Combined Cycle Turbomachinery - Program 79

Program Overview

Program Description

The use of natural-gas-powered single-cycle (SC) and combined-cycle (CC) plants is likely to benefit from the increased worldwide supply of natural gas fuel, the availability of these fuels at lower and stable prices, and the continued environmental pressure to limit the use of coal-based power plants. The use of SC and CC plants will also likely benefit from the expected limited growth of new nuclear power generation and the ability of natural-gas-powered plants to operate in cycling duty to accommodate the current increase of wind and solar power sources in some areas of the grid.

The asset value of natural-gas-fired gas turbines, especially in combined-cycle plants, is on the rise. But cycling and high-temperature operations can adversely affect combustion turbine component life. Life-cycle costs, premature wear, failure risks, and environmental performance are critical issues affecting plant performance, reliability, and cost. Improved operational flexibility can help plants address load demands. At the same time, gas turbine and combined-cycle technologies continue to evolve, providing significant efficiency gains and relative improvements in installed cost. Informed decisions about technologies and plant designs are especially important because selection affects efficiency, emissions, availability, maintainability, and durability.

EPRI's Combustion Turbine/Combined-Cycle programs provide techniques and emerging technologies to quantify risk and reduce operations and maintenance (O&M) costs, while maintaining reliability and performance. The goal is to effectively manage the risks, costs, and availability of these complex, increasingly important, and widely used assets.

For 2013, EPRI staff consulted with members of Programs 79 and 88 to make several strategic changes that will broaden EPRI’s focus on SC and CC plants. The members provided valuable feedback on key natural gas generation issues with emphasis on their current and future SC and CC portfolios, and on how EPRI can more fully respond to these specific issues and future research and development (R&D) opportunities. The changes are to consolidate three existing programs (P79, P80, and P88) into two programs structured as a coordinated and complementary set to address all aspects of gas turbine (GT) and CC research areas. The new program titles are:

- Combined Cycle Turbomachinery (P79)
- Combined Cycle Heat Recovery Steam Generator (HRSG) and Balance of Plant (P88)

The Electric Power Research Institute's (EPRI) 2013 Combined Cycle Turbomachinery program (Program 79) provides resources to address all aspects of the life management and the operational and maintenance (O&M) improvements of conventional and advanced GTs. It also addresses all aspects of CC plant-wide integration, including specific issues relating to the steam turbine (ST) and generator for CC applications.

Research Value

Members of this program can use the R&D to respond to the issues, challenges, and opportunities related to integrating and operating CC assets in a rapidly expanding and changing power generation environment; implement specific and detailed engineering analyses in the areas of CC turbomachinery life assessment, risk management, and improved operation and maintenance of current assets; and gain a thorough understanding of the technologies incorporated into the latest gas turbine and steam turbine offerings for improved decision-making in the CC project development process.
**Approach**

The program portfolio has two primary technical objectives:

- Use a holistic approach and perspective on all R&D elements related to integrating all the equipment and systems of a CC plant
- Address all aspects of managing CC turbomachinery assets, including life assessment/risk management, O&M improvements, and technology advancements

Specific technical interaction and allocation of resources between P79 and other programs such as the HRSG and Balance of Plant program (P88) and the Steam Turbine-Generator program (P65) will effectively utilize existing EPRI technical expertise and resources without duplication between programs.

Program members receive information on:

- Plant-wide integration – topics including operational flexibility and controls, performance improvement and optimization, and GT, HRSG, and ST interaction and inter-system dependence
- Life assessment and risk management – topics including damage detection, root cause and solutions, and monitoring and life-predicting analyses
- O&M Improvements – topics including component durability and damage tracking, and repair and refurbishment guidelines
- Technology advancements – topics including engineering and economic assessments, reliability and availability statistics of current turbomachinery RAM performance, and new and advanced equipments offerings and capabilities

Program additions in 2013 include a greater emphasis on CC plant-wide topics. An online survey will capture the interests, comments, and feedback of the program members relating to the potential products, and the feedback from the survey could lead to additional potential products in the 2013 program activities.

The EPRI staff and the P79 advisors have identified modifications and additions to the program for transition to 2013. This initial planning is part of a major five-year R&D plan for the new CC programs (P79 and P88). The EPRI staff and the P79 advisors are to explore activities, projects, and products for 2013 that will be presented and prioritized at the 2012 fourth-quarter Generation advisory council meeting. The number of products completed in 2013 will be based on the yearly funding levels, coupled with member prioritization provided during each year’s third-quarter Generation advisory council meeting.

**Accomplishments**

For the last 30 years, EPRI’s GT and CC programs have provided high-quality technical evaluations and products to support better operation and maintenance of existing assets, and objective, timely, life-cycle perspective on technology choices and improved plant designs, including:

- Model-specific repair guidelines for widely used 50/60-Hertz (Hz) machines
- Replacement part procurement guidelines for D/E- and F-Class models
- Compressor and rotor root-cause analysis and O&M solutions
- O&M guidance for DLN combustor systems and segmented feed pumps
- Selective catalytic reduction (SCR) and CO catalyst deactivation assessment and improved emission controls tuning
- Component durability analysis and damage tracking
- Combined cycle performance monitoring and recovery
- GT technology comparisons, best practices, and procurement guidelines/specifications
- Lessons learned in GT/HRSG repowering
Current Year Activities

Program R&D for 2013 will seek to broaden EPRI’s focus on CC plant-wide integration issues, and increase interaction and joint projects with the new P88, and other EPRI programs. The program also will seek to mitigate current GT dependability issues and reduce O&M costs, and track the characteristics of current and next-generation technologies. Specific efforts may include:

- Assessment of GT-HRSG-ST interface operational optimization
- CC performance recovery and improvement guidelines: monitoring and diagnostics
- Electric generator advanced monitoring and diagnostics
- Design assessment of steam turbines for CC applications: differences and similarities
- Improved rotor non-destructive evaluation (NDE) for extended life
- Automatic tuning of dry, low-NOx combustors: field experience and demonstration
- New/updated GT hot-gas-path repair guidelines
- Design evolution, durability, and reliability for current GT models
- Converting SC plants to CC plants: major challenges including plant capital expenditures

Estimated 2013 Program Funding

$4.0M

Program Manager

Robert Steele, 704-595-2925, rsteele@epri.com

Summary of Projects

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>Description</th>
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<tbody>
<tr>
<td>P79.001</td>
<td>Plant-Wide Integration</td>
<td>Integrated perspective on the entire combined cycle identifies methods for improving start-up times, cycling capability, low-load operation and heat rate, and highlights strategies and technologies currently being developed and deployed in the generation fleet.</td>
</tr>
<tr>
<td>P79.002</td>
<td>Life Assessment/Risk Management</td>
<td>In-depth investigations and guidelines address high-risk component failure mechanisms. Corrective solutions and damage mitigation techniques, such as advanced inspection and monitoring approaches, are developed, evaluated, and demonstrated.</td>
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<tr>
<td>P79.003</td>
<td>Operations and Maintenance Improvements</td>
<td>Repair, procurement, and damage-tracking guidelines for compressor, combustor, and turbine components reduce maintenance costs of gas turbines, steam turbines, and generators in combined-cycle plants.</td>
</tr>
<tr>
<td>P79.004</td>
<td>Technology Advancements</td>
<td>Design features, related risk issues, and reliability-durability experience of gas turbines and steam turbines used in combined-cycle plants support upgrade and new technology procurement decisions.</td>
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</tbody>
</table>
P79.001 Plant-Wide Integration (073436)

Key Research Question
Increased utilization of existing and newly commissioned CC assets has elevated the importance of assessing, improving, and optimizing the integration of the GT, HRSG, ST, and balance-of-plant equipment for improved performance and decreased O&M costs.

Approach
This project addresses core issues facing current CC engineering and site operations staff by:
- Identifying and evaluating operational approaches and controls with greater flexibility for peaking, intermediate, cycling, and baseload operation
- Improving and optimizing component and multi-component performance to reduce O&M costs
- Evaluating the interaction and interdependence of the GT, HRSG, ST, and balance-of-plant equipment
- Quantify and compare existing life-cycle costs for various plant configurations

Impact
- Decrease outage duration and increase intervals between outages
- Improve operational flexibility
- Improve thermal efficiency
- Increase component part life and decrease costs

How to Apply Results
Members can use the products of this project to enhance their ability to analyze and quantify the challenges of operating CC assets in a rapidly expanding and changing environment as the electric power industry reduces existing fossil-based assets and introduces more renewable assets.

2013 Products

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<tr>
<td>Assessment of Combined-Cycle Startup/Shutdown Practices: This report reviews the experience with standard cold-warm-hot startups and rapid startups for different combined-cycle designs. Particular emphasis is placed on the temperature transients imposed on critical gas turbine, HRSG, and steam turbine hardware and the relationship to observed damage. Recommendations for control modifications to mitigate temperature/stress conditions across the centerline power train will be outlined.</td>
<td>12/31/13</td>
<td>Technical Update</td>
</tr>
<tr>
<td>Demonstration of GT-HRSG Temperature Alignment: Report covers the plant demonstration of the adjustment of gas turbine startup exhaust temperatures to better accommodate the slower steam production rates in the heat recovery steam generator using EPRI guidelines.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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**Future Year Products**

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<tr>
<td><strong>Online Combined-Cycle Stress Analyzer for Major Components:</strong> Conceptual design of online monitoring system driven by temperature sensors located on critical gas turbine, HRSG, and steam turbine components. The monitor would provide creep and fatigue damage estimations used for planning major outage maintenance and component repair/replace intervals.</td>
<td>12/31/14</td>
<td>Technical Update</td>
</tr>
<tr>
<td><strong>Plant Modifications for Improved Operational Flexibility:</strong> The project identifies specific plant modifications aimed at improving operational flexibility: rapid starts/load following, lower turndowns, or fuel variability. Where possible, plant case histories are featured.</td>
<td>12/31/15</td>
<td>Technical Update</td>
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**P79.002 Life Assessment/Risk Management (073437)**

**Key Research Question**

Operational Reliability Analysis Program (ORAP) combined-cycle plant operating statistics indicate that gas turbines and steam turbines are the dominant contributors to unplanned outages, with an unplanned unavailability rate of over 4-6% for the typical plant. Complex, tightly integrated gas turbines in particular are subject to cascading damage from failed inlet compressor blades, combustor hardware, or hot section parts. High backpressure steam turbines and electric generators also are becoming a concern as damage accumulates from years of cycling service. Rebuilding such equipment with custom, high-cost components often requires an extended outage to accommodate the long lead time of manufacturing new components and transport to off-site repair facilities. The challenge is to identify specific short- and long-term equipment risks and manage potential impacts safely and cost-effectively.

**Approach**

This project helps members with early detection of incipient damage, as well as in-depth understanding of the mechanisms and the underlying root causes driving component damage and increased risk of outright failure. In certain cases, a technical assessment is performed and provides solutions, such as redesigns, repair modifications, or changes in operations.

- The project develops and validates inspection and monitoring techniques, collects field experience, and characterizes component design features. Engineering component models are constructed to evaluate damage tolerance, remaining life, and effectiveness of corrective measures.
- For the gas turbine compressor, work is aimed at the early detection of FOD (foreign object damage), rubbing, erosion/corrosion, and aerodynamic instabilities leading to liberation of stator or blade airfoils.
- For the gas turbine combustor, the focus is on dry low-NOx burner thermo-acoustic pulsations and lean blowout conditions leading to fuel nozzle damage and downstream hardware cracking.
- For the gas turbine hot section, cracking in rotating blades and loss of prime-reliant cooling is a key concern in advanced, high-temperature designs. Component durability analysis provides insights into design deficiencies.
- For the gas turbine rotor, component stress analysis and material testing are used to address cracking in rim attachments and the general structural integrity of engines subjected to high hours and high starts.
- For the steam turbine generator, new work is planned to characterize issues specific to combined cycle designs including general damage assessment and notable failures such as for certain outlet L-0 blade designs or generator windings.
Impact

- Improved monitoring and inspection techniques provide early awareness of abnormal conditions and the opportunity to take countermeasures.
- Evaluate the potential effectiveness of design modifications using validated engineering models.
- Assess the useful economic life of high-value components on a wellformulated, engineering basis.

How to Apply Results

Where possible, the implementation of new monitoring techniques builds on the existing equipment instruments and plant data historian. Investigation reports, supplemented by technical presentations, provide an understanding of damage mechanisms and field experience. An engineered solution likely will require the involvement of the OEM, repair shop, or other service provider.

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<tr>
<td>Compressor Monitoring Guidelines: The guidelines provide a description of instrumentation and monitoring systems for tracking the performance and structural integrity of the gas turbine compressor section. Temperature, acoustics, vibration, and static and dynamic pressure monitoring techniques are covered. Of particular interest is tracking precursor conditions such as stall flutter and other aerodynamic anomalies that could lead to cracking and excessive fretting damage in blades and vanes. Monitoring field experience, where it is available, is summarized.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td>DLN Combustor Monitoring Guidelines: Update: Dry low-NOx (DLN) combustors are subject to dynamics, lean blowout, and elevated emissions levels. These operating issues generally become more pronounced with lower emissions, increased turndown, and fuel quality variability. These guidelines update previous EPRI work and include current monitoring system practices, advances in fault diagnostics, and experience with auto-tuning techniques.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td>Rotor NDE and Material Properties for Life Extension: Retired gas turbine rotor components are obtained and sectioned for testing. Material property testing is performed to establish the rate of aging due to creep, low cycle fatigue, and embbrittlement. Improved data on degraded material property is used to improve the accuracy of component life estimations. Advanced nondestructive evaluation and miniature material sampling techniques are developed using the scrapped rotor components.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td>Low-Pressure Steam Turbine Issues and Experience in Combined Cycles: The long last-stage blades of the low-pressure steam turbine are subject to high exhaust flows and back pressures. This report reviews the design challenges presented by such conditions. Field experience with specific cases of cracking in attachments is covered. The work scope will be jointly created with input from P65 (Steam Turbines-Generators and Auxiliary Systems) staff, and their expertise will be utilized.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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Future Year Products

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<tr>
<td>Component Failure Investigations and Risk Mitigation Guidance:</td>
<td>12/31/14</td>
<td>Technical Update</td>
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<tr>
<td>Repetitive failures or chronic durability shortfalls of turbine components are identified as higher-risk issues. A detailed investigation is conducted involving documenting the failure history, materials assessment, engineering modeling, and evaluation of maintenance solutions or alternative designs.</td>
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<tr>
<td>Advanced Condition Monitoring Instrumentation: Novel instrumentation and analysis techniques suitable for long-term plant monitoring are identified, such as for high-temperature strain, rotating-blade high-cycle fatigue, or protective coating degradation.</td>
<td>12/31/14</td>
<td>Technical Update</td>
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<tr>
<td>Application of Small Punch and Indentation Techniques for Rotor Life:</td>
<td>12/31/14</td>
<td>Technical Report</td>
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<tr>
<td>Small punch and indentation techniques offer promise as a step-change improvement over conventional hardness and replica component testing for assessment of material property degradation. Correlations with test data from rotor material destructive test results will be developed.</td>
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<tr>
<td>Demonstration and Validation of Component Modification and Damage Mitigation Techniques:</td>
<td>12/31/15</td>
<td>Technical Update</td>
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<tr>
<td>Modifications to high-risk components and related operating conditions may safely extend the useful life of these components. Detailed engineering analysis is conducted of candidate modifications. Where viable solutions are determined, plant demonstrations will be sought.</td>
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P79.003 Operations and Maintenance Improvements (073438)

Key Research Question

Maintenance of the power centerline equipment (gas turbine, steam turbine, generator) represents the largest portion of the combined-cycle non-fuel plant budget. With increasing capacity factors, fewer windows are available to schedule maintenance. A related factor is the long lead times often required to obtain new and refurbished costly, custom parts such as model-specific superalloy blades or generator windings. To achieve high plant availability in a reasonably cost-effective manner requires that maintenance activities be addressed on different levels: tactical (reactive for daily issues) and a more strategic dynamic level that anticipates major expenditures over the next 3-10 years. For the gas turbine, key strategic challenges include: balancing maintenance costs and risks and creating future qualified options for parts and repairs.

Approach

Effective maintenance management of the major combined-cycle turbomachinery focuses on three elements: optimizing maintenance intervals, extending service life by repair, and obtaining lower cost/longer-life replacement hardware. EPRI's R&D supports all three areas:

- The high life-cycle cost of gas turbine hot section components is second only to the fuel costs for the plant. A series of model-specific guidelines address the repair, damage tracking, design evolution, and replacement of superalloy blades and vanes. The 50/60 Hz conventional and advanced model combustor and hot-gas-path components are addressed, including all F-class engines.
- Tuning and monitoring of dry low-NOx combustors to mitigate dynamics while maintaining low emissions levels are addressed in practical guidelines addressing a range of OEM design variations. The effectiveness of periodically tuning on-site, remotely, or continuously (auto-tuning) is investigated. Combustor modifications to accommodate low-load operation, fuel quality variations, and rapid starts also are addressed.
The gas turbine compressor flow path is subject to fouling, rubbing, clashing, and impact damage. Monitoring performance and structural issues, and performing limited repair of airfoil damage are taken up in field guidelines and associated training activities.

Although the gas turbine OEM provides explicit maintenance intervals based on hours and starts, equivalent guidance is not available for the steam turbine and generator. A longer-range project goal is to provide such steam generator maintenance interval guidance for prevalent combined-cycle designs.

**Impact**

- Achieve cost savings from competent, cost-effective services made possible by the repair guidelines.
- Reduce replacement hardware costs by procuring more durable designs and competitive bidding.
- Reduce fallout rate from repair cycles and possibly extend overall economic life using damage-tracking guidance to optimize maintenance intervals.
- For those machines covered by extended service agreements, EPRI products play a role in overseeing quality repairs, establishing objective run/scrap criteria, and factoring in technology improvements to the overall life-cycle management.

**How to Apply Results**

Repair and procurement guidelines are used to support competitive bidding and overseeing quality delivery of products and services. Damage tracking can be used to make manual estimations, but is most effective incorporated directly into the plant historian and parts inventory system. A consultant or service provider may be needed to apply guidelines during a repair process or to implement combustor tuning.

**2013 Products**

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<tr>
<td><strong>Compressor Blade Trimming and Blending Guidelines:</strong> Guidelines are developed for different gas turbine compressor designs. Trimming and blending techniques are explicitly defined on a stage-by-stage basis to address commonly encountered gas-flow-path damage such as blade tip rubs, bent tips, corner losses, and leading-edge impacts. Structural modeling is used to determine that safe margins are maintained when the airfoil shape and mass are altered. Prior work performed on the GE 7FA compressor will be extended to other GE models.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>GTCC O&amp;M Cost Analyzer:</strong> Excel spreadsheet-based software estimates the O&amp;M costs for simple-cycle and combined-cycle plants for user-specified operating scenarios. Gas turbine model-specific costs are based on component replacement and repair costs, life estimates, and maintenance intervals. A probability analysis feature incorporating industry experience data allows the user to examine the impact of unplanned maintenance events. This is a shared product with P88.</td>
<td>12/31/13</td>
<td>Software</td>
</tr>
<tr>
<td><strong>Plant Maintenance Basis Database:</strong> Program 79 will join with EPRI’s Generation Maintenance Application Center (GenMAC, Program 104) to include PMBasis in the suite of tools available for members to improve the reliability of the combined-cycle turbomachinery equipment.</td>
<td>12/31/13</td>
<td>Technical Resource</td>
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<tr>
<td><strong>Integrated GT Parts Tracking/Damage Tracking:</strong> Report addresses the practices used for tracking gas turbine replacement parts, approximately 500 per engine, over the entire life cycle of a plant or across a larger fleet. Approaches are investigated to optimizing the overall economic return of a pool of parts considering impacts of changing duty cycles (hours/starts), component design evolution, repair fallout, and different restoration techniques. Damage tracking encompasses OEM conventions and EPRI component lifing models.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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**Product Title & Description**  | Planned Completion Date | Product Type
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**Hot Section Life Management Guideline:** The hot section management guideline covers the process of assessing the condition of critical components, such as the rotating turbine blades, for extended service. The role of advanced inspection and material testing using miniature specimens is covered. The choices between different repair techniques and components modifications are discussed. Several case histories are provided to illustrate the overall process. | 12/31/13 | Technical Update

**Advanced Thermal Barrier Coating for Combustion Hardware:** Low-K (conductivity) thermal barrier coatings (TBC) provide improved high-temperature protection for air-cooled combustor components. Prior work helped establish that the low-K TBC specimens provided performance and durability characteristics suitable for application on combustor hardware. The follow-on phase addresses application and demonstration on full-scale gas turbine hardware. | 12/31/13 | Technical Update

**Field Guide for GT Borescope Inspections:** Gas turbines are designed with inspection ports in the compressor and hot section. The field guide reviews equipment and techniques used to perform inspections of assembled engines using visual borescopes. Practical tips and examples are provided to assist those contracting a service or performing inspections directly. | 12/31/13 | Technical Update

**Gas Turbine Repair Guidelines: New and Updated:** Eighteen gas turbine models are covered in separate repair guidelines volumes. Each volume provides individual component specifications, addressing the specific design features and repair considerations for hot-section blades and vanes and combustion hardware. Guidelines routinely are updated to include the latest features, restoration techniques, typical component damage, and repair techniques. | 12/31/13 | Technical Report

**Air-Cooled Generator Failure Mechanisms:** Continuing with the series of Program 65 Field Guides, which are a proven useful tool for failure identification and mitigation, EPRI will produce a field guide focused on the air-cooled subset of electric generators. This will focus on the issues unique to this class of equipment and provide utility personnel with a tool to increase reliability of their fleet. This product will be jointly funded with P65. | 12/31/13 | Technical Report

**Future Year Products**

**Product Title & Description**  | Planned Completion Date | Product Type
---|---|---
**Inlet Air Filtration Media Evaluation:** New filter media for the compressor inlet air conditioning potentially offers improvements in maintaining gas turbine efficiency, reducing the need for compressor washing, and limiting other contaminates that may promote corrosive damage throughout the machine. The project conducts independent testing of filter media and collects early field experience. | 12/31/12 | Technical Update

**Component Durability Analysis and Damage Tracking:** Based on field experience, detailed durability modeling, and component material testing, improved methods for tracking hot-section component damage are developed and refined. As specific component designs evolve, damage estimates are accordingly updated to take into account improvements in cooling, coating, materials, and structural design. | 12/31/14 | Technical Update
Repair Shop and Alternate GT Component Supplier Capabilities: The capabilities of repair shops and alternate gas turbine component suppliers are evolving to meet the needs of advanced turbine owners. The report surveys worldwide capabilities with emphasis on assessing the level of experience at the model component-specific level.

Advanced Thermal Barrier Coating for Hot Section Hardware: Thermal barrier coating (TBC) plays a key role in critical high-temperature components performing reliably and achieving design service life. The project seeks to qualify a new generation of topcoat TBCs and underlying metallic bond coats, which offer reduced conductivity (lower effective metal temperature) and better durability.

Improved Repair Development and Qualification: The project examines new repair techniques and different application approaches used across the industry. Candidate topics for investigation include advanced welding, high strength brazing, restoration of internal coatings, and rejuvenation heat treatments.

P79.004 Technology Advancements (073439)

Key Research Question

Power plant owners, operators, and project developers want to know the characteristics of current and next-generation technologies, including performance and risk attributes, life-cycle costs, and best-in-class approaches for specifying the plant configuration and procuring new equipment. A thorough understanding of the technologies incorporated in the latest gas turbines and steam turbines, and lessons learned from previous experience help to support informed decisions and improved results for upgrades and new projects.

Approach

Research needs are addressed by a range of actions focused on turbomachinery technology advancements:

- Identify the status, challenges, and opportunities associated with advanced technologies
- Report current information from industry conferences, contacts, periodicals, and news releases on industry trends, new equipment offerings, and capabilities
- Analyze reliability and availability statistics to benchmark current turbomachinery RAM performance
- Provide a life-cycle cost perspective on operations/maintenance costs and technology risks related to unplanned maintenance
- Guide new plant designs and procurement through lessons learned from early adopters
- Develop timely, accurate engineering and economic studies to support the decision-making process
- Perform parametric studies of plant options to identify relative impacts on capital costs, performance, and levelized cost of electricity

Impact

- Develop new projects based on solid information and thorough preparation
- Understand opportunities and risks of deploying advanced technologies
- Achieve improved efficiency, emissions, availability, maintainability, and durability
- Quantify costs of cycling and unplanned maintenance in turbomachinery
- Reduce overall costs to generate electricity over plant life
How to Apply Results
Members use the products by incorporating the assessments and data in their decision-making for technology selection and procurement early in the project development process.

2013 Products

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<tr>
<td><strong>Gas Turbine Design Characteristics, Durability and Reliability:</strong> Reports describe the latest commercial offerings by the OEMs, provide historical reliability and availability performance, identify events that cause unplanned maintenance, describe durability issues that affect operational risk and maintenance costs, and provide listings of site installations. For 2013, updates on Siemens, Alstom, and Rolls-Royce engines are planned.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Design Characteristics, Durability and Reliability of Steam Turbines and Generators in Combined-Cycle Applications:</strong> Report describes the latest commercial advances by the major OEMs, provides historical reliability and availability performance, identifies events that cause unplanned maintenance, and describes durability issues that affect operational risk and maintenance costs. Current model offerings by Alstom, General Electric, Mitsubishi, Siemens, and others will be addressed.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<tr>
<td><strong>Combined Cycle Environmental Control Technologies Handbook:</strong> Report update assesses advancements in equipment and systems for emissions controls and provides technical guidance for regulatory issues affecting plant siting. Typical regional permit levels for priority pollutants are included. Trends in new regulatory requirements are discussed (shared with P88).</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<td><strong>Performance and Economic Evaluation of Combined Cycles with State-of-the-Art Steam Cycles:</strong> Study identifies the performance improvements when using higher-pressure, higher-temperature steam cycles recently introduced and quantifies efficiency gains and impact on plant profitability.</td>
<td>12/31/13</td>
<td>Technical Update</td>
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<td><strong>Procurement Guideline for Steam Turbines:</strong> Updates steam turbine procurement guideline, incorporating latest OEM equipment offerings. Guideline addresses new design features to accommodate higher temperature/pressures, more flexible startup operation, and improved durability.</td>
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<td><strong>Synopsis of Emerging Gas Turbine Combined Cycle Innovations:</strong> A synopsis of emerging gas turbine combined-cycle innovations focuses on technology advancements most likely to practically affect progression towards higher efficiency, improved operability, and reduced life-cycle cost. The migration of aircraft technology to land-based engines is a key trend to monitor.</td>
<td>12/31/14</td>
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**Supplemental Projects**

**Gas Turbine Rotor Life (066745)**

**Background, Objectives, and New Learnings**

Gas turbines (GTs) are used in simple-cycle configuration to supply peaking power generation service. These machines acquire many cycles but relatively few hours of service. They also are idled for extended periods and thus are subject to corrosion from condensation. GTs in combined-cycle configuration can be deployed in either daily cycling or more baseloaded service. As such, combined-cycle rotor life may be governed by hours of operation or a combination of hours and starts.

GT rotors typically are inspected during hot gas path and major maintenance intervals when casing covers are removed. The original equipment manufacturer (OEM) typically will assist in these inspections and will judge whether the rotor is suitable for continued service. Sections of the rotor may be deemed nonserviceable after 100,000 to 250,000 hours or 2500 to 5000 starts. The impacts of an extended outage for a rotor rebuild may be mitigated by using a pooled spare rotor—if one is available.

OEMs have been notifying GT owners that rotors used on high-hours machines should be shipped off-site and disassembled for extensive inspection. Pending inspection results, a limited operation extension may be granted. For high-starts machines, the recommendation often is to retire them without inspection. The engineering basis for rotor operational extension or retirement is unclear, with little field experiential data to establish a quantifiable risk.

**Project Approach and Summary**

The overall work scope is structured around two major tasks: Rotor Life Inspection and Evaluation Guidelines, and Model-Specific Component Evaluation. Life prediction procedures are developed for the particular rotor design and material, with particular emphasis on rim-blade interface, bolt holes, and center bores or alternatively welded rotors. The component focus can be adjusted to suit a specific machine operating mode, anticipated issues, or inspection results. Where available, destructive mechanical testing of retired components may be included to further quantify material degradation.

**Benefits**

Results from this project will provide GT owners with procedures and technical information to objectively evaluate the condition of their GT rotors. Rotor rebuild/replacement, along with the associated outage, is estimated to exceed $6 million per machine.

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**Advanced Plant Cycle Evaluation:** The project examines, from both theoretical and economic standpoints, the viability of gas-based power cycles beyond the conventional Brayton-Rankine design. Past work looked at innovations such as compressor inter-cooling, recuperation, and humidification. It is anticipated that more novel innovations will be first introduced at smaller sizes suitable for distributed generation.

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<th>Product Title &amp; Description</th>
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<td>Advanced Plant Cycle Evaluation</td>
<td>12/31/15</td>
<td>Technical Update</td>
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Reducing Life Cycle Costs for Gas Turbine Hot Section Components (064708)

Background, Objectives, and New Learnings

Gas turbine (GT) combustion parts and the downstream hot section vanes and blades routinely are inspected, refurbished, and replaced. The cost of extensive maintenance associated with the gas turbine life-cycle can exceed the initial equipment cost by as much as a factor of three. Each model type has design-specific features that require specialized knowledge to effectively manage machine O&M. For instance, each turbine model has unique blade designs made of superalloy thin-walled castings, requiring complex internal cooling, oxidation, and thermal barrier coatings to survive in a high-temperature environment.

Faced with such specialized hardware, gas turbine owners seek to reduce O&M expenses without increasing risk by optimizing all the activities and costs related to the inspect/repair/replace life cycle. To effectively support this goal requires model-specific, objective knowledge of component design, repair, and degradation mechanisms experienced in their own units.

To meet this basic need, EPRI has developed core competencies in hot-section design analysis and repair procedures and applied them to different CT models. EPRI collaborative projects supported by the owner/operators of 50- and 60Hz models have created an extensive knowledge base addressing widely used conventional and advanced engines.

Project Approach and Summary

The general approach for each model-specific project is optimize the hot-section economic life-cycle at either the plant or fleet level according to how the parts inventory is managed. Tools are developed to manage critical aspects of the lifecycle: repair procedures, accumulated damage tracking, and replacement/upgrade procurement guidelines. Component testing may be included if suitable specimens are available.

Benefits

The technical knowledge base provided by this project enables participants to more effectively manage gas turbine hot-section life-cycle costs and the maintenance-related technical issues. The technical issues are equally relevant to both OEM and independent O&M providers. If the knowledge base is used as part of an overall maintenance strategy, participants can realize cost savings of 25% or more. These savings can range from $500,000 for conventional D/E-Class machines to as much as $3.2 million for advanced F-Class machines per hot gas path, depending on model and operating duty cycle.

Combustor Dynamics Monitoring for Improved Gas Turbine Reliability (072056)

Background, Objectives, and New Learnings

This project is a continuation of EPRI R&D that developed a basis for detecting combustion system failures in dry, low-NOx (DLN) gas turbines, based on analysis of dynamic pressure data. This detection analysis approach is a significant advancement over the threshold detection methodologies currently available with existing combustion dynamics monitoring systems (CDMS). This field test effort project continues this work by applying these methods to additional host site gas turbines. It will focus on the refinement of these methods of failure detection for DLN combustion systems while minimizing false alarms alerts due to sensor failures, ambient condition changes, and control system variations.

The objectives of this project are to provide host sites with an on-line tool to improve operational flexibility and avoid DLN combustion system failures; to investigate any data anomalies and identify potential or emerging problems over a 24-month period; and to generate guidelines to avoid DLN combustion system failures.
The knowledge developed by this project can provide gas turbine operators with information to improve operational flexibility and avoid further in-service failures. This knowledge will assist in avoiding DLN combustion system failures and reduce operational risks. The results will be incorporated in a series of EPRI design and O&M guidelines that address increased combined-cycle operational flexibility.

**Project Approach and Summary**

The EPRI diagnostic tool will be installed in the host site’s existing combustor monitoring system. The diagnostic data will be monitored over a 24-month period. The plant receives regular status reports and alerts of impending combustor system malfunctions.

**Benefits**

Combustor dynamics monitoring provides improved diagnostic capability and risk avoidance. The EPRI diagnostic tool provides advanced warning beyond the conventionally supplied combustor monitoring system.

**Combined Cycle Performance Recovery and Improvement Guideline - Plant Validation and Refinement (072058)**

**Background, Objectives, and New Learnings**

The benefits of improved performance of combined-cycle power plants continue to grow as the costs of fuels and emissions rise, and the possibility of a carbon dioxide cap-and-trade program looms on the legislative horizon.

The mode of operation for many combined-cycle units has changed, whereby they spend more time on-line with higher capacity factors. Thermal performance now has a much larger effect on the plant's economics.

This project will compile a report, promulgating both the methodology and the technical details of a performance improvement and maintenance program for equipment-specific combined power plants.

**Project Approach and Summary**

To produce a report that extends the EPRI generic Combined Cycle Performance Monitoring and Recovery Guideline to equipment-specific combined-cycle configurations and draws in actual plant experience.

The steps in developing this guide include:

- Review of existing combined-cycle plant performance assessment guidelines, publications, and training courses
- Review of utility best practices for combined-cycle plant performance assessment

The report will address both the programmatic and technical elements that comprise a performance monitoring and improvement program, including:

- Heat Rate Basics
- Equipment-specific Combined Cycle Components
- Performance Parameters and their relationship to Plant Heat Rate
- Instrumentation Requirements
- Regular, Periodic Actions to Maintain Good Plant Performance
- Hardware and operational modifications to improve performance

The report will provide many benefits, including methods for equipment-specific performance assessment, charts for root-cause diagnosis of performance issues, and identification of corrective action for improved performance of combined cycle power plants.
The application of project results will allow plant owners and operators to:

- identify sources of performance degradation
- define key performance recovery activities
- quantify resulting performance improvements

**Benefits**

The benefits of heat rate reduction are substantial. Lower fuel costs directly affect the bottom line. In addition, heat rate improvement is the only commercially proven and the most cost-effective control for lowering CO2 “on the margin.” And all other emissions are also lowered on a ton/MW basis.

For example, a 1% heat rate reduction at a typical 500-MW natural gas-fired combined cycle plant, operating at 50% capacity factor, can cut CO2 emissions by 10,000 tons/year, which equates to $200,000 if a $20/ton CO2 tax is enacted. The plant also will experience more than $700,000 in fuel savings for the same 1% improvement in heat rate, based on a fuel cost of $4/Mbtu.

**Repowering Fossil Steam Plants with Combustion Turbines (072059)**

**Background, Objectives, and New Learnings**

Many conventional fossil steam plants face uncertainty in future operation due to environmental regulations that would require significant upgrades to meet new emission standards. The capital expenditures required may be relatively high, particularly for moderately-sized to smaller-sized units firing coal or heavy oil. Older units may need significant boiler refurbishment to continue operation into the future. A reduction in carbon emissions also may be desired. One option commonly considered is conversion to a natural gas-fired combined-cycle configuration while maximizing reuse of existing equipment. This option is being more frequently implemented in the industry now that a period of secure availability of natural gas and relatively low fuel prices is projected.

The objective of this project is to support the decisions involving the future of existing fossil steam plant assets in the generating fleet, particularly for those assets that require capital improvements and can no longer continue to operate at the status quo. In particular, owner/operators need to assess alternatives based on natural gas firing, such as repowering with combustion turbines in a combined-cycle configuration and either reusing the steam turbine(s) or installing a new combined-cycle unit at the existing plant site.

This project adds the experience and lessons learned in repowering over the last decade to the background of EPRI experience in repowering to provide general guidance on repowering configurations, cost and performance attributes, and considerations unique to repowering existing fossil steam plants. These lessons then are applied to specific site repowering, leading to additional new insights.

**Project Approach and Summary**

EPRI will conduct targeted evaluations of existing fossil plants to identify the technical and economic issues associated with converting conventional fossil steam units to combined-cycle operation. EPRI will use an extensive background from previous repowering studies and modeling tools, such as the SOAPP Combustion Turbine/Combined-Cycle and SOAPP Repowering Workstations, to provide an initial screening evaluation. After initial screening and focus, a detailed engineering evaluation of repowering the designated site will be performed. Information on completed repowering projects will be gathered, and lessons learned from completed projects and studies will be compiled.

**Benefits**

Results from this project provide plant owners with a thorough assessment of costs to repower their sites with combustion turbines in a combined-cycle configuration, including reuse of existing equipment such as the steam turbine. Comparisons of performance and life-cycle costs with an all-new combined-cycle plant lead to better-informed decisions regarding repowering options. In addition, updated repowering guidelines summarize lessons learned from previous repowering projects that can be applied to other plants in the owner’s fleet.
Carbon Capture for Combined-Cycle Plants (068863)

Background, Objectives, and New Learnings

If legislation mandating a reduction in CO₂ production from fossil power plants is enacted, natural gas-fired combustion turbine/combined-cycle (CTCC) plants might also be required to capture and store carbon dioxide (CO₂). CTCC plants produce less than half the CO₂ per MWh of their pulverized coal (PC) counterparts, but they still are CO₂ emitters. As companies plan their future generation portfolios, there is growing interest in the feasibility and costs associated with applying large-scale carbon capture and storage (CCS) to CTCC plants and the impact on performance. That leads to questions about future emissions from CTCCs, including:

- Will highly dispatched CTCCs be challenged to reduce their CO₂ emissions level?
- Will CTCC plants require retrofit in the future?
- What preparations and pre-investments could be made to make the plant CO₂ capture-ready?
- What are the corresponding cost, performance, and operational implications of retrofitting CCS?

The objective of this project is to provide CTCC owners/operators with the information they need to understand the impact that a CCS retrofit would have on their plant performance and economics. This project provides new learning in the cost and performance of retrofitting post-combustion advanced amine solvent-based CCS to an existing or new CTCC plant. For a new planned plant, the project includes recommended provisions to enable a less-costly retrofit with CCS at a later date (i.e., “capture-ready”).

Project Approach and Summary

EPRI will examine CO₂ post-combustion capture (PCC) on a combustion turbine combined-cycle (CTCC) power plant for retrofit or planned application. Based on a planned or existing CTCC power plant designated by a host participant, the study will highlight the technical and economic issues associated with applying advanced amine post-combustion capture technology, one of the most developed processes available today.

EPRI has extensive background in evaluation of new and retrofit coal-fired applications of CCS and currently is conducting a technical and economic assessment study of post-combustion capture on natural gas-fired combined-cycle plants as a means to reduce CO₂ emissions from a typical F-class 2x1 CTCC plant. The current study will compare costs and performance for the generic new-build and retrofit cases and provide background for examining site-specific CCS applications.

For this proposed project, EPRI will examine post-combustion capture on a CTCC power plant for retrofit applications. It will include the knowledge gained from previous coal plant studies and current CTCC plant study, including process design improvements uniquely applicable to CTCC plants such as exhaust gas recirculation to improve CO₂ capture economics, and integration of the heat recovery steam generator (HRSG) with the post-combustion capture plant to minimize reduction in steam turbine output.

Benefits

Results from this project provide plant owners with a site-specific assessment of the costs to include carbon capture and compression in their designated site. Cost and performance for site retrofits then can be compared to generic differences between retrofit and new-build, leading to informed decisions regarding CCS options and risks. In addition, participants can gain insights into other host site configurations that can be applied to their own fleets.
Combined-Cycle Plant Design, Cost and Performance Software - SOAPP (057519)

Background, Objectives, and New Learnings

Companies in the electric utility industry increasingly find it difficult to allocate sufficient resources to study the latest developments, evaluate alternatives, and optimize solutions for new plants. The impact of different scenarios on plant cost and performance, and consequently on the most cost-efficient plant design, often is neglected. Competitive pressures have driven engineering towards more standardized designs, which offer cost/performance for "average" applications but often are sub-optimal for any specific application. State-of-the-Art Power Plant (SOAPP®) software products address these issues.

Starting with user-defined inputs and guidance from initial default values, the SOAPP-CT Workstation validates inputs, sizes and costs equipment, and performs detailed performance and economic analyses of the resulting conceptual design. Outputs include plant performance summaries, equipment lists and sizing, capital costs and O&M costs, diagrams and drawings. Financial outputs include capital outlay schedules, capacity and energy payments, pro forma income and cash flow statements, and internal rates of return.

Ongoing support and development are key to providing an up-to-date software tool for the user and incorporating state-of-the-art information. The key objectives of this supplemental project are to:

- Provide development of scientific tools for analysis of performance, design, and profitability of power projects in a site-specific context to enable a life-cycle cost perspective on power plant projects
- Provide technology transfer and strategic decision support for developing new electric power generating plants

The SOAPP software enables the evaluation of alternatives through the scientific modeling and simulation of power plants, and generates substantial new learning by using feasible scientific and technical solutions for the problems of identifying and communicating state-of-the-art complex technical relationships. Accurate planning and optimized projects for minimum electricity cost, lessened environmental impact and maximum reliability, are made possible through the funders’ use of the software for improved productivity of their technology assessment efforts and ability to evaluate potentially beneficial alternatives. Major technology trends related to new gas turbines and steam turbines underlie SOAPP software development. The SOAPP-CT Workstation software captures the performance and costs of these new state-of-the-art innovations.

Project Approach and Summary

The project develops new versions of the SOAPP-CT Workstation to incorporate new design characteristics of combined-cycle plants, up-to-date performance and cost information, and additional enhancements, as well as supports funders through updates to the SOAPP website and preparation of training materials and communications to current and prospective funders.

Benefits

The fully-integrated SOAPP-CT Workstation enables users to quickly develop a detailed plant conceptual design and then evaluate the impact of different equipment choices and design criteria on plant design, performance, emissions, and costs. This allows business and technical decisions to be made in concert, encouraging development of project-specific power plant designs with the lowest life-cycle costs. The CT Technology Modules summarize and compare viable, commercially available state-of-the-art technologies and can be used for general technology transfer and training. The Windows-based SOAPP software has an extensive on-line help function. The software and user manual are distributed on CD-ROM for installation on individual PCs. SOAPP helps to optimize the numerous decisions tied to a typical $200 to $500 million combined-cycle project. Use of the SOAPP products can lead to better-informed decisions regarding construction of new power plants and the upgrading of existing plants, and reducing the cost of electricity and environmental impact. The SOAPP-CT Workstation reduces a task that otherwise could take several man-months of effort to less than an hour, resulting in productivity savings. More importantly, it enables users to evaluate many more alternatives than they
could afford without SOAPP and thus achieve an optimal design. Substantial benefits can be realized when the use of the SOAPP-CT Workstation results in the choice of technologies that produce a different, more economical plant design. The public benefits from accurate planning and optimized projects for minimum electricity cost, reduced environmental impact, and maximum reliability, made possible through the funder’s use of the software for improved productivity of their technology assessment efforts and ability to evaluate potentially beneficial alternatives.

**Compressor Diagnostic Monitoring (073440)**

**Background, Objectives, and New Learnings**

EPRI has been investigating the sources of dependability loss in gas turbine compressors, particularly those associated with the widely used FA model. Of particular concern to engine owners has been the occurrence of cracks, rubs, and related damage in rotating blades and stationary vanes. Root cause investigations often have not led to a single clear-cut explanation, but rather a set of probable complex interactive mechanisms.

Aerodynamic anomalies such as rotating stall, flutter, or incipient surge flow reversals may manifest themselves at various levels of severity during transients or partload conditions under certain ambient conditions. Standard compressor instrumentation generally is viewed as insufficient to adequately detect the onset of such conditions.

The objective of this project is to demonstrate the effectiveness of advanced instrumentation and associated diagnostic techniques to detect the onset of adverse compressor operating conditions and early damage indications.

**Project Approach and Summary**

The project team will design, engineer, and procure instrumentation, data acquisition systems, and related software for installation at the Alabama Power Plant Barry 7FA combined cycle unit. Three monitoring techniques are planned for installation:

**Dynamic Pressure:** Piezoelectric pressure probes can be installed in existing compressor casing access ports used for inspection. Fluctuating pressure spikes may be associated with the onset of flow instability. Pockets of low-pressure transients potentially could create conditions in which downstream airfoils deflect into upstream components, causing clashing and severe fatigue damage.

**Acoustic Emissions:** Transducers located on the outside of the casings can monitor for structure-borne acoustic events associated with internal clashing, rubbing, and foreign object damage. Specialized AE monitoring techniques have been developed for monitoring the initiation and growth of cracks in components such as in piping systems. Application of AE monitoring to detecting vane damage events and progressive damage (crack growth) in an operating compressor will be demonstrated.

**Performance and Process Analysis:** Gradual performance degradation may play a contributing role to increasing the possible occurrence of aerodynamic anomalies such as stall or surge. Mechanisms for collecting GT process data and other performance indicators will be developed in accordance with Southern Company. IT security protocols will be developed to capture the operating state of the engine and to correlate with dynamic pressure and acoustic emissions events.

The project team will review the dynamic pressure, acoustic emissions, and performance/process plant data over approximately 24 months of service. Initially, the team will analyze early data to establish the baseline and set provisional thresholds. The project team will continue to review data from the monitoring systems over the entire 24-month period to investigate any data anomalies and identify potential or emerging problems. An annual progress report will be prepared summarizing the field experience. At the conclusion of the project, an overall summary report will be prepared.
Benefits

The knowledge developed by this project will provide gas turbine operators with information to improve operational flexibility, potentially avoid further in-service failures, assess remedial/corrective actions currently offered, and identify alternative corrective solutions and strategies.

This knowledge will assist in understanding operating conditions that contribute to GT compressor failures and maintenance improvements, and fine-tune the EPRI research specific to gas turbine life-cycle costs reductions, failure avoidance, and component reliability improvement. The results will be incorporated in a series of design and O&M guidelines that address GT compressor dependability, which are available under the EPRI CT O&M program (P79) and to the general public for purchase, or otherwise.

The results of this project will assist gas turbine operators with information to potentially avoid or mitigate in-service failures. The public benefits from lower power generation operating cost and reduced future risks of a power interruption or power outage due to compressor flow path failures.