ELECTRIC POWER RESEARCH INSTITUTE

Power Plant Optimization Industry Experience

2005 Update

1011794

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Technical Update, December 2005

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Energy Technologies Enterprises Corp.

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CITATIONS

This document was prepared by

Energy Technologies Enterprises Corp.
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McLean, VA 22102

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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:

Power Plant Optimization Industry Experience: 2005 Update. EPRI, Palo Alto, CA: 2005. 1011794.

PRODUCT DESCRIPTION

This report reviews industry experience with optimization software. Since the early 1990s, power plant optimization software has been used extensively by U.S. electric utilities. More than 400 units (coal-, oil- and gas-fired) have used optimization software products. Of this number, approximately 280-300 are coal-fired boilers; 100 to 130 of these systems are still in operation, all of them in close-loop mode.

Results & Findings

This study briefly surveys commercially available optimization software, provides an overall assessment of the extent optimization is currently used in the U.S. utility industry, summarizes the experience of U.S. electric utilities, and details the lessons learned, focusing on what makes a project successful.

Challenges & Objective(s)

The report's goal is to document the present status of power plant optimization and the lessons learned from the utility industry regarding the viability of optimization projects. The report also identifies reasons previously installed units are no longer in use, lists performance improvements that can be achieved by optimization, suggests ways utilities and vendors can work together successfully, and identifies typical costs for optimization projects.

Applications, Values & Use

Information in this report will assist utilities in successfully implementing optimization projects, from identifying components that can benefit most from optimization to establishing long-term working relationships with vendors.

EPRI Perspective

In September 1998, EPRI published the Proceedings from the Second Workshop on Power Plant Optimization (TR-111316), followed by the Power Plant Optimization Guidelines (TR-110718) in December 1998. In December 1999, the beta version of the Total Plant Cost Optimization Guidelines (EPRI AP-114702) was released. This tool to assist utilities in assessing the benefits of optimization has not yet been released as a final report.

The term "optimization," as it is used in this report, needs clarification for a number of reasons. In the past, most of the emphasis on EPRI-initiated work has been on combustion optimization using software based on neural networks. Combustion optimization was a key area due to the importance of optimizing the tradeoffs among NOx emissions, unburned carbon, and boiler efficiency. Recently, utilities also have become interested in optimizing other areas, such as flue gas desulfurization (FGD), selective catalytic reduction (SCR), and sootblowing. For this reason, the term "optimization" is used in this report to mean on-line multi-variable and multi-objective optimization of a single unit independent of the optimization technique used. Not included in the report are applications used off-line or intended to optimize maintenance activities.

Approach

The project team contacted U.S. utilities that have installed optimization software. Since the list of optimization users was long and many on the list preferred to keep their names and experience confidential, the team relied on a sample of responses. The estimate of optimization systems in operation (100-130) was based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). Information from these contacts was used to develop an estimate of the general experience in the industry. Rather than describe specific projects, the team focused directly on lessons learned and used examples from contact sites to illustrate those lessons.

Keywords

Fossil-fired power plants
Optimization
Heat rate
Performance
Neural networks

ACKNOWLEDGEMENTS

The author would like to acknowledge the significant contribution of the electric utility and optimization vendor staff, who provided valuable information and guidance for this report.

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- Dynegy: Mike Dinkelman, Sam Korellis, and Byron Veech
- Great River Energy: Mark Ness
- LG&E: Don Keisling (Roanoke Energy Facility)
- MidAmerican: Leon Gertsch and William R. Whitney
- Ontario Power Generation: Ken Bachalo (Lambton Station)
- Portland General Electric: David Rogers
- Reliant: Shawn Smith
- South Carolina Electric & Gas: Freddie Collins
- Southern Company: John Sorge and Damon Woodson
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ABSTRACT

This report gives an overview of commercially available optimization software, assesses the extent optimization is currently used in the U.S. utility industry, summarizes the industry's experience, and details the lessons learned with an emphasis on what makes a project successful. The document's goal is to describe the status of power plant optimization and the lessons learned in terms of the feasibility of optimization projects. Project information came directly from contacts with U.S. utilities that have installed optimization software. The team's estimate of optimization systems currently in operation on coal-fired boilers (100-130 out of a total of 280-300 installed) was based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). The team used contact information to develop an estimate of the industry's general experience with optimization software, focusing directly on lessons learned rather than specific projects. For this report, "optimization" refers to on-line multi-variable and multi-objective optimization of a single unit independent of the optimization technique used.

CONTENTS

1 EXECUTIVE SUMMARY

Since the early 1990s, multi-variable and multi-objective power plant optimization has been used extensively by U.S. electric utilities. A number of key factors contributed to this development: 1) the Clean Air Act Amendment of 1990 required NOx emissions reductions, but also provided flexibility on how this reduction would be achieved; 2) deregulation in the U.S. utility industry put pressure to reduce operating costs, providing an additional incentive to increase plant efficiency; and 3) neural-network-based software reached maturity and became available as commercial products.

Reportedly, more than 400 units (coal-, oil- and gas-fired) have used such optimization software, of which approximately 280-300 are coal-fired boilers. However, it also is clear that while many of these units have used optimization software for some time (after they have been installed and calibrated successfully), they are not using them any more. This is the result of many factors, including the fact that a number of optimization products are not available in the market anymore because they have been acquired by competitors.

Under these circumstances, EPRI member utilities are interested in learning more about the present status of power plant optimization. Most important are the lessons learned from the utility industry regarding the viability of optimization projects and the factors that contribute to a successful project. This study is in response to this need and attempts to provide

- a brief overview of commercially available optimization software,
- an overall assessment of the extent to which optimization is used in the U.S. utility industry, and
- lessons learned that contribute to implementing successful optimization projects.

Key Findings

- Presently, there are 100 to 130 coal-fired units in the United States that are using optimization software, all of them in closed-loop mode. This represents 35-45% of the units that have installed optimization systems; the remaining are not using them any more for a variety of reasons, including
  - Ultramax had approximately 65 installations that are not operational because they were never set-up in closed-loop mode and stopped being used as soon as the company ceased to exist;
  - operating objectives have changed since the optimization system was installed; incentives to reduce NOx emissions through combustion optimization is not the highest priority as units have been retrofitted with post-combustion NOx controls;
  - changes in hardware (especially installation of selective catalytic reduction, or SCR, units but also replacement of economizers and air preheaters) or significant changes in coal

quality require recalibration of the optimization system, which was perceived to be costly;

  - o perceptions of plant operators and performance engineers that optimization systems may have adverse effects on their job security; also, their perception that costs outweigh benefits; and
  - o older power plants without digital control systems and adequate instrumentation and remote control capabilities installed optimization software, but realized that the systems were not effective.

The estimate of optimization systems in operation (100-130) is based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). This number does not cover all plants with optimizers, but was used to develop an estimate of the general experience in the industry and was considered adequate for the purposes of this report.

- Recent experience confirms earlier estimates about performance improvements that can be achieved by optimization. NOx emissions can be reduced by 5-35% depending on the number of control variables available, the operating range of each variable, and whether the unit was tuned. Heat rate in base-loaded units was improved by up to 1.0 percentage point and in load-following and cycling units up to 2.0 percentage points. Units that are not recently tuned and units with many control variables and a wide operating range for each variable should achieve performance improvements at the high end of the above range.
- Reports from two cyclone units are consistent with the performance improvement of other types of boilers. Cyclones are singled out because they have inherently less operating flexibility. However, the addition of overfire air ports and instrumentation for each cyclone provides adequate flexibility to achieve reasonable performance improvement.
- Realignment of optimization vendors is continuing with power plant controls vendors becoming more active. The key optimization suppliers in the market are Emerson, Invensys, NeuCo, Pegasus, and URS. The power plant controls vendors (Emerson and Invensys) represent one-third (1/3) of the total optimization installations in operation with the remaining two-thirds (2/3) supplied by the traditional neural-network-based optimization suppliers (NeuCo, Pegasus, and URS).
- All suppliers are capable of implementing successful optimization projects, but attention should be paid to the specific experts that suppliers are committing to each project. Utilities should request resumes, interview prospective vendor experts (if possible), and ask for assurances that they will be available to support the project as needed.
- Optimization vendors are making significant efforts to expand optimization to other components and objectives such as sootblowing, post-combustion controls (SCR and selective non-catalytic reduction, or SNCR), flue gas desulfurization, on-line heat rate, maintenance optimization, and overall economics. However, it is not clear how successful these integrations will be both in terms of technical feasibility and cost-effectiveness. Integration of post-combustion NOx controls seems to be the most promising and problem-free. The others are yet to be demonstrated convincingly.

The industry experience is full of examples of what makes a successful optimization project and what contributes to an unsuccessful one. These are the key lessons learned:

- Corporate commitment is essential.
- Plant staff buy-in early in the project is important; there are negative perceptions related to optimization system cost-effectiveness and impacts on plant staff job security that need to be dispelled early on.
- A plant champion is needed at the plant and, preferably, at headquarters, too.
- The implementation team should bring together the following disciplines: 1) power plant engineering (plant design and operation); 2) instrumentation and controls; and 3) optimization techniques. Whether such expertise is in the utility organization or the optimization supplier is not important; what is important is to make sure that these experts are available to support the project when needed.
- Utilities should sign a maintenance contract with optimization suppliers to provide technical support on an as-needed basis and to provide software upgrades.
- Providing remote access to optimization suppliers has significantly improved the effectiveness of optimization systems. With cyber-terrorism and safeguarding proprietary data being major concerns for U.S. utilities, such access is not as simple as it used to be. Corporate guidelines and industry requirements need to be followed in providing such access. However, it is essential and needs to be arranged in the early stages of projects, certainly before contracts with optimization suppliers are signed.
- Optimization suppliers claim that optimization systems could be in closed-loop mode within three to four months from the project kick-off meeting. Experience shows that utilities should plan for a minimum of five to six months.
- Typical costs of optimization projects:
    - Optimization supplier contract: $400,000 for the first unit and $300,000 for subsequent units at the same plant. However, there is significant pressure and prices could decline by 30-40% from these levels.
    - Optimization supplier maintenance/technical support agreement: $20,000 – 40,000 per year.
    - In-house costs:
        - Three to four man-months during optimization installation and calibration.
        - Ten to twenty percent of a performance engineer's time after the optimization system is operating in closed-loop mode. Higher levels of support would be needed if significant hardware or coal quality changes require recalibration of the optimization software.

2 INTRODUCTION

Power plant optimization has developed into a technical area of interest for electric utilities. In the early 1990s, a number of software packages were introduced such as Ultramax, Pegasus' NeuSight, Pavilion's Process Insights, GNOCIS, and NeuCo's ProcessLink. These packages raised utilities' interest in multi-variable and multi-objective optimization. The timing was good because it coincided with the need for NOx emission reductions (required by the Clean Air Act Amendments of 1990), as well as competitive pressures (through deregulation of the utility industry) to improve plant efficiency.

Since then, approximately 280-300 coal-fired units in the United States have been reported to implement optimization. However, it is not clear how many of these units are still using optimization, how it is used, and how satisfied the utilities are. Consolidation of optimization vendors makes the situation even more complicated because some of them do not exist anymore as separate companies and their products are not marketed and supported.

Responding to the need of its members, EPRI supported a review of industry experience with optimization software, which is documented in this report. More specifically, the objectives of this report are to

- provide a brief overview of commercially available software,
- assess the approximate number of installations that continue to use optimization, and, more importantly,
- focus on the experience of U.S. electric utilities with optimization software and the lessons learned from successful projects.

To clarify both the extent to which optimization software continues to be used and to draw lessons learned from that use, the project team contacted key utilities and power plants that have implemented optimization software. With regard to lessons learned, initially the plan was to identify four to five projects and describe them in detail, hoping that this would highlight the lessons learned. However, as more utilities were contacted, it became clear that there were a number of reasons to switch from describing specific projects to stating directly the lessons learned and use examples from various sites to illustrate them. The reasons for this change in presentation are as follows:

- Most utilities were not willing to be quoted in a report; however, they were willing to share details (especially with regard to project schedule and costs) provided that their names would be kept confidential and the information would be included in the report as general experiences and conclusions not tied to specific companies and facilities.
- EPRI's objective is not to make any company look bad (whether utility or optimization supplier); the goal is to present the lessons learned so future projects can benefit from what works and from what does not.

- The lessons learned covered many more projects than just four or five.

This report is divided into four sections. In addition to Sections 1 (Executive Summary) and 2 (Introduction), Section 3 provides a brief description of commercially available optimization products, including Emerson, GNOCIS, Invensys, NeuCo, and Pegasus. The information collected on industry experience and lessons learned is presented in Section 4. In this section, we state each conclusion and then provide further clarification, including examples from utilities and power plants that had relevant experience.

Definitions and Terminology

The term *"optimization,"* as it is used in this report, needs to be clarified for a number of reasons. In the past, EPRI-initiated work on combustion optimization has primarily focused on using neural-net-based software. (Of course, this was not exclusive, as illustrated by Ultramax, which is not based on neural networks). Combustion optimization also was a key area due to an industry emphasis on optimizing NOx emissions, unburned carbon, and boiler efficiency. However, utilities have recently become interested in optimizing components such as flue gas desulfurization (FGD), SCRs, and sootblowing. For this reason, the term "optimization" will be used in this report to mean on-line multi-variable and multi-objective optimization of a single unit independent of optimization technique used.

A few limitations placed on this definition to keep the effort focused include the following:

- Methods that are applied off-line are not included. This does not mean that these methods are not important; they have been documented in numerous EPRI reports and studies and there is no substantial new information to provide.
- Optimization of maintenance activities is not included in this report. Performance optimization obviously has long-term impacts on unit reliability and maintenance requirements; however, integration of such activities has substantially increased the complexity of the optimization problem, and there are not many initiatives to report at this time.

Relevant EPRI Products:

- *Power Plant Optimization Guidelines* (TR-110718)
- *Total Plant Cost Optimization Guidelines* (Beta Testing Version; TR1001130)
- *Proceedings, Second Annual EPRI Workshop on Power Plant Optimization* (TR-111316)

3
DEVELOPMENTS ASSOCIATED WITH COMMERCIALLY AVAILABLE POWER PLANT OPTIMIZATION PRODUCTS

There have been a number of important commercial developments during the last two to three years:

- Consolidation of optimization suppliers: A number of optimization suppliers do not exist any more. The early leader in optimization software, Ultramax, was acquired by Pegasus Technologies, Inc. Pegasus also acquired the rights to the technology of Pavilion, which withdrew from the utility market.
- Power plant controls suppliers are becoming more active in optimization: Organizations such as Emerson and Invensys started offering optimization software for both specific components and unit-level optimization.
- Some optimization suppliers are becoming less active: In particular, URS (offering GNOCIS) and General Electric-Praxis (offering PECOS) have not introduced any new projects during the last couple of years.

Many other companies are continuing to be or are becoming active in plant optimization through performance monitoring (for example, Alstom, Black & Veatch, and General Physics) and parametric testing and off-line optimization (for example, Lehigh University, which signed a marketing alliance with METSO Automation). However, the project team decided that these products were not the focus of this report. Instead, we focused on software products for on-line multi-variable and multi-objective optimization that have at least one installation in a U.S. utility power plant. As a result, this section includes information on Emerson, GNOCIS, Invensys, NeuCo, and Pegasus.

This section provides a brief summary for each product. Detailed information on these products can be obtained from the vendors' web sites (which are provided in this report), as well as earlier EPRI publications, such as TR-111316 (Proceedings: Second Annual EPRI Workshop on Power Plant Optimization).

3.1 Emerson

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Description

Emerson offers a number of optimizer and advisory modules as part of their SmartProcess Software Suite:

- Combustion Optimizer
  - Low NOx Optimizer
  - Opacity Optimizer
- Cyclone Boiler Optimizer
- Economic Optimizer
- Fleet Emissions Optimizer
- Steam Temperature Optimizer
- Sootblower Optimizer
- Global Performance Advisor

Emerson also is developing optimization modules for SCR and FGDs.

These modules use empirical correlations, neural networks, and fuzzy logic or a combination of these techniques depending on the optimization objective. For example, the Combustion and Economic Optimizers use neural networks and are designed to allow for multi-objective optimization.

These modules are integrated in a closed-loop manner and provide optimal bias signals or revise the set-points in the control system.

The SmartProcess Software Suite has sensor validation capabilities through the following modules: PCS ACM, SmartSignal eCM, and Sensor Replacement.

Industry installations and experience

Emerson reports 108 installations worldwide employing some of these optimization modules. Seventy-five of these installations are coal-fired power plants (a few blend fuels). Most of these installations optimize NOx emissions and boiler efficiency.

Key installations of Emerson Optimizers include

- Ameren's Coffeen #2 (a cyclone unit) in 2004 and Newton #1 and 2 in 2002/03
- Constellation Power's Crane #1 and 2 (cyclone units) in 2002/03
- Duke Power's Allen #2 and 3 (T-fired units) in 2002/03
- Dynegy's Hennepin #2 (T-fired unit) in 2004
- Electric Energy's Joppa #1, 2, 3, 4, 5, and 6 in 2001/02
- We Energies' Oak Creek #7 and 8 in 2004, Presque Isle #3-6 in 2001, and Valley Power 1-4 in 1999-2000
- Xcel Energy's Sherburne County 1-3 in 2002 and Pawnee in 2001

Optimizers also were installed at some gas-fired boilers, including Entergy's Nine Mile Point, Xcel's Nichols, and Florida Power & Light's Martin County stations.

References

1. *Power Engineering Magazine,* "Neural network technology optimizes cyclone boilers at Constellation Energy's C.P.Crane station", October 2004 issue, page 73.

3.2 GNOCIS Plus

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Description

GNOCIS is a multi-variable optimization system designed for application at power plants. A detail description of GNOCIS is provided in EPRI report TR-111316, among others publications.

The original version of GNOCIS used Pavilion optimization technology. GNOCIS Plus, which replaced GNOCIS, uses core optimization technology developed by PowerGen Ltd of UK (presently E.ON UK).

Industry installations and experience

GNOCIS Plus was installed in approximately twenty power plants of the Southern Company power system, as well as TVA's Kingston #9. However, in the last two years, there are no new projects announced, and reportedly only one plant (Lansing Smith of Gulf Power) is actually using the software.

Both URS and E.ON UK[1] are active in power plant performance optimization and are likely to continue being involved, potentially with new products or services:

- URS is developing sootblowing optimization software (jointly with Synengco) that is being tested at TVA's Widow's Creek and Bull Run plants.
- E.ON UK is active in power plant optimization in Europe and offers PROATES, a plant performance monitoring and thermodynamic analysis tool.

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Description

Invensys, parent company of Foxboro and Simsci-Esscor, offers the ConnoisseurTM APC platform, which includes multi-variable model predictive control/optimization, dynamic neural network modeling, fuzzy logic, expert systems, and on-line model adaptation. The core of the system is dynamic multi-variable, model predictive constraint control (MVC) with on-line optimization. The product is integrated directly with the base control system of the plant and is designed for continuous closed-loop applications.

Key features of Connoisseur:

- built-in data acquisition and trend graphing;
- data historian and archiving facilities for a specified amount of process data;
- sensor validation;
- neural-network-based nonlinear optimizer for modeling and controlling NOx, CO, and other nonlinear responses;
- feed-forward variables for dynamic response to external changes;
- steam temperature and throttle pressure control;
- proprietary Burner Zone Module "provides virtual sensors for each burner" (estimates burner stoichiometry based on distributed control system, or DCS, data and design data);
- smart sootblowing system;
- mill optimization;
- dynamic control capability;
- on-line model learning throughout the load range; and
- off-line data analysis capabilities.

Connoisseur software runs on the Windows platform and supports up to nine (9) simultaneous users with one (1) user able to make changes.

Invensys projects that approximately three months are needed from contract award to a fully operational system in a closed-loop mode in one unit.

Industry installations and experience

Invensys has 15 installations of optimization systems, ten coal-fired and five oil/gas-fired. All installations focus on optimization of NOx emissions and combustion efficiency. Some of them, in addition, optimize steam temperatures and opacity. Also, there are six sites that use Invensys' sootblowing optimization.

Key U.S. power plants with Connoisseur are

- Entergy's Independence #1 and 2, each 800-MW coal-fired (2004);
- Dayton Power & Light's Stuart #1, 2, 3 and 4, each 600-MW coal-fired (2004);
- South Mississippi Electric Power Association's Morrow #1 & 2 (coal);
- NRG Energy's Huntley #67 and 68, each unit 200-MW firing coal (2001); and
- LCRA's Fayette station (coal-fired) and Sim Gideon #1, 2 and 3 gas-fired boilers (total 650 MW).

References

1. Barnoski, S., et al, "Coal mill and combustion optimization on a once-through, supercritical boiler with multivariable predictive control", presented at the 15th Annual Joint ISA POWID/EPRI Controls and Instrumentation Conference, Nashville, TN, June 5-10, 2005.
2. Labbe, D., et al, "Entergy Independence NOx/Heat rate optimization and steam temperature control with neural net/model predictive control combo", presented at the 15th Annual Joint ISA POWID/EPRI Controls and Instrumentation Conference, Nashville, TN, June 5-10, 2005.
3. Power Engineering Magazine, "Process optimizing offers performance boost without major capital improvements", February 2003 issue, page 17.

3.4 NeuCo's ProcessLink

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Description

NeuCo's ProcessLinkTM is a neural-network-based optimization system designed for fossil-fuel-fired power plants. Capabilities include

- Data validation and error-checking
- On-line, automatic retraining of the model
- Data historian
- Option to obtain data from another software or input to a dedicated ProcessLink database
- Sensitivity profiles

In addition to ProcessLink, which is considered the base platform (essential software), NeuCo offers optimizers that focus on specific equipment or objectives:

- CombustionOpt
- SCR-Opt
- SNCR-Opt
- Soot-Opt
- FGD-Opt
- MaintenanceOpt
- PerformanceOpt (unit performance optimization)
- ProfitOpt (optimization among multiple units, too)

ProcessLink runs on standard personal computers.

According to NeuCo, ProcessLink can be operational in closed-loop configuration in about four months from contract signing. More information on project schedule and training requirements are provided in the vendor's web site.

Industry installations and experience

According to NeuCo, there are more than 100 installations with the ProcessLink software. Power plants that are known to have installed ProcessLink include

- Canal Electric's Canal Generating #2, a 565-MW oil- and gas-fired (Babcock & Wilcox once-through subcritical) boiler;
- Arizona Public Services' Four Corners #3, a 250-MW Foster Wheeler boiler;
- Santee Cooper's Winyah units #2, 3 and 4 (each 180-MW Riley turbo boilers);
- Cajun Electric's Big Cajun II # 1 and 2 (each 600-MW Riley turbo boilers);
- LG&E's Roanoke Valley energy facility (two coal-fired units: #1 180-MW and #2 50-MW);
- AES' Harding Street #7, a 429-MW tangentially-fired boiler burning Illinois Basin coal;
- CMS' D. Karn #2, a 265-MW wall-fired boiler;
- Colorado Springs Utilities' Martin Drake #6 and 7;
- Portland's Boardman, a 585-MW unit burning Powder River Basin (PRB) and Utah coals;
- Deseret's Bonanza plant;
- Reliant's
    - Cheswick, a 570-MW T-fired boiler; and
    - New Castle with three operating units, two 103-MW units and one 142-MW unit.

NeuCo also has received $8.4 million co-funding from the US Department of Energy (DOE) to install ProcessLink at Dynegy's Baldwin station. The total project cost is $18.6 million and is expected to develop and demonstrate a host of capabilities including optimization of

- sootblowing,
- SCR,
- overall unit thermal performance, and
- plant-wide production costs.

<u>Industry Partnerships</u>

NeuCo is working closely with Black & Veatch (B&V) to interface PerformanceOpt with B&V's OPM (On-line Performance Monitoring) software.

References

1. James, R., et al., "Optimization with ProcessLinkTM at the Roanoke Valley Energy Facility" presented at the PowerGen 2000, Orlando, FL, November 14-16, 2000.
2. Keisling, D. and Spinney, P., "ProcessLinkTM at the Roanoke Valley Energy Facility", presented at the EPRI Heat Rate Conference, Dallas, TX, January 30, 2001.
3. Power Magazine, "Four Orion stations to implement process-optimization software," March/April, 2001.
4. Smith, S., et al, "Combustion optimization case studies & emerging applications", presented at the Combined Power Plant Air Pollutant Control Mega Symposium, May 19, 2003.
5. Spinney, P, et al, "Colorado Springs Utilities expands combustion optimization system to incorporate advanced instrumentation" presented at the Power-Gen 2002, Orlando, FL.

3.5 Pegasus

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Description

Pegasus' optimization products are part of the DeltaE3TM product line, a tool kit of programs that includes

- DeltaE3 Combustion Optimizer
- DeltaE3 FGD Optimizer
- DeltaE3 SCR Optimizer
- DeltaE3 ESP Optimizer
- DeltaE3 Coal Blending
- DeltaE3 Visual Analysis
- DeltaE3 Performance Index
- DeltaE3 CIA (Carbon In Ash) Predictor
- DeltaE3 Sootblow Optimizer

DeltaE3 evolved from the previous generation of software, including NeuSIGHT (developed by Pegasus), Power PerfecterTM (developed by Pavilion and acquired by Pegasus), and others. The application includes neural-network-based software designed for multi-variable optimization of power plant performance and is customized to fit the specific needs of each power plant or application. Capabilities include the following:

- data validation and substitution;
- pattern recognition;
- on-line self-tuning;
- PERFIndex, a real-time boiler performance index that can be used as an indicator of the impacts of controllable losses on unit performance; and
- linkage to an Intelligence Sootblowing system offered by Pegasus.

Other recent improved features include

- multi-variable predictive controller;
- operation in the Windows platform, as well as in UNIX, the original platform;

- enhancement of the user interface; earlier versions of NeuSIGHT required changes in two different models that were maintained (for example, adjustment in constraints of variables). The new version allows users to make the changes only once.

DeltaE3 is operating system platform-neutral; NeuSIGHT used to run on UNIX requiring a Sun Workstation, but DeltaE3 can run on Windows, too.

Pegasus' typical installation takes about 5-½ months from contract award to full commissioning. More information on project schedule, as well as system design specifications, training requirements, and operator guide, are provided in the vendor's web site.

Acquisitions of optimization technologies

Pegasus has purchased the rights to Pavilion power plant optimization software as they apply to single-unit licenses and incorporated this technology into DeltaE[2]. Some projects that had Pavilion technology at the time of the acquisition upgraded the software to Pegasus; others kept the Pavilion software, which is maintained either by utility staff or by third parties.

Pegasus also acquired Ultramax Corp. with its sequential process optimization software. Since the acquisition, there have been no new projects using Ultramax technology and, reportedly, all plants that had it installed have stopped using it. Pegasus developed a product for industrial boilers that is based on the Ultramax technology.

Industry Partnerships

Pegasus has entered into a partnership with Alstom Environmental Control Systems to develop a range of "environmental control products" focusing on optimizing SCR and FGD systems in addition to boiler performance. Reportedly, they are in the process of developing SCR and FGD optimization modules. Alstom is authorized to license and resell Pegasus products.

A reseller agreement also has been signed with ABB's Industrial ITTM Solutions.

As of October 2004 , Pegasus entered into an alliance agreement with Ready Engineering Corp. to market and license worldwide Ready's intelligent fuel management system for coal-fired power plants.

Industry installations and experience

Pegasus has about 70 installations in U.S. power plants with more plants overseas as well as installed industrial (mainly chemical process) applications. Most of these applications are closed-loop.

Key installations and utilities that are implementing Pegasus products in the United States include the following:

- Ameren was one of the first utilities to install optimization software at its Labadie station, all four units (each 575-620-MW); after Labadie, Ameren installed the application at Meramec #1 and 2 (2004), Rush Island #1 and 2 (2004), and Sioux #1 and 2 (2005).

[2] *Power Engineering Magazine*, Oct. 2004, pg. 22.

- Cinergy purchased Pegasus software to be installed throughout its power generation system. Although the software has been installed on virtually all of the units larger than 160 MW, a number of them have been turned off by the operators for many of the reasons discussed in this report.
- Carolina Power & Light's Asheville #1 installed the software on a 210-MW wall-fired boiler.
- MidAmerican tried the software successfully first at Council Bluffs #3 in 2002 and Neal 4, then installed it at Neal #1, 2 and 3, Louisa #1, and Riverside #5.
- TXU first tried the software at Big Brown #1 in 2002; then in 2003-04, they implemented it at Big Brown #2, Martin Lake #1, 2, and 3, Monticello #1, 2 and 3, and Sandow #4.
- Georgia Power installed the software at Scherer #1, 2, and 3 (2004-05), with an option to install it on unit #4.

In October 2004, Pegasus was selected by DOE to receive $6.1 million to "demonstrate the capability of sophisticated control processes and advanced sensor technologies to optimize mercury speciation and control from existing lignite and Power River Basin subbituminous coal". This project (valued at a total of $12.2 million) will be implemented jointly with Texas GenCo.

<u>References</u>

1. Nicholson, G. and Lockert, C.A., "How to make flyash an income generator", Power Magazine, pgs 64-65, October 2005.
2. Partlow, B., et al, "Experience with advanced control when combined with an ultra low NOx combustion system", Texas Municipal Power Authority.
3. Wilson, T.L., et al, "Application of a neural network based, closed-loop control optimization system to a load following utility boiler", Carolina Power & Light Co.

4
THE EXPERIENCE OF U.S. UTILITIES USING POWER PLANT OPTIMIZATION

This section includes two main parts: 1) a description of the industry's overall experience , especially how many power plants have used optimization and what results they have achieved; and 2) lessons learned from this industry experience.

4.1 General experience of the utility industry

During the last 10 years, optimization software has been installed in approximately 280-300 coal-fired units; 100 to 130 of these systems are still in operation, all of them in close-loop mode.

Developing a definite estimate about the number of plants using optimization software is very difficult and time-consuming; also, many utilities and optimization vendors are not willing to share such information. However, this study's objective is not to count every single project but rather to get an accurate overall picture of what is happening in the industry.

The estimate of optimization systems in operation (100-130) is based on contacts with 15 utilities that have installed optimizers in multiple plants (representing a total of approximately 100 units). This number does not cover all plants with optimizers, but was used to develop an estimate of the general experience in the industry and is considered adequate for the purposes of this report. More specifically, the estimate for the plants using optimization was developed considering a number of different developments:

- ULTRAMAX had approximately 65 installations, none currently operating. In addition to the fact that Ultramax Corp. does not exist any more, Ultramax software was not configured to operate in closed-loop mode and, as such, it stopped operating as soon as plant engineers stopped using it.
- GNOCIS had approximately 20 installations with only one still operating.
- Some Pavilion installations continue to operate while others do not (Pavilion technology was acquired by Pegasus). Based on a sample of users contacted by phone, it is estimated that 50% of the software is still in use. However, these installations either need to upgrade to more advanced versions of the commercially available software or stop operating soon. Availability of maintenance and technical support is a key issue facing these installations. Some plants have obtained technical support from Pegasus, others (for example, Reliant's Conemaugh and Keystone) from third parties, and a few are maintaining the software themselves.
- Thirty to fifty percent of plants that have installed NeuCO and Pegasus software are not using the products any more for a variety of reasons (see below). In many cases, lack of use is not necessarily due to dissatisfaction with the optimization software.

- Emerson reports 108 installations of optimization software, but many of them involve optimization of steam temperatures alone; only 24 coal-fired installations were identified with multi-variable and multi-objective optimization.

In addition to cases where optimization suppliers were acquired or stopped operating (for example, Pavilion and Ultramax), other important considerations have contributed to the decision to stop using an optimization system that had been installed, calibrated, and successfully operated. Key factors contributing to shutting down such optimization systems include the following:

- *The initial motivation for the optimization project no longer exists*. This has been the case with many of the early projects (in the mid-1990s). The Clean Air Act Amendments (CAAA) of 1990 provided incentives for early compliance and flexibility to implement optimization to avoid installation of low-NOx burners or overfire air. However, subsequent regulations required installation of low-NOx burners and (in many cases) SCR systems, which reduced the need for NOx reduction through optimization.
- *Change of hardware required recalibration of the optimization system.* This is closely related to the previous factor and involves mostly installation of NOx controls (for example, low-NOx burners, overfire air, SCR, and SNCR). Also, there were cases in which the economizer or the air heater was replaced or the coal quality changed significantly. Theoretically, such changes do not eliminate the need for optimization. In fact, they provide an additional incentive for optimization. For example, in the case of SCR, an optimum operating point can be sought that reduces the ammonia costs while satisfying NOx emission requirements. However, some utilities found it more practical to shut down their optimization systems. Their main reason was that recalibration of the optimization system, while feasible in many cases, was not simple (certainly not as simple as changing a few parameters by the plant performance engineer, which some software suppliers claimed). Recalibration requires the support and involvement of the optimization supplier, which means additional expenses. So, the perception of some utilities was that the effort exceeded the expected benefit. Getting approval at a time of tight budgets to pay the optimization vendor to assist in recalibration also was perceived as too expensive or too difficult .
- *Operators and performance engineers perceived that the benefits from the optimization system did not outweigh the costs.* While the cost-benefit relationship is very site-specific, most optimization projects that have been evaluated thoroughly have concluded that optimization is very cost-effective, with payback periods less than three to four years and often less than one year. Nevertheless, there is often a perception that benefits do not justify costs, and a decision is made to shut down the optimization system. Examples of such perceptions (in most cases, without proof) were
    - optimization increases furnace slagging and backpass fouling;
    - optimization cannot handle frequently varying coal quality (this was stated by two utilities using lignite);
    - too many variables outside the control of the optimization system (for example, changes in coal quality or condenser backpressure) constrain its ability to achieve significant performance improvement;

- operators did not understand the need for and did not like the frequent operating changes required by the optimization system, especially during software calibration;
- a smart operator can do as well as the optimization system; and
- the job security factor: the optimization system will replace the operator and/or the performance engineer.

- *As soon as the plant champion was transferred out of the power plant, the optimization system was shut down.* This was the case in a number of power plants that successfully completed installation, calibration, and operation of the optimization system.
- *Some older units without DCS and adequate instrumentation installed the software, but it was proven ineffective.* Lack of a digital control system (DCS), lack of adequate instrumentation, and a limited number of control variables (for example, lack of remote capabilities to adjust air registers) were some of the reasons stated for shutting down optimization systems. This experience was recounted by a number of utilities (for example, MidAmerican and Cinergy) that were planning to install optimizers in all units, but stopped short of installing them in old units with inadequate instrumentation and controls.

Many utilities have either a system-wide license or have decided to optimize most of their units.

A number of utilities have obtained system-wide licensing:

- Ameren installed Pegasus at all four units of its Labadie station (each 575-620-MW), Meramec #1 and 2 (2004), Rush Island #1 and 2 (2004), and Sioux #1 and 2 (2005).
- Cinergy (Pegasus) at Cayuga #1 and 2, Gallagher #2 (2002), and remaining plants later on.
- MidAmerican (Pegasus) at Council Bluffs #3 and Neal 4; MidAmerican also plans to optimize Neal #1, 2 and 3, Louisa #1, and Riverside #5.
- TXU (Pegasus) at Big Brown #1 in 2002; in 2003-04, TXU implemented Pegasus at Big Brown #2, Martin Lake #1, 2, and 3, Monticello #1, 2 and 3, and Sandow #4.
- We Energies (Emerson) at Valley Power #1-4 in 1999-2000, Presque Isle #3-6 in 2001, and Oak Creek #7 and 8 in 2004.

Dynegy is the utility that has used the most commercially available optimizers, including Ultramax (in four plants), Pegasus (at Hennepin #1), Emerson (at Hennepin #2), and NeuCO (at Baldwin and Wood River[3]). Dynegy also is planning to install more optimizers at Havana #6 in 2006, Danskammer #3 in 2006, Danskammer #4 in 2007, and Roseton #1 and 2 later on. Dynegy's approach is to evaluate the available optimizers on a plant-by-plant basis.

Optimization proves effective in reducing NOx (5-35%) and heat rate (up to 1.0 percentage point for base-loaded units and higher for load-following or cycling units).

Recent experience confirms earlier reports (for example, EPRI's TR-110718) that NOx reduction in the 5-35% range can be achieved with optimization software. Of course, most well-tuned boilers tend to fall in the lower end of the range (5-20%) depending on the number of control

[3] Both planned projects; not operational yet.

variables available and the operating range for each variable; the higher the number of variables and the wider the operating range, the higher the probability for a higher NOx reduction.

NOx reductions above 25% often resulted from the fact that the unit was not well tuned. In these cases, significant NOx reduction could have been achieved by tuning and using knowledge of NOx formation in boilers before optimization was implemented (for more details, see EPRI TR-110718 and TR-105109[4]).

Heat rate improvement up to 0.5% at full load and higher (up to 1.5-2.0%) at lower loads has been reported. However, these are approximate estimates because it is difficult to monitor heat rate on-line. There also are numerous external (uncontrollable) parameters that may affect heat rate more than controllable parameters that are available to the control system and the optimizer.

<u>Cyclone boilers</u>

Specifically for cyclone boilers starting to implement optimization systems, a concern was expressed by some utilities regarding potential adverse impacts and the likelihood of achieving significant NOx emission reductions and performance improvements. There are a number of cyclone units that have already used optimization software. Two pertinent plants are

- Constellation Power's Crane station #1 and 2 and
- Ameren's Coffeen #2.

Both of these plants have installed Emerson's optimizer. Crane reports[5] NOx reduction in the 17-44% range with an average of 25% over the load range, which is consistent with the experience of other types of boilers.

Utilities in the early stages of deploying optimization in cyclone boilers are

- MidAmerican at Neil #1 (Pegasus),
- Ameren at Sioux #1 and 2 (Pegasus), and
- Dynegy's Baldwin (NeuCo).

The difference between cyclones and other types of boilers is that cyclones have a narrow window of operating conditions and less flexibility (lower number of control variables) to change their operating conditions. The addition of overfire air ports increases operating flexibility and the number of control variables and makes it more suitable for optimization. To optimize cyclone boilers effectively, each cyclone must be monitored and controlled. In most cases, this requires new instrumentation.

The industry is making a significant effort to expand optimization (beyond combustion and boiler performance) and link it to other modules, but the experience is not conclusive yet.

The first expansion of the optimization system is the extension from combustion or boiler performance optimization to include post-combustion NOx controls (SNCR and SCR) and FGDs. Nearly all optimization suppliers are developing such models, but it is not clear yet how valuable integrating these components with boiler optimization will be. For post-combustion

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[4] TR-105109, *NOx emissions testing and optimization for coal-fired utility boilers*.
[5] *Power Engineering*, October 2004, page 72.

NOx control, there is a clear incentive to reduce ammonia costs and optimize catalyst life, both of which can be affected by combustion optimization. However, it is not clear whether integrating a module, such as FGD, offers an added benefit.

Another component considered for integration is sootblowing optimization. Many such systems have been developed recently and optimization vendors are active in trying to integrate them into their product offerings or at least be able to interface with them. So far, we know of no experience of a combustion or boiler optimization system fully integrated with a sootblowing system.

Also, there were plans to integrate on-line heat rate monitors with optimization software. Portland General Electric's Boardman plant was planning to integrate Exergetic Systems' Calculational Engine with NeuCo's optimizer, and Constellation Power's Brandon Shores was planning to link the Calculational Engine with the Pegasus optimizer. Both utilities have abandoned their plans for such integration after encountering a number of problems. No details have been made available regarding specific issues; whether the problems were related to the approach followed at the specific site or were more fundamental to these types of systems could not be determined by this study. The author believes that it is the former; with appropriate configuration and interfacing of these two systems, they should be able to interface without serious problems.

Some vendors claim full integration among many of the above modules, as well as coal blending and maintenance optimization. However, smooth integration and operation has not yet been proven.

Realignment of optimization suppliers continues with more active participation of power plant controls suppliers

With the GNOCIS team becoming less active in the last two years, the leading suppliers of optimization systems are Emerson, Invensys, NeuCo, and Pegasus. The latter two have, from the beginning, developed and applied neural-network-based optimization systems. Emerson and Invensys are traditional power plant controls vendors who expanded their product line to optimization.

There are some differences in the approaches these two groups take, which utilities should take note of:

- Controls vendors are more inclined to offer many "topical" optimization modules and put less emphasis on global multi-objective optimization, which has been the trademark of neural network optimization systems.
- Neural network optimization suppliers have (or more accurately, are developing) a broader array of optimization modules and are expanding the technology envelope to include optimization modules such as SCR, FGD, electrostatic precipitation (ESP), and maintenance, as well as links to enterprise-level software.
- Controls vendors use all techniques available (including neural networks, artificial intelligence, and empirical correlations) on an as-needed basis instead of relying almost exclusively on neural networks.
- Controls vendors also have optimized systems outside the boiler, most notably steam temperature optimization, which has not been the focus of neural network vendors.

- Controls vendors seem to be exerting downward pressure on optimization system costs, including both the system's initial price and maintenance agreements. Most likely, this trend is related to the fact that the incremental cost of offering an optimization system should be lower from those companies that may already have offered a controls system and are already on site providing maintenance support to the utility.

This is not an endorsement of either group; every application has unique characteristics and requirements that may be more suitable for one or the other approach. Also, pricing varies significantly from project to project, making it necessary for utilities to consider all suppliers and evaluate them based on what they are offering for their specific project.

4.2 Lessons learned

All vendors of power plant software are capable of implementing a successful optimization project. Specific individuals involved in the project team could make a difference in a project's success.

Every single supplier of optimization software has demonstrated that it is capable of having a successful project. What has made the difference between successful and unsuccessful projects has been the specific expertise of the individuals involved in the project. While optimization software is capable of handling the optimization task, very often it is up to specific individuals to effectively communicate the project's objectives and operating constraints and, in general, use their knowledge in power engineering, controls, and optimization to achieve the project's objectives. A number of utilities have concluded that it is important to review carefully the resumes of all project participants and (ideally) interview them before selecting an optimization vendor.

For optimization projects to succeed, a corporate commitment to improve plant performance is needed.

There are a number of good examples of successful optimization projects that more than anything else reflect the corporate commitment to performance. This commitment is reflected in the allocation of an appropriate budget, availability of staff both at headquarters and in the plant, installation and calibration of instrumentation, use of modern control systems, and the right emphasis and incentives to performance improvement. Examples of such commitment include the following:

- Ameren Corp. considers plant performance enhancement a capability that gives them a competitive advantage and, as such, they try to build and keep this capability within the organization. For this reason, Ameren's performance engineers are very knowledgeable in power engineering and combustion and are very involved in installing and maintaining optimization systems. Also, they monitor developments in the industry and are prepared to invest in new technologies. However, their "focus is not technology, but achieving results." Recognizing that they may not have all the power engineering expertise, they have a close working relationship with a large architect engineering (AE) company to which they provide on-line access for performance monitoring and seek advice on an as-needed basis. Ameren recognizes that instrumentation is very important and is prepared to add what is needed to make optimization successful. Examples include feedwater heater monitors and on-line condenser air leakage monitors. A "report card system" ensures that all instrumentation and control (I&C) related issues are addressed on a frequent basis (monthly meetings). Each plant has a performance improvement champion supported by the engineering staff from headquarters. As a result, Ameren has some of the most successful optimization projects, including the four units at Labadie that have had Pegasus optimization software for more than four years and have received national recognition.

- Portland General Electric is another company committed to performance enhancement. While its approach is different from Ameren, it has invested heavily on monitoring and heat rate enhancement and achieved significant improvements at its Boardman station, even though optimization software eventually did not play an important role there. As documented in EPRI report TR-1004749[6], the company invested heavily in
    - new instrumentation, including temperature and pressure measurements in feedwater heaters, turbine cross-over piping, steam turbine inlets, feedwater pump and boiler feed booster pump, additional O2 probes in the stack to account for flow stratification, moisture monitors at the stack, and orifices in steam lines;
    - extensive parametric testing and analysis to determine heat losses and significant heat rate improvement by reducing air in-leakage and eliminating water/steam leaks;
    - installation of an on-line heat rate monitor (from Exergetic Systems); and
    - installation of an optimization system (from NeuCo).

  New instrumentation, parametric testing, and analyses were part of Portland's on-line heat rate optimization that used Exergetic Systems' Calculational Engine™.

In most cases, optimization projects are easily justified by cost-benefit analysis, but very often utility management is reluctant to approve such projects. Having corporate support and commitment is essential for making decisions to implement optimization projects.

Get plant buy-in before starting to implement an optimization project.

There are many optimization projects that have been implemented successfully, but as soon as the project team left the site, plant staff did not continue using them. These were cases where utility headquarters conceived of the optimization project and proceeded to implement it without an effort to get plant staff buy-in. Project success depends almost exclusively on whether plant staff has been convinced of optimization's value.

Plant staff has its own concerns and perceptions that need to be addressed early on; staff needs to be convinced why the project is valuable and how it is going to enhance employees' abilities to better do their job. As mentioned earlier, there are frequent misconceptions that need to be addressed:

- *"The optimization system will replace the operator and/or the performance engineer:"* Obviously, this is not true, but plant operators deserve an explanation on how optimization will allow them to do their job better; they need to be convinced that optimization is giving them the flexibility to change performance objectives, analyze alternative operating conditions, improve set points and, in general, reduce plant operating costs. It should be clear that it is beyond the capabilities of the human mind to monitor a high number of

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[6] On-line Heat Rate Monitor Assessment/Results of the Demonstration and Application of Exergetic Systems' Calculational Engine, Dec. 2004.

parameters and conflicting objectives, and optimization is just another tool to allow us to analyze a complex situation. The plant operator and performance engineer are needed, nevertheless, and the optimization system will not replace them!

- *"Optimization costs outweigh benefits:"* Site-specific evaluations have shown conclusively that this is not the case for most plants. However, plant staff (including plant manager, operators, and performance engineers) needs to be convinced of the value of optimization by credible and detailed analysis.
- *"Optimization increases furnace slagging and backpass fouling:"* This is not a necessary outcome of optimization. If the formulation of the optimization problem is not done appropriately, increased slagging and/or fouling are possible outcomes. However, many optimization projects have demonstrated that not only can such adverse impacts be avoided, but persistent slagging and/or fouling can be eliminated or reduced through optimization.
- *"Optimization cannot handle frequently varying coal quality:"* Similar to slagging and fouling, variability in coal quality can be handled adequately. Of course, a sudden and substantial change in coal quality would require that the optimization system be recalibrated for the new coal.
- *"A smart operator can do as well as the optimization system:"* As mentioned earlier, this is true when the number of parameters (control variables) is limited and there is a single objective (for example, reduce NOx emission or improve boiler efficiency). However, with many parameters being monitored and the need to optimize multiple and often conflicting objectives, it is nearly impossible for a plant operator to achieve optimum results without a well-designed optimization system. For example, the objective may be to balance NOx reduction with heat rate improvement, unburned carbon, and economics related to consumption of ammonia (in the SCR/SNCR) and sorbent (in the FGD). It is impossible for an operator to keep track of so many parameters and objectives and to identify the optimum solution.
- *"Operators do not understand the need for and did not like the frequent operating changes required by the optimization system, especially during software calibration:"* This is, indeed, an issue that is encountered in many plants. In fact, the more knowledgeable the plant engineer is on power engineering design and operation, the more difficult it is to accept the need to frequently change operating conditions so the optimization system can "learn" the plant's performance characteristics. Training should address this issue and provide engineers with a good understanding of how the optimization system is learning the plant's characteristics.

One approach utilities may consider is to have a demonstration project in one of its plants during which engineers and operators from other plants have a chance to participate and learn before the system is implemented in their plant. Such projects also may provide an opportunity to create "a team of champions" who can be assigned to the other plants to assist in implementing optimization projects.

Make sure there is a "plant champion."

A plant champion is not necessarily a promoter of optimization, but rather somebody who is able and willing to use the optimization system and can assist others in using it as the need arises. The plant champion has been trained to modify the settings of the optimization system, use it to analyze specific operating conditions, troubleshoot it, and, in general, use it to improve plant performance. Most often, the plant champion is a performance engineer.

Having a champion at the plant was singled out as the key element that contributed to the success of optimization projects. Examples:

- Ameren's Labadie consistently achieved excellent results by having one electrical and two mechanical engineers dedicated to providing performance improvement support, part of which was for optimization.
- Similarly, Dynegy's Hennepin plant was equipped with Pegasus on Unit #1 and Emerson software on Unit #2; originally there were two engineers on site and one at headquarters who provided optimization support.
- There are numerous cases where a successful project was terminated as soon as the plant champion moved out of the plant. For example, application of GNOCIS software was completed successfully at TVA's Kingston Unit #9. However, after the optimization champion moved to another plant, optimization was not used and plans to apply it to the plant's remaining units were changed. The same outcome occurred at three Dynegy plants that implemented Ultramax optimization.

The implementation team of an optimization project needs to bring together expertise in 1) power plant engineering (knowledge of power plant design and operation), 2) instrumentation and controls, and 3) optimization techniques.

Knowledge in all three areas (power plant engineering, I&C, and optimization) is essential for the success of an optimization project. It is not important whether an expert is part of the utility staff or the optimization vendor as long as the expert is available and committed to support the project when needed. There are many examples in which a vendor who had just completed a very successful project failed in a new project simply because the people with the right expertise were not available.

Often, some of the expertise, especially in power engineering and I&C, resides with the utility, either at headquarters or the plant or both. It is important to make sure that such experts are available to support the project.

The level of expertise available in-house varies significantly from utility to utility, and frequently the need arises for certain experts to be provided by the optimization vendor. In the 1990s, when optimization software first came on the market, many vendors had adequate expertise in optimization techniques and software engineering, but very limited expertise in power engineering and I&C. Since then, most of them have recognized the need for such expertise and have hired the right people.

However, optimization vendors have gone through phases when they did not have adequate expertise in power engineering and I&C. This lack of expertise was due to staff turnover or varying volumes of business, which forced them to lay off experts. There were other times when too many projects were being implemented at the same time, and the few experts they had in these technical areas (power engineering and I&C) were not available to support all projects.

Many utilities recommended (and we concur) that

- *you should request resumes of all the people provided by the optimization vendor;*
- *if possible, you should ask to interview these vendor experts; and*
- *you should ask for assurances (in writing) that the experts will be available and committed to your project.*

Furthermore, it is ideal to keep the implementation team together for multiple projects (in more than one unit and power plant) of the same utility. For example, TXU noted that they were very fortunate to have the same team implement optimizations at six different power plants. The fact that all these units were tangentially-fired boilers (similar design) helped, too.

Long-term maintenance and technical support by the optimization vendor is a must.

A long-term technical support agreement with optimization suppliers is highly recommended. The strategy of some utilities is to build expertise in-house in the use, modification, and maintenance of the system. Even in these cases, optimization vendors could be helpful (for example, when significant changes in the equipment or the operating conditions require recalibration of the optimization system). Also, the utility should have access to software upgrades that improve its usefulness and add capabilities. The long-term maintenance-technical support agreement can be designed to fit the needs of each utility and power plant.

Following are two examples covering the spectrum of support provided by optimization suppliers:

The minimum support case: Ameren has a maintenance support agreement with the optimization supplier (Pegasus for most of its plants), but the support provided is minimal. Ameren staff is using the optimization system and has become familiar with most adjustments that need to be made as part of routine operation and minor software maintenance. The optimization supplier is called to address only major changes and problems (on demand only, since no electronic access has been provided).

The maximum support case: The Roanoke Valley Energy facility (part of Louisville Gas & Electric) is a small utility and has a technical support agreement with NeuCo, which monitors the optimization system remotely and makes all required changes. Sometimes NeuCo makes changes based on what it sees in the optimization system and sometimes in response to requests from plant staff.

Maintenance support agreements are not fixed price, and significant differences have been observed from supplier to supplier. Utilities also have been able to negotiate agreements at very reasonable costs, depending on how the overall project has progressed (for example, whether the utility is satisfied with the overall performance, and whether the vendor was able to meet guarantees).

Remote access by the optimization vendor is a must.

Most utilities started implementing projects without giving remote access to the optimization vendor. Soon, they realized the value of providing such access, which has become a standard feature in most projects. As soon as remote access was arranged, there was usually significant improvement, especially in the reliability of the optimization software and the results achieved.

There are two types of remote access:

- Full access
- Access on demand

In the first case (full access), which is the most common and most effective, the optimization vendor can log into the plant optimization system anytime and make changes. Of course, changes are made after consultation with plant staff or based on an agreed-upon protocol. In the second case (access on demand), the optimization vendor has to call utility staff to obtain access.

With cyber-terrorism being a major concern for utilities, remote access may not be as simple as it used to be. First of all, there are communication standards that are being developed and used industry-wide. For example, software should be compliant with the Electric Utility Cyber Security Guidelines (NERC 1300/CIP 002-009). Utilities and optimization vendors should be aware that these standards are revised periodically.

Each utility has established guidelines that need to be followed to provide access to third parties (including passwords and security clearance procedures). These guidelines need to be made available to optimization vendors during bidding or negotiations, certainly before the contract is finalized and project implementation starts.

In some cases, optimization vendors may provide remote client software, which facilitates remote access for tuning and monitoring. Also, the preferred communication method—VPN (Virtual Private Networking), modem, or access through DMZ servers—needs to be specified.

Schedule: Allow for a minimum of five to six months from kick-off meeting to closed-loop operation.

Optimization vendor estimates of the time from kick-off meeting to closed-loop operation of the optimization software range from three to six months. Utility experience has proven that it is more realistic to plan for five to six months. Certainly, there have been projects that were implemented in four months, but there also are others that required more than 12 months. In some cases, extended schedules resulted from difficulties calibrating the optimization system. In other cases, delays were not related to the optimization system, but to plant issues. Such issues included lack of critical instrumentation, plant staff decisions to wait until significant hardware or operating changes were made to the plant, and longer-than-expected delivery of computer hardware or instrumentation. There were two cases where schedules were delayed more than 12 months because the optimization system did not meet guarantees, and plant staff decided to wait until hardware changes were completed before attempting to recalibrate the optimization system.

The project start date also is a factor that may affect the schedule. Minimum duration should be expected when the optimization project starts in early spring or early fall, and there are no outages planned for units that will be optimized. In this case, the units have more flexibility in terms of operation (system dispatch requirements are less demanding during spring and fall) and are least likely to be affected by adverse weather conditions.

A typical project schedule is outlined below:

	Weeks from kick-off meeting
• Contract award and kick-off meeting	0
• Workplan, functional design, and test plan review	6
• Hardware acquisition and integration for plant data acquisition	8
• Problem formulation, optimizer on-line and model development	12
• Data acquisition, model calibration, and testing	22
• Closed-loop integration	24
• Acceptance testing and training	25

Acceptance testing could take as little as one day or up to one month. The schedule above assumes that acceptance testing is one week.

Different optimization vendors have different requirements in terms of

- use of historical data,
- need for parametric testing, and
- model development (off-line or automatically).

Such activities may stretch or reduce the project's duration .

Optimization of multiple, identical units at the same plant could be done in a shorter schedule. After the first unit at the plant is optimized, the next unit could take 30-40% less time. While optimization of many units in parallel is feasible, it is not recommended. However, after the first unit is optimized, parallel optimization of the remaining units is less likely to encounter problems.

Typical costs for an optimization project

The costs of optimization projects should include the following:

- Out-of-pocket costs for software acquisition and installation
- Out-of-pocket cost of annual maintenance
- Internal costs for
    - Software acquisition and installation
    - Software maintenance and use

Out-of-pocket costs for software acquisition and installation

The average out-of-pocket cost for recently implemented optimization projects (based on at least 10 power plants that reported costs, as well as estimates provided by optimization vendors) is $400,000 for the first unit and $300,000 for the next unit at the same plant. However, the most recent projects show clear downward pressure on prices with suppliers willing to reduce prices by 30-50% below the $400,000 level. This downward trend is expected to continue, but it is not easy to predict whether prices will stabilize at a certain level or continue their downward spiral. A price in the range of $200,000-300,000 for the first unit seems possible within the next few years.

The above estimates include computer hardware (which should not cost more than $5,000), but do not include instrumentation that may be needed to enhance the effectiveness of the optimization system.

Out-of-pocket cost of annual maintenance

Annual maintenance costs are negotiable and range from zero to about $50,000 per year. No cost (zero) has occurred when the optimization supplier has installed a new controls system at the same site. Zero cost also has resulted when the supplier did not meet optimization project guarantees and offered maintenance free of charge for a couple years. For planning purposes, maintenance support agreements should be calculated in the $20-40,000 range per year.

Internal costs

These costs are usually overlooked; also, they are more difficult to estimate. Software acquisition, installation, and calibration are a project's most labor-intensive tasks. Assuming six months for installation, calibration, and closed-loop integration, it is estimated that three man-months of a performance engineer are needed, including training. This is approximately 50% of one engineer during this period of time. If more engineers are involved, the estimated level of effort may reach four man-months.

During software use (after calibration is completed and optimization is operating in closed-loop mode), an engineer responsible for the optimization system should monitor it periodically, adjust objectives, maintain it as needed, communicate with the optimization vendor, and use it to analyze plant performance.

Ten to twenty percent of an engineer's time is needed for an optimization system once it has been integrated to operate in closed-loop mode. Utilities interviewed suggested that 10% of an engineer's time is a minimum and 15-25% is most desirable. For example, one assigned plant engineer indicated that he spends 5% of his time with the optimization system, but according to him this is clearly inadequate.

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