Program Overview

Program Description

The design of modern heat recovery steam generators (HRSGs) and balance-of-plant (BOP) systems is a complex interrelationship between many parameters and variables. HRSGs pose a unique set of operational challenges, due in part to their rapid startup capabilities, high operating efficiencies, multi-pressure circuits, reheat, once-through, combined drum/once-through systems, and numerous varieties available in the basic design. Preventing HRSG tube failures (HTFs) is a priority, but complex failure paths, which are influenced by cycle chemistry or thermal transients, are difficult to understand and mitigate. Limited access and other complexities make inspection and repair of HRSGs very difficult.

Today, the design philosophy of combined-cycle plants is evolving just as the electric power industry is evolving due to an influx of renewable energy, low natural gas pricing in the United States even as costs are much higher internationally, and environmental issues. Many owners and investors of combined-cycle plants are now rethinking the concept of baseload operation to cycling operation. Because current combustion turbines do not have low turn-down capabilities while maintaining emission limits, the ability to cycle a unit is the alternate solution.

Cycling plants are units designed to optimize plant operations by providing rapid startups, partial loading, and short shutdowns. These frequent changes in plant operation are not easily obtained in current OEM and operating design limits. To achieve cycling operation, both equipment and system design have to be considered. For this reason, cycling design should accommodate several new features that are not considered for baseload units. Cycling operation should ensure satisfactory operation throughout the full operating range of the unit. Facility or plant designs should also consider conditions when the unit is not operating. A combined-cycle plant with operating flexibility can provide start, stop, and partial-load operation to match changing demand for power. However, these benefits can bring added costs due to wear and tear on equipment through thermal fatigue. These added costs associated with plant cycling cannot be totally eliminated, may be minimized but must be considered for long-term reliability.

The Electric Power Research Institute’s (EPRI’s) Combined Cycle HRSG and BOP program (Program 88) provides a complete set of technical tools to improve the performance and reliability of combined-cycle HRSGs and BOP equipment. The program includes a background of HRSG design and development, particularly over the last 10 years, in which HRSG designs have become remarkably complex, operating at significantly higher pressures and temperatures. It provides a comprehensive understanding of available designs and tools for preparing procurement specifications for both new and used HRSG and BOP components based on past research and new technologies.

Research Value

Projects include unit-specific and pressure-circuit-specific chemical treatment methods and limits; optimal approaches to preventing HRSG tube failure; and methods for life assessment, nondestructive evaluation (NDE) options, welding, and other repair methods. Using the R&D from this program, members can:

- Achieve tube failure rates consistent with their risk tolerance and financial models
- Increase reliability through better understanding of thermal transients
- Increase understanding and control of flow-accelerated corrosion (FAC) through an initial predictive code and other technologies
- Optimize HRSG operational and shutdown chemistry through better understanding of the chemistry cycle
• Identify and correct cycling and thermal transient problems through chemistry cycle guidelines and methods
• Optimize HRSG inspection and repair by using new hardware, NDE guidelines, and techniques for improving access
• Establish inspection routines and life assessments of major components

Approach

The program portfolio has two primary technical objectives:

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

Specific technical interaction and allocation of resources between P88 and other appropriate EPRI programs, such as Boiler Life and Availability (P63), and Combined-Cycle Turbomachinery (P79), will be defined and implemented as required to effectively utilize existing EPRI technical expertise and resources without duplication between programs.

Program members receive:

• Operator guidelines that help monitor, identify, and minimize the effects of shutdown, startup, and thermal transients on fatigue life
• A diagnostic expert system that helps control and maintain optimal chemistry
• Regional workshops covering HRSG tube failure, cycle chemistry, inspection, and FAC that effectively transfer the knowledge gained through this program
• Information on life assessment and risk management – topics including damage detection, root cause and solutions, and monitoring and life-predicting analyses
• HRSG tube failures and life-assessment research, which is continuing to develop a comprehensive methodology to assess cycling capability, including optimizing startup in terms of thermal transients. The program also continues to document case studies and develop life-assessment tools and methodologies
• HRSG NDE and repair R&D, which includes developing and demonstrating external inspection techniques with remote capability, developing final equipment for HRSG tube elbow replacement near headers, and assessing an internal coating technology to provide protection against FAC
• Information on O&M improvements – topics including component durability and damage tracking, and repair and refurbishment guidelines
• Technology advancements – topics include engineering and economic assessments, statistics of current HRSG and balance-of-plant reliability, availability and maintenance (RAM) performance, and new and advanced equipment offerings and capabilities

The EPRI staff and the P88 advisors have identified modifications and additions for transition to 2014. 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 P88 advisors are to explore activities, projects, and products for 2014 that will be presented and prioritized at the 2013 fourth-quarter Generation advisory meeting. The number of products completed in 2014 will be based on the yearly funding levels, coupled with member prioritization.
Accomplishments
EPRI’s thermal transient and cycle chemistry guidelines provide quantitative, specific suggestions for attaining the best possible performance from existing HRSGs. The guidelines also provide guidance applicable to new units for appropriate design of pressure parts.

- EPRI has developed comprehensive guidelines on cycle chemistry for all HRSGs, including shutdown/startup chemistry and chemical cleaning.
- EPRI has developed a complete approach to identifying reasons for thermal transients, as well as related analytical tools.
- EPRI has developed a troubleshooting guide that, through a group of 57 questions, can help identify whether and which underlying causes (or both) of thermal transients are present in the operating practices or in the design of the HRSG.
- Unique repair technology has been developed, as well as a revision to the interim NDE guidelines, to include case studies of visual techniques and technology transfer materials.

Current Year Activities
Program R&D for 2014 will continue to focus on thermal transients and chemistry directly responsible for damage to HRSG pressure parts. The scope of the program is expanding to address end-of-life issues in the major components of the HRSG and incorporate balance-of-plant equipment.

Specific efforts will include:

- Exploration of technologies to address HRSG tube failures (HTFs)
- Technology to assess control of steam-side deposition
- Case studies and development of HRSG life-assessment tools and methodologies
- Further development and demonstration of remote capabilities for external inspection techniques
- Exploration of technology for organics treatment
- Introducing preventive maintenance processes (PM Basis) to the HRSG
- Investigation of flexible operation short- and long-term effects

Estimated 2014 Program Funding
$2.75M

Program Manager
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Summary of Projects

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<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>Description</th>
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<tr>
<td>P88.001</td>
<td>HRSG Reliability</td>
<td>This project R&amp;D helps reduce HRSG tube failures by providing guidelines to improve cycle chemistry and thermal transients through management of key failure mechanisms.</td>
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<tr>
<td>P88.002</td>
<td>Life Assessment/Risk Management</td>
<td>This project provides in-depth investigations and guidelines, addressing high-risk component failure root-cause mechanisms. Corrective solutions and damage mitigation techniques are developed, evaluated, and demonstrated.</td>
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<tr>
<td>P88.003</td>
<td>Operations and Maintenance Improvements</td>
<td>This project develops technologies and techniques to improve HRSG and BOP availability through enhancement of personnel skills, personnel safety, technology implementation, and automation of information systems.</td>
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<tr>
<td>P88.004</td>
<td>Technology Advancements</td>
<td>Members can use this project's deliverable products by incorporating the assessments and data into their decisionmaking for technology selection and procurement. If this information is utilized early in the project development process, substantial benefits can be realized for the overall availability and reliability of the unit.</td>
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P88.001 HRSG Reliability (073443)

Description

There is a growing concern within the industry regarding the long-term reliability/availability of the HRSGs. The drivers for this concern include cycling, startups, and design shortcomings relating to the actual operating conditions vs. original specifications.

EPRI's suite of guidelines on HRSG tube failures and cycle chemistry are designed to manage all of these failure mechanisms. Program 88 has completed a series of projects with reports on thermal transient and cycle chemistry issues. As gas takes on a growing role in the generation of electricity, maintaining and improving HRSG reliability becomes more important. The research for 2014 aims to support these goals.

Approach

Projects include unit-specific and pressure-circuit-specific chemical treatment methods and limits, optimal approaches to preventing HRSG tube failure, and methods for life assessment, nondestructive evaluation (NDE) options, welding, and other repair methods. Using the R&D from this program, members can:

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- Optimize HRSG inspection and repair by using new hardware, NDE guidelines, and techniques for improving access
- Establish inspection routines and life-assessments of major components
Impact

- Significant reduction and improved management of chemistry-thermal-related generation losses in HRSGs
- Improved unit availability and reduced O&M costs through prevention of chemically and thermally influenced HTF
- Control of corrosion damage and deposition problems in HRSGs
- Control of HRSG tube failures to an acceptable corporate level

How to Apply Results

Members can benchmark their tube failure and chemistry programs independently or in collaboration with EPRI staff to identify areas of deficiency and determine approximate costs. The content of the guidelines then can be used to identify specific actions needed to address those deficiencies in a manner consistent with individual unit characteristics. For example, the chemistry guidelines can be consulted to verify proper selection and optimization of HRSG water chemistry used in individual fossil units. The benchmarking process should be repeated periodically as a means of checking the overall effect of improvements implemented. Success can be gauged by measuring progress against a rigorous set of performance metrics consistent with the EPRI guidelines.

P88.002 Life Assessment/Risk Management (073444)

Description

The underlying driver for component condition assessment is the need to manage component life to achieve plant safety, reliability, and economic objectives. Recent changes in the power industry have heightened the importance of these objectives, especially costs, and in many instances have renewed interest in comprehensive condition assessment and condition monitoring. Knowledge of component condition and expected remaining life is critical to successfully extending major maintenance outage intervals and to managing generating units dedicated to load following, two-shifting, and other cycling modes. The large number of startups and rapid load changes that cycling entails adds substantial thermal stress to many boiler components and makes water chemistry more difficult to control, promoting corrosion and other material degradation phenomena. These conditions can translate into greater risk of component failure. Similarly, rapid load changes and cyclic operation can exacerbate certain damage mechanisms, such as fatigue and corrosion. For many plants, maintenance challenges are greater today when staff and budgets have been reduced, forcing them to "do more with less."

Reliable condition assessments are crucial for managing units dedicated to load-following, two-shifting, and other cycling modes. Knowledge of component condition and expected remaining life is similarly critical to success when efforts are made to extend major maintenance outage intervals to reduce costs and improve availability.

Approach

This project will begin development of a predictive methodology for HRSG component life assessment. Work will continue on development and validation of research on HRSG pressure-part, thermal transient limits, and mitigation. Research will be able to factor in how the operation of the unit affects the life calculation, inspections, and testing requirements. This work also is being extended to the balance of combinedcycle plant components.

Impact

- Achieve significant improvement in combined-cycle plants, including the HRSG and balance-of-plant availability
- Reduce operations and maintenance cost through reduced component failure throughout the combined cycle HRSG and BOP


How to Apply Results

The end-of-life methodology can help combined cycle HRSG and BOP owners/operators determine when inspections should occur, the types of inspection/testing needed, and how to plan for replacement or repairs. The approach will take into account the previous years’ work on thermal transient, cycling, and design issues.

P88.003 Operations and Maintenance Improvements (073445)

Description

Research in new maintenance strategies will become increasingly important to EPRI members as they continue to look for ways to reduce costs while maintaining high availability. This project is expected to help members stay focused on both existing and emerging technologies while understanding the impact that these technologies have on plant operation and maintenance.

Approach

As the equipment ages, the costs of the labor and materials necessary to keep a power plant’s equipment in good operating condition typically increase. With time, the equipment can become less reliable and have higher maintenance costs. This project addresses these core issues facing plant staff today.

Impact

- Improve unit availability
- Improve O&M activities through peer-to-peer involvement, lessons learned, experience, and industry best practices
- Reduce tube/header examination and repair times
- Experience fewer HTFs through improved operation and maintenance activities
- Validate damage assessment and models

How to Apply Results

The documents produced and PM modules added to the PM Basis software database can be used when a utility is faced with equipment repair or testing or component condition assessment. Members can integrate the content in these guidelines in their own procedures and training materials. The guidelines can be placed on internal networks and provide an excellent resource for continuous improvement training, as well as new-hire orientation for system owners and maintenance staff. Utilities planning new equipment purchases can take advantage of the guidelines’ content in preparing their own site-specific procurement specifications.

P88.004 Technology Advancements (073446)

Description

Nearly 237 gigawatts of natural-gas-fired generation were added between 2000 and 2010. This capacity represents about 81% of all generation capacity added over that period. Most of this capacity is in the form of combined-cycle plants, and about 65% of current natural gas generation capacity launched since 1980 used combined-cycle units. This trend is expected to continue as the need to replace older coal-fired generation is dominated by expected low U.S. natural gas prices, and the shorter construction times and lower capital costs for gas-fired generation.

Approach

Optimization of a HRSG and BOP design is more than just maximizing thermal efficiency for a single performance point. HRSG development has introduced many new advances not previously available to plant developers as systems become more complex with higher temperatures and pressures. HRSGs have increasingly been operated in cyclical mode, and less often in baseload, even as high-efficiency, three-pressure-reheat units become standard. There is a need to better understand and design for the new technology advancements.
Impact

- Improve unit availability significantly
- Reduce operations and maintenance costs via technologies incorporated in newbuilds that allow for an increased awareness of the thermal and chemistry factors contributing to HRSG tube failure as well as effective inspection and repair techniques

How to Apply Results

Some of the latest advances in HRSG design include improved tubing materials, advancements in once-through technologies, improved "constructability" concepts, automated manufacturing processes, improved thermal expansion capabilities, improved fin attachment processes, enhanced HRSG internals access, improved exhaust flow routing, and improved tube bundle manufacturing processes. This project looks to improve on the technologies already available and establish HRSGs and BOP equipment able to meet the demands required by the new operating environment.
Supplemental Projects

SCR Catalyst Replacement Options for Gas Turbine/Combined Cycles (71350)

Background, Objectives, and New Learning
Selective catalytic reduction (SCR) technology for controlling nitrogen oxides (NOx) is broadly applied to natural gas-fired combustion turbines, operating in combined cycle. The SCR performance depends on numerous design and operating variables, including catalyst activity (K). Ideally the SCR could run for an indefinite period of time; however, factors such as trace metal deposition will cause the catalyst to deactivate. A catalyst is considered to be at end-of-life when the required NO removal cannot be achieved, or can be achieved only with significant residual NH₃ (ammonia slip). The widespread industry commitment to SCR technology is now reaching a level of maturity, where catalyst is reaching the end-of-life, and plants are now considering options to add, replace, or regenerate catalyst.

This project evaluates the least-cost way of maintaining the NO-removal capabilities of SCR systems, as installed in natural-gas-fired combustion turbines operating in combined cycle. In the context of this discussion, the NO-removal capabilities are the control of NO, without excessive ammonia slip, for a minimal gas pressure drop.

The knowledge developed by this project will assist in understanding the gas turbine emission control system configurations(s) and fine-tune the EPRI research specific to current best practices, vendor capabilities, and SCR catalyst system design improvements.

Project Approach and Summary
The approach in this project is to evaluate the cost and performance of three catalyst management options. Cost and performance data will be solicited from catalyst suppliers and regenerators.

Notably, only new catalyst is considered commercially proven. The two major providers of regeneration services have never commercially “regenerated” catalyst for natural-gas-fired combustion turbines. Although one catalyst supplier offers an ammonia destruction catalyst, experience is limited to one, small combined-cycle unit. Performance has not been thoroughly documented. Consequently, there is uncertainty in these approaches.

A host site or sites for an engineering and risk assessment of these options will be defined. The details of the SCR design — combustion turbine process conditions, specifics of the HRSG — will be established, as well as the geometric details and activity of the catalyst.

Benefits
The results will assist gas turbine owners and operators in their investigation into the selection of SCR catalyst system design alternatives and will directly benefit the public because it lowers environmental emission levels and future risks of a power interruption or power outage due poorly functioning emission control technologies.
Optimizing Heat Recovery Steam Generator Drains (070753)

**Background, Objectives, and New Learning**

Failure to adequately drain high-pressure superheaters (HPSH) and reheaters (RH) is one of the leading thermal mechanical loading mechanisms determined by EPRI to cause premature pressure-part failure. Severe thermal-mechanical fatigue damage to the HPSH, RH, headers, and steam piping of horizontal gas path heat recovery steam generators (HRSG), due primarily to ineffective drainage of the condensate that is generated in the HPSH and RH at every startup, continues to be a significant industry problem, resulting in avoidable deterioration of unit reliability and significant unnecessary maintenance costs.

Addressing this quenching problem first requires installing a system that can distinguish the difference between saturated liquid and vapor within the drain system during both cold and hot startups. Most operators find the retrofit of drain pots impractical due to their large size and high cost. Presently, most HRSG operators have no way to determine when drains need to be open and when they may be closed. Premature closure of the HPSH or RH drains can result in severe tube, piping, and header damage, while excessive use of the drain system wastes considerable thermal energy and overheats drain components.

This project will assess the viability of a smaller and less-expensive alternative to the level-sensing drain pot for controlling HPSH and RH drains during all startup conditions.

**Project Approach and Summary**

This project will examine the function of high-pressure superheaters and its associated drain piping. We are seeking a host unit from a project participant for the study. Criteria for host selection will include site availability for research and testing activities and prevalence of the host’s HRSG design. Other criteria include accessibility to drain lines and valves under the HRSG, configuration of the existing HPSH and drain system, evidence of condensate quenching of the superheaters and reheaters during startups, and the frequency of cycling.

Project activities will include:

- Establish a work plan based upon the scope of estimated work and the available project funding
- Correct existing drain system deficiencies, and install the necessary tube-temperature-monitoring instrumentation, ultrasonic transducers, and drain control valves
- Evaluate tube temperature data during startups, and modify drain control system and operating procedures, as required to obtain effective drainage

**Benefits**

This project seeks to develop a reliable and cost-effective means of determining the presence of condensate in HPSH and RH drain systems. Many HRSGs currently in service have ineffective drain systems; even those recently installed with automatic drains systems intended to detect and effectively drain condensate during startup are incapable of doing so under all startup conditions. HRSGs subjected to regular quenching by entrained condensate also are being subjected to significant drains-related thermal-mechanical fatigue (TMF). This TMF damage accumulates over time and often goes undetected until a crack initiates and propagates through the tube, header, or pipe wall. By the time these failures begin to occur, the other similar fatigue-prone locations will already have expended most of their fatigue life.

The major project value is the long-term benefits of greatly reducing thermal-mechanical fatigue to HRSG components during startups. These benefits will be directly reflected in improved unit availability and a significant reduction in forced outages due to avoidable damage.