomponents for signs of wear, corrosion, cracking, pitting, deformation or heating.	Functional test.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: SWITCH - PRESSURE

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Functional test.
Out of calibration / adjustment		Calibration by simulating switch input and adjusting switch actuation set point.	
Ruptured bellows / diaphragm	Performance test to determine performance within manufacturer's or design parameters under the range of operating conditions.	Internal inspection of subcomponents for signs of wear or deformation including disassembly and tolerance checks where required.	Functional test.
Subcomponent failure	Performance test to determine performance within manufacturer's or design parameters under the range of operating conditions.	Visual inspection of subcomponents for signs of wear, corrosion, cracking, pitting, deformation or heating.	Functional test.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: TANK - STORAGE (VARIOUS TYPES)

Failure Mode: External leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Cracked housing / body / tube			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gasket / O-ring failure	Monitor leakage by tracking supply tank level.	Overhaul replacing gaskets and seals.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection		Bolt torque / tightness check to manufacturer's specifications or in the absence of specifications, securely tighten.	Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: TANK - STORAGE (VARIOUS TYPES)

Failure Mode: Internal leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Gasket / O-ring failure		Overhaul replacing gaskets and seals.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: TERMINAL (FLUID & GAS CABLE)

Failure Mode: External leakage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gaskets			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure		Visual inspection for chipped porcelain and external damage. Visual inspection - clean and recoat porcelain as needed.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: TERMINAL (SOLID CABLE)

Failure Mode: External leakage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Corrosion			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Gaskets			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Loose bolts / threaded connection			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

Failure Mode: Fails to provide insulation level			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Insulation failure		Visual inspection for chipped porcelain and external damage. Visual inspection - clean and recoat porcelain as needed.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: VALVE - BALL

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Subcomponent failure			Manual valve stroke to check stroke length and smoothness of operation.
Seizure of subcomponent		Overhaul to include adjustments within manufacturer's specifications and replace worn, damaged or degraded components.	
Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Subcomponent failure		Overhaul to include adjustments within manufacturer's specifications and replace worn, damaged or degraded components.	Manual valve stroke to check stroke length and smoothness of operation.

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: VALVE - CHECK

Failure Mode: Fails to close			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Stem / shaft binding		Overhaul/replace.	Functional test (open & close).
Subcomponent failure		Internal inspection of subcomponents for signs of wear or deformation including disassembly and tolerance checks where required. Overhaul/replace.	Functional test (open & close).
Seizure of subcomponent		Overhaul/replace.	Functional test (open & close).

Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seizure of subcomponent		Internal inspection of subcomponents for signs of wear or deformation including disassembly and tolerance checks where required. Overhaul/replace.	Functional test (open & close).

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: VALVE - CHECK

Failure Mode: Internal leak			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seat wear		Internal inspection of subcomponents for signs of wear or deformation including disassembly and tolerance checks where required. Overhaul / replace.	

REFERENCE DATA FOR UNDERGROUND TRANSMISSION

EQUIPMENT TYPE: VALVE - RELIEF - SPRING LOADED

Failure Mode: Seat leakage			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seat wear			Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.
Failure Mode: Fails to open			
FAILURE CAUSE	**ROUTINE MAINTENANCE TASKS**		
	Condition Monitoring	Time Directed	Failure Finding
Seizure of subcomponent			Pop test while installed. Visual inspection for signs of leaking such as fluid weeping, wetness, standing or running fluid, or low fluid level.

C

MAINTENANCE TECHNOLOGIES OVERVIEW

This portion of the Technical Reference provides an overview of maintenance tasks and technologies, and how and why these tasks and technologies are appropriate to address a variety of equipment failure modes and causes. For example, sophisticated technologies such as vibration spectrum analysis and simple techniques such as functional testing can have a wide range of applications for power distribution equipment. This section provides a general description of how these techniques and technologies are appropriate for preventing failures and identifying incipient failures in power distribution equipment. No attempt is made to discuss specifically how these technologies are applied. Attention is focused on providing an explanation of field proven applications. The information presented provides technical justification for selecting maintenance techniques. This justification is an essential element in supporting the technical accuracy of RCM recommendations.

It should be noted that corrective maintenance procedures are not discussed in this presentation of data, and the use of the predictive and preventive maintenance techniques as troubleshooting tasks is not emphasized. The primary focus is to present a brief guide on the use of these maintenance techniques in support of predictive and preventive maintenance programs.

The following techniques and technologies are discussed:

AC Breakdown Test (Dielectric Fluid)

Acoustical monitoring

Alignment Verification

Bearing Wear Monitoring

Bolt Torque Check

Breaker Travel/Timing Test

Calibration

Change Lubrication Oil/Lubrication

Check Lubricant Level

Clean and Inspect

Clearance Check

Coil Signature Analysis

Concentric Neutral Corrosion Detection

Contact Resistance Test

Continuity Check

Current Signature Analysis

DC Proof Test

Dew Point

Discharge Capacity Test

Dissolved Gas Analysis

Electrical Surge Test

Fall of Potential Test

Functional Test

Herbicide Application

High Potential

Hydrostatic Test

Insulation Power Factor Test

Insulation Resistance Test

Internal Inspection

Linear Operating Force Measurement

Low Voltage Trip Test

Lubricant (Lube Oil) Analysis

Oil Quality Test

Overhaul

Partial Discharge Detector (Acoustic)

Partial Discharge Detector (Electrical)

Pole Decay Inspection

Pole Internal / External Treatments

Replace Equipment / Component / Subcomponent

Resistance Check

Self Test

Specific Gravity Check

SF6 Gas Analysis

Temperature Monitoring

Thermographic Analysis

Time Domain Reflectometry

Transformer Impedance Test

Transformer Recovery Voltage

Ultrasonic Analysis

Visual and Audible Inspection

Wear Particle Analysis

Winding Excitation

Winding Ratio Test

Winding Resistance

Maintenance Technologies

AC Breakdown Test (Dielectric Fluid)

Description: AC breakdown (dielectric strength) tests are maintenance tasks to detect deterioration of cable dielectric fluid. Other similar tests include dissolved gas analysis (DGA), and Tanδ (insulation power factor) tests. These tests are generally used in combination as an aid in assessing the integrity of the cable dielectric fluid, and by inference, that of the fluid-filled cable system.

Usage: The AC breakdown test makes use of a standard test cup and electrode arrangement, together with an adjustable AC voltage source. The test cup is filled with a sample of dielectric fluid and then the voltage is raised until the electric gap between the cup and the electrode (through the dielectric fluid) breaks down. The magnitude of the breakdown voltage is a measure of the quality of the dielectric fluid. ASTM D 877 and D 1816 are standards that specify the use and documentation of the tests.

Applications: An AC breakdown test can be made on a sample of dielectric fluid from fluid-filled cable of any age. The test is most useful in combination with other tests (see above). Low values of AC breakdown may be indicative of the presence of moisture or particulate matter in the fluid.

Acoustical Monitoring

Description: This task provides remote monitoring of process fluid flow or electrical activity by providing indication of system noise level changes.

Usage: The noise level changes associated with a physical change to the equipment of a system with fluid flow or electrical activity indicate system integrity failure or an internal failure. Comparisons to known base-line data allow trending of internal performance as well as boundary integrity. Instrumentation coupled to the transducer output can provide caution, warning, and alarm signals.

Applications: Acoustical monitoring can be used detecting corona discharge associated with punctured insulators, and for loose parts monitoring in flowing systems that may not be accessible. Monitoring downstream of pumps or valves is used to confirm internal integrity. The noises associated with leaks, such as in leaking pilot and operating valves, are detectable by noise sensitive transducers.

Alignment Verification

Description: This task ensures that moving equipment that interact with each other, such as arcing and stationary contacts and linkages in electrical isolating equipment or the driver and load of a rotating assembly, are arranged such that their centerlines are matched.

Usage: Verification of alignment minimizes the mechanical stresses on the moving parts of equipment or assemblies, such as bearings or bushings.

Applications: Arcing can be reduced when accurate measurements are used to properly align switch blades and breaker contacts. Coupling face-to-face measurements are used to specify the amount to adjust the moveable equipment such as pump / motor, compressor / motor and engine / generator assemblies. Similar alignment techniques can be used for static situations such as flange-to-flange couplings.

Bearing Wear Monitoring

Description: The use of installed detectors within the bearing material provides a signal when contact is made as a result of material erosion.

Usage: An electrical circuit is completed when bearing material has been sufficiently worn to allow contact of the imbedded probes in the bearing with the rotating element. Indication at a remote location allows an operator to know the status of a bearing.

Applications: Bearing wear monitors are used in applications where access to the rotating assembly is restricted or where disassembly for wear monitoring inspection is not practical. It is also used to provide an early indication of wear which will result in the need for corrective maintenance, rather than allowing operation until failure.

Bolt Torque Check

Description: This maintenance task involves ensuring that fasteners are sufficiently pre-tensioned, during assembly and periodically, to counter relaxation of the threaded connection. Rotational torque values may be generic based upon fastener size or assembly specific based upon unique material, lubrication, or other design features.

Usage: This maintenance task ensures that threaded fasteners are pre-loaded during assembly to verify that each fastener remains tight during operation. Generally, threaded fasteners require tightening in a specified sequence in order to evenly apply the necessary assembly pressures to avoid warping the item. Likewise, sequencing care must be applied in disassembly for the same reason.

Applications: Torque values for threaded fasteners are specified for many critical items for example, compression connectors, battery terminals, and bus connectors. Verification of torque values ensures that the integrity of assemblies is maintained. Note that bronze bolts, used in electrical connections may stretch when retorqued which can lead to mechanical failure.

Breaker Travel/Timing Test

Description: The breaker travel / timing test evaluates the dynamic operation of a breaker as it goes from either a closed state to an open state or from an open state to a closed state. The test evaluates the mechanism movement and event timing.

Usage: The test can reveal problems associated with mechanism and contact adjustment, stored energy systems, and control circuitry.

Applications: The timing / travel test can be used on any high voltage breaker having an external operating mechanism.

Calibration

Description: Calibration is the adjustment of the output of a measuring device, indicator, or sensor based upon a comparison to a known standard.

Usage: Out of calibration instruments and sensors may present an indication of failure when none exists, or conversely, they may mask an actual out of tolerance condition when it is present.

Applications: Calibration is a routine time-directed maintenance task for some items and a condition-directed task for others. It generally involves instrumentation but may include physical dimensions associated with mechanical assemblies such as pressure relief devices.

Change Lubrication Oil/Lubricate

Description: This maintenance task provides for the replacing of lubricants or the application of specific lubricants to the equipment.

Usage: This maintenance task is primarily used to reduce mechanical friction or its effects. Replacement of lubricants may become necessary, if analyses of the lubricants show increasing amounts of contaminants. In contamination cases, root cause analysis should be used to determine the fundamental cause of the contamination and the cause corrected before this maintenance task can be effective.

Applications: Lubrication is normally specified for moving or rotating mechanical equipment as a function of their design and expected loading. Under normal conditions, planned lubrication and scheduled replenishment serve to continue the reliable operation of the equipment.

Check Lubricant Level

Description: This task ensures that the designed amount of lubricant is available.

Usage: Proper amounts of lubricants are verified mechanically, acoustically, electrically, or visually. Occasionally, more than one means of determining that neither too much nor too little lubrication is provided. The indication may be local, remote, or both.

Applications: Level checks apply to equipment such as underground cable tunnels, vaults, or transformer cooling oil reservoirs; and bearing cavities, transmission and differential cases, couplings, and gearboxes associated with rotating equpment.

Clean and Inspect

Description: This task expands the simple task of cleaning to include an overview observation of the equipment and environmental conditions into a single maintenance task.

Usage: Cleaning of equipment is often required to be able to properly perform an inspection, yet the cleaning may be considered a useful preventive maintenance task in its own right. The inspection may detect that a condition-directed task is called for by the symptoms discovered or it may reveal a problem, such as excessive heating of circuit board equipment, which could lead to a failure that is not evident to the operator at a remote location.

Applications: Both portions of the task are varied as appropriate to the equipment involved. The cleaning may call for water washing to remove dirt and contamination from insulators, the removal of dust from electrical equipment with a vacuum cleaner, the dissolution of hardened grease from a switch or machine bearing, or the delicate removal of dust from an electronic board. Inspections are typically visual, with the minimum of disassembly, yet may include the observation of locally displayed performance indicators such as temperature.

Clearance Check

Description: This maintenance task checks clearances in bearings, linkages or other mechanisms.

Usage: This task is widely applicable to mechanical joints, bearings, linkages, etc.

Applications: Clearance checks are used to determine changes in alignment, mechanical drift, and wear which may lead to eventual failure of the parts in close proximity.

Coil Signature Analysis

Description: Coil signature analysis is a graphic representation of the operating value (current or voltage) versus time.

Usage: Coil signature analysis is used to determine if a change has occurred in the operating force of operating coils that serve as electrical mechanical interfaces. A change in the profile will indicate a change in the mechanical system.

Applications: Monitoring trip and close coils for circuit breakers systems can reveal mechanical binding and lubrication problems.

Concentric Neutral Corrosion Detection

Description: Techniques for detecting concentric neutral corrosion include applying selective frequency current to in-service cable and measuring voltages, and injecting current into a neutral and comparing resistance measured against the resistance of a new reference neutral of the same size.

Usage: Selective frequency measurements combined with cable above ground walkdowns may locate degradation locations, plus splice locations in some circumstances. Resistance comparison measurements provide the level of degradation (number of failed strands) within the neutral conductor. Cables and neutrals remain in service during the test.

Applications: Concentric neutral corrosion detection is used for underground distribution to identify the severity and location of corrosion and failures of the concentric neutral. These techniques are especially useful since underground distribution cable is inaccessible in most areas.

Contact Resistance Test

Description: The contact resistance test measures the DC resistance of a breaker pole in micro-ohms.

Usage: The test can be applied to all circuit breaker conduction paths.

Applications: The test can be useful in determining if significant deterioration of the current carrying contacts has taken place. It can also identify connection problems.

Continuity Check

Description: This maintenance task verifies that a circuit or wire is or is not open.

Usage: The task has wide application to electrical and electronic circuits and equipment.

Applications: Normally accomplished using an ohmmeter to establish whether a short (zero or very little resistance) or open (infinite or very large resistance) circuit exists between two points.

Current Signature Analysis

Description: An electronic analysis (measuring current vs. time) of induction motors that uses line current and slip frequency spectra while the motor is running under load.

Usage: The presence of a problem with an operating motor creates resonance in the line current spectrum that differs from a normal signature; analysis identifies the problem without disassembly.

Applications: Typically used for electric motors. The technique is used to detect broken rotor bars, cracked end rings, worn gear train, bearing problems, bent shafts, or binding in linkages.

DC Proof Test

Description: A maintenance task used to detect deterioration of impregnated-paper insulated fluid-filled cables. This test consists of applying a high direct voltage from the cable's conductor to its grounded sheath or shield. The duration of voltage application is usually five minutes. The leakage current is measured and interpreted. A badly deteriorated or damaged cable may experience a dielectric failure during the test requiring immediate repairs.

Usage: Cable DC test equipment is available commercially for purchase or lease. Cable and accessory manufactures, and industry specification should be consulted about test voltages.

Applications: A DC proof test should be made only after a thorough evaluation of the possible consequences and benefits. The test can lead to insulation failure in extreme circumstances.

Dew Point

Description: The dew point temperature is the temperature at which a gas containing water vapor becomes saturated and condensation just begins to take place.

Usage: The dew point can be used to measure the dryness of an insulation system. It is one of a series of tests than can be used to measure the water content of an insulation system.

Applications: The test can be applied to sealed transformers.

Discharge Capacity Test

Description: This task records battery parameters during a controlled discharge to determine the ability of the battery to perform under load. It records the rate and duration of the battery's discharge.

Usage: Measurement of a battery's performance under load allows the prediction of the life of the battery, as well as identifying cells with internal problems. Comparison of the performance at a specific discharge rate to the previously recorded values allows the projection of response during future applications.

Applications: Emergency and back-up batteries for generators, lighting, control equipment, and sensitive instrumentation benefit from confirmation of design capacity.

Dissolved Gas Analysis

Description: The test measures the volume of specific gasses dissolved in insulating oil. The presence of many of these gases is indicative of an incipient electrical fault.

Usage: The DGA test can be used as a screen to measure the relative health / condition of an electrical insulation system. The presence of key gases can indicate overheating, corona, or arcing is taking place under the oil.

Applications: The test is applicable to any mineral oil insulated system, e.g., oil filled cables or power transformers. It may also be applied to other insulating fluids but the industry experience is more limited.

Electrical Surge Test

Description: This maintenance task is used to determine the condition of a motor insulation system. This test generates a turn-to-turn and a phase-to-phase voltage by discharging a capacitor into a winding and rapidly pulsing the voltage up to a pre-selected level. The pulse generates a damped sine wave between the inductor (the winding) and the capacitor. The test voltage pattern is viewed on an oscilloscope.

Usage: Surge testing has long been used as a quality control tool in motor manufacturing and motor rewind facilities. The development of portable field test instruments has allowed the test to be adopted as a predictive tool.

Applications: The major limitation of electrical surge testing for in service motors is that the test is conducted at twice the operating voltage plus 1000 volts. At this voltage a pin hole in the ground wall insulation can develop. It is recommended that a DC high potential test be performed prior to the surge test to determine the strength of the motor insulation. Note: Care should be exercised since high potential tests can be destructive in nature.

Fall of Potential Test

Description: Maintenance test to determine the range of “influence” of a ground. The test determines the distance to a “remote earth” location, which is sufficiently removed from the ground that no residual effects are encountered. This frees the location for alternate uses.

Usage: The test involves applying a current to the ground and measuring the voltage at a distant location. The calculated resistance between the ground and the distant location - the resistance should level off (zero slope) at a set distance from the grid.

Applications: The test is usually used to determine the remote earth distance from substation grounding grids, but may be applied to other grounds in some cases.

Functional Test

Description: A functional test involves operating equipment and observing that its intended design functions are satisfactorily accomplished.

Usage: The functional test is an effective maintenance task for evaluating the capabilities of equipment. The functional test may be more qualitative, since it merely confirms operability and does not necessarily measure performance.

Applications: Functional tests vary in complexity from simply test starting and running equipment, to opening and closing a breaker or disconnect, to complex interrelated tests which require coordination of several systems and elaborate prerequisites.

Herbicide Application

Description: The application of herbicides to vegetation by a variety of techniques including spraying or painting. A wide variety of herbicides are available on the market.

Usage: Herbicides are used to eradicate undesirable vegetation from below overhead distribution and transmission lines. Use of herbicides, where permitted, can be considerably more cost-effective than mechanical means of vegetation control.

Applications: Various herbicides are used selectively to remove only the vegetation that can grow into the lines leaving other vegetation unharmed. The choice of herbicide is usually determined by cost factors, types of vegetation requiring removal, and local environmental conditions.

High Potential

Description: The test analyzes portions of an electrical insulation system by stressing the system with high AC or DC voltage and measuring the resultant leakage current. The test is similar to an insulation resistance test with the measured parameter being current rather than resistance.

Usage: Hipot tests provide general assurance that the insulation system can functionally operate in a high voltage environment.

Applications: Hipot testing is useful in determining the integrity of vacuum and gas interrupters. DC hipot testing is also used to determine the integrity of high voltage cables, but may shorten the remaining life of the insulation.

Hydrostatic Test

Description: This task involves pressurizing equipment to specified limits and monitoring for leakage over a period of time.

Usage: Hydrostatic testing confirms integrity and strength by pressurizing equipment to specified limits and monitoring any decay of pressure or observing any test fluid leakage.

Applications: This task is used to ensure closed system capabilities of various equipment such as oil filled cables, potheads, splices, and reservoirs, after new construction or after significant repair. The test fluid may be liquid or gas.

Insulation Power Factor Test

Description: This test analyzes portions of an electrical insulation system by measuring the response to a 60hz signal. The test measures the phase angle between the applied voltage and current.

Usage: Insulation power factor readings can be used to determine the condition of electrical insulation found in equipment such as transformers, breakers, cables, and rotating machinery. The test provides a means of measuring the effects of environmental conditions such as moisture and carbon as well as trending the aging process.

Applications: Contamination levels (generally moisture and carbon content) can be measured for empirical comparisons to determine if corrective actions such as dry out or filtering are necessary. The test does not necessarily provide absolute results.

Insulation Resistance Test

Description: Insulation resistance tests analyze portions of an electrical system or equipment response to an applied signal.

Usage: Insulation resistance tests are used to monitor resistance readings to determine the condition of transformer windings, cables, connectors, and so on. This task provides a means to check for the effects of environmental conditions and age on insulation, and the build-up of carbon in electrical motors.

Applications: Electrical breaks, shorts, areas of high and low resistance, and insulation breakdown in electrical circuitry are revealed during insulation resistance testing.

Internal Inspection

Description: This task involves visual inspection of the inside of equipment. A variety of techniques are currently in use from the unaided eye to flexible fiber optics.

Usage: This task verifies the existence, position, and visible condition of internal parts. It can also reveal foreign objects that are present inside the equipment.

Applications: Troubleshooting, problem identification, and equipment integrity are frequently dependent on internal inspections.

Linear Operating Force Measurement

Description: This task monitors the stress forces applied to equipment during operation.

Usage: Determination of the remaining life of equipment based upon the severity and frequency of the stress forces (tension, compression, and shear) is possible with this technique. Equipment fatigue characterized by cracking or deformation may be determined with the use of strain gauges which change their electrical resistance when deformed. Analysis and comparison to previous data ensure that the material of the equipment does not exceed its elastic limit.

Applications: Piping systems, pressure vessels, and structural equipment receive monitoring of the applied linear forces.

Low Voltage Trip Test

Description: The test determines whether a breaker will trip when the control circuit is energized with a lower than nominal voltage.

Usage: Breakers are designed to operate with a control voltage much below nominal. Failure of the breaker to trip at this low voltage can indicate the presence of lubrication problems or mechanical drift.

Applications: The test can be applied to most breakers having an electromechanical control scheme. A go, no go value can be determined and serve as a benchmark for future tests. Failure to trip at this reduced voltage should result in further maintenance/investigation.

Lubricant (Lube Oil) Analysis

Description: This maintenance task serves to analyze the chemical and physical properties of a lubricant to detect deterioration or contamination.

Usage: Lubricant analysis can be applied to almost all lubricants. It is most commonly used on pumps, diesel engines, air compressors and synchronous condensers. This maintenance task is frequently performed in conjunction with wear particle analysis.

Applications: Deteriorated lubricants, in time, inevitably lead to failure because the protection normally provided is depleted.

Oil Quality Analysis

Description: Oil quality analysis is a battery of tests used to assess the properties of insulating oil. The tests usually include tests for dielectric strength (either to ASTM D-877 or D-1816 specifications), acidity, interfacial tension, power factor, resistivity, steam emulsion number, color, and pour point. (Dissolved gas in oil is treated as a separate technology.)

Usage: Oil quality analysis is used to determine the condition of insulating oil and its continued usefulness as an insulator.

Applications: Transformers, circuit breakers, reactors, cables, and regulators are examples of equipment that will require oil quality tests.

Overhaul

Description: An overhaul is the extensive refurbishment of equipment to return the item to a "like new" or "zero operating time" condition involving complete disassembly and restoration with replacement parts as needed.

Usage: Overhaul is warranted when equipment reaches a pre-defined "wear out" age or is no longer able to perform its task, yet full replacement is not practical nor economical. When an inspection of a complex item shows that many parts are approaching the end of their useful lives, overhaul of the item rather than multiple corrective maintenance repairs may be a cost-effective alternative. The quality of overhauls may vary from "field serviceable" to "factory new" tolerances.

Applications: Manufacturer recommendations of service life generally establish "wear out" intervals which lead to overhauls. Complex equipment may be subject to numerous and repeated failures of their component parts, since many components have shorter service lives. Thus, the complex equipment overhaul may involve components with a variety of time in service.

Partial Discharge Detector (Acoustic)

Description: This technology employs an acoustic sensor to detect the initial insulation breakdown in transformer windings and other electrical equipment.

Usage: Partial discharge detection is used to detect incipient failures before significant damage has occurred. Partial discharges resulting from water, particulate contamination and from other dielectric problems in electrical equipment can be detected.

Applications: Partial discharge is used to monitor the insulation condition of transformer windings, coupled capacitor voltage transformers, insulators, terminators, and, in the future, cable insulation. Partial discharge detectors are also useful in detecting radio and television interference problems.

Partial Discharge Detector (Electrical)

Description: This technology employs an electrical sensor to detect the initial insulation breakdown in electrical equipment such as insulators and terminators.

Usage: Partial discharge detection is used to detect incipient failures before significant damage has occurred. Partial discharges resulting from particulate contamination and from other dielectric problems in insulators and terminators can be detected.

Applications: Partial discharge is used to monitor the insulation condition of electrical equipment, and to detect the source of radio and television interference.

Pole Decay Inspection

Description: Maintenance tasks to detect internal and external decay for in-service wood poles at the groundline region. Techniques include sounding with a hammer, probing, drilling, core sampling, instrument testing (Shigometer, Poletest, etc.) and visual inspections, including groundline circumference measurements. The pole is inspected up to four to six feet above ground, and usually to a depth of two feet below ground.

Usage: The inspections and tests determine the condition and remaining strength of the wood pole. Sounding along with boring detects internal decay within the pole. Drilling is used to measure pole shell thickness - poles are replaced or reinforced when shell thickness decreases below a set value, usually about two inches. Groundline circumference measurements may also be used as a criteria for pole replacement or reinforcement.

Applications: Inspection techniques can be applied to wood poles of any composition or age. Inspection frequency varies - new poles are routinely inspected ten to fifteen years after installation; subsequent inspections are performed every eight or twelve years. Fumigation and other treatments, and/or repairs are made to the pole, based on inspection results.

Pole Internal/External Treatment

Description: Treatments consist of preservatives and fumigants applied to the interior or exterior of wood poles to arrest or prevent wood decay. The preservatives and fumigants sterilize the pole, halting decay caused by insects, fungi, and other agents.

Usage: Internal treatments may consist of fumigants (such as chloropicrin or vapam) or pastes such as boron fluoride. External treatments usually consist of greases containing preservatives such as pentachlorophenol, creosote, or copper naphthenate. Treatments can be used on any in-service pole, but vary in effectiveness and environmental impact. Treatments can extend the pole life from 10 to 20 years.

Applications: Internal treatments are usually applied by drilling holes into the poles just above the groundline, and adding the treatment chemical. The hole is plugged to prevent treatment from escaping to the atmosphere. External treatments are applied to the pole during the first inspection after installation and at subsequent maintenance inspections, based on pole condition. The treatment is added to the exterior of the pole, which is then wrapped with paper or plastic to prevent the treatment from escaping into the ground.

Replace Equipment/Component/Subcomponent

Description: In this task, some or all of the equipment is replaced when there is evidence of fatigue or wear, which if left unattended, could result in a failure.

Usage: This is a frequently used maintenance task because it ensures functional equipment without fatigue or wear effects.

Applications: The replacement of a badly worn but still serviceable equipment falls into the category of "replace equipment" maintenance task. Often, equipment that costs more to repair or overhaul than to replace are candidates for replacement. This equipment is often relatively small, common, and inexpensive. It should be noted that the replacement of equipment, without adequate analysis or investigation, may disguise design or application errors and can lead to unnecessary maintenance expenses in the future.

Resistance Check

Description: This maintenance task is designed to detect equipment degradation or failure. An ohmmeter is used to check the resistance value of equipment and compare the reading with the specification in the applicable drawing or marked on the equipment.

Usage: Resistance checks are commonly used in conjunction with corrective maintenance as a trouble shooting aid to determine the cause of a circuit failure. Resistance checks can also be part of an alignment or calibration procedure.

Applications: Complex electrical circuits contain many parallel electrical paths. To obtain accurate readings, all parallel paths must be taken into consideration. Resistance checks are easiest to make when the equipment to be tested can be effectively isolated from the circuit.

Self Test

Description: This maintenance task utilizes the self-testing features designed into equipment. A self test will gather data, compare results to pre-established acceptance criteria, and show the results to the operator for additional action, if necessary.

Usage: This maintenance task takes advantage of operating equipment circuitry and may allow an on-line confirmation of functional readiness. Self testing ensures consistency of parameter measurements by eliminating personal techniques and interpretations.

Applications: Self testing features are frequently provided in electronic or computer-based equipment. The self tests may range from simple checks of light bulb operability to complete electronic diagnostic routines of control equipment.

Specific Gravity Check

Description: This maintenance task provides for the checking of the electrolyte in a lead acid battery. Once access to a battery cell is gained, a small sample of the electrolyte is drawn into a hydrometer. The reading on the hydrometer is the specific gravity of the electrolyte.

Usage: When corrected for temperature and electrolyte level, the specific gravity of the electrolyte in a battery cell reflects the state of charge for that cell.

Applications: As a condition-monitoring maintenance task, specific gravity checks determine when a battery needs to be recharged. When recharging, the specific gravity check verifies that the battery is fully recharged.

SF6 Gas Analysis

Description: An analysis technique to identify the presence of by-products, such as fluorinated hydrocarbons, that result from the electrical arc associate with operation of an SF6 interrupter.

Usage: A collection device is used to take samples from a manifold for later analysis.

Applications: This technique is applicable only to SF6 breakers.

Temperature Monitoring

Description: This condition-monitoring (usually continuous) maintenance task uses the measurement of temperature of equipment as a predictor of failure.

Usage: Temperature sensors can be used to provide temperature indication of almost any equipment. Typical applications are top oil, hot spot, connectors, splices, switches, transformers, cables, compressor stages, bearings, and heat exchanger inlets and outlets.

Applications: Several technologies are available to perform this task, including thermometers, infrared imaging, bi-metallic sensors, resistance temperature detectors, thermocouples and temperature-sensitive materials. High, low, or inconsistent temperatures can all provide information useful in predicting or detecting failures.

Thermographic Analysis

Description: This maintenance task utilizes an infrared imaging device to detect differences in temperature of equipment imaged.

Usage: Thermography has been used very successfully in monitoring electrical equipment to locate hot spots indicative of high resistance connections, weak contacts, or mismatched phases. It can also be used with hot/cold fluid or gas piping and valves to locate leaks or blockages. When used to monitor radiators and heat exchangers, cooler spots may indicate clogged passages.

Applications: Prediction is best based on relative comparisons of readings at the same monitoring point over a period of time. These readings are then used to develop historical (relative) patterns and correlation with adverse conditions and other analysis methods.

Time Domain Reflectometry

Description: This task analyzes an electrical system or equipment response to an applied signal.

Usage: The task monitors the impedance readings to determine the conditions of electrical circuits, cables and connectors. This task provides a means to check for the effects of environmental conditions, improper repairs, age, or abuse. Time domain reflectometers (TDR) are used to monitor each change in impedance encountered as a pulsed electrical current is sent down a conductor. Thus, the presence, magnitude and location of any problem may be observed on test equipment.

Applications: Electrical breaks, shorts, areas of high and low resistance, and insulation breakdown in electrical circuitry are revealed during impedance checks.

Transformer Impedance Test

Description: The impedance tests measures the input impedance of a transformer winding when one of the other windings is shorted. The test is performed by applying an AC signal to the unshorted winding and measuring the resultant current. The impedance is calculated by dividing the applied voltage by the current. The measured impedance is proportional to the amount leakage flux.

Usage: The impedance test can determine if winding movement or deformation has taken place. Since on power transformers, the impedance is linear function of the voltage, the percent impedance can be calculated and compared to the nameplate value.

Applications: The test is applicable to most power transformers. It is generally not applicable to smaller units requiring a significant amount of excitation current.

Transformer Recovery Voltage

Description: A test used to assess the reliability of transformer insulation based on a measurement of moisture content.

Usage: Charging voltage is applied to transformers under test and then recovery voltage is measured to determine the moisture content of paper insulation.

Applications: The recovery voltage test is used to measure the moisture content of paper insulation in transformers.

Ultrasonic Analysis

Description: This ultrasonic imaging and analysis task measures the thickness of metal objects by measuring and recording the time required for a sound pulse to travel between opposite surfaces of the material and return to the transducer.

Usage: Confirmation of the thickness of metal equipment ensure system integrity and the lack of corrosive or erosive effects. Cracks may also be identified with this technique. Trending can show the history of corrosive or erosive effects and allow the prediction of service requirements.

Applications: Heat exchanger tube monitoring, air receiver tank thickness and pipe wall thickness checking employ the use of this technique. The boundary material thickness measurements of valves, pumps, and pipe bends and tees are also possible with ultrasonic analysis.

Visual and Audible Inspection

Description: This inspection technique is a valuable maintenance tool for monitoring the condition of equipment as well as providing an overview of the equipment's environmental conditions.

Usage: The visual and audible inspection techniques possess an important advantage over many other inspection techniques - they involve the human brain's capability for pattern recognition and differentiation. Visual and audible inspections can be useful externally, internally, during disassembly, or with the external relationships between equipment.

Applications: Visual and audible inspections are used to monitor a wide variety of equipment and systems. Visual and audible inspections can be conducted directly by an observer or remotely by the use of transmission technology. The degree of detail of an inspection varies from a simple examination of an item evaluating its external condition up to a detailed comparison of observed visual and audible characteristics to a defined standard.

Wear Particle Analysis

Description: This maintenance task uses spectrometric analysis, ferrography or micropatch techniques to check lubricants for evidence and characterization of wear particles from bearing deterioration.

Usage: Wear particle analysis can be applied to almost all lubricants and lubricating systems. It is most commonly used on pumps, turbines, diesel engines, air compressors and synchronous condensers. This maintenance task is frequently performed in conjunction with lubricant analysis.

Applications: Spectrometric and ferrographic results are precise enough to permit trending and can be used to predict bearing wear and eventual failure. Knowledge of the material makeup of the equipment is essential to pinpoint locations of wear.

Winding Excitation

Description: The winding excitation test measures the current required to excite a transformer winding at a standard voltage.

Usage: The excitation test can be applied to most inductive elements including power, current, and potential transformers.

Applications: The excitation test can readily identify shorted turns in transformer and regulator windings.

Winding Ratio Test

Description: The winding ratio test measures the turns ratio between a primary and secondary winding in a transformer.

Usage: Transformers are manufactured to have a turns ratio within 0.5% of the nameplate rating. Winding ratios outside this window indicate the presence of shorted or open turns.

Applications: The winding ratio test can be applied to power, current and potential transformers.

Winding Resistance

Description: The winding resistance test is a measure of the DC resistance of a transformer winding at a know temperature.

Usage: The winding resistance test can be applied to any winding ranging in size from a small trip coil to a large power transformer.

Applications: The test can identify if one or more conductors is open in a winding made up of several parallel conductors. It can also identify shorted turns or high resistance connections.