ELECTRIC POWER RESEARCH INSTITUTE

Large Steam Turbine Component Retrofits and Replacements: Lessons Learned

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Large Steam Turbine Component Retrofits and Replacements: Lessons Learned

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PRODUCT DESCRIPTION

This guide provides information that will be of interest to utilities considering retrofit and replacement projects for life extension and performance improvement of fossil and nuclear steam turbine-generators. The report provides a summary of the risks that a utility should consider when retrofitting or replacing turbine-generator equipment and presents methods for mitigating those risks. Potential pitfalls, best practices, and lessons learned by the industry provide additional insights.

Results and Findings

There is a varied range of experience in the generation industry in terms of how utilities meet their needs for retrofitting and replacement of steam turbine-generator equipment. Some utilities have always used original equipment manufacturer (OEM) equipment and rely almost exclusively on the OEM to provide replacement equipment and parts, while others always consider available third-party (non-OEM) equipment. Today's competitive market has led to some attractive claims of improved performance, superior quality, and favorable pricing.

The utilities that routinely use non-OEM equipment have established procurement policies and engineering support to evaluate bidders, assess technical issues, and manage risks. They always include OEMs in the bid process and specify their requirements. All bidders bid to the same specification, and the company can determine which offering provides the best value. Other utilities, with limited engineering resources, tend to specify more general requirements and rely more heavily on the bidders (both OEM and non-OEM) to provide detailed equipment specifications and other criteria. This requires additional effort to evaluate the bids and select the best value for the equipment.

Challenges and Objectives

As steam turbine-generators age and the landscape of existing suppliers changes shape due to mergers, acquisitions, and business failures, it may become more difficult to find OEMs to provide direct retrofit equipment. The information provided in this report will help plant managers and utility design and engineering departments to improve the success of steam turbine-generator retrofit and replacement projects, whatever their choice of vendor.

Applications, Value, and Use

As the traditional OEMs serving turbine-generator owners continue to change and more non-OEM providers emerge, the marketplace will offer new technologies, improved performance, and increased equipment life spans. Utilities will need to assess the value of these offerings, balanced with the probability for success. This report outlines some of the critical areas of concern that must be addressed for a turbine-generator refit or replacement project to be successful under today's conditions.

Approach

This report was developed by surveying existing EPRI publications and other available documents and obtaining input from various utility sources. Other input came from a turbine-generator workshop held to identify potential pitfalls and lessons learned. In addition, a survey was conducted to determine the amount of steam turbine-generator retrofit and replacement work that is anticipated by EPRI members and collect details regarding past experience with such projects. The information was then organized and reviewed by a technical advisory group (TAG) to ensure that the report adequately addressed the issues.

EPRI Perspective

Because up to 70% of outages planned for steam power plants involve work on the turbine, power producers continually seek ways to optimize operation and maintenance (O&M) activities on aging turbine-generator fleets. Optimized O&M can reduce maintenance costs, improve component reliability, and increase generator output. Maintaining a detailed awareness of effective maintenance techniques, however, is challenged by the evolutionary nature of operating experience, by the complexities of advanced materials and upgrade options, and by reduced staffing levels and retirement of experienced personnel. This report is designed to help utility engineers, project managers, procurement specialists, and senior management understand the issues involved in turbine-generator retrofit and replacement projects and benefit from the lessons learned by others.

Keywords

OEM
Non-OEM
Retrofit
Replacement
Steam turbine-generator

ABSTRACT

Retrofitting and replacement of steam turbine-generator equipment is one avenue that utilities should consider to help improve the efficiency and lower the cost of repair of generating assets. However, the procurement process, project management, and the equipment itself all pose potential challenges that can affect the success of a retrofit or replacement and ultimately impact unit performance, revenue, and asset value.

Successful retrofit and replacement projects include risk assessments and a complete project management plan. The risk assessment is performed to identify the issues that are critical to the success of the project. Each project will have unique risks, and risk mitigation methods must be tailored to address these risks, in consideration of the utility risk profile and the experience and expertise of the project team, the vendors, and the plant staff.

Following a general introduction in Section 1 of this report, Section 2 outlines a process for identifying the risks associated with a steam turbine-generator retrofit or replacement. Section 3 of the report summarizes guidance regarding project management techniques for risk mitigation, including bid specification and evaluation, design reviews, quality plans, witness programs, development of contract terms, and identification of technical support and outside resources needed to mitigate the identified risks. Section 4 presents lessons learned, and Section 5 presents specific examples and recommendations.

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1.1 Retrofit and Replacement Drivers

Because up to 70% of outages planned for steam power plants involve work on the turbine, power producers continually seek ways to optimize operation and maintenance (O&M) activities on aging turbine-generator fleets. Optimized O&M can reduce maintenance costs, improve component reliability, and increase generator output. Maintaining a detailed awareness of effective maintenance techniques, however, is challenged by the evolutionary nature of operating experience, by the complexities of advanced materials and upgrade options, and by reduced staffing levels and retirement of experienced personnel.

Retrofitting and replacement of steam turbine-generator equipment is one avenue that utilities should consider to help improve efficiency and lower the cost of repair of generating assets. There are many reasons for retrofitting and replacing major equipment, including the following:

- Cost (capital and O&M)
- Schedule
- Performance improvement (improved efficiency, reliability, increased capacity)
- Plant life extension
- Subcomponent end of life due to material issues
- Dissatisfaction with current equipment (parts obsolescence, technical support issues, maintenance issues, manufacturing problems, and other industrywide generic problems)
- Technology improvements

When considering retrofit and replacement equipment suppliers, utilities are faced with a dwindling list of original equipment manufacturers (OEMs) plus new third-party suppliers to consider. This presents utility managers with additional challenges with respect to due diligence, project review, and project management requirements as they seek to select the best equipment and mitigate risk. At the same time, utilities have reduced staffing levels, and expertise and experience levels have declined due to retirements and lack of growth in the industry. This report will provide insight into these considerations.

1.2 Experience with Non-OEM Equipment

The retrofitting or replacement of a steam turbine-generator is a major undertaking and requires the commitment of significant human and financial resources. The suppliers of major steam turbine-generator equipment and components have changed over the years. In the past, utilities relied heavily on the OEMs to provide expertise and replacement and retrofit equipment. Today and in the future, this will not always be the case, because suppliers have merged, sold portions of their enterprises, or simply gone out of business. Third-party suppliers or OEMs other than the original OEM have entered the market to fill the void. This situation creates additional issues that need to be addressed by utilities to minimize potential equipment, performance, and financial problems related to a retrofit and/or replacement.

As utilities attempt to extend the life of older units, the number of retrofits is expected to increase. However, recently there have been some retrofit projects that have encountered significant problems, highlighting the need for a sound process for risk assessment and management of equipment retrofit and replacement projects to ensure the success of future projects. Although many utilities may have detailed procurement and specification procedures in place, this may not be adequate for major retrofit or replacement projects because the existing procedures are geared toward using OEM expertise or are based on past practices.

As with any major equipment modification project, a detailed and deliberate process for developing and implementing the modification has to be followed to ensure that issues are properly addressed and that the modification is as cost-effective as possible. This report provides guidance on risk assessment and risk mitigation methods to increase the success of retrofit and replacement projects and is intended to supplement existing procedures and guidelines. The primary focus of this report is on the lessons learned from actual retrofits and replacements of steam turbine-generator equipment.

1.3 Definitions

For the purposes of this guideline the following definitions will be used:

- **Retrofit.** Retrofit equipment is expected to serve a purpose similar to that of existing equipment, but may be designed to meet different technical conditions or be provided by non-OEM suppliers. OEM-supplied equipment and components may be categorized as retrofits due to changes in metallurgy, design conditions, or other features that may impact plant O&M or performance.
- **Replacement.** This term refers to the installation of equipment and components that meet the original design dimensions and performance criteria. In general, replacement equipment and components will be considered original equipment provided by the OEM. The installation of a complete steam turbine by a non-OEM should not be considered a replacement, because the non-OEM will not have access to the original design documents and other critical or proprietary information.
- **Project management plan.** Identified risks should be addressed in developing the project management plan. A project management plan should include design reviews, quality plans, witness programs, contract terms, and technical support and outside resources needed to mitigate the identified risks. Critical elements of the project management plan include the bid specification and evaluation process, design reviews, quality plans, shipping and handling requirements, a witness program, schedule tracking, and technical support. Project management plans are described in Section 3.

2
RISKS ASSOCIATED WITH THE PROCUREMENT OF RETROFIT AND REPLACEMENT EQUIPMENT

There are many reasons for the retrofitting and replacement of steam turbine-generator components. However, there are risks involved. The procurement process, project management, and various aspects of the equipment are fraught with potential problems that can seriously affect the success of any retrofit or replacement and ultimately impact unit performance, revenue, and asset value.

A risk assessment should be performed as part of any analysis of equipment replacements and retrofits. The purpose of the risk assessment is to identify the issues that are critical to the success of the project, including the following (see Figure 2-1):

- **Equipment selection.** The condition of the existing unit, and its operating status, should be assessed to identify any potential issues when existing equipment is replaced with new equipment. Design changes and performance improvements may also impact other existing unit components and may require additional modification to the unit. Changes in manufacturing process, design tools, and metallurgy may impact the reliability and operating margins of the new equipment.
- **Vendor selection.** Identification and evaluation of potential vendors requires a significant amount of due diligence. It is necessary to evaluate each prospective vendor's technical and manufacturing capability, quality program, contract performance, and financial strength.
- **Available resources.** An honest assessment of available technical and historical O&M information, internal processes, tools, and personnel available to execute the work should be performed, and any additional resources that may be needed should be identified.
- **Other risks.** Each project and utility will have unique risks. The project team should ask "what else can go wrong" questions regarding possible unforeseen effects to other plant systems and plant operations and maintenance. Items to consider include schedule changes, cost impacts, equipment damage or loss, vendor bankruptcy, natural disasters, terrorist attacks, labor unrest, government instability, and failure of vendors to meet technical or contract requirements.

Identified risks should then be addressed in developing the project management plan. Critical elements of the project management plan include bid specification and evaluation, design reviews, the quality plan, shipping and handling, a witness program, schedule tracking, and technical support.

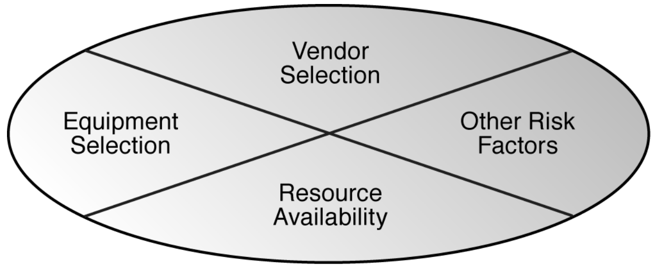

Figure 2-1
Risk Assessment Components

2.1 Equipment Selection

The task of selecting replacement and retrofit equipment has grown in complexity. In the past, utilities generally replaced equipment with the original manufacturer's equipment. At one time (in the 1990s), OEM shops were full and other sources needed to be researched and sourced. As units aged and manufacturers changed or went out of business, utilities had to look to other sources for replacement and retrofit equipment. In addition, the drive to improve performance and eliminate chronic operating and maintenance issues resulted in consideration of non-OEM (third-party) equipment suppliers. Therefore, it is now even more critical to consider equipment risks associated with retrofit or replacement projects.

Aspects to consider include changes in plant operations, technical requirements, and equipment history.

2.1.1 Changes in Plant Operation

The condition of the existing unit, and its operating status, should be assessed to identify any potential issues when existing equipment is replaced with new equipment. Retrofit and replacement equipment should be designed to meet current and expected plant operations. Design changes and performance improvements may also impact other unit components and may require additional modifications to the unit. Issues that need to be addressed are:

- The expected operating regime—baseload, cycling, and so on
- The expected remaining life of the unit
- Any impacts on unit performance—efficiency, capacity, availability, forced outages, and so on
- Any changes in staffing and O&M procedures
- The impacts on dispatch, ramp rates, startup times, and so on

2.1.2 Technical Issues

The technical requirements of the equipment are based upon the specific design requirements. These requirements form the basis for the technical specification that is provided to prospective vendors during the bidding process and in the final purchase contract. Any potential technical issues that may impact performance, capacity, availability, and O&M of other plant systems and components must be considered when developing the system design basis, equipment design, and equipment history.

2.1.2.1 System Design Basis

System design basis requirements should address those system parameters that the replacement/retrofit equipment design must meet, such as the following:

- Normal and upset operating conditions
- Seismic requirements
- Environmental conditions
- Nuclear system and component safety classifications
- Requirements exceeding industry/code requirements
- Interface points and work associated with connecting interfaces

Information provided should reflect the current and expected plant configuration and operating condition.

2.1.2.2 Equipment-Specific Issues

The questions faced include the following:

- Is a retrofit called for, or a replacement? Retrofitting a turbine-generator component entails different risks than replacing a complete turbine.
- Are there any design tools or manufacturing techniques that might introduce risk? Are there any changes in manufacturing process, design tools, or metallurgy that could impact the reliability and operating margins of the new equipment?
- Is the equipment an exact replacement? Specific issues for evaluating nuclear plant equipment replacements are outlined in the EPRI report *Plant Support Engineering: Guidelines for the Technical Evaluation of Replacement Items in Nuclear Power Plants, Revision 1* (1008256) [1].

2.1.2.3 Equipment History

The operating and maintenance history of the equipment should be reviewed to identify any performance problems or inherent equipment issues. Unfortunately, new designs and non-OEM equipment will often not have any significant operating history. Choosing a new design or unproven equipment, therefore, must be considered carefully before proceeding. The following information will provide insight into the performance of a particular piece of equipment:

- Number of units in service
- Years of service
- Equipment availability and forced outage rates
- Outage and curtailment causes
- Existence of any unresolved issues
- Availability of extended warranties
- History with regard to performance guarantees

2.2 Vendor Selection

Identification of qualified suppliers should be based upon their ability to provide items in accordance with the procurement document requirements (see ANSI N45.2.13 Section 4) [2]. There are many issues to be considered when developing a list of qualified bidders. A more detailed description of the vendor selection process can be found in the EPRI report *Project Management Guidance When Upgrading Steam Turbines at Nuclear and Fossil Power Plants* (1014717) [3].

As mentioned earlier, identification and evaluation of potential vendors requires a significant amount of due diligence and needs to evaluate each prospective vendor’s technical and manufacturing capability, quality program, contract performance, and financial strength. The evaluation process for vendor selection should be documented and should include an evaluation of past performance and current and future capabilities, as appropriate for each situation.

2.2.1 Evaluating Past Performance

Evaluation of past performance will identify potential issues that can adversely impact the overall success of a retrofit or replacement. In qualifying a potential supplier, the project team should determine the supplier’s ability to deliver equipment that meets performance and technical requirements.

Past performance is even more critical for third-party (non-OEM) suppliers. Even if the third-party supplier is a relatively new supplier for the equipment being procured, history on other projects and equipment will often provide insight to the suppliers' capabilities. Some questions to ask are the following:

- Has the supplier provided similar equipment before?
  - Determine where and when installation was done.
- What kind of experience have others had with the supplier?
  - Obtain contacts and references, and follow up on them.
- Has equipment performed as designed?
  - Identify any technical issues and resolutions.
  - Identify any performance issues.
  - Identify any maintenance issues.
- Were there any issues with labor or manufacturing?
- Did the supplier provide competent field, training, and technical support?
- Were there any significant contract compliance issues?
  - Determine whether documentation was accurate and in compliance with specifications.
  - Identify any unusual contract requirements.
  - Identify any deviations from schedule and deliverable commitments.
  - Liquidated damages (LDs) and warranty.
  - Identify any contract issues that required arbitration or legal action.
- What was the general working relationship with the supplier?
  - Adversarial
  - Open and forthcoming
  - Secretive
  - "No nonsense" or strictly contractual

2.2.2 Determining Current and Future Capabilities

Shop loading, technical resources, and financial strength must be verified to ensure that the vendor will be able to meet current and future commitments:

- Verify that current quality records meet company and industry standards.
- Review implementation of the vendor's quality assurance (QA) program. If the replacement component is being procured from a new supplier, an initial qualification evaluation (for example, an audit or commercial-grade survey) can be performed.

- Verify that supplier has the necessary technical and quality capabilities to support the project.
  - Visit facilities and meet with personnel.
  - Verify the quality and technical capabilities of outsourced technical and design service suppliers.
- Verify manufacturing capability.
  - Consider shop space, organization, and cleanliness.
  - Assess the labor situation—if union, is the contract open for negotiations during the manufacture of equipment?
  - Check the safety record.
  - Determine manufacturing lead time.
  - Verify the quality and manufacturing capabilities of materials and equipment suppliers.
- Verify that the supplier has the financial strength to execute the work.
  - Review bonding capabilities and financial information—revenue projections, working capital, stock value, and outstanding debt.
  - Assess work backlog.
  - Check for existence of significant current or future litigation that could impact the financial situation.

2.3 Resource Availability

A retrofit or replacement of major equipment will require a significant amount of resources. It is therefore important to identify the available resources in order to develop a course of action to address any gaps. The required resources include data and information on the plant and equipment, human resources, and management tools necessary to execute the work.

2.3.1 Data and Information

There are many factors that will dictate the extent of the information included in the technical description, including the following:

- The company-specific or proprietary procurement requirements
- The supplier’s level of involvement in the equipment design
- The complexity of the equipment replacement or retrofit
- Any vendor-specific materials and manufacturing processes
- The conditions the equipment must meet as part of the overall system

Information on the installed equipment is not always available. Drawings and manuals may not exist or may be outdated, or operating and maintenance histories may not be complete. The amount and level of detail available will have an impact on the equipment design and performance. Information should reflect the current and expected plant configuration and operating condition as well as historical data.

The following types of information should be addressed:

- Normal and upset operating conditions
- O&M history
- Drawings (as built) and manuals
- Special tools
- Lifting requirements
- Environmental conditions
- Nuclear system and component safety classifications
- Requirements exceeding industry/code requirements
- Descriptions of all interface points

2.3.2 Human Resources

Staffing levels have been decreasing as utilities strive to be more efficient and cost-competitive in today's market. Outsourcing of engineering and project management is becoming necessary to effectively manage large retrofit and replacement projects. An assessment of the available resources and potential outsourcing requirements should be performed prior to committing to a steam turbine-generator equipment replacement or retrofit. Verify that competent engineering and project management resources exist to help support the project (internally or externally, as appropriate).

2.3.2.1 Project Team Considerations

A strong project management team should be organized to effectively implement these guidelines and manage the project. Utilities continue to reduce staffing levels through retirements and severance programs in an effort to reduce costs. As a result, they may not have the appropriate resources to properly staff the project.

Key elements to consider when assembling the project team include:

- Project management: experience and skill sets, experience with similar work, and familiarity with the vendors and the equipment
- Engineering and other technical resources: design and technical capabilities; inspection and testing; analysis; and drawing reviews

- Plant staff: maintenance supervision and craft skills availability
- Procurement and expediting: shop visits, hold points, shipping, and so on
- Planning and scheduling: schedule resources, outage coordination and planning, familiarity with scheduling tools, and reporting process
- O&M resources: modification of operating procedures and maintenance practices; startup, training, and project support
- Other resources: document management, quality assurance and quality control (QA/QC), contracts, and legal

2.3.2.2 Outsourcing

Although it may be ideal to staff projects with personnel from the utility staff, this may not be possible or prudent due to limited resources or workload. The following additional elements should be addressed to identify outsourcing requirements and concerns:

- Engineering and other technical resources—availability of competent vendors to provide technical support including design reviews and testing support
- Plant staffing—additional craft requirements for outage and equipment installation
- Procurement and expediting—shop visits, hold points, shipping, and so on
- Planning and scheduling—need for additional planning and scheduling resources
- O&M resources—identification of the parties responsible for training, startup, and revision of operating and maintenance procedures; decision regarding outsourcing of this work
- Unique fabrication or manufacturing processes
- Testing requirements including nondestructive examination (NDE)
- Shipping, storage, shelf life, and maintenance and staging requirements
- Evaluation and recommendation for spare and replacement parts
- Design verification methods
- Accuracy of plant-specific and supplier drawings and revision levels
- Compatibility of the vendor's documentation process with those of the equipment supplier and the utility
- Maintaining compliance to a qualification report or seismic conditions

2.4 Other Risks

As mentioned previously, each project and utility will have unique risks. The project team should ask "what else can go wrong" questions regarding possible unforeseen effects to other plant systems and plant operations and maintenance. Items to consider include schedule changes, cost impacts, equipment damage or loss, vendor bankruptcy, natural disasters, terrorist attacks, labor unrest, government instability, and failure to meet technical or contract requirements.

2.4.1 Schedule Concerns

Replacement or retrofit of turbine-generator equipment requires a significant plant outage. Outage duration and timing are established in accordance with system load requirements and must be integrated with the retrofit/replacement equipment delivery schedule.

Outage timing and duration, shipping and receiving schedules, and equipment testing impact the overall project schedule, but may also impact systemwide outage planning, power dispatch, and power sales contracts. Changes to a unit outage may also impact the staff labor and other planned unit outages. Repairs to other system generation equipment may need to be delayed, shortened, or even postponed in order to meet system load requirements.

A risk assessment of potential schedule impacts should take into account the following considerations to identify potential schedule issues:

- Level of design completed prior to start of manufacturing
- Fast-track scheduling
- Shipping plans and routing (determining whether the routes are capable of supporting the heavy or wide loads)
- Need for transportation permits
- Manufacturing facility workforce potential contract issues
- Manufacturing backlog
- Level of detail in the project schedule, and update frequency
- Amount of schedule float, on major tasks and overall

2.4.2 Cost Control

The best way to avoid cost overruns is to ensure that the design and contract requirements are as compete as possible. Change orders, modifications, errors, and omissions all affect project costs, and efforts and controls should be in place to minimize them. However, changes may be necessary and appropriate.

Changes in the schedule can affect outage duration and impact plant labor costs and other planned outage work.

In order to minimize cost overruns and ensure that appropriate funding is available for the project, the project team should do the following:

- Ensure that the change order process is defined and followed
- Identify the total cost of changes
- Identify and obtain pricing for options prior to contract signing
- Consider establishing a not-to-exceed price

2.4.3 Risk of Loss

The risk of loss of major turbine-generator equipment may be low; however, the impact of the loss is significant. Losses can occur during any stage of equipment design, manufacture, shipping, and installation. Contract language should clearly specify when the risk of loss changes from the vendor to the owner.

2.4.3.1 Manufacturing

During manufacturing the equipment may be damaged due to improper rigging, handling, machining, heat treating, and many other potential problems.

2.4.3.2 Transportation and Shipping

The method of shipping and the time of year should be considered.

Overseas shipping issues include proper shipping preparation, customs, and on-shore handling and storage requirements.

2.4.3.3 Fire and Weather

In order to avoid damage due to fire and weather, ensure that equipment shipping and storage requirements are understood and identified. Depending on the time of year, equipment could be damaged by hurricanes, typhoons, tornadoes, snow, ice storms, and rain (see also Section 2.4.3.7, Natural Disasters).

2.4.3.4 Wars, Terrorist Acts, and Labor Unrest

Understand when contracts are due to expire and any contract issues that may impact manufacture of the equipment. Are there any work-arounds? If equipment is being manufactured in a foreign country, is the government stable?

2.4.3.5 Bankruptcies

Are the vendor and its subcontractors and suppliers financially viable? What are the alternatives for completing the work if one declares bankruptcy or goes out of business?

2.4.3.6 In-Service Failure

A failure of the equipment during the warranty period should be covered by the warranty. However, damage to other equipment, lost revenue, and "in and out" costs may not be covered. The consequences of an in-service failure may be significant. Proper warranty management and potential failure modes should be reviewed.

2.4.3.7 Natural Disasters

The potential for natural disasters such as tornadoes, earthquakes, and hurricanes to impact a project will depend on the location of the plant and the manufacturing facilities, transportation routes and weather conditions, and other factors that may be beyond the control of the project team. However, proper assessment of potential problems can prevent or minimize potential risks.

2.4.4 Poor Performance Loss of Revenue

Determine the potential for not meeting the performance requirements of the contract. Quantify the costs and consider including penalties for non-performance in the contract as well as ensuring that the liquidated damages are equivalent to the poor performance.

2.4.5 Damage to Other Equipment

Damage to other equipment may be the result of physical impacts from the new equipment—such as damage caused by a loose part that becomes a projectile—or long-term damage, such as erosion, vibration, or metal fatigue. Identified issues should be in contract terms and/or addressed by insurance.

3 MANAGING THE RISK OF EQUIPMENT RETROFIT AND REPLACEMENT

Each retrofit and replacement project will have unique risks, and the risk mitigation methods must be tailored to address the project risks, the utility risk profile, and the experience and expertise of the project team, vendors, and plant staff. Section 2 of this report outlines a process of identifying the risks associated with a steam turbine-generator retrofit or replacement. The present section of the report summarizes the guidance regarding project management techniques to manage the risk mitigation process, including the following aspects:

- Bid specification and evaluation
- Utilization of design reviews
- Quality plans
- Witness programs
- Development of contract terms
- Identification of the technical support and outside resources needed to mitigate the identified risks

EPRI has published a number of additional guidelines for project management and risk mitigation, some of which are included as references in this report. Successful project execution will depend on the effectiveness of the project team at implementing and executing techniques to mitigate the risks that have been identified. The other EPRI publications along with this report will provide the project team with a set of tools to effectively execute steam turbine-generator retrofit and replacement projects.

Figure 3-1 identifies risk mitigation strategies relevant to retrofit and replacement projects.

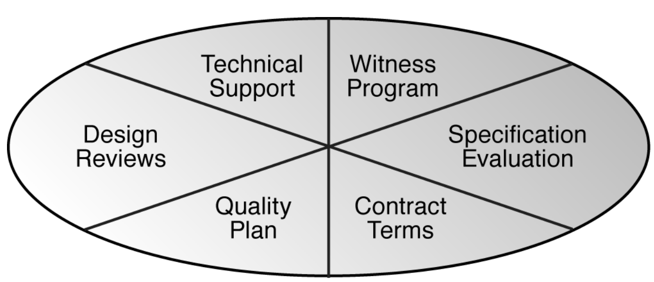

Figure 3-1
Risk Mitigation Strategies

A strong project management team and sound policies and procedures form the basis for risk mitigation. In the past, utilities relied more heavily on the OEM to provide overall project management and technical support. However, because of the changing market, some OEMs have gone out of business, and some no longer have the technical expertise to provide the project management and technical leadership needed to ensure a successful retrofit or replacement project.

The overall objective of any project management plan is to manage and minimize risk. The EPRI report *Project Management Guidance When Upgrading Steam Turbines at Nuclear and Fossil Power Plants* (1014717) provides a solid foundation for managing the risks associated with replacement and retrofit projects [3]. Key elements of a project management plan include the following:

- Bid specification
- Bid evaluation
- Design reviews
- Quality plan
- Contract language
- Witness program
- Descriptions of outsourced support services

3.1 Bid Specification

The bid specification provides the technical and commercial requirements to prospective vendors and forms the basis for evaluating proposals, selecting the vendor, and finalizing the purchase agreement for the equipment. In order to obtain acceptable quality and comparable bids, the bid specification should include detail sufficient to communicate all of the required design criteria while allowing enough flexibility for multiple suppliers to bid. The level of detail will be dependent on the project-specific requirements, the equipment being replaced or retrofitted, and company commercial requirements.

More detailed guidance for developing specifications for major equipment and component replacement can be found in the EPRI report *Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections, Volume 4: Turbine-Generator Component Procurement Specifications* (1014729) [4].

For steam turbine-generator retrofits and replacements, the bid specification must address the requirements for the equipment design and operation as well as the installation and technical support required to ensure that the components meet their intended performance parameters. These requirements may be included in a single turnkey bid specification or in separate packages for the design and manufacture, installation, and technical support.

3.1.1 General Requirements for All Specifications

The following information should be included in all bid specifications. The level of detail may vary depending on the scope of supply and the project complexity.

- The scope and anticipated schedule for the work
- Expectations for performance and future maintenance interval requirements
- Several heat balances to predict performance at all expected loads the unit will operate at
- Description of organizational interfaces and roles/responsibilities among members/organizations composing the project team
- Quality requirements
- Required documentation and drawings, including test data, as-built drawings, and design data; this general category may include the following:
  - Deviation notices
  - QC reports (nonconformance reports)
  - Submittals to explain the design basis of the upgraded component and results of analyses performed by the upgrade OEM
  - Maintenance manuals
  - Conformed drawings/as-built drawings
  - Supplier instruction manuals (including maintenance recommendations)
  - Qualification reports
  - Certified material test reports
  - Nondestructive test reports
  - Personnel certifications
  - Inspection reports
  - QA manuals
  - Performance test reports
  - Certificates of conformance/compliance
  - Recommended spare/replacement parts lists
  - Material safety data sheet (MSDS) information
- Document format, submittal, and review requirements
- Required vendor meetings and site visits
- Bid submittal requirements

- Commercial terms and conditions including insurance, bonding, and warranty requirements; the type of bid; liquidated damage levels; payment terms; and any company-specific requirements
- Description of the bid evaluation process and evaluation criteria—not absolutely necessary, but an element that will result in more uniform bid submittals and can improve the vendor selection process
- Applicable codes and standards
- Personnel qualification requirements such as resumes and experience lists and references
- Equipment and personnel safety issues and as low as reasonably achievable (ALARA) concerns (for nuclear licensees)
- Any “boiler plate” needed from suppliers to satisfy regulatory and insurance issues

3.1.2 Design and Manufacturing Bid Specification Requirements

The following additional items should be included in a design and manufacturing bid specification:

- Design and performance information for current equipment, including the original design as well as current operating parameters and any modifications that have been made
- Technical requirements for the replacement or retrofit component
- Witness, testing, design review, and hold requirements
- Performance testing requirements
- Requirements for the submittal of a manufacturing, delivery, and storage plan and schedule
- Documentation of installation
- Post-installation testing requirements and acceptance criteria for verification of design performance parameters
- Clarification on all interface points and methods used to ensure that new components fit remaining components
- Agreement on performance testing requirements, locations of measurements, and correction factors to be applied as well as any other assumptions that are made, such as assumed pressure drop across valves or exits of blades to piping
- Any other information that might be beneficial for the utility in the future—asking for it up front prior to awarding the job ensures an interested audience

3.1.3 Installation and Construction Bid Specification Requirements

The level of detail and scope of the installation or construction specification will depend on who is responsible for installing the retrofit or replacement components. The installation bid specification should include the following information:

- Any required demolition and disposal of existing components including any hazardous materials.
- Limits of the work including all interface points and work associated with connecting interfaces.
- Requirements for modifications to adjacent or ancillary systems such as moving piping and instrumentation.
- Site-specific requirements including any site-specific or company-specific installation issues, such as safety, lay-down space, available lifting devices and capacities, labor requirements (if any), schedule requirements, work to be done by the owner, and other similar items.
- Flow diagrams and site drawings showing the removal of the old components and the installation of the replacement.
- Special lifting/handling requirements and a listing of any plant equipment, such as cranes, that may be utilized by the installer.
- Requirements for testing of cranes and lifting and rigging plans.
- Verification that existing cranes will support the new weights of the supplied components.
- Witness and hold points for inspection and testing during the installation process.
- In-process testing required as the replacement component is being installed.
- Documentation of installation.
- Post-installation testing requirements and acceptance criteria for verification of design performance parameters. (Note: these parameters need to be defined in the design process to ensure that all parties are in agreement. Waiting until the installation is too late.)
- Special tools or scaffolding required for installation.
- Requirements for the submittal of an installation plan and schedule.
- Description of organizational interfaces and roles/responsibilities among members/organizations composing the installation team.
- Access routing and special considerations for moving the components into their designated positions.
- Storage/staging requirements (such as power, air, and lighting).

Many of these installation issues are discussed in more detail in Section 10 of the EPRI report *Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections, Volume 4: Turbine-Generator Component Procurement Specifications* (1014729) [4].

3.1.4 Service Specification Requirements

Specifications to procure various services in support of the retrofit or replacement should include the following general requirements:

- The type of service needed
- Technical requirements for the services
- Witness, testing, design review, and hold requirements
- Performance testing requirements and acceptance criteria
- Requirements for the submittal of testing plans, protocols, and results
- Documentation of installation and post-installation testing requirements for verification of design performance parameters
- Personnel certifications and resumes
- The forms of inspection and performance testing
- QA manuals

3.2 Bid Evaluation

The bid evaluation process must meet the company procurement requirements and ensure a thorough assessment of the commercial and technical aspects of the bid. Section 2 of ANSI N45.2.13 requires that the licensee establish measures for the control of the procurement of a replacement component, including appropriate planning [2].

Proper planning is required to ensure that the methods to be used in procurement activities are properly documented. To support this, applicable procedures should exist prior to the initiation of each activity, a sequence of events with milestones should be developed, and a process to track progress should exist.

How the commercial and technical portions are evaluated and then utilized to provide a complete bid evaluation will vary based upon each utility’s procurement and QA programs. However, certain evaluation criteria are required, as outlined in this section.

Another factor that should be considered that is not explicitly described in ANSI N45.2. 13 is the division of QA program responsibilities between the project team and various organizations in the supply chain. These factors are discussed in more detail in the following section.

Section 5 of ANSI N45.2.13 states, in general, that a licensee should establish a documented system for reviewing and evaluating the bids and awarding of contracts. This established process should be used for the evaluation of bids for replacement components [2]. The general bid evaluation process used by many utilities is illustrated in Figure 3-2. Bids are typically received by the company procurement organization, and the appropriate portions of the bid are provided to individuals on the project team or company organizations for evaluation of the various components of the bid in relation to the bid specification. The technical and commercial evaluations are performed separately and then combined to develop an overall evaluation and recommendation.

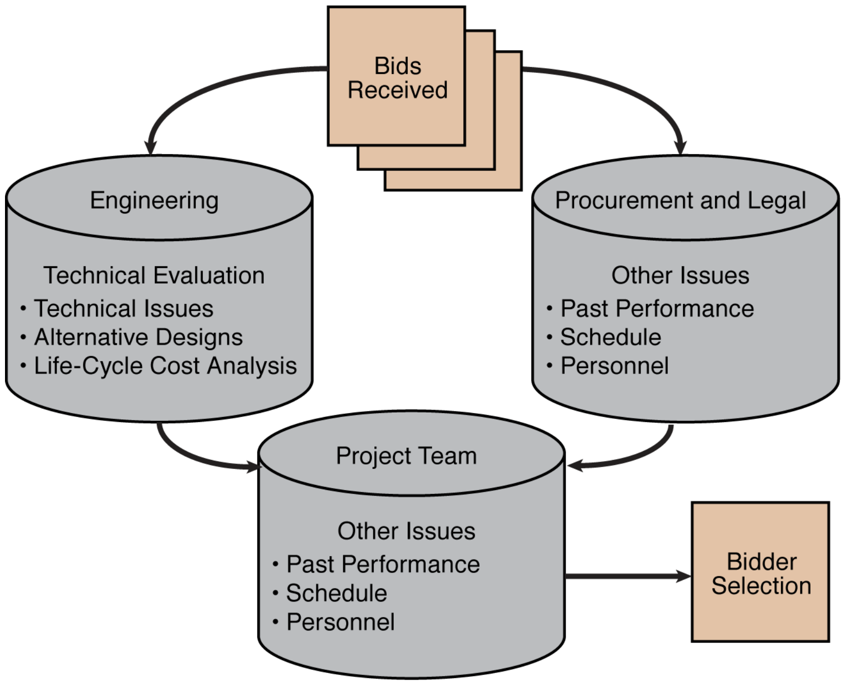

Figure 3-2
Typical Bid Evaluation Process

3.2.1 Technical Issues

The project technical team should perform a thorough evaluation of the technical merits of the bid to identify areas where the bid does not comply with the specification. Where practicable, a value for comparison purposes should be determined for any differences from the bid specification. In most cases, this will be based on the net present value of the technical deviation. Typical items that may be included are:

- Alternative designs
- Performance impacts
- Determination of the vendor’s solutions to reduce solid particle erosion, stress corrosion cracking potential, and moisture erosion; extend creep life of bolting; address ease of future maintenance; and so on [5]
- Missing components
- Technical exceptions
- Quality assurance requirements

- Determination of the vendor’s methodology for ensuring that there are no component interface issues (for example, use of 3D modeling with direct output to manufacturing) [5]
- Experience and technical competence of the vendor’s project team
- Schedule adherence
- Testing plans and capabilities
- Manufacturing capabilities
- Acceptance testing
- Vendor’s production capability
- Evaluations of exceptions to the bid
- Performance enhancements or deviations
- Startup and training capabilities

3.2.2 Commercial Issues

The project procurement team should evaluate the bid in relation to the terms and conditions and other nontechnical aspects of the bid compared to the specification in the following areas:

- Payment terms
- Change order process
- Insurance
- Warranty
- Guarantee
- Liquidated damages
- Limitations on liability
- Bonus and penalty requirements
- Delivery schedule
- Acceptance testing
- Risk of loss and transfer of ownership

3.2.3 Other Factors

Other factors to consider may include any of the following:

- Supplier experience/reputation/recognition in the industry
- Manufacturing facility locations
- Ease of doing business

- Shipping and storage plans
- Other items specific to the project and/or the balance-of-plant equipment
- Previous working experience with the vendor
- Past performance
- Vendor systems compatibility with the owner's systems

3.3 Design Reviews

Another key element of risk management is design reviews. The nature of equipment replacement and retrofit projects makes design reviews an important project management tool. Design reviews provide a formal method for the project team to ensure that the project design will meet the overall project objectives throughout all phases of project execution. The primary objectives of design reviews are as follows [6]:

- Ensure that the equipment design meets the required performance and technical requirements.
- Ensure that maintainability and operability issues are addressed.
- Ensure successful installation and operation of the equipment.
- Identify all critical design, manufacturing, and quality details.
- Provide confidence in the supplier's capability. Design reviews will provide additional confidence that the supplier's manufacturing and design capabilities will meet the requirements of the specification and other appropriate industry and government requirements.
- Provide a more in-depth understanding of proposed design features and margins.
- Identify any "first time" or other unique features and determine whether testing has been performed to prove that the design is acceptable.
- Ensure that all interfaces have been properly evaluated.
- Incorporate lessons learned from previous projects.

3.3.1 Keys to Successful Design Reviews

A design review is a formal process that requires meticulous cross-team preparation and planning to be effective. The keys to a design review process that can mitigate project risk are the following [6]:

- Specifications and contracts that identify the utility's specific design review requirements
- Emphasis on quality throughout the project
- Active buy-in and participation by dedicated vendor and utility project teams

- Developing a strong trust between the utility and the vendor with documented follow-up on commitments
- Disciplined follow-up, presence, and oversight at the vendor's facilities
- An unwavering desire on the part of the project team to identify and resolve potential problems
- Support, involvement, and buy-in from corporate and plant management, the engineering design department, and plant O&M

3.3.2 Elements of Design Reviews

3.3.2.1 Timing

In order to be effective, design reviews need to be scheduled so as to allow changes in the equipment design, manufacture, testing, schedule, shipping, and so on. The required timing and participants should be incorporated into the vendor's contract. Typical review points are as follows [6]:

- During the design phase
  - Conceptual design
  - Final design
- Prior to the start of manufacturing
- Prior to shipping
- Prior to installation
- Prior to final acceptance
- After final acceptance

Review points should be adjusted by the project team based on the complexity of the project, the experience with the equipment supplier, and the results of previous reviews.

3.3.2.2 Design Review Meetings

Meetings should be conducted at the vendor's design and manufacturing facilities depending on the stage of the project. The meeting agenda, location, and schedule should be developed jointly.

Successful design review meetings depend on careful preparation. The utility project team should prepare detailed questions and provide them to the vendor's project team prior to any design review meeting.

The project team should enlist consultants, plant operating and maintenance staff, systems engineers, and other experts when appropriate to ensure that all aspects of the project are discussed, including the following [6]:

- Civil and structural design attributes
- Mechanical design attributes
- Electrical design attributes
- Interfaces and plant O&M impact
- Installation considerations
- Manufacturing QA/QC
- Shipping and storage

The vendor’s project team should come to the meetings prepared to discuss and answer the questions. The vendor’s subject matter experts should be available to address issues as necessary.

Be sure to allow enough time to fully address all issues and review each meeting for completeness and develop action item lists as required for follow-up or to address any unresolved issues.

One individual should be assigned to lead and “own” the meetings and ensure that action items and other unresolved issues are addressed and a resolution found. All unresolved issues should be assigned to the appropriate persons or groups, with committed dates for follow-up and resolution.

3.3.2.3 Surveillance and Follow-Up

The design review process is designed to identify any potential issues before they can assume major proportions. It is therefore critical that the project team continually follow up on any issues and vendor commitments.

The project team should maintain an active presence and oversight at the vendor’s facilities to ensure that commitments are fulfilled during all phases of the project. This surveillance will:

- Ensure that the project teams understand the original design.
- Validate that the design is compatible with modern manufacturing techniques.
- Verify that the facilities are fully qualified and tested. This is especially important for first-time manufacturing processes and non-OEM suppliers.
- Verify that any remote manufacturing facilities or subcontractors fully understand design. criteria and are working to same quality standards agreed to by the vendor in the contract.
- Identify deviations and nonconformance and required customer approvals.

3.4 Quality Plan

3.4.1 Quality Assurance and Quality Control

The quality requirements for replacement or retrofit equipment should be developed and specified in the procurement document and contract. These quality requirements must pass to all subcontractors that vendors use for supply of materials, parts, labor, and fabrication. The design of the quality program will depend on the equipment complexity, the manufacturing process, the utility's QA program and Final Safety Analysis Report (FSAR; for nuclear licensees), and appropriate regulatory and industry standards.

For nuclear licensees, the quality requirements for commercial-grade components used in nuclear safety applications demand special consideration. Commercial-grade purchases should not have nuclear-unique standards imposed in the purchase documents (for example, see 10 CFR50 Appendix B and 10 CFR 21); however, special acceptance requirements may be required (see the EPRI report, *Guideline for the Utilization of Commercial-Grade Items in Nuclear Safety-Related Applications* (NP-5652) [7].

The following quality requirements are typically specified on the procurement document:

- The specific requirements of the quality assurance program
- The type and frequency of supplier audits
- Source verifications (including witness and hold points)
- Material specifications
- Receiving inspections
- Personnel qualification and certification
- Other special quality requirements that may include any of the following [7]:
  - Qualification testing, including mockup access requirements for inspection, audit, or surveillance
  - Defect reporting according to 10 CFR 21 for nuclear suppliers
  - Dedication methodology according to EPRI NP-5652
  - Performance of subsupplier's inspection/audit/surveillance/sampling according to established procedures or recognized standards
  - Special processes and/or cleanliness requirements
  - Field verification, by the turbine upgrade vendor, of all interface points (may be scheduled and integrated into an upcoming outage to minimize operational impact)
  - Requirements for shock or vibration monitoring during shipment
  - Tracking via global position monitoring

3.4.2 Quality and Deviation Review Prior to Shipment

A thorough quality and deviation review should be conducted by the project team prior to shipment of the equipment. This is the time to review all deviations and solutions with the vendor. Unresolved deviations should be resolved prior to shipment if at all possible. Most deviations identified during the manufacturing process should be addressed while the equipment is still in the vendor's shop. Allowing shipment with manufacturing deviations could result in significant delays to the project. In addition, field modifications might not be made to the same level of accuracy because machinery might not be available at the plant site.

3.5 Contract Language

The contract forms the basis of the relationship between vendor and owner. The project complexities, utility contracting practices, and vendor requirements will determine the form of contract. There are several key issues that the project team should strive to include in any contract for steam turbine-generator retrofit and replacement projects, as discussed below.

3.5.1 Contract Type

The procurement of retrofit equipment is traditionally conducted through competitive bidding, based on a specification and execution of a fixed-price contract for a defined scope of supply:

> If the price is fixed, the contractor has an incentive to perform the work as inexpensively as possible to improve the contractor's profit. If the price is a variant of a "cost plus" contract, the contractor does not have the same incentive to perform the work as efficiently or in as timely a fashion as they might otherwise. In the latter case, the owner has to take more control over quality and schedule outcomes; otherwise, costs may escalate beyond budget.
>
> The traditional approach encourages an adversarial relationship between owner and contractor, especially if the price is fixed and competitive bidding has taken place. Contractor claims of additional compensation, overpriced extras, and delays are frequent issues. In the worst cases, these contracts wind up in arbitration or in the civil courts. In cases that are settled, one party or the other often feels that they have been taken advantage of [8].

Performance-based contracting is an alternative that should be considered for retrofit projects:

> Performance-based contracting is intended to create a non-adversarial contracting relationship by rewarding good results with bonuses and punishing bad results with liquidated damages. Performance-based contracting methods are intended to ensure that required performance quality levels are achieved and that total payment is related to the degree that the services performed meet or exceed contract standards. Performance-based contracts describe in specific terms the results required of the work. They use measurable performance standards and quality assurance surveillance plans. The contract specifies

> procedures for reduction of fees (for time and material contracts) or reduction to the price (of a fixed-price contract) when services are not performed or do not meet contract requirements. It also includes performance incentives where appropriate.
>
> Familiarity with and use of performance-based contracts may lead to the creation of business relationships that recognize the efficient and effective nature of these arrangements. They may also build an atmosphere of trust that can then lead to teaming arrangements, alliances, or partnerships to the mutual benefit of the contracting parties [8].

Additional information on the elements of performance-based contracts, including the scope of work, scheduling, cost, quality of work expected, and safety provisions that are to be in place, is provided in the EPRI report *Guidelines for Performance-Based Contracts for Fossil Fueled Power Plants* (1004829) [8].

3.5.2 Standard Terms and Conditions

Contract terms and conditions include the legal requirements for the parties and the protections and rights of the parties for the project. If a project goes well, the legal terms and conditions are seldom referenced. However, when a project encounters problems, solid terms and conditions can provide the utility some protection from damages and related costs for a retrofit project.

Contracts for steam turbine-generator retrofit and replacement projects typically include contract language to address the following areas:

- **Title and risk of loss.** The vendor should retain the risk of loss until the equipment is accepted by the owner. This transfer of ownership should occur as late as possible so that any loss or damage to the equipment during manufacturing, transportation, storage, installation, testing, and commissioning will not accrue to the utility.
- **Warranty.** Warranties should include the cost of repair and replacement of the failed equipment, component, or part and the cost of removing and reinstalling the equipment whenever possible. Warranties should also state when they begin, define the duration, and rewarrant equipment that fails during the warranty period. Typical equipment warranties of one year from installation or first operation should be achievable for standard or proven equipment. Failed components should be warranted for an additional year from the date of the replacement, not to exceed a total of 18 months.
- **Limitations of liability; liquidated and consequential damages.** Liquidated damage amounts should be based upon the actual direct damages to the utility if possible. Consequential damages are rarely accepted by contractors. The limitation of liability should exclude any insurance proceeds and be set as high as possible.
- **Codes, standards, and government regulations.** All applicable codes and standards must be identified and included in the contract.
- **Indemnity.** Mutual indemnities are common.

- **Insurance requirements.** Most utilities have established equipment and liability insurance policies with deductible amounts that are compatible with the utility's risk and cost assessment. The utility may choose to provide the project insurance policy or have the contractor supply specific insurance coverage. The level of insurance required and the deductible amounts must be coordinated with the limits of liability terms in the contract to ensure adequate coverage.
- **Change process.** Changes happen on even the best managed project. Change orders should require written authorization by the project manager and include any changes to the schedule, cost, and technical specifications of the project.
- **Dispute resolution.** Most disputes are handled on a daily basis by the project team. For cases in which the disputes cannot be resolved by the project team, a procedure should be in place to resolve the issues in a timely manner. The formal process includes time limits on filing notices of dispute and responding to claims. Dispute resolution can ultimately result in arbitration or in court proceedings. It is important to try to structure the dispute resolution process so the cost and time required to resolve the dispute are proportional to any time or money in dispute.

3.5.3 Additional Retrofit Terms and Conditions

Due to the size, cost, and risks associated with steam turbine-generator retrofit and replacement projects, additional contract provisions should be considered. These terms and conditions must be tailored to address specific project, vendor, and technical concerns. They are particularly critical when using non-OEM suppliers or newer technologies.

- **Extended warranty.** Extended warranties should be included for new technologies, changes in metallurgy, and other technical advances proclaimed by vendors. Warranty coverage should be as broad as possible to include damage to other components and equipment as well as labor needed to access, remove, and reinstall equipment.
- **Bonuses and penalties.** Bonus and penalty provisions should be included to address equipment performance guarantees. Although the value of any bonus or penalty will be negotiated, it should be based on the direct cost impact to the utility. Bonus and penalty provisions may also be included for schedule milestones, delivery of drawings, inspection reports, and safety performance.
- **Meetings, inspections, testing, and witness points.** Oversight and vigilance are critical to the success of a project. Required inspections, testing, and witness points must be included in the contract. The project schedule, meetings, and document submittals and reviews must be delineated.
- **Payment terms.** Payment should be tied to specific milestones, project progress, and testing results. Final payment should be conditioned on successful completion of all work, passing a performance test, submittal of all as-built documentation, and removal of the contractor's equipment and personnel. It may be desirable to retain some funds for punch-list items or warranty work.

The EPRI report *Packaging, Shipping, Storage, and Handling Guidelines for Nuclear Power Plants* (TR-107101) provides additional guidance (for example, component-specific guidance) pertinent to contract issues related to steam turbine-generator equipment retrofits and replacements for the nuclear power industry [9].

3.6 Witness Program

The witness program should include design review meetings, shop visits, inspections, and testing of the equipment. The purpose of the witness program is to ensure that the product meets all of the requirements of the specification and to identify discrepancies and nonconformities early to avoid costly changes and delays. The program should include inspections and testing, shop visits, and witness and hold points.

3.6.1 Inspections and Testing

Testing may consist of nondestructive examination (NDE) during fabrication and installation as well as other equipment tests to verify technical and operational performance. Table 3-1 provides a list of tests and inspections to consider throughout the project.

Table 3-1
Fabrication, Installation, and Performance Tests

Type of Test	Fabrication	Shipping and Storage	Prior to Installation	During Installation	Prior to Commissioning	Commissioning	Prior to Acceptance	Operation/ Warranty
Weld Examination	X			X				
Clearance and Alignment	X			X				
Materials Testing: Hardness, Chemical Makeup, Tensile Strength, and so on	X							
Nondestructive Examination	X		X	X				X
Static and Dynamic Balance	X		X			X		
Electrical Tests	X		X	X		X		
Pressure and Leak Tests	X	X	X			X		
Controls and Logic Tests				X		X		
Instrument Calibration				X			X	
Performance Testing						X		X
Inspections	X	X	X	X	X			X
Blade Frequency Tests	X							
Final Product Testing							X	X

3.6.2 Shop Visits

Shop visits should be made to the vendor's design and manufacturing facilities on a periodic basis. Shop visits are typically scheduled for welding, assembly, insulating, coating, heat treatment, machining, and testing, based upon the equipment complexity, experience with the equipment design, the supplier's capabilities, and the criticality of the retrofit equipment.

Additional surveillance may be necessary in order to provide the project team with the opportunity to witness special processes or critical stages of the project. If there are any concerns about the project, additional unannounced visits should be made.

During critical phases of the manufacture and testing it may be prudent to have a full-time owner's representative at the vendor's work location. The owner's representative may be supplied by a third party depending on the location of the vendor's manufacturing facility, the utility technical and contract management expertise, and utility and project staffing requirements.

Shop visits should be documented in writing and shared with the project team. Findings, actions, and due dates should be documented and communicated to the project team.

3.6.3 Witness and Hold Points

Witness and hold points should be established and included in the project schedule to ensure that the project team has an opportunity to witness and verify that the equipment conforms to the design requirements. Some witness points may require a specific hold on the project until an inspection or test is successfully completed. Care should be taken to minimize potential impacts to the project schedule and cost.

For example, the project team should consider witnessing the NDE and electrical testing, including the following:

- Ultrasonic testing
- Eddy current testing
- Liquid penetrant testing
- Magnetic particle testing
- Radiographic testing
- Megger and Hi-pot testing

Additional information on NDE can be found in many other EPRI technical reports and source documents.

3.7 Outsourcing Support Services

The procurement, design, fabrication, installation, and commissioning of turbine-generator equipment retrofit and replacement projects are all critical to the success of the project. Many companies may have the internal resources and want to manage all aspects of the project themselves. However, there are times when it may be prudent to outsource specific services that are critical to successful project completion.

The risk assessment process will identify areas of concern and potential shortcomings that may be best addressed by utilizing additional outsourced services. Outsourcing services can be a way to provide resources that strengthen the project team, provide specific expertise when needed, and reduce travel and other project costs. If contract support services are under consideration, they should be discussed as part of the bid specification to ensure open willingness of the vendors. Non-disclosure agreements may be required.

The support services that may be considered for outsourcing include the following:

- **Specialized testing.** This may include laboratories for verifying materials, or companies with special test equipment to verify the vendor's data.
- **Expediting and shop visits.** As a resource enabling avoidance of costs associated with sending company representatives, there are specialists who can provide specific witnessing and verification of progress and testing compliance. This service can be very cost-effective if the manufacturing site is far from the project site.
- **Commissioning and startup services.** Using a contractor to manage the commissioning of the equipment can alleviate the plant staff of this task and allow them to focus on the actual operation of the equipment. Contract services can also develop revised operating procedures for the retrofit equipment as required.
- **Training services.** Vendor training may not be adequate or may only address the specific retrofit equipment. Additional training and coordination with the potential impacts on the balance-of-plant (BOP) equipment can provide valuable improvement in operator performance.
- **Supplementing the project team.** If the requisite expertise does not exist within the utility staff, outsourcing should be considered. Because utilities have reduced staffing over the years and people have retired, the necessary resources may not exist within the current staff. Not having the right skill sets and expertise can doom a project to failure. Consider using retirees and technical consulting firms to fill any gaps in the project team.

3.8 Project Completion

Steam turbine-generator retrofit and replacement projects are not over when the equipment is installed. The risk management efforts should continue through project close-out, transition to O&M, and the warranty period.

The project team will be attempting to close out the contracts and move on to the next project. At the same time, the plant staff will be in the process of returning the unit to service, understanding what changes to the plant operation are required, and identifying any restrictions on operation that may be required by warranty and performance guarantees under the contract.

3.8.1 Project Close-Out

The project team responsible for project close-out will manage the turnover of the equipment to plant management and O&M and ensure that the contractor has met all of its obligations for the project. Project close-out activities begin as the equipment installation is nearing completion. During project close-out, work activities are transitioning from a construction phase to an operating phase.

Project close-out activities include the following:

- Verifying test results
- Verifying that all required documents have been provided
- Identifying punch-list items to be completed
- Scheduling and coordinating training
- Ensuring that contractors have met all contractual requirements
- Commissioning and testing of the equipment
- Obtaining as-built drawings
- Managing and closing out any changes or disputes
- Working closely with the plant staff to transition the project information to the plant staff
- Resolving any payment issues and making final payment to contractors
- Managing the turnover process and coordinating with the plant staff

3.8.2 Training and Procedure Development

The existing operating and maintenance procedures will need to be revised to reflect any changes related to the turbine-generator retrofit or replacement. Any vendor-provided O&M procedures will need to be adapted to the plant's procedure format and integrated with other plant equipment. Any training provided by the vendor should be coordinated with the recommissioning of the equipment and address the changes in the equipment operation. Some of the items that should be addressed are the following:

- Trip and alarm points
- Startup and shutdown
- Normal operation
- Emergency operation

- Lubrication requirements
- Calibration of instrument and controls
- Cautions and actions
- Performance issues and interpretation of data

3.8.3 Transition to O&M

The transition from the project team to the plant management team is a critical point in all retrofit projects. Failure during this phase of a project can result in loss of warranty, performance degradation, and damage to the equipment.

In order to facilitate the transition, the plant should appoint an O&M coordinator, who will be responsible for the following:

- Accepting the equipment and turnover packages from the contractor
- Managing and coordinating the lockout and tagout procedures
- Coordinating training
- Leading the commissioning effort
- Communicating information to the rest of the plant
- Coordinating parts requirements with maintenance, procurement, and the contractor
- Ensuring that instruction manuals and other documents are provided for reference as needed
- Developing O&M procedures

3.8.4 Warranty and Performance Monitoring

Proper warranty management and performance monitoring can reduce repair costs and may prevent future litigation in the event of a major issue with the equipment. In order to protect the equipment warranties, a performance monitoring program should be established. This program should include the following elements:

- Equipment operating limits
- Alarms and trip conditions and controls
- Emergency procedures
- Warranty start and end dates
- Special and extended warranty requirements

- Required inspection intervals
- Notification requirements
  - Contact names
  - Phone numbers
  - Time requirements
  - Information requirements

The status of the warranty should be tracked and monitored to protect the utility from unexpected repair costs.

Performance guarantees may require monitoring in order to verify that the equipment is performing as required. If the retrofit was a new technology or provided by a non-OEM supplier, additional monitoring may be prudent to identify potential problems early. Monitoring requirements should be clearly identified and reported to plant management as necessary.

If the equipment performs as expected, the project should be finally closed at the end of warranty and performance monitoring period.

4
LESSONS LEARNED

4.1 Potential Pitfalls

Replacing or retrofitting a steam turbine-generator is a complex, expensive, and time-consuming process. With appropriate controls, proper personnel, and the discipline to remain focused the project can be successful, but there are many possible problems, as evidenced by input from EPRI member utilities. Some of the potential pitfalls are outlined briefly here.

4.1.1 Out-of-Date or Incomplete Drawings and Data

Drawings for existing plant equipment need to be provided to contractors so that replacement equipment can be designed to fit existing foundations, piping, electrical configurations, and design performance requirements.

If modifications are not shown on as-built drawings or if drawings do not exist, additional effort may be needed to ensure that the design of the replacement equipment incorporates all required parameters.

Vendors need to understand the current operating conditions and any operating issues that the utility is trying to solve with the retrofit. Information on normal and off-normal operation as well as any limitations on operation imposed by other plant equipment should be identified and communicated to vendors.

4.1.2 Inaccurate Measurements

Double-check critical dimensions and have the selected bidder verify all measurements.

The project team should be clear about the type of units depicted on drawings (International System of Units vs. English units) and about the standards that are applicable (for example, Deutsches Institut für Normung [DIN] or American Society of Mechanical Engineers [ASME]).

4.1.3 Inspections

One of the most important project activities is inspection of the equipment during unit shutdowns. Inspection considerations are described next.

4.1.3.1 Inner Casing Inspections

Suggestions regarding inner casing inspections include the following:

- Develop a plan to walk down the support structure for the inner casing to perform a general visual inspection for degradation.
- During a turbine retrofit project, the area between the lower casing and the condenser boundary will be exposed. In the course of the outage, a photo-documented inspection for inaccessible areas will be performed, to ensure that no gross deficiencies exist that could affect long-term performance of the turbine. The area is expected to contain structural members used in support of the turbine, bearing pedestals, and condenser.
- The relevant information from procedures suggests that the following guidance would be appropriate for this inspection:
  - Include the following items in the examination of integrally welded attachments:
    - Examine for degradation of attachment weld(s).
    - Examine for degradation of attachment, lugs, and so on.
    - Examine for distortion, displacement, or lack of attachment.
    - Examine for structural distortion or displacement of parts.
    - Examine for loose, missing, cracked, or fractured parts, bolting, or fasteners.
    - Examine for foreign materials or accumulation of corrosion products.
    - Examine for corrosion or erosion.
    - Examine for wear of mating surfaces.
  - The following normally inaccessible areas should merit particular attention:
    - Struts and gusset plates inside the exhaust hoods
    - Structures supporting bearing cones
    - Structures supporting inner casing support pads
    - Structures supporting centerline keys
  - Check mechanical and structural integrity to define conditions that may need further evaluation:
    - **Loose parts.** Components shall exhibit no evidence of missing, detached, or loosened support items (bars, bolting, springs, fasteners, jam nuts, cotter pins, and snap rings).
    - **Abnormal corrosion.** Components shall be free of abnormal corrosion, which reduces the load-bearing capacity of the component. For purposes of this procedure, localized corrosion, which visibly reduces the cross sectional area of the component, is unacceptable.
    - **Wear.** Components shall be free of wear, which visibly reduces the cross-sectional area of the component.

- **Erosion.** Components shall be free of erosion due to corrosion, steam cutting, or any type of erosion that visibly reduces the cross-sectional area of the component.
- **Corrosion.** Close-tolerance, machined, or sliding surfaces shall be free of general corrosion. General corrosion on other components is acceptable provided it is not localized and does not reduce the cross-sectional area (for example, affecting close tolerance or sliding surfaces; excessive corrosion between protection saddles and the sliding surface). General corrosion is defined as an approximate uniform wastage of the surface of the component, through chemical or electrochemical reaction, free of deep pits or cracks.
- **Loss of integrity.** Bars, clamps, rods, bolting, or other support items shall exhibit no visible signs of deformation due to overstress conditions. Welds, plates, bars, rods, and other support components shall be free of cracks or crack-like conditions.
- **Physical displacement.** Support components shall show no evidence of displacement, such as loose/dislocated base plates, pulled anchors, or deformed support structures.
- **Structural adequacy.** Structural elements and members, such as I-beams, shall be structurally adequate to provide support to the component. Conditions such as deformed I-beams, bent rods, and sheared bolting are unacceptable.
- **Conditions such as broken grout or concrete around the area of the base plate.** Such conditions should be handled in accordance with applicable recording and reporting requirements.
- **Tightness of bolting.** Bolting to structural elements, such as base plates, shall be verified as intact, with no visible air gap. Loose bolting that has been previously staked is acceptable, provided the nut or bolt cannot be totally disengaged and will not vibrate off during operation

4.1.3.2 Boroscopic Inspection

With the extraction steam piping severed for installation of new upper bellows with new low-pressure turbine (LPT) casings, the opportunity to inspect the inner shields of the lower bellows with a borescope should be considered. This also affords the opportunity to perform a foreign material exclusion (FME) inspection prior to reinstalling the extraction steam piping. Keep the following points in mind:

- Ensure that you have the ability to manipulate the borescope satisfactorily. (It should be of the proper length and should be pushable instead of just gravity fed).
- Ensure that you have a vacuum with a hose long enough to access the inevitable material that you will want to retrieve.

- Know what “good” looks like. As an illustration, consider the following experience of one utility: its first inspection (of three condenser inspections) enabled a view of the low-pressure feedwater heater (LP FWH) tube bundle. During the inspection of the second FWH, the tubes were not visible because of the impingement plate surrounding them. The third FWH was constructed similarly. When made aware of this, the heat exchanger supplier finally determined that the first FWH was installed (initial construction, circa 1970) without the impingement plate.
- Capture inspection findings either with a borescope having digital media capability or a separate camera to record the borescope screen.

4.1.3.3 Extraction Piping Inspection

Verify that the orientation of all extraction piping matches drawings in every condition and is understood, with no unidentified cross-connects existing that could compromise evaluations of new bellows. This inspection should be performed during an outage prior to the retrofit work being performed.

4.1.4 Testing

As pointed out in Section 3, the design reviews and witness testing must be addressed during contract development to ensure that the owner’s design requirements are met. The following testing should be considered for any retrofit project.

4.1.4.1 Blade Frequency Testing

One example of shop testing that is critical in large steam turbine procurement relates to verifying that tuned LP rotor blades have proper frequencies to avoid resonance vibration and subsequent fatigue damage in operation. Typically, manufacturers approach this at two levels:

- Testing of the first production rotor assembled in a spin-pit test facility with appropriate instrumentation to detect blade frequencies
- Production testing of 100% of the blades in a test fixture designed to simulate root fixity (and comparison of those data against an acceptable range)

Plant owners need to ensure that both types of tests are conducted on tuned blades and that there is an opportunity to review the spin-pit test results. Also, the records of all individual blade frequency test results should be considered part of the documentation that accompanies the component delivered. This must be negotiated prior to the awarding of a contract, to avoid the manufacturer later taking the position that the data are proprietary if a blade failure occurs and an independent root-cause analysis is necessary.

4.1.4.2 Rotor Balancing

Balancing of the rotor should be performed prior to installation. The preferred method is to spin-balance the equipment under conditions as close to possible as the normal operating conditions. Spin balancing may not eliminate the need to balance a rotor after installation; however, it will eliminate any uncertainty in the balancing procedure and reduce the time needed for balancing if it is required.

4.1.5 Impacts on Other Technical and Operational Parameters

Failure to consider the impact of a replacement turbine-generator on other plant components can result in damage to the existing equipment or require additional modifications and lead to increased costs for maintenance and operation.

4.1.5.1 Rotor Dynamics and Torsional Stability

Low-pressure turbine blade failures occur due to torsional excitation from the generator, created by phase/load imbalances at 120 Hz and occasional transients caused by grid power line faults.

Virtually all OEMs have experienced LP turbine blade failures related to torsional excitation, and failures continue to occur. The following information from the Web site of one specialist consulting firm summarizes a number of important points [10]:

> TG Advisers, Inc. attributes the most common failures to incomplete or incorrect modeling and assumptions of the turbine-generator train after a major upgrade (for example, LP or generator rotor changes or blade upgrades). In some cases, requirements for avoiding 120-Hz torsional resonance were not included in the owner specification or supplier design criteria. In all cases, the supplier performing the upgrade failed to properly evaluate the impact on overall train torsional frequencies. Sometimes the supplier was not the OEM of the original equipment and made incorrect assumptions in modeling the non-upgraded, original components.
>
> TG Advisers, Inc. recommends that when upgrading existing units, utilities should require the supplier to demonstrate (through both modeling and field verification) that there are no unacceptable torsional natural frequencies between 113 Hz and 128 Hz. This is a conservative requirement but one that will prevent problems.
>
> Note that it is possible to have acceptable torsional frequencies in this range. For example, if a mode shape is symmetric through the generator, the excitation torque will net zero due to cancellation. If the mode shape is not symmetric, that particular mode may be problematic if sufficiently close to 120 Hz.

In order to ensure compatibility with other components, the team should review Campbell diagrams, torsional models, and so on and ensure that safe margins exist. They should also consider verification of models to ensure accuracy [5].

4.2 Nuclear Licensing Concerns

Additional concerns must be addressed when replacing and retrofitting steam turbine-generator equipment in nuclear plants. To avoid impacting their licenses, owners of nuclear plants must ensure that replacement equipment is of equal quality and available for timely replacement. However, the longer that nuclear power plants remain in operation, the greater the possibility that identical replacement parts and components have been discontinued. Furthermore, suppliers are increasingly unwilling to assist plants in researching replacement items for discontinued products and certifying the equivalence of those items with the originals.

The EPRI report *Plant Support Engineering: Guidelines for the Technical Evaluation of Replacement Items in Nuclear Power Plants - Revision 1* (1008256) presents a systematic approach for establishing technical and quality requirements of replacement items. The information provided in that report as well as other documents referenced in the report can be applied to the procurement of new items for plant modifications [1].

EPRI report 1008256 contains six major sections that provide a systematic approach to determining appropriate technical and quality requirements for replacement items. The technical evaluation methodology includes the following:

- Identification of the need for a technical evaluation
- Functional classifications of components and parts
- Analysis of failure modes and their effects
- Determination of a “like-for-like” or “alternate item” type of procurement
- Evaluation of equivalency for alternate items
- Specification of technical and quality procurement requirements

4.3 Balance-of-Plant Impacts

The replacement or retrofit of a steam turbine-generator can impact other plant components. The following issues have been experienced on previous retrofit projects [5]:

- Impacts related to tolerance of the turbine inlet nozzle area and the potential for increased turbine steam flow can result in the capacity of feedwater system being exceeded.
- Increased efficiencies can alter extraction pressures and temperatures from present superheater and reheater safety valve capacity—review them if steam flow changes.
- Future maintenance execution issues—for example, ability to move or adjust diaphragms, weights of components, access to balance planes, and so on—may arise.
- Reduced leakage can alter downstream flows.
- The increased weight of rotors can add to bearing loading, and changes in the steam flow path can alter thrust bearing loading and can impact turning gear requirements and the need for lift pumps.

4.4 Best Practices

A roundtable discussion was held at the August 2010 Turbine-Generator Users Group (TGUG) meeting in St. Louis, Missouri. The following is a summary of the comments and lessons learned, as provided by the participants.

4.4.1 General

- Do your homework and make sure the utility and all vendors associated with the project are on the same page.
  - Before issuing a specification, issue a notification to see what is available in the market.
  - Take advantage of every opportunity during maintenance outages to allow vendors to measure the units, thus allowing competitive bidding.
  - One utility brought in OEMs to suggest solutions to problems and then issued the specification.
- An integrated project schedule is a must.
  - Project schedules should include all companies working on the project.
  - Include meetings, scaffolding activities, turnover, and preoutage activities.
  - Drawing version schedules need to be agreed upon up front to allow for adequate review time and clarification of design issues.
  - Witness testing and inspections and holds need to be built into the schedule.
- Both the vendor and the utility must agree on performance and other test plans and procedures before the job starts. This is a critical issue because monetary damages or bonuses will be tied to the guarantee points. Any tolerances should be specified, and the acceptable testing uncertainty should be agreed upon. The testing uncertainty is only a measure of how accurate the testing to be performed is to be and should never be agreed upon as part of a tolerance.
- Develop a high-vibration troubleshooting plan integrated in with the as-found and as-left inspection sheets. Develop failure logs in preparation for disassembly and reassembly. Include instructions to document inspection results in anticipation of root cause analysis (RCA) of any failures found. Examples of components to be inspected and analyzed are bearing pedestal foundation condition, shifting alignment, bearing condition, probe installation, and oil deflector and prior balance weight condition.
- Both the vendor and the utility must have a single point of contact at the job site to make as many decisions in the field as possible. Having to go back to the company for every decision causes many problems.
- Expect and plan for changes. Ensure that you have contingency plans in case components fail to arrive on time. Delays can and do happen. (For example, an LPT rotor was inadvertently dumped into the New Brunswick Bay while being loaded on a barge in 2008.) There are always implementation challenges in the field.

- QA and QC are needed on both the utility side and the vendor side.
- Clearly identify the number and extent (degree of comprehensiveness) of shop visits. Ensure that the vendor understands that your representative is going to the shop for inspections and surveillance witnessing of work be performed on the components. Clarify all required factory acceptance tests (FATs).

4.4.2 Personnel

- Make sure the right people are assigned and that they are involved in the entire project.
  - Both the utility and the vendor must bring the right people to design reviews.
  - O&M people must be involved in the whole process, including design reviews.
  - The roles and responsibilities of the project team should be clearly defined.
  - Vendors must have adequate support staff. For example, lack of a clerk impacts badging and scheduling.
  - Technical expertise of the project manager is critical. You frequently “get what you pay for” by not having the qualified and experienced people involved with the process.
  - Third parties can be useful for supplementing the workforce and providing specialized expertise.
- Be aware of the possibility of language barriers.
  - Today there can be language barriers and other communications issues that arise when major components are made in different countries by multiple vendors and subvendors.
  - It is essential to communicate clearly and often, to make sure the project team understands the issues.

4.4.3 Technology

- With modern technology, advances in component design and construction occur quickly in the industry. It is important to consider vendors other than the original OEM for retrofits and rebuilds, for optimum operation.
- One inherent problem with utilizing new technology is the risk of operation with a new system in an old plant. The risk of operating a new plant is the risk of failure due to new design and new components. The risk of operating an older plant is typically clear as a plant approaches its life expectancy. With a retrofit within an older plant there will be a combination of the risk factors, both old and new. This aspect should be very clearly analyzed prior to proceeding with a retrofit or replacement project. Clearly there are advantages of new designs and new equipment; however, there is the new combined risk of failure.

- Technology can be put to work to improve project management.
  - Internet
  - Scheduling and other software
  - Video conferencing
  - Testing and alignment tools and equipment

4.4.4 Vendors

Input from vendors provides useful insights into the bidding process from the vendors' perspective. Understanding this perspective can help a utility develop better bid specifications and improve bid evaluations.

- Utilities often do not build a relationship with the suppliers today.
- Vendors know who they will be bidding against.
- Vendors know which utilities will always go back to the OEM and not consider non-OEM suppliers.
- Sometimes, qualified bidders choose not bid because they believe that the utility will take the cheapest approach and they know that their product will not compete on price with lesser products.
- Vendors are building and bidding the cheapest products because that is what utilities are buying.
- OEMs have a lot of experience manufacturing products. This tends to give them an advantage during bid evaluation.
- Vendors and suppliers do not perform good design reviews.

4.4.5 Specifications and Bid Process

In some cases, the number of qualified vendors is limited, forcing utilities to consider non-OEM suppliers in order to obtain enough bids. Ultimately, a new model is needed. In order for retrofit and replacement projects to succeed, utilities and the suppliers must work in partnership.

Below are a few of the suggestions for improving the specification and bid process.

- When you formulate your specification, incorporate lessons learned from previous retrofits.
- Prequalify bidders to understand their equipment, project execution, personnel, and contracting approach.

- Identify what is expected from the replacement equipment:
  - Utility expectations
  - Problems that warrant a replacement
  - Operating history of components
- Describe the performance testing plan:
  - Measuring equipment and tolerances
  - Any data adjustments
  - Number of tests and duration
- Be aware that the following items may be addressed in a retrofit or replacement specification:
  - Required specialty tools, lifting beams, and rigging devices
  - Installation of inspection ports
  - Balance planes and accessibility
  - Hydraulic coupling bolts, pumps, and clocking tools
  - Degraded components—glands, expansion joints, slop drains, sample lines, steam seal headers, and so on
  - Performance monitoring devices
- Use supply-and-erect contracts whenever possible.

  There are cases of risk of installation of the major replacement component by a vendor other than the supplier. This can cause multiple opportunities for finger pointing and needs to be managed well by the utility. The vendors can have different opinions of what is an adequately installed specification requirement.
- Vendors and OEMs may build and assemble components at locations all over the world which can lead to emphasis on different aspects of the manufacturing processes at each location. It is imperative that the standard requirements are clear during the bid process and in the contract. For example, if U.S. standards for cleanliness are to be required and verified prior to and after component shipping, then it must be stated. There should be a clearly developed list of all the standards agreed on between the owner and supplier.
- Technical advisors and labor contractors need to have common scopes for installations. Tolerances of equipment are a good example of an area that needs clarification. There cannot be arguments about how close tolerances should be or the number of measurements that are needed. The hierarchy of technical responsibilities at site must be clear. All parties must be represented in the project meetings, including the daily meetings. The scheduling of project activities should be clear and conflicts between installation and supplier avoided.

- An economic evaluation should be performed to determine the best value to the utility. The evaluation criteria should be provided to prospective vendors as part of the specification. Items typically considered include the following:
  - O&M avoided costs for repairs
  - Reduction in forced outages
  - Fuel savings due to increased efficiencies
  - Increased efficiencies resulting in increased capacity
  - Future operating modes—full arc versus partial arc
  - Marketing group input

5
SPECIFIC EXAMPLES AND RECOMMENDATIONS

The information in this section is provided to highlight some of the issues and recommendations from utilities that have executed steam turbine-generator retrofits and replacements. The utility and plant names have been withheld.

5.1 Generator Rotor Rewind

One plant chose not to perform a high-speed balance after a generator rotor rewind. Project oversight was even more critical to ensure proper balance of the machine. The following recommendations are based on the experiences of the project team and are provided so that future projects can benefit from this experience.

5.1.1 Provide Shop Oversight

During the rotor rewind in question, problems occurred and the wrong amortiseur was installed during a time when no utility oversight was present. If the rotor is being rewound off site at an OEM service shop where there are critical activities around the clock, consider having around-the-clock coverage. It is a must if a high-speed balance will not be performed and is strongly recommended even if a high-speed balance is scheduled to be performed.

Replaced parts should be inspected and weighed to ensure the same form, fit, function, and weight. The OEM had informed the utility that identical parts were used for replacement; however, the unit had excessive vibration during startup. The outage was extended by two weeks to disassemble the generator and install the correct part.

5.1.2 Establish Hold Points

Hold points should include inspections to ensure proper installation of blocking, wedges, and amortiseurs. Verify that the distance blocks are in the proper location and properly secured. If the distance blocks are not in the proper location, an imbalance can result.

5.1.3 Perform a High-Speed Balance

If time permits, perform a high-speed balance. A high-speed balance can avoid problems that can prolong outage durations, particularly if on-site surveillance is not utilized and replacement parts are not weighed and inspected. A low-speed balance is **not** recommended after generator rewinds.

5.1.4 Other Recommendations

- Ensure that critical parts are available. Many parts have long lead times.
- Consider bringing a lathe to the OEM service shop, and measure runouts on the fan rings and retaining rings at the completion of the job.
- Ensure that a prejob briefing is conducted prior to installing the retaining rings, so everyone knows the sequence of installation and the lines of communication.
- Verify that the vendor agrees with established work practices, as written in your procedures, well ahead of the outage. Last-minute challenges create much confusion, especially on non-safety-significant systems with little or no documentation to detail the bases for changes.
- If vendor is to match-mark large parts in a lay-down area for more efficient assembly on the congested turbine deck, consider having a utility representative witness this evolution. Incorrectly identified parts can require many hours of delays and rework to remedy.
- Determine if any of the old components being removed (such as blocking) have asbestos. If so, plan accordingly.
- Consider other work that could be done during the retrofit, including replacement of the LPT inlet piping steam bellows and removal of any remaining bearing pedestal slop drains, to leverage the unprecedented access afforded by the LPT replacement.

5.2 Experiences from Steam Turbine Retrofits

Vendors and utilities have significant experience with steam turbine-generator retrofits: one utility alone has replaced over 40 steam turbine rotors. Table 5-1 summarizes this utility's experience with different manufacturers [5]. Vendor and utility experiences are outlined below.

Table 5-1
Retrofitted Rotors at One Utility

Retrofit Manufacturer	High-Pressure or High-Pressure/ Intermediate-Pressure	Low-Pressure
Alstom	9	19
General Electric	3	4
Siemens	1	1
Toshiba	2	0
Hitachi	0	4
Total	15	28

This experience is incorporated into the utility's lessons learned for future retrofits and is provided here to share the knowledge with other EPRI members. A key point that the utility emphasizes is as follows:

> Thorough vendor oversight during the fabrication and installation will minimize potential operational issues after returning the unit to service: **Trust but verify.**

The following are some of the issues the utility experienced on steam turbine retrofits.

5.2.1 Bearing Failures

- **Thrust bearing.** Thrust bearing failures occurred due to the changes in the thrust loading direction and imposed higher thrust loads as the result of installation of retrofit turbines. In one case, it was determined that the Waukesha-supplied load equalizing bearings had the pivot offset from the centroid of the pad, thus not allowing full load carrying capacity of the pad. The main thrust runner was machined to remove hot spots. The pivot was temporarily relocated inward by 0.285 inch (7.239 mm), the leveling plates were restored, and the pads were rebabbited. The bearing was replaced at a later date by a Kingsbury design with radial offset and chrome copper backing, which increased the overall load carrying capability.

  In another case, the pockets of the cage were not allowing the pads to fully equalize during high thrust loads. To correct the problem, bearing pockets were machined deeper to allow the bearing to fully equalize during high thrust loads.
- **Bearing tilt.** In response to a thrown LPT blade event, it was decided that the individual bearing "keep" would be stiffened to add margin to the bearing's ability to withstand a similar mass imbalance event. The new vendor proposed installing a flat shim between the bearing lower-half housing and the retaining ring ("keep"), thereby removing the previously designed gap. It was unrecognized during the design that not all of the keeps were flat, so by installing a flat shim metal to metal, tightening the keep caused some of the bearings to tilt excessively, ultimately wiping two. Unrecognized at the time was the magnitude of the effect that condenser vacuum played on the bearing foundation (suspended as they are away from the turbine pedestal).

5.2.2 Manufacturing and Assembly Problems

Failure to closely monitor the manufacturing and assembly of the equipment can result in unexpected problems. The manufacturing of components at different locations of an international vendor can lead to emphasis on different aspects of the manufacturing processes. Below are some examples of manufacturing and assembly problems found on retrofit projects.

- **Poor alignment of the outer LP turbine hood.** An LP turbine retrofit required a new outer hood. Upon assembly, 218 out of 244 bolt holes were found to not align with the existing base. The new hood was made to an original drawing, which obviously had been modified without documentation. Since the OEM was doing the work, the utility elected not to require them to take measurements. Immediate repairs required elongating the holes by machining;

Figure 5-1
Low-Pressure Turbine Hood Misalignment

- **Improper installation of piping.** During unit startup, steam leaks were visible at two of the steam glands. An investigation revealed that the diffuser plates inside the steam gland fabrication were directing the supply and exhauster flows to the improper annulus areas.

  The piping was modified inside the condenser to redirect the flows to the proper annulus areas. See Figure 5-2.

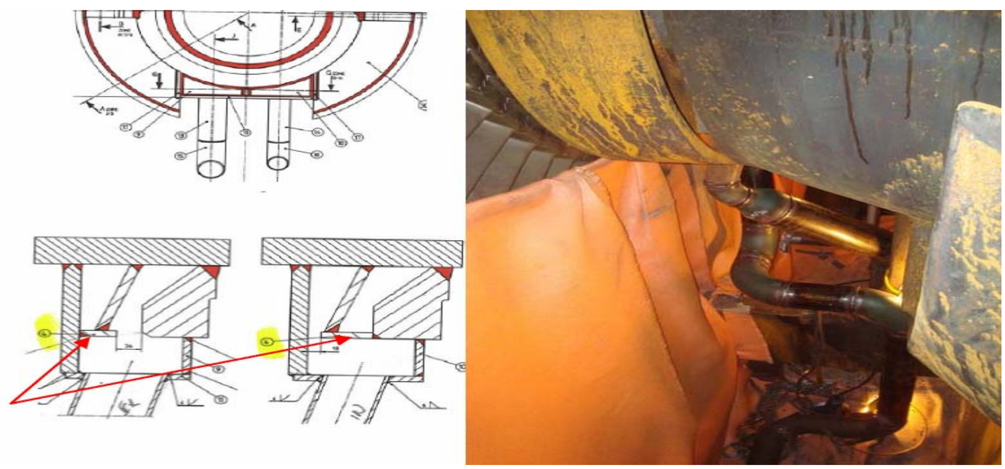

Figure 5-2
Gland Steam Piping

- **Failure to utilize alignment tools.** After a turbine retrofit, proper condenser vacuum could not be maintained during startup. An investigation determined that the steam glands on three of the four glands had interference between the gland diffuser box and the lower cone extension, thus preventing a metal-to-metal fit. The turbine had to be disassembled and the steam glands sent out to a local machining shop to correct the interference issues. During reassembly an electronic radial alignment gauge (ERAG) was used to ensure proper alignment of the glands to the shaft. Proper assembly techniques by skilled craft labor should have identified this issue; however, the issues were never communicated until after the problem was identified. Additionally, the use of an ERAG during assembly would have caught and prevented this issue during initial assembly. See Figure 5-3.

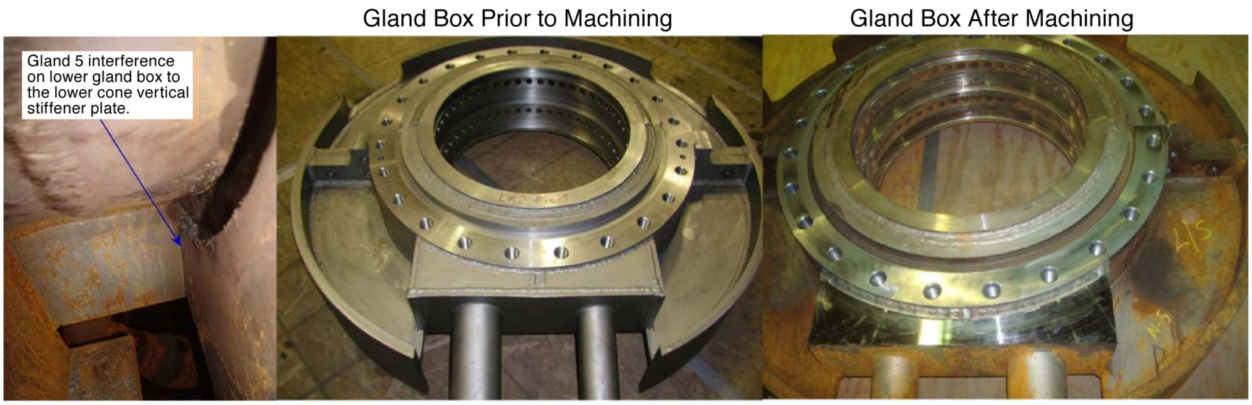

Figure 5-3
Steam Gland Modifications

- **Turbine supervisory instrumentation (TSI) thermocouples in a BWR.** Dual-element thermocouples were installed in a new Bently Nevada 3500 TSI system. The leads for each ran to a terminal box under the turbine skirt, inside the bioshield wall. One thermocouple's indication was suspect, but dose constraints precluded swapping leads. It would have been better for equipment reliability to run indicator leads to a terminal box outside the shield wall.
- **Removing old key phasor—possible need for balancing.** During the TSI modification development it was not recognized that removing the old key phasor changed the static balance of the high-pressure (HP) turbine.
- **LPT rupture disk.** Part of the LPT inspection procedure was to replace the LP hood rupture disks. Replacing the LPTs used a different procedure—one that did not include replacing the rupture disks.
- **Schedule Issues.**
  - Steam turbine generator (STG) alignment activities interfere with other activities. The use of a tight wire for centerline alignment has been industry standard for decades. The alternative is to use a laser for centerline alignment. The use of a laser allows other activities to proceed around the STG during alignment. In the past, when a tight wire was used, even the use of the crane around the turbine could affect the tight wire relationship with the centerline. Nearly all of the activities around the STG must stop when alignment with a tight wire is taking place. It is critical to ensure that the STG centerline alignment is properly coordinated with other work, to minimize interference and delays. If a laser is to be used, only very experienced personnel should perform the alignment. Personnel qualification should be reviewed. Experience has shown that novices and inexperience can extend an alignment activity by weeks.

- Consider condenser mockup training to provide scaffolding carpenters with invaluable "Just-In-Time" training prior to the outage, ensuring a more efficient, more cost-effective, less critical-path consuming effort.

- Safety Issues
  - Communicate with condenser crews regarding the use of Kroil or other solvents and chemicals during disassembly, to avoid accidents. There have been several reports of workers becoming ill because of an unknown substance in the condenser during scaffold erection.
  - Consider overventilating the condenser during welding activities. Heat and smoke can impact work after the condenser hoods have been reinstalled during the final days of the outage.
  - Double-check rigging calculations and be sure to account for D:d ratio. Rigging with wire ropes is difficult; straps work better.

5.2.3 Design and Materials Problems

Even small changes, if not properly addressed, can create significant problems after retrofit of steam turbine-generators, as demonstrated by the following examples.

- **Steam leak at horizontal joint.** Approximately 500 hours after the startup of a new turbine, a steam leak developed at the horizontal joint of the new outer shell. Testing and investigation revealed that the space between the inner and outer shell in the "dead zone" was cooler than designed and was causing a higher than expected thermal gradient. This gradient was causing distortion and thus the leakage. The material of selected studs was changed from 12% chrome to Inconel. Inconel can be stressed to a higher level and still have less creep relaxation over time. See Figure 5-4.

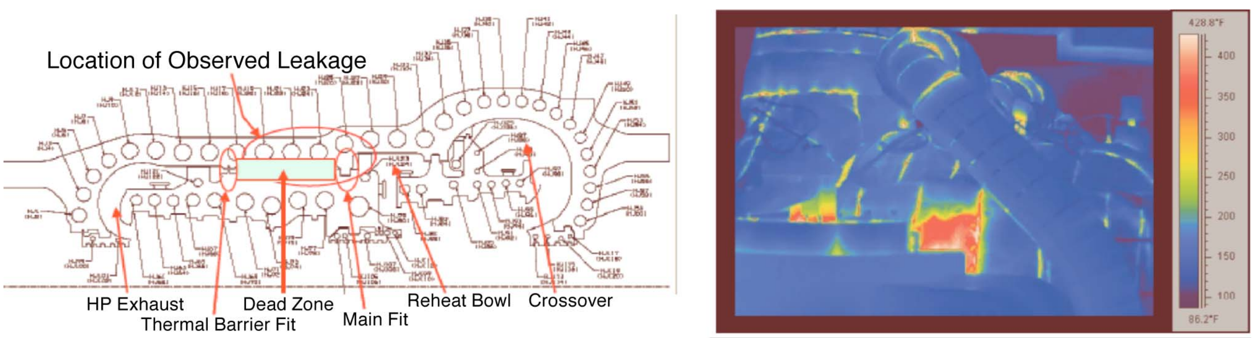

Figure 5-4
Outer Shell Steam Leaks

- **Nozzle bolt cover failure.** The nozzle bolt cover welds cracked and allowed the cover to fret and eventually come loose, going downstream. The root cause was determined to be a design deficiency on the bolt cover plate, the welds, and the plate sizing. During thermal transients, the cover plates loosened and migrated downstream, damaging the nozzle blocks and first stage blading. Temporary repairs were made by opening the nozzle back up to design throat areas, blending out damaged areas on the blades, and removing all debris. Permanent repairs consisted of a replacement nozzle with a different bolt cover design, with repairs to the downstream diaphragms and blades.
- **Temperature differential.** During startup, the top-to-bottom differential temperatures allowed a rub that resulted in a bowed rotor prior to unit shutdown. The new rotor had five times more teeth at the center span packing than the original and was not as forgiving, resulting in the rub. Repairs were made to the rotor and diaphragms to allow the unit to be returned to service. Digital control system changes were made to institute stricter adherence to the maximum allowed top-to-bottom differential temperatures and to institute automated vibration trips. The operators were trained on the requirements and the implemented changes. A replacement rotor was eventually purchased and installed.
- **First-stage diaphragm cracking.** Thumbnail cracking of the first-stage diaphragm was discovered during a boroscopic inspection. The root cause was determined to be vibration induced from the blade passing frequency. The diaphragm was redesigned to reduce the number of blades and will require a major outage to install.
- **Iron (Fe) content of feedwater post-retrofit (BWR).** Different metallurgical makeup of the replacement LPTs yielded less iron in the feedwater. This difference affects feedwater chemistry (secondary in PWRs, primary in BWRs).
- **Differential expansion detector.** It was not recognized that the rotor long/short convention by which QDC read the differential expansion detector was 180° out from what Bently Nevada considered normal, and no one thought to verify it. As a result, the turbine rotor indicated “short” following turbine-generator startup. The range of the “short” indication was more limiting than that of the “long” indication, thereby requiring a software change to enable the annunciator to be used. Swapping leads would not accomplish the same thing.
- **Incorrect hood spray distribution ring.** The “Hood Spray On” annunciator in the control room is actuated by a static pressure switch downstream of the hood spray air-operated valve (AOV), but upstream of the distribution ring. The old hood spray had a 360° distribution ring on each last stage, with nozzles at the bottom that ensured drainage. The new hood spray ring had only the top 180° ring, with no ability to gravity-drain the static pressure in the supply pipe once the AOV closed. The control room annunciator remained “lit” until the trapped water evaporated—several days later.

5.3 Generator Stator Rewind

There have been dozens of successful projects in which synchronous generator stators have been rewound by non-OEM contractors. One utility has completed about 12 stator rewinds on units from 100 MW to 500 MW using a non-OEM for the stator bars or the entire rewind (material and labor).

5.3.1 Specification for a Rewind

The key to success in a rewind is a clear, concise, and complete specification. The responsibilities of the bidder and utility must be clearly identified. All of the issues discussed in Sections 1 through 4 of this document should be carefully reviewed.

5.3.2 Generator Data

It is very important to give the bidders all of the existing data on the generator, including the core and winding dimensions and the past operating and maintenance history. The core, slot, and winding geometry dimensions are essential for a non-OEM bidder.

Utilities should plan in advance for future rewinds, even if they may be several years away. The stator should be opened at the next outage by removing the upper frame end brackets (end bells). Potential bidders should be invited to come and measure the existing stator core and winding. Spare stator bars, if available, should be provided to the bidders. Typically, a non-OEM bidder will do this free of charge. It is a good practice to invite competing OEM and non-OEM contractors to inspect and take essential measurements any time the generator rotor is removed. One visit with the rotor removed is generally sufficient to get all the necessary data. Remember that many non-OEM bidders may have data from a sister unit—just ask.

5.3.3 Some Potential Problem Areas

There are a few issues that could cause delays and cost increases.

- One issue is the presence of asbestos in the original stator bar insulation. Ask the OEM to state whether asbestos does exist; there may be a legal requirement for the OEM to do this. Most generators manufactured after 1980 do not contain asbestos. Asbestos was generally used on the strand insulation and as filler in putty-like material used at the brazed connections.
- Another issue is the presence of a lead carbonate film. This generally applies to the older hydrogen-cooled units. The fins on the hydrogen cooler tubes were often soldered to the tubes. After years of operation, the lead in the solder was distributed throughout the stator frame, especially at the cold gas discharge area of the cooler housings. The time requirements for abatement of this film can range from insignificant (a few hours) to significant (a few days).
- As in any outage, the turbine room floor can be an issue. A well-planned, well-scheduled stator rewind can be completed in about 30 days (rotor out to rotor in). However, the rewind bidder needs first access to the turbine room floor and lay-down space. The new stator bars may be 20 feet (6 m) long; they require a lot of space. The structural integrity should be verified to ensure that it can support the weight of the stator bars.
- Closely related to the turbine room floor is the overhead crane. Be sure to schedule the use of the crane with the outage coordinator.

5.3.4 The Stator Core Iron

The utility should never take the outage time or spend the significant funds to rewind a generator stator without performing a full flux (loop) core test after all of the stator bars are removed and the core iron is cleaned.

The potential exists that the test may discover excessive core iron overheating (hot spots) that could require replacing the stator core, a very undesirable finding with major impact on the plant's budget. This potential problem should be discussed with the utility management team and all bidders. Have a contingency plan and carefully review the core loop test and acceptance criteria with the bidders.

5.3.5 The New Winding (Stator Bars)

Insulation materials and stator winding design software have developed and improved over the past several decades. The need for a rewind affords an opportunity to improve the performance of the generator by reducing the stator winding current losses (I^2R). Newer insulation systems may be thinner than the older systems. This will allow a bidder to use more copper, which will reduce the winding resistance and the heat generated. Discuss this improvement potential with all bidders, both OEM and non-OEM.

5.3.6 The State of the Art

We are now in the 2010s, and the electric utility industry is over 100 years old. However, the laws of nature have not changed since the beginning of time. All OEMs are using the same basic materials and design criteria. The number of acceptable bidders (OEM and non-OEM) is limited to those that are successful. Do not be afraid to competitively bid a stator rewind among those bidders still in business.

5.3.7 Industry Guide

A useful reference is IEEE Std 1665-2009, *IEEE Guide for the Rewind of Synchronous Generators, 50 Hz and 60 Hz, Rated 1 MVA and Above* [11].

6
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A
SURVEY OF PAST AND PLANNED RETROFITS AND REPLACMENTS

A survey of past and future steam turbine-generator retrofits was developed and completed by EPRI members attending the August 2010 TGUG meeting in St. Louis, Missouri.

The survey was developed to provide a snapshot of past and future steam turbine retrofits and replacements. Past experiences are reflected in the discussions in this report, while the future plans provide an indication of the amount of retrofit work that is facing the power industry in the next 5 to 10 years. A copy of the survey is provided in Figures A-1, A-2, and A-3.

Lessons Learned from Steam Turbine/Generator Retrofits and Replacements
Data Survey

Utilities are constantly looking for methods of managing risk, cost, and performance of assets. When considering retrofit and replacement equipment, utilities are faced with a dwindling list of OEM's and several third party suppliers to consider. In many cases the OEM has merged, gone out of business, or sold the rights to others. This presents utility managers with additional due diligence, project review, and project management requirements in order to select the best equipment and mitigate risk. At the same time utilities have reduced staffing levels and the expertise and experience levels have declined due to retirements and lack of growth in the industry.

EPRI is developing a report on lessons learned when retrofitting and replacing Steam Turbine/Generator and major components to aid utilities as they continue to strive to reduce costs and meet customer needs. EPRI is requesting yor support in this effort and would appreciate you taking a few minutes to complete and return the following survey.

1 **Please complete the following table for any Steam Turbine/Generator equipment that you have retrofitted or replaced in the last 5 years.**

Equipment
Check all that apply

Steam Turbine
- ☐ HP Casing
- ☐ HP Rotor
- ☐ IP Casing
- ☐ IP Rotor
- ☐ LP Casing
- ☐ LP Rotor
- ☐ Other: ________________

- ☐ **Generator**
- ☐ Stator
- ☐ Generator Rotor
- ☐ Exciter/AVR
- ☐ Other: _________________

OEM
- ☐ Allis
- ☐ Alstom
- ☐ Ansaldo
- ☐ Brown Boveri
- ☐ General Electric
- ☐ Mitsubishi
- ☐ Parsons
- ☐ Toshiba
- ☐ Siemens
- ☐ Westinghouse
- ☐ Other: _____________

Unit Information
- ☐ **Type**
- ☐ Nuclear
- ☐ Fossil

- ☐ **Steam Conditions**
- ☐ Supercritical: ______ psi
- ☐ Subcritical: _______ psi
- ☐ Reheat
- ☐ Non-reheat

Size
- ☐ Less Than 100 MW
- ☐ 100 MW to 250 MW
- ☐ 251 MW to 500 MW
- ☐ Greater Than 500 MW

Reason
Check all that apply
- ☐ Capital Cost (Capital and O&M)
- ☐ O&M Costs
- ☐ Reliability
- ☐ Efficiency
- ☐ Capacity
- ☐ Life Extension
- ☐ Inadequate Parts Supply
- ☐ Lack of Technical Support
- ☐ Generic equipment Problems
- ☐ Improved technology
- ☐ Other:____________________

Supplier
(Replacement Equipment)
- ☐ Allis
- ☐ Alstom
- ☐ Ansaldo
- ☐ General Electric
- ☐ Mitsubishi
- ☐ Toshiba
- ☐ Siemens
- ☐ Other: _____________

2 **Did the project meet its original objectives?**

	Yes	No
Budget	☐	☐
Schedule	☐	☐
Quality	☐	☐
Performance	☐	☐
Customer Service	☐	☐

Figure A-1
Survey Page 1

2b **If no, why not?** ____
____
____

3 Which party provided lead management of the project?

- ☐ Plant Management
- ☐ Home Office
- ☐ Supplier
- ☐ Contractor/Consultant

4 Which of these elements were incorporated into the project? (Check all that apply.)

- ☐ Design Reviews
- ☐ Risk Assessment
- ☐ Verify Vendor Qualifications and Capability
- ☐ Quality Plan
- ☐ Shop Visits
- ☐ Manufacturing Witness Points
- ☐ Inspections and Testing
- ☐ Scheduling
- ☐ Used Consultants to supplement staff
- ☐ Other: ___________________

5 Were any special contracting methods utilized?

- ☐ Competitive Bids
- ☐ Direct Award (no bid)
- ☐ Performance Based Contract
- ☐ Liquidated Damages
- ☐ Consequential Damages
- ☐ Extended Warranties
- ☐ Bonus/Penalty
- ☐ Special Terms and conditions
- ☐ Other: ___________________

6 Did you have adequate information/data/resources?

- ☐ Up-to-date drawings
- ☐ O&M history and records

Figure A-2
Survey Page 2

☐ Accurate Measurements
☐ Adequate specifications.
☐ Technical expertise and capabilities
☐ Project Management Tools

7 **Please complete the following table for any Steam Turbine/Generator equipment that you expect to retrofit or replace in the next 5 to 10 years.**

Equipment Check all that apply	OEM	Unit Information	Reason Check all that apply	Supplier (Replacement Equipment)
☐ **Steam Turbine**	☐ Allis	☐ **Type**	☐ Capital Cost (Capital and O&M)	☐ Allis
☐ HP Casing	☐ Alstom	☐ Nuclear	☐ O&M Costs	☐ Alstom
☐ HP Rotor	☐ Ansaldo	☐ Fossil	☐ Reliability	☐ Ansaldo
☐ IP Casing	☐ Brown Boveri		☐ Efficiency	☐ General Electric
☐ IP Rotor	☐ General Electric	☐ **Steam Conditions**	☐ Capacity	☐ Mitsubishi
☐ LP Casing	☐ Mitsubishi	☐ Supercritical: ______ psi	☐ Life Extension	☐ Toshiba
☐ LP Rotor	☐ Parsons	☐ Subcritical: _______ psi	☐ Inadequate Parts Supply	☐ Siemens
☐ Other: _______________	☐ Toshiba	☐ Reheat	☐ Lack of Technical Support	☐ Other: _____________
	☐ Siemens	☐ Non-reheat	☐ Generic equipment Problems	
☐ **Generator**	☐ Westinghouse		☐ Improved technology	
☐ Stator	☐ Other: _____________	**Size**	☐ Other:___________________	
☐ Generator Rotor		☐ Less Than 100 MW		
☐ Exciter/AVR		☐ 100 MW to 250 MW		
☐ Other: _________________		☐ 251 MW to 500 MW		
		☐ Greater Than 500 MW		

8 **Do you have any recommendations for improving Steam Turbine/ Generator equipment retrofits and replacements in the future?**

____
____
____
____

9 **What third party equipment suppliers would you consider to supply steam turbine generator retrofit and replacement equipment?**

____
____
____

10 **May we contact you in the future for clarifications and follow up ?**

☐ Yes Name: ____________________
Phone: ____________________
E-mail: ____________________

☐ No

Figure A-3
Survey Page 3

A.1 Summary of Survey Results

A summary of the past and planned equipment replacements and retrofits is shown in Figure A-4. Based upon the responses received, 70% of the retrofits and replacements are on nuclear units, with 80% of the projects for units with a generating capacity greater than 500 MW.

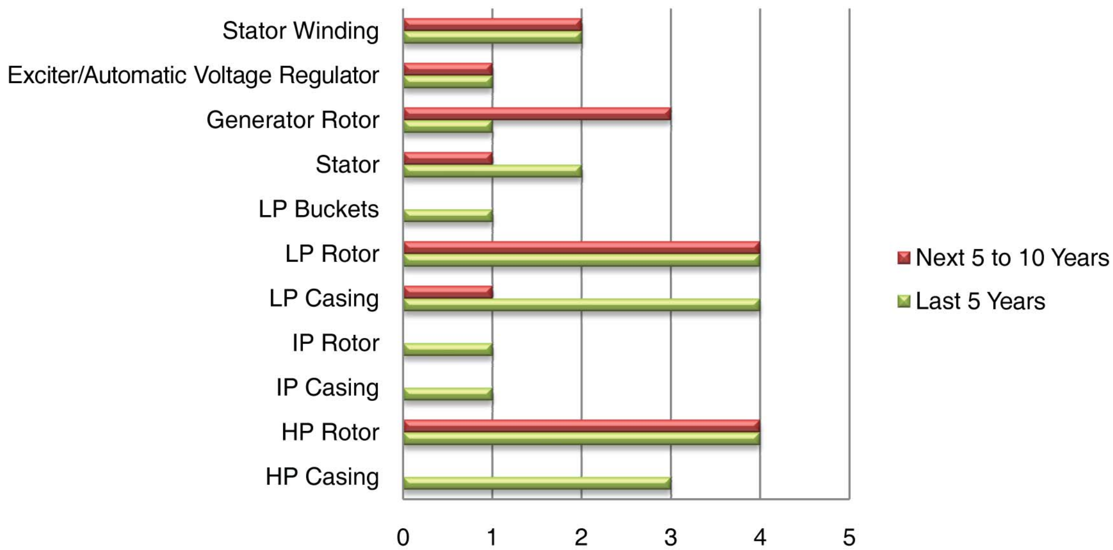

Figure A-4
Equipment Retrofits and Replacements

Most retrofits are driven by reliability issues and life extension concerns. The most significant reasons for retrofitting or replacing steam turbine-generator equipment are shown in Figure A-5.

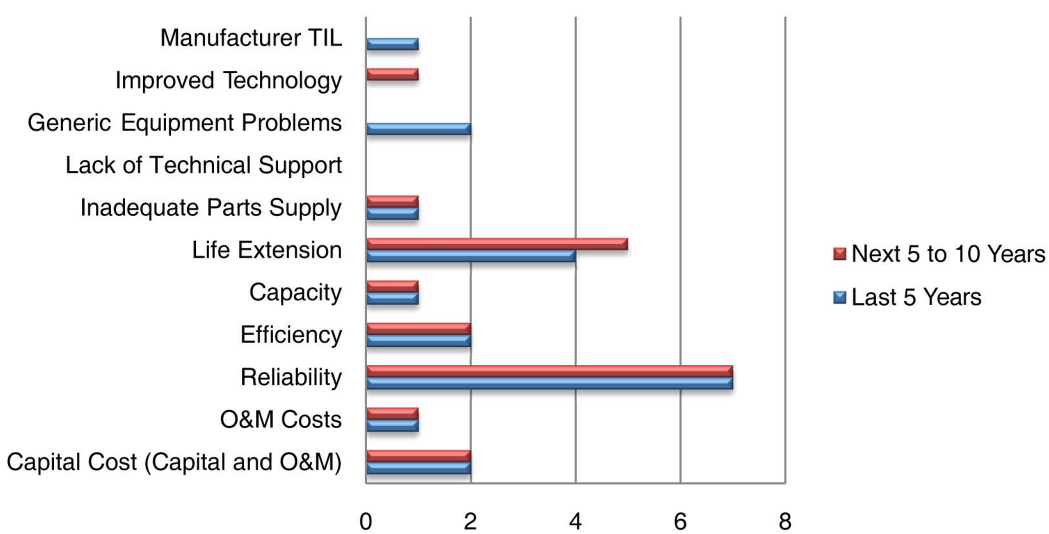

Figure A-5
Reasons to Retrofit

General Electric equipment has the most retrofits in the United States, as shown in Figure A-6.

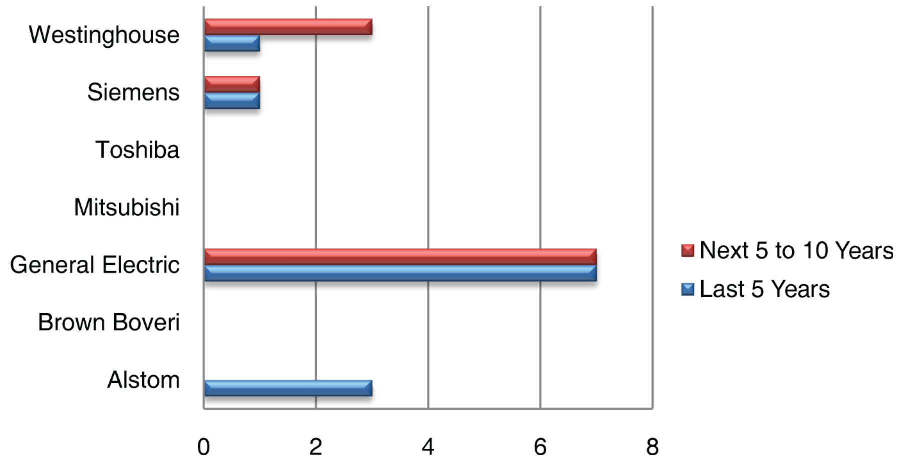

Figure A-6
OEM Equipment Retrofits

Most retrofits have been performed by the OEM; however, Siemens and Alstom have both retrofitted equipment on other manufacturers' steam turbine-generators. Figure A-7 provides a summary of past and predicted future suppliers for OEM equipment replacement.

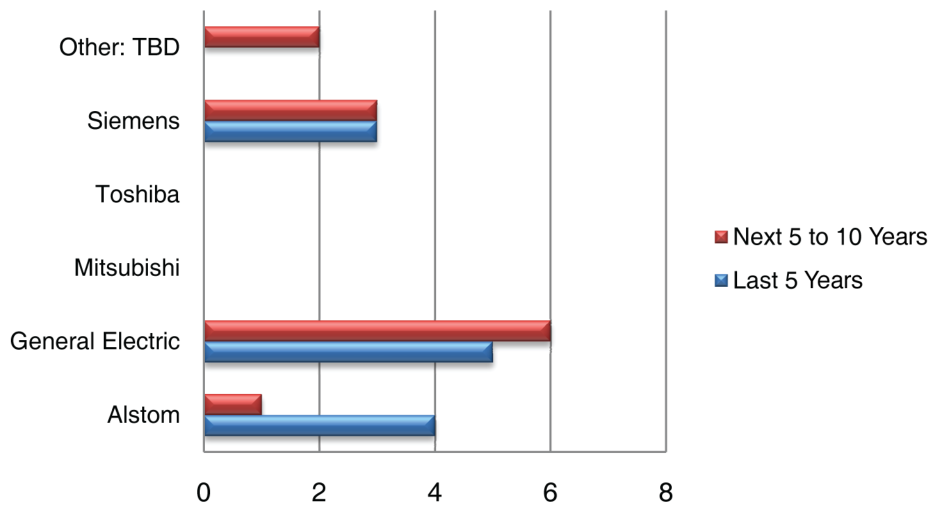

Figure A-7
Suppliers for Replacement Equipment

The experience with steam turbine-generator retrofits and replacements is generally good because the proper risk mitigation elements were implemented by the project teams. Reported issues included the following:

- Manufacturing errors
- Failure to achieve capacity guarantee
- Schedule extension

Figure A-8 shows the various risk mitigation elements that were utilized by teams over the past five years.

Figure A-8
Utilization of Risk Mitigation Elements

A variety of contracting methods were employed, with some projects electing not to bid the work, but award it directly to the OEM. In these cases extended warranties and bonus/penalty provisions were included in the contract. Figure A-9 summarizes the most significant contracting issues.

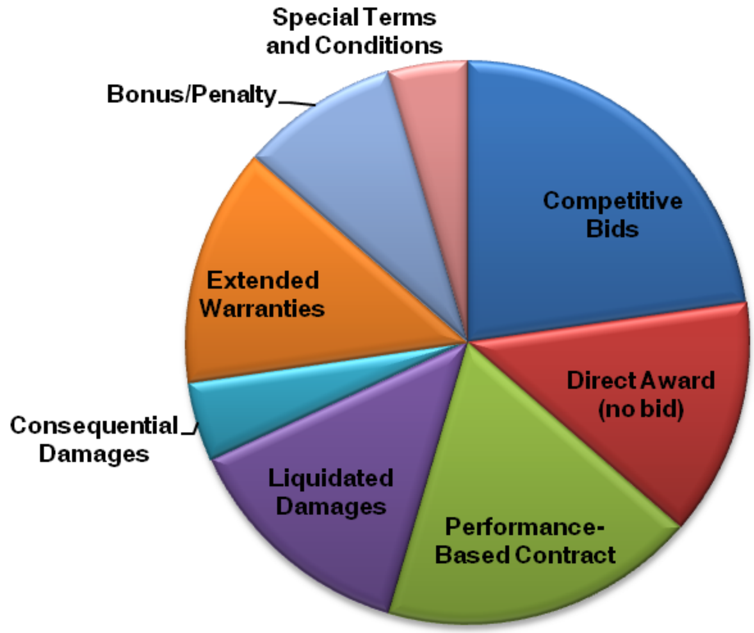

Figure A-9
Contracting Issues

The reporting utilities indicated that they had adequate technical support. As expected, the most commonly reported shortcomings were to the result of inadequate specifications and out-of-date drawings. The results are summarized in Figure A-10.

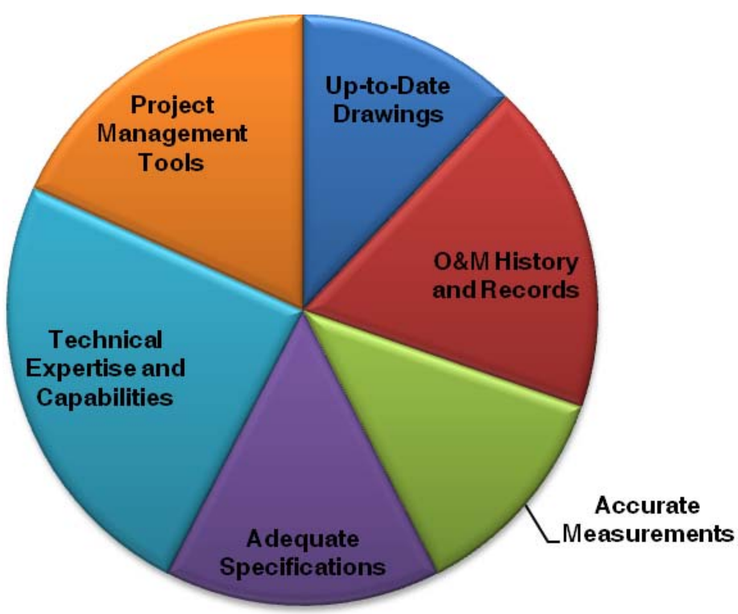

Figure A-10
Available Data Resources

A.2 Recommendations from the Survey

Specific recommendations for improving steam turbine-generator equipment retrofits and replacements include the following:

- Use complete and formal specifications.
- Perform thorough design reviews prior to release for manufacturing.
  - Challenge the contractor and the project team in meetings in all phases of the project: design, implementation, planning and testing.
- Be involved and have a good purchase order and contract terms.
- Strongly recommend a peer review and reporting back to users in a forum organized by vendors or EPRI (TGUG, for example).
- Use a standard reporting method to share experience on manufacturers regarding:
  - Manufacturing quality
  - Non-compliance reporting methods
  - Use of lessons learned
  - Thoroughness of engineering reviews
  - Overall satisfaction
  - Project critiques

Export Control Restrictions

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