ELECTRIC POWER RESEARCH INSTITUTE

Compilation of Results and Feedback Regarding Turbine Upgrades at Nuclear and Fossil Power Plants

1018346

Compilation of Results and Feedback Regarding Turbine Upgrades at Nuclear and Fossil Power Plants

1018346

Technical Update, November 2008

EPRI Project Manager

J. Stallings

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

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Sequoia Consulting Group, Inc.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

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

CITATIONS

This document was prepared by

Sequoia Consulting Group, Inc.
9042 Legends Lake Lane
Knoxville, TN 37922

Principal Investigator
M. Tulay

This document describes research sponsored by the Electric Power Research Institute (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

Compilation of Results and Feedback Regarding Turbine Upgrades at Nuclear and Fossil Power Plants. EPRI, Palo Alto, CA: 2008. 1018346.

PRODUCT DESCRIPTION

This report compiles results and feedback and draws a number of conclusions and lessons learned regarding steam turbine generator upgrades at nuclear and fossil power plants.

Background

Over the past 10-15 years, an increased number of nuclear and fossil power plants have undertaken plant modifications to increase the power rating and/or improve the heat rate of selected units. Many of these actions have resulted from physical upgrades to steam turbine generators, as well as enhancements to auxiliary components.

Over this time, various organizations in EPRI have collected data on performance after steam turbine upgrades, but the data did not specifically quantify MW enhancements, heat rate improvements, and how effectively each uprate met owner expectations. This project compiles current results of performance upgrades to produce a single technical report summarizing the findings.

Objectives

- To publish EPRI results regarding experiences of nuclear licensees and fossil power plant owners after physical upgrades to their steam turbine generators.
- To assist other utilities and electric-generating companies anticipating turbine-generator upgrades at their sites.

Approach

In cooperation with interested EPRI members from both nuclear and fossil power plants, a task group of utility engineers and industry experts developed, administered, and responded to a comprehensive survey. By answering a series of specific and focused questions provided in the electronic survey, feedback was obtained regarding each respondent's upgrade scope, objectives, and results. This feedback confirmed key issues associated with turbine-generator modifications and provided input for preparing the guidance in this document. Development of the report was closely coordinated and reviewed to ensure consistency with current industrywide guidance and lessons learned. Experience-proven practices and techniques were identified and compiled.

Results

A total of seventy-two (72) responses were received by EPRI, which are discussed in detail in this report. Responses were comprised of forty-nine (49) representing fossil power plants and twenty-three (23) representing nuclear power plants. The responses provided a source of data from which numerous conclusions and lessons learned were documented.

EPRI Perspective

This guideline presents a significant collection of information—including techniques and good practices—related to issues associated with turbine-generator upgrades at nuclear and fossil power plants. The guideline provides a single point of reference for both current and future plant engineering and management personnel. Using this document, along with industry guidance, EPRI members should be able to significantly improve and consistently implement the processes associated with turbine-generator upgrades. This guided implementation will subsequently help members achieve increased component availability and reliability after modifications and provide valuable lessons that will ensure expectations are reasonably determined and achieved.

Keywords

Turbine-generator
Power uprate
Turbine upgrade
Heat rate
Heat reduction
Thermal efficiency

ACKNOWLEDGEMENTS

EPRI would like to thank the following individuals who made significant contributions through their participation in the survey and review of this report. Their valuable insight and experience was essential in the successful completion of this project.

Respondent's Name	**Utility Name**
Mark Fauber	Ameren Energy LLC
Mark Litzinger	Ameren UE
Ken Porter	Arizona Pubic Service
John Glover	Arizona Pubic Service
Ian Garbutt	British Energy
Duane Hill	Dairyland Power Coop
Eric Sorg	Detroit Edison
John Gibson	Dominion Nuclear CT
Christopher Essex	DTE Energy
Tim Tidwell	Dynegy
Bob Swanson	Entergy Nuclear Vermont Yankee
Joe Reda	Exelon Nuclear
Phil Schuchter	First Energy
Woss Ernest	Florida Power & Light
Ken LaMont	Hoosier Energy
	Kernkraftwerk Leibstadt AG
Pete Ulvog	Luminant Generation
John Cizek	Nebraska Public Power
Greg Carlin	Nova Scotia Power Inc
William McGinnis	NRG Energy Texas
David Rollins	Omaha Public Power District
Kelly Stemmler	PPL
Matthew A Hober, Jr	PPL
Gary Loeb	PSEG Nuclear LLC
Scott Bannerman	Sask Power

Respondent's Name	Utility Name
Gareth Coady	Southern Nuclear
Randy Bunt	Southern Nuclear
Russell Chetwynd	Southern California Edison
Rob Frazee	STP Nuclear Operating Company
Jerry Best	Tennessee Valley Authority
Rick Frazier	Tennessee Valley Authority
Matt Koly	Tri-State Generation & Transmission

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION AND OVERVIEW

1.1 Background

Over the past 10-15 years, an increased number of nuclear and fossil power plants have undertaken plant modifications to increase the power rating and/or improve the heat rate of selected units. Many of these actions have resulted from physical upgrades to their steam turbine generator, as well as enhancements to auxiliary components.

Over this time, various organizations in EPRI have undertaken studies to collect data on performance after steam turbine upgrades, but the data did not specifically quantify MW enhancements, heat rate improvements, and how effectively each uprate met owner expectations. This project compiles current results of performance upgrades to produce a single technical report summarizing the findings.

1.2 Purpose

The purpose of this report is to provide results obtained through EPRI regarding the experiences of nuclear licensees and fossil power plant owners after physical upgrades to their steam turbine generators. By answering a series of specific and focused questions provided in an electronic survey, feedback was obtained regarding each respondent's upgrade scope, objectives and results. This report compiles the data and draws a number of conclusions and lessons learned to assist other utilities and electric generating companies anticipating turbine-generator upgrades at their sites.

1.3 Scope and Organization of the Report

The scope and organization of this report follows the general content of issues illustrated on Figure 1-1.

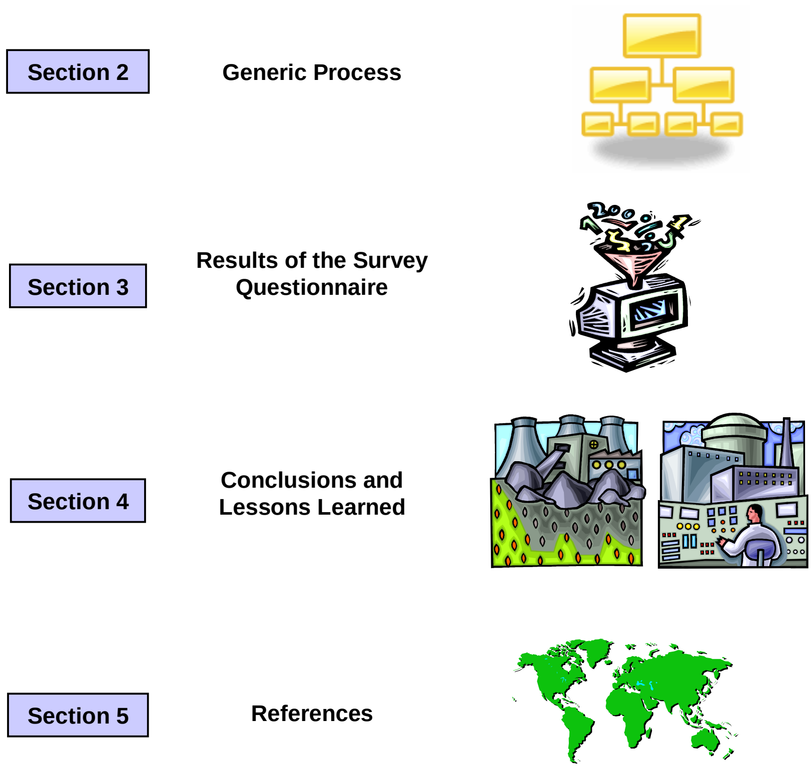

Figure 1-1
Overview of Issues and Report Content

1.4 Basic Premises

1.4.1 Confidentiality of Survey Results

The results presented in this report are formatted in a way so all respondents cannot be identified with any particular set(s) of data. Protecting the anonymity of respondents was a condition set forth in the survey and was established to maximize the number, details, and quality of responses.

1.4.2 Exoneration of Turbine Manufacturers

The results presented in this report are not intended to imply fault or negligence on the part of any particular turbine manufacturer, whether they were the original equipment manufacturer or the organization that performed the turbine upgrade modifications. To ensure there are no unintended implications of any supply organization, the names of these organizations are not correlated to any specific data or results presented and discussed in this report.

1.5 Key Definitions and Glossary of Terms

1.5.1 Key Definitions

Power Uprate – An uprate is distinctive from a performance upgrade in that the increase in power output is achieved by increasing the inlet temperature or mass flow into the turbine, thereby providing more available energy to the original turbine components and increasing output. The term power uprate is commonly used to indicate an increase in reactor thermal power and is commonly used in reference to nuclear plants.

Steam Turbine Performance Upgrade – An upgrade seeks to provide additional output by extracting more work from the available energy, or to reduce the operating heat rate by more efficient use of the available energy. Within the context of this guideline, an upgrade is considered as a practical (or commercially available) retrofit action, which involves the replacement of selected components on a portion of an existing turbine steam path with more aerodynamic and thermally efficient designs.

1.5.2 Glossary of Terms

Component – A piece of equipment such as a vessel, pump, valve, core support structure, relay or circuit breaker, which is combined with other components to form an assembly. Components typically are designated with an identification number.

Equipment Designer – The organization in the owner’s supply chain responsible for designing the equipment so it is suitable for the intended applications.

Fabricator – The organization in the licensee’s supply chain responsible for fabricating parts, assemblies, and sub-components needed to manufacture the replacement component.

Manufacturer – The organization in the licensee’s supply chain responsible for manufacturing and assembling the replacement component to the extent required by the licensee.

Supplier – The organization furnishing a commercial grade item or basic component. This could include an original equipment manufacturer, part manufacturer, or distributor.

1.6 Acronyms

EPRI – Electric Power Research Institute

HP – High Pressure

HTSH – High Temperature Superheater

IO – Input/Output

IP – Intermediate Pressure

LEFM – Leading Edge Flow Meter

LP – Low Pressure

MWE – Megawatt Electrical

NSR – New Source Review

NSSS – Nuclear Steam Supply System

O&M – Operations and Maintenance

OEM – Original Equipment Manufacturer

RX – Reactor

TR – Technical Report

VWO – Valve(s) Wide Open

2
GENERIC PROCESS USED TO OBTAIN LICENSEE FEEDBACK

2.1 Overview of the Generic Process

Figure 2-1 illustrates the process used to compile the data for this report and the milestones reached throughout the duration of the project.

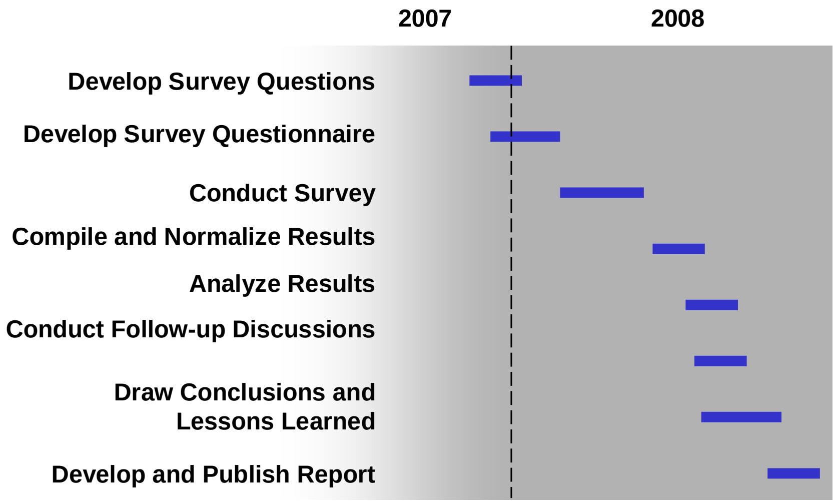

Figure 2-1
Process Used to Collect Turbine Upgrade Data

2.2 Development and Content of the Survey Questionnaire

2.2.1 Purpose and Scope of the Survey

The purpose of the survey was to collect feedback from nuclear and fossil power plant owners regarding the results of selected power uprates and turbine upgrades performed at their facilities. The survey questions were developed with input from a team of EPRI and utility personnel in a manner so as to optimize the number and quality of responses, and to ensure questions were worded objectively. Special care was taken so as not to imply any shortcomings with the work performed by the organizations performing the turbine upgrades or furnishing the replacement equipment.

2.2.2 Conduct of the Survey

The survey was conducted between February 2008 and July 2008 using an electronic-response software tool developed by EPRI. This tool enabled respondents to respond anonymously to the questions (if desired) and facilitated completing the survey via the Internet. As noted in Section 3 of this report, a total of 72 responses were compiled.

2.2.3 Compile, Normalize and Analyze Results

The survey results were compiled electronically using the software described above, but because there were numerous units/upgrades included in a single response in some cases, the data was manually reviewed to ensure one response was provided for each upgrade. A manual review process was also employed to ensure that multiple responses for the turbine upgrade were combined into a single entry.

Once the data were normalized as described above, a thorough analysis of the data was performed during 3rd quarter of 2008.

2.2.4 Conduct Follow-up Discussions

In some cases, it was necessary to follow-up with certain respondents via telephone interviews to clarify the information initially provided in the survey. Special care was taken to ensure that only those individuals indicating a willingness to discuss the upgrades in more detail were in fact contacted. Through these discussions, additional lessons learned and more detailed results were obtained, that were instrumental in developing the conclusions presented in this report.

3
RESULTS OF THE SURVEY QUESTIONNAIRE

3.1 General Results of the Survey

The following sections provide an overview of the general results of the survey in terms of the number of respondents (utilities and plants), and the number and types of plant (fossil or nuclear) participating.

3.1.1 Number of Respondents

A total of seventy-two (72) responses were received by EPRI, which will be discussed in detail in Section 3.2 of this report. The responses were comprised of forty-nine (49) representing fossil power plants and twenty-three (23) representing nuclear power plants.

3.1.2 Number of Utilities Responding

Table 3-1 lists the 16 utilities that provided the 49 responses representing fossil power plants. Similarly, Table 3-2 lists the 15 utilities that provided the 23 responses representing nuclear power plants.

Table 3-1
List of Fossil Utilities Responding to the Survey

Utility Name	Number of Responses (One Per Unit)
Ameren UE	4
British Energy	4
Dairyland Power Coop	1
DTE Energy	4
Dynegy	3
First Energy	3
Hoosier Energy	1
Luminant Generation	3
Nebraska Public Power	1
Nova Scotia Power Inc	2
NRG Energy Texas	6
PPL	8
Sask Power	3
Tri-State Generation & Transmission	1
TVA	4
Unidentified Utility	1

Table 3-2
List of Nuclear Utilities Responding to the Survey

Utility Name	Number of Responses (One per Unit)
Ameren Energy LLC	1
Arizona Pubic Service	3
Detroit Edison	1
Dominion Nuclear CT	2
Entergy Nuclear	1
Entergy Nuclear Vermont Yankee	1
Exelon Nuclear	1
FPLE	1
Kernkraftwerk Leibstadt AG	1
Omaha Public Power District	1
PPL	1
PSEG Nuclear LLC	1
Southern California Edison	2
Southern Nuclear	2
STP Nuclear Operating Company	2
TVA	2

3.1.3 Number of Participating Power Plants

Table 3-3 lists the 25 fossil power plants participating in the survey. Similarly, Table 3-2 lists the 17 nuclear power plants participating in the survey.

Table 3-3
List of Fossil Plants Providing Data

Plant Name	Number of Responses (One per Unit)
Baldwin	3
Big Cajun II	1
Boundary Dam	1
BRF	1
Bruce Mansfield	3
Brunner Island	3
Corette	1
Craig Station	1
F.E. Ratts Station	1
Gerald Gentleman	1
Hartlepool	2
Heysham	2
JP Madgett	1
Labadie Plant	4
Limestone	2
Martin Lake	3
Martins Creek	1
Monroe PP	4
Montour	3
PAF	3
Point Tupper	1
Poplar River	2
Trenton	1
Unidentified Plant	1
W A Parish	3

Table 3-4
List of Nuclear Plants Providing Data

Plant Name	Number of Responses (One per Unit)
Fermi	1
Fort Calhoun	1
Hatch Nuclear Plant	1
KKL	1
Millstone	2
Palisades	1
Palo Verde	3
Salem	1
San Onofre	2
Seabrook Station	1
Sequoyah Nuclear	2
South Texas	2
Susquehanna	1
Three Mile Island	1
Vermont Yankee	1
Vogtle	1
Unidentified Nuclear Plant	1

3.2 Detailed Results of the Survey

The following section details the actual results of the survey for each question.

3.2.1 Original Turbine Manufacturer (OEM)

Table 3-5 lists the turbine manufacturers and equipment cited in the survey. The results presented in this report are not intended to imply fault or negligence on the part of any particular turbine manufacturer, whether they are the original equipment manufacturer or the organization that performed the turbine upgrade modifications. To ensure there are no unintended implications of any supply organization, the names of these organizations are not correlated to any specific data or results presented and discussed in this report.

Table 3-5
List of Original Turbine Manufacturers and Equipment Cited in the Survey

Original Turbine Manufacturer Cited in the Survey	Number of Turbines	Percentage
Alstom	2	3%
Asea-Brown-Boveri (ABB)	2	3%
English Electric (pre-GEC)	1	1%
GE	28	39%
GE (British Company)	4	6%
Hitachi	3	4%
MAN	1	1%
Parsons	2	3%
Siemens-Westinghouse	23 (Note)	32%
Unidentified or Unknown	6	8%
	72	

Note: Siemens acquired the Westinghouse turbine division about a decade ago and the names have been used interchangeably since. All responses citing either Westinghouse, Siemens-Westinghouse, or Siemens have been combined to reflect the merger.

3.2.2 Portions of the Turbine-Generator System that were Modified

Table 3-6 represents the portions of the turbine generator that were modified in each of the responses provided in the survey.

Table 3-6
Overall Number of Cases Various Portions of the Turbine were Modified

Portion(s) of the Turbine That Were Modified	Number of Cases	Number of Cases (Fossil)	Number of Cases (Nuclear)
High-Pressure Turbine ONLY	21	14	7
Intermediate-Pressure Turbine ONLY	1	1	Not Applicable
Low-Pressure Turbine ONLY	17	6	11
All Three Portions	11	11	Not Applicable
High-Pressure and Intermediate-Pressure Turbines	2	2	Not Applicable
High-Pressure and Low-Pressure Turbines	14	10	4
Unknown or Unidentified	6	5	1
	72	49	23

3.2.3 Organization that Performed the Turbine Upgrade

Table 3-7 lists the organizations that performed the turbine upgrades and modifications included in the scope of survey responses. In some cases more than one organization performed the modifications over a several year period.

Table 3-7
Organizations that Performed the Turbine Upgrades

Organization	Number of Cases	Percentage
GE	21	29%
Siemens-Westinghouse	21	29%
Alstom	18	25%
GE (British Company)	4	6%
Hitachi	3	4%
Parsons	2	3%
Toshiba	1	1%
Asea-Brown-Boveri (ABB)	1	1%
Unknown or unidentified	4	6%
	72	

3.2.4 Objective of the Modifications

Table 3-8 lists the overall objectives of the turbine upgrades/modifications as reflected in the responses to the EPRI survey. Turbine upgrades may have multiple objectives and many responses reflected more than one objective.

Table 3-8
Overall Objectives of the Turbine Upgrades

Objectives of the Turbine Upgrade/Modifications	Number of Cases	Percentage
Increase power capacity	55	76%
Increase component integrity or remaining life	47	65%
Decrease heat rate	43	60%
Increase thermal efficiency	26	36%
Improve reliability	25	35%
Reduce seasonal effects	1	1%
Improve ramp rates	1	1%
Other	10	14%

Note: The percentages shown are the number of cases divided by the total number of respondents (i.e., 72). This technique is used because in many cases respondents provided more than one objective for the turbine upgrade.

Table 3-9 lists the overall objectives of the turbine upgrades/modifications as reflected in the responses to the EPRI survey for fossil power plants. Responses were not limited to one objective per upgrade.

Table 3-9
Overall Objectives of the Turbine Upgrades for Fossil Power Plants

Objectives of the Turbine Upgrade/Modifications	Number of Cases	Percentage
Increase power capacity	40	82%
Decrease heat rate	33	67%
Increase component integrity or remaining life	30	61%
Increase thermal efficiency	20	41%
Improve reliability	16	33%
Reduce seasonal effects	1	2%
Improve ramp rates	1	2%
Other	8	16%

Note: The percentages shown are the number of cases divided by the total number of respondents from fossil power plants (i.e., 49). This technique is used because in many cases respondents provided more than one objective for the turbine upgrade.

Table 3-10 lists the overall objectives of the turbine upgrades/modifications as reflected in the responses to the EPRI survey for nuclear power plants. Responses were not limited to one objective per upgrade.

Table 3-10
Overall Objectives of the Turbine Upgrades for Nuclear Power Plants

Objectives of the Turbine Upgrade/Modifications	Number of Cases	Percentage
Increase component integrity or remaining life	17	74%
Increase power capacity	15	65%
Decrease heat rate	10	43%
Improve reliability	9	39%
Increase thermal efficiency	6	26%
Reduce seasonal effects	0	0%
Improve ramp rates	0	0%
Other	2	9%

Note: The percentages shown are the number of cases divided by the total number of respondents from nuclear power plants (i.e., 23). This technique is used because in many cases respondents provided more than one objective for the turbine upgrade.

3.2.5 Other Changes Made to the Unit

The purpose of this question was to determine what other changes, if any, were made to the unit that contributed to the turbine upgrades to meet the overall objectives. Table 3-11 lists those other physical changes made to each respective unit contributing to achieving overall objectives of the turbine upgrades.

Table 3-11
Other Changes Made to the Unit

Other Plant Modifications Supporting the Turbine Upgrade	Number of Cases	Percentage
Change in the main steam flow rate	26	36%
Modifications to the boiler/steam generator	16	22%
Transition of valve designs from partial to full arc admission	15	21%
Generator modifications	14	19%
Changes to the feedwater system	6	8%
Maintenance to improve cycle isolation	5	7%
Changes to the exciter	3	4%
Changes to the boiler feed system	1	1%
Other	19	26%

Note: The percentages shown are the number of cases divided by the total number of respondents (i.e., 72). This technique is used because in many cases respondents provided more than one objective for the turbine upgrade.

3.2.6 Overall Owner/Licensee Expectations and Results

Table 3-12 lists the overall expectations and actual results achieved by the respondents to the EPRI survey for nuclear power plants.

When asked whether the upgrade met their expectations, approximately 51% of the respondents indicated the results met or exceeded their expectations. The number of cases where expectations were exceeded was very low in all instances (3%). Table 3-13 summarizes how effectively expectations were met in terms of both number of actual cases and percentages.

Table 3-12
Overall Expectations and Actual Results

Decreased Heat Rate	Expectations		Actual Results	
0-2%	13	20%	16	28%
2-4%	32	50%	21	36%
4-6%	3	5%	4	7%
6-8%	0	0%	1	2%
8-10%	6	9%	4	7%
>10%	0	0%	0	0%
N/A	10	16%	12	21%

Increase In Power Capacity	Expectations		Actual Results	
0-2%	2	3%	6	12%
2-4%	33	54%	21	43%
4-6%	13	21%	14	29%
6-8%	1	2%	1	2%
8-10%	7	11%	4	8%
>10%	2	3%	2	4%
N/A	5	8%	7	14%

Increase In Thermal Efficiency	Expectations		Actual Results	
0-2%	12	22%	19	37%
2-4%	29	53%	22	42%
4-6%	5	9%	3	6%
6-8%	1	2%	1	2%
8-10%	1	2%	3	6%
>10%	3	5%	0	0%
N/A	4	7%	4	8%

Table 3-13
How Effectively Expectations of the Upgrade Were Met

	Decreased Heat Rate		Increase In Power Capacity		Increase In Thermal Efficiency	
	Number of Cases	Percentage	Number of Cases	Percentage	Number of Cases	Percentage
Yes	36	50%	40	55%	29	40%
Poorer Than	8	11%	8	11%	12	16%
Better Than	2	3%	2	3%	3	4%
No Response	26	36%	23	32%	29	40%

One interesting aspect of this portion of the survey is the unusually high percentage (36%) of participants who did not provide a response to this question. The lack of response to this question may be contributed to the difficulty and cost of conducting an accurate turbine performance test. During a power plant outage of sufficient length to permit major turbine modifications, many other activities will occur that will also have an effect on the unit's heat rate and capacity. Therefore heat rate or capacity test results may not accurately describe the gains solely coming from the turbine modifications. Results from full scale ASME PTC 6 tests would isolate the turbine's performance and probably provide an accurate value to the realized performance gain (or loss) resulting from any turbine modifications. Those tests are very expensive to conduct, potentially in the range of hundreds of thousands of dollars; therefore very few are planned or conducted. Some turbine vendors have begun to state and guarantee the expected improvements in terms of turbine section efficiency. Those turbine section efficiency values for HP and IP turbines can be more easily determined through a fairly simple test procedure, known as an enthalpy drop test. The downsides are converting those improvements in turbine efficiency to unit heat rate or capacity gains. Either is an extrapolation containing significant uncertainty (enthalpy drop tests are not applicable to most LP turbines, excluding approximately 1/3 of the turbines modified).

Table 3-14 illustrates a slightly different response by revising the table to remove those who did not respond to this question.

Table 3-14
How Effectively Expectations of the Upgrade Were Met (without "no responses")

	Decreased Heat Rate		Increase Power Capacity		Increase In Thermal Efficiency	
	Number of Cases	Percentage	Number of Cases	Percentage	Number of Cases	Percentage
Yes	36	78%	40	80%	29	66%
Poorer than	8	17%	8	16%	12	27%
Better than	2	4%	2	4%	3	7%

The results clearly suggest that a majority of those attempting the upgrade (73-84%) achieved or exceeded their expectations.

3.2.7 Reasons Why Expected Results Were Not Achieved

Table 3-15 lists a number of reasons from respondents for why expected results were not achieved. Special care was taken during the development of this portion of the survey to ensure that turbine manufacturers or the organization(s) performing the turbine modifications were not unfairly implicated or blamed for not meeting customer objectives or contractual obligations. Some units provided multiple responses/reasons why expectations were not achieved.

In seventeen cases, other reasons were provided by the respondents that were not offered as options in the survey. Some of the same reasons were noted for multiple upgrades and as such, a summary of those reasons is provided below:

- High-temperature superheat and reheat sections were changed out (steam conditions changed)
- Replaced the boiler economizer sections as well
- Installed new feed-flow venturis and LEFM Checkplus
- Reactor maximum license power increase limited to 3%
- Performed in conjunction with reactor power uprate
- Changed turbine control and supervisory system
- Cycle isolation improved to support turbine test
- Impulse blading was replaced with reaction blades
- Control system was upgraded, and the low-pressure turbine was refurbished
- Steam generators were replaced (steam conditions changed)
- Replaced copper tubes in condenser and heaters

Table 3-15
Reasons Expectations Were Not Achieved

Reasons Expectations Were Not Achieved	Number of Cases	Percentage
Not applicable because all expected results were met	17	24%
Overestimated thermal gains from leakage reduction because of seal design	10	14%
Mechanical problems (e.g., vibration)	10	14%
Adverse impact from uncertainties regarding transition from partial- to full-arc admission	4	5%
Blade geometry did not render efficiency increase	3	4%
Improper distribution of enthalpy drops across the stages of the turbine	3	4%
Unanticipated change(s) in cycle parameters (e.g., reheat temperature, inlet pressure, mass flow, exhaust/condenser pressure) that were not accounted for in the design modification	3	4%
Mismatch between turbine and exhaust hood volume and geometry	1	1%
Steam path geometry was incorrect	1	1%
Test never conducted	1	1%
Attempted to conduct test, but never successfully completed it	1	1%
Don't know why expectations were not met	3	4%
Other (see details below)	17	24%

Note: The percentages shown are the number of cases divided by the total number of respondents (i.e., 72). This technique is used because in many cases respondents provided more than one objective for the turbine upgrade.

3.2.8 Side Benefits or Problems that Accompanied the Turbine Upgrade

Table 3-16 lists several side benefits or problems that accompanied the turbine upgrade.

Table 3-16
Side Benefits or Problems that Accompanied the Turbine Upgrade

Side Benefits or Problems	Number of Cases	Percentage
More expensive spare parts	6	13%
Reheat temperature drop	1	2%
Additional service water pumping power required for additional generator cooling	1	2%
Other (see details below)	40	83%

In the vast majority of cases, other reasons were provided by the respondents. Some of the same responses were noted for multiple upgrades, and as such, a summary of those side benefits or problems is provided below:

- Generator stator rewind eliminated water leakage.
- Manufacturer was over-optimistic on guarantee
- Permit not yet received to allow us to go to higher load
- Copper deposits in HP turbine (4 units)
- Units not tested due to boiler performance
- Turbine design assumptions and practices & other
- Nitrogen seal leakage
- Vendor underestimated performance of old turbine
- Stationary blade row vibration (4 units)
- Increased time interval between inspections (9 units)
- Vibration issues at low load
- Change in extraction steam flow
- Reduction in boiler slagging (3 units)
- Vibration levels greater than expected
- LP feedwater heater problems
- Decrease in condenser heat load
- Cycle isolation problems
- Control instabilities (4 units)
- Generator rewind eliminated water leakage

4
CONCLUSIONS AND LESSONS LEARNED

4.1 Summary of Results

In discussions with survey respondents, a majority replaced or modified their turbines to increase generation. In order not to trigger New Source Review (NSR) and the resulting emissions restrictions in fossil units, these increases to generation must occur without increasing steam generator thermal input. Hence, they must be accomplished through turbine efficiency enhancements and not solely by increasing flow passing capability. A portion of the turbines were modified or replaced to recover lost efficiency or generation, but many were advancing their potential generator output to levels well above initial design and historic performance. Approximately one third of the respondents stated that reliability was the primary driver behind the work, but the increased efficiency and generation also helped further justify the projects.

Nuclear units are not subject to NSR, but are legally limited to a maximum thermal power level, also known as licensed power. Historically, nuclear units' design contained large design margins and an opportunity to increase output once the design margin was fully evaluated. Therefore, power uprates have been a recently popular method to increase generation without the difficulties and expenses of siting a new power plant. Through detailed evaluations the large safety margins are slightly reduced to still acceptable levels; and with the expenditure of some capital, 2-10% additional power generation capability becomes available. For large nuclear units, that additional power generation ranges from 10 to 80 MW. The result of the uprate is typically an increased steam flow. A turbine replacement or major modification occurs in many of those uprates to accept and utilize the increased steam flow.

Although many nuclear turbine replacements were justified on the basis of reliability, the newer designs provided greater generation levels as a side benefit. For some of the older nuclear units, this is their second turbine replacement. Nuclear units do not have IP turbines; therefore, the numbers reported in this survey on HP and LP sections replaced will be inflated when compared to IP sections replaced in fossil-fired units. One third of the respondents were nuclear units.

While no financial information was requested or collected, these multi-million dollar modifications were justified in advance of installation based on the potential gains or prevention of potential losses.

One utility reported that their high-pressure turbine replacement resulted in a steam path that is too constricted, causing the unit to operate at valves wide open (VWO) to attain full power. While they attained the expected performance, operating at VWO is uncomfortable for both operators and the system dispatcher, as it is more difficult to follow load or control frequency.

Many of the units reporting turbine modifications or replacements also converted from partial arc to full arc admission. Historically, partial arc admission was preferred, as it is a more efficient operating scheme across the load range. At some points in their lives, some large machines were temporarily converted to full arc admission based on HP turbine reliability concerns. Most of those machines returned to partial arc admission. Modern full arc admission designs may provide for slightly more efficient turbine operation, but only at valves wide open. Most power plants do not operate continuously at full load which is required for valves wide open and therefore may not realize the efficiency improvement. This survey did not uncover the rationale for the conversion to full arc admission; therefore, additional research is warranted to fully disclose the costs and benefits of this turbine modification.

Overall, approximately 60% of the turbine modifications were done by original equipment manufacturers. That percentage jumped to nearly 90% for the nuclear units modified. Comparing Tables 3-5 and 3-7, the overall market shares for each vendor changed.

4.2 Conclusions

Utilities and generating companies conducting turbine upgrades have experienced a high success rate, achieving expectations in approximately 80% of the cases reported. No single problem was linked to cause of the majority of the 20% or so of modifications not achieving expected results. The most commonly mentioned problem was that of high vibration. There were some side benefits noted; the most prevalent being an increased time interval between required turbine outages/inspections.

5
REFERENCES

1. *Description of Past Research—EPRI Fossil and Nuclear Steam Turbines and Generators—Volume 3*. EPRI, Palo Alto, CA: June 2008. 1016900.

A
SURVEY QUESTIONNAIRE

The purpose of this Appendix is to provide the survey that was used to collect and compile data regarding the results of power uprates and turbine-generator upgrades.

Background

Over the past 10-15 years, a number of nuclear and fossil power plants have undertaken plant modifications to increase the power rating of selected units. Many of these power uprates have resulted from physical upgrades to their steam turbine generator, as well as enhancements to auxiliary components.

Over this time, various organizations in EPRI have undertaken studies to collect data on performance after steam turbine upgrades, but the data did not specifically quantify MW enhancements, heat rate improvements, and how effectively each uprate met owner expectations. This project will compile existing EPRI data as well as obtain current results of performance upgrades to produce a single technical report summarizing the findings.

Purpose and Scope of the Survey

The purpose of this survey is to collect feedback from nuclear and fossil power plant owners regarding the results of selected power uprates and turbine upgrades performed at their facilities. Following the survey, EPRI will compile the data, and share the results with other EPRI member utilities.

Survey Questions

Respondent's Name:
Phone:
e-mail:
Utility Name:
Plant Name:
Unit Number:

Question 1: Original Turbine Manufacturer (OEM)

- Alstom
- Asea-Brown-Boveri (ABB)
- General Electric (US company)
- General Electric Company (British company)
- Hitachi
- Mitsubishi

- Parsons
- Siemens-Westinghouse
- Toshiba
- Westinghouse
- Other (please indicate OEM name)

Question 2: Portions of the Turbine-Generator System that were modified (indicate all that apply)

- High-pressure turbine
- Intermediate-pressure turbine
- Low-pressure turbine

Question 3: Organization that performed the turbine upgrade

- Alstom
- Asea-Brown-Boveri (ABB)
- General Electric (US company)
- General Electric Company (British company)
- Hitachi
- Mitsubishi
- Parsons
- Siemens-Westinghouse
- Toshiba
- Westinghouse
- Other (please indicate OEM name)

Question 4: Objective of the modifications (indicate any that apply)

- Decrease heat rate
- Increase power capacity
- Increase section thermal efficiency (HP, IP, LP)
- Increase component integrity or remaining life
- Reduce seasonal effects
- Improve reliability
- Improve ramp rates
- Other

Question 5: Other changes made to the unit contributing to meeting objectives (indicate any that apply)

- Change in the main steam flow rate
- Transition from partial to full-admission valve designs
- Modifications to the boiler/steam generator
- Changes to the exciter
- Generator modifications
- Changes to the feedwater system
- Changes to the boiler feed system
- Maintenance to improve cycle isolation
- Other

Question 6: Overall owner expectations (decrease in heat rate, increase in power capacity, or increase in section thermal efficiency, etc.)

- 8-10%
- 6-8%
- 4-6%
- 2-4%
- 0-2%

Question 7: Actual results achieved following the modifications

- 8-10%
- 6-8%
- 4-6%
- 2-4%
- 0-2%

Question 8: If expected results were NOT achieved, indicate any of the reasons listed below that apply

- Not applicable because all expected results were met
- Seals were damaged during rotor installation
- Blade geometry did not render efficiency increase
- Steam path geometry was incorrect
- Exhaust annulus was incorrect
- Design modifications were compromised to accommodate existing steam extraction conditions
- Adverse impact from uncertainties regarding transition from partial to full-admission valve designs
- Overestimated thermal gains from leakage reduction because of seal design

- Improper distribution of enthalpy drops across the stages of the turbine
- Mismatch between turbine and exhaust hood volume and geometry
- Improper moisture removal devices for a particular stage of the turbine
- Unanticipated change(s) in cycle parameters (e.g., reheat temperature, inlet pressure, mass flow, exhaust/condenser pressure) that were not accounted for in the design modification
- Unexpected change to turbine blade surface (e.g., pitting, fouling, corrosion, etc.)
- Mechanical problems (e.g., vibration)
- Test problems
- Test never conducted
- Large corrections to test results increased uncertainty, making results meaningless
- Attempted to conduct test, but never successfully completed it
- Other
- Don't know why expectations were not met

Question 9: Please indicate any side benefits or problems that accompanied the turbine upgrade (indicate all that apply)

- Reheat temperature drop
- Flatter IO curve, poorer heat rates at lower loads, therefore unit is either dispatched at full load or cycled off
- More expensive spare parts
- Additional service water pumping power required for additional generator cooling
- Other

Would you or someone in your organization be willing to discuss your experience in more detail with an EPRI representative?

- Yes
- No

If yes, please provide the following:

NAME:
PHONE:
E-MAIL:

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together…Shaping the Future of Electricity

1018346

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com