Least-Cost Power Generation Using PECOS: A Status Report for the Project at Genoa

Dr. Andrew Maxson

Praxis Engineers, Inc.

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Abstract

The Plant Environment and Cost Optimization System (PECOS) is an on-line supervisory control software package designed to optimize the operation of fossil-fired power plants while meeting all operational, environmental, and safety constraints. PECOS provides least-cost setpoint recommendations to operators by assessing all of the economic tradeoffs inherent in power plant operation.

PECOS consists of three core modules:

- *Coal Blend Automation System (CBAS)* recommends the use of optimal coal blends based on power generation requirements, emissions constraints, fuel availability, and cost.
- *Boiler and NO_x Control System (BANCS)* recommends optimal boiler side control setpoints to operators in real-time. BANCS also acts to control NO_x while achieving the best balance between other emissions, heat rate, and generation costs without violating operational constraints.
- *Steam Cycle Optimization System (SCYCLOPS)* recommends optimal steam side control setpoints to operators in real-time while making sure that operational constraints on steam side equipment are not violated.

Each module uses detailed computational modeling to simulate plant operations. The modeling balances the computational speed inherent with real-time control with the need to produce reliable setpoint recommendations. To that end, PECOS uses a mix of analytical and neural models to simulate plant performance.

PECOS has been customized for the Genoa Thermal Station located in Wisconsin. As a first step, a complete PEPSE model was assembled for Genoa. Upon establishing its accuracy in comparison with measured data, its outputs were then used as a guideline for simplifying the PECOS modeling to improve its computational speed without unnecessarily compromising its accuracy. The long term goal is to use PEPSE as a tool to generate data for the PECOS models

for off-load and abnormal firing conditions instead of performing costly and time consuming tests on the actual plant.

This paper presents a status report of the ongoing PECOS project at Genoa, as well as details of how PEPSE was used to aid the modeling efforts.

Introduction and Background

With the increasing emphasis on environmental concerns, coupled with increasing competition, utilities operating coal-fired power plants need effective tools to maintain optimal, least-cost operations even when coal quality, emission goals, operational constraints and load conditions are changing. The Plant Environmental and Cost Optimization System (PECOS™) is a supervisory control software package designed to optimize the overall operation of fossil-fired power plants while meeting all operational and safety constraints, including in particular emission limits. Specifically, PECOS provides real-time control setpoints to operators for running the plant at minimum cost without violating system constraints.

PECOS assists the operator in making setpoint control decisions by using more real-time data and process knowledge than the operator is otherwise able to take into account. However, PECOS only provides the operator with *recommendations* that can be implemented at his or her discretion.

PECOS is designed to consider the entire power plant as a whole. Typically, subsystem control systems are independently operated units designed with little regard to their interactions with the rest of the plant. Process controls that are not well integrated with the main plant process controls cause the systems to react non-optimally to changes in coal quality, load shifts, out of service equipment, and other plant operating parameters. Simply put, a plant can be operated at lower overall cost if its operations can be optimized as a whole, rather than as a collection of unrelated subsystems. PECOS determines the optimal control setpoints by automatically assessing all of the economic trade-offs inherent in system-wide power plant operation.

This paper presents an overview of PECOS, including a technical description and a discussion of benefits. In addition, the paper gives a status report of the customization of PECOS for the Genoa Thermal Station, and the use of a detailed PEPSE model written for Genoa to improve the speed of the PECOS software.

Product Description

PECOS consists of three core modules that represent the most important systems in the plant:

- *Coal Blend Automation System (CBAS™)* models the entire coal handling system from receipt through to the burners. CBAS recommends the use of optimal coal blends based on power generation requirements, emissions constraints, fuel availability, and cost.
- *Boiler and NO_x Control System (BANCS™)* models the entire boiler side of plant operations. BANCS recommends optimal boiler side control setpoints to operators in real-time. BANCS also acts to control NO_x while achieving the best balance between other emissions, the sale or disposal of ash, heat rate, and generation costs without violating operational constraints.
- *Steam Cycle Optimization System (SCYCLOPS™)* models the entire steam side of operation. SCYCLOPS recommends optimal steam side control setpoints to operators in real-time while making sure that operational constraints on steam side equipment are not violated.

Each of these three core modules can be used separately or in combination to optimize key aspects of the plant or the entire plant, as desired. Common with each module is a central architecture that is integrated with the existing plant distributed control system (DCS) or data highway.

The PECOS family of products is designed to be easy to use, with simple user interfaces used by operators and managers alike via a local or wide area network (LAN or WAN). Much of the required information used by PECOS concerning plant performance is obtained automatically through the data acquisition system, but considerations such as emission constraints or unit cost information are manually entered through the interface by the appropriate users. In addition, PECOS has the capability of performing what-if scenarios as a performance guide for investigating changes in plant conditions or alternate operating cases.

The PECOS is connected via a host computer gateway to the plant DCS. PECOS was developed in C++, using object-oriented programming (OOP). Using an OOP framework makes it easy to swap-out or upgrade subsystem models, algorithms, or other components without affecting the rest of the system. This reduces the cost of the final product and enhances its robustness, flexibility, and maintainability.

PECOS employs a modern Graphical User Interface (GUI) for ease of operator training and use, and runs under the utility's multitasking operating system. The entire system is integrated into the LAN and WAN, allowing management, engineering, and operators simultaneous access to PECOS with the ability to input or use information for their own purposes.

Benefits of PECOS

While power plants are concerned with improving *subsystem* efficiencies such as boiler efficiency, they are operated without considering overall *generation* efficiency, especially where interacting environmental, operational and economic issues are involved. For example, only a few plants pay attention to all of the changes in performance brought about as a result of changing coal quality. As a consequence, they not only pay excessive prices for coal but also frequently suffer opacity- or SO_2-related derates. Management of the coal in the yard combined with blending control and properly selected operational setpoints can result in optimal performance wherein derates are eliminated and costs are reduced. Another example involves the control of NO_x, where a number of operating variables including coal quality, excess air, mill settings, grind fineness, distribution of combustion air, and burner biases, interact with one another while also affecting other emissions, heat rate, and generation costs. These competing issues and priorities are reconciled by PECOS to achieve the best balance between operational and emission targets and economics by optimizing them under a single cost function, namely overall cost of generation.

PECOS is particularly valuable in the present climate of increasingly stringent environmental regulations and competitive pricing pressures in the marketplace. Plant operators have to consider a large and ever-growing pool of information and data to make control decisions in order to achieve compliance on the one hand and cost-effective operation on the other. In most cases it is simply not possible for an operator to integrate all of the necessary information in real-time without computational assistance. PECOS provides just this type of help to the operators by integrating all technical and economic data and presenting them with concise recommendations for the necessary plant settings. This approach will result in improved heat rates, thereby lowering CO_2 emissions, achieve better and easier compliance with opacity, SO_2, CO, and NO_x emission targets, and do so at the lowest possible cost of generation.

Other benefits provided by PECOS include:

- It assists in avoiding derates used as a method of avoiding emissions exceedences.
- It aids in eliminating differences in operator-to-operator performance.
- It provides detailed on-line cost breakdowns.
- It can be easily updated by the utility to integrate the performance of new, advanced control subsystems as they become available in the future, allowing the utilities to maximize their benefits from the new systems.

The combined benefits from the use of PECOS in the areas of NO_x reduction, CO and LOI control, SO_2 credits, sootblowing strategy, the potential sale of waste products such as ash or gypsum produced from a FGD plant, fuel savings, and improvements in operations can be significant. Expressed as equivalent savings in terms of fuel cost, they can amount to savings of 3% or more. Thus, a 500-MW power plant using a 12,500 Btu/lb coal with a heat rate of 10,000 Btu/kWh could save up to 50,000 tons of coal per year. Assuming a delivered price of $40/ton, this amounts to annual savings of $2,000,000, while meeting or improving on emissions requirements.

Technical Description and Design

The basic merit of optimal supervisory control systems lies in their ability to process a large body of both measured and calculated information on the state of the plant, performance related issues, emissions, and economic factors in real-time. In order to perform the necessary computations, update its models, and validate its performance, relevant on-line performance data from all included subsystems must be available to PECOS. The data are automatically acquired from the plant control systems. An overview of the technical description of each of the three core modules of PECOS follows.

CBAS Module

CBAS contains models for all of the equipment associated with coal handling, including coal piles, hoppers, silos, bunkers, diverter gates, conveyers, trippers, and feeders. CBAS works in conjunction with the Silo Flow Model™ developed by Praxis Engineers, Inc. that is capable of calculating the complex mixing patterns that occur when coal flows through a silo, bunker, or pile. The modeling enables CBAS to track all coal from receipt through the coal handling system directly to the burners and accurately predict the coal quality at the mill discharge.

Based on the knowledge determined from its models of the quality and location of coal as a function of time, CBAS uses blend advisor consisting of a set of fuzzy logic engines to recommend the proper coal blend for the boiler in advance of its actual arrival there. The blend recommendation can be based on a number of competing factors such as price, heating value, sulfur content, nitrogen content, slagging potential, and opacity potential. The blend advisor assigns weights to each factor to choose the optimal blend within the operating constraints of the coal handling system.

CBAS does not require the installation of on-line quality measurement devices and can work with quality data obtained from the supplier or generated by the utility. Coal quality data is entered manually using easy-to-use GUIs. All other data concerning the operation of coal handling equipment is read on-line directly from the DCS, PLC, historian, or even from analog mimic panels. These data are those commonly available from any coal handling system, such as conveyer on/off status, belt and feeder speeds, weigh scales, etc.

BANCS Module

BANCS combines both physical models and neural models to simulate plant performance. BANCS uses on-line data to validate and adapt its models to provide accurate plant modeling even when plant conditions are changing with time.

Based upon the detailed plant modeling, BANCS uses a powerful optimizer to calculate least-cost setpoints within the specified operational constraints. A combination of genetic algorithms coupled with classical techniques has been developed as the method for the optimization, in order to insure BANCS finds the global cost minimum, rather than a local minimum.

All emissions, performance and cost models are pre-built into BANCS at the beginning of the project, using either neural nets or analytical equations, as appropriate for each model type. Models are calibrated with on-line plant data from each host site. These models include:

- NO_x production
- CO production
- Opacity generation
- ESP or baghouse operation
- Mill and feeder performance
- Sootblowing operation
- Steam cycle performance
- SO_2 credits
- Heat rate
- SO_2 production
- LOI or carbon-in-ash
- FGD or scrubber system operation
- Fan and airheater performance
- Boiler operation and efficiency
- Station service
- Ash and gypsum sales and disposal

The modeling techniques used in BANCS have been selected and adapted to the problems under consideration and are not used indiscriminately. Physical modeling is always preferable to neural modeling, where it is feasible, because it can be applied to all operational regimes and is not dependent upon a large historical database to work. Thus, neural nets are employed only for the specific problems where physical modeling is difficult, complex, and, most importantly, computationally slow. Simple physical models are used for performance models such as pulverizer or fan power draws, and for economic calculations such as fuel costs. Candidates for neural modeling include NO_x, CO production, LOI, opacity, steam temperatures, turbine efficiencies, and condenser heat transfer coefficients.

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The common PECOS architecture uses on-line plant data directly taken from the plant data systems for training and re-training the neural nets during operation, making the neural models adaptive to changing plant performance. A similar method is used to adapt empirical constants used in physical models such as air heater leakage or condenser heat transfer coefficient.

SCYCLOPS Module

SCYCLOPS combines both physical models and neural models to simulate steam cycle performance and include its impacts into the global plant optimization. While a steam cycle model is always included in BANCS regardless if SCYCLOPS is used at a particular site, the addition of SCYCLOPS to the PECOS system provides the additional benefits of the optimal distribution of extraction steam to feedwater heaters, an improvement in condenser performance, and a reduction in pump power. Similarly to BANCS, SCYCLOPS uses on-line data to validate and adapt its models to provide accurate modeling even when plant conditions are changing with time.

Models are customized with on-line plant data from each host site. These models include:

- Heat rate
- Turbine performance
- Pump performance
- Condenser performance
- Feedwater heater train performance
- Station service

Status of the Customization of PECOS for the Genoa Thermal Station

Praxis Engineers, Inc. is completing the customization and installation of BANCS and CBAS for Dairyland Power's Genoa Thermal Station. SCYCLOPS is not included in the optimization at this time, but a detailed steam cycle model has been developed to increase the accuracy and flexibility of BANCS at Genoa. BANCS will be installed in August 1997 while CBAS will be installed in 1998, following a planned plant controls upgrade.

Description of the Genoa Thermal Station

The Genoa Thermal Station, located on the Mississippi River in Genoa, Wisconsin is a 350-MW double reheat power plant. The unit is not base-loaded but rather follows a fairly predictable daily load cycle. The plant uses western and eastern coal blended together to produce a sufficient heating value a lower cost.

The boiler side consists of a set of FD fans and airheaters and four mills equipped with exhauster fans. After the double reheat boiler, the flue gas passes through a set of ESPs and ID fans before exiting through the stack. The boiler uses burner tilt to control reheat temperature and has both low-NO_x burners and overfire air to help remediate NO_x emissions.

The steam cycle consists of 12 turbine stages: a 2-stage high pressure turbine with a subsequent high pressure reheat, then a 2-stage high intermediate pressure turbine followed by a low pressure reheat, then a 2-stage intermediate pressure turbine and finally a set of two 3-stage low pressure turbines. In addition, the boiler feed pump is driven by a steam turbine. The cycle has 4 condensers, including a low and high pressure condenser following the low pressure turbines, an auxiliary condenser that condenses the steam leaving the feed pump turbine and a gland condenser. The feedwater heating system has 4 low pressure surface heaters, 4 high pressure surface heaters and one high level deaerator.

Need for CBAS and BANCS

The need for CBAS and BANCS at Genoa arose in an effort to reduce costs to make the plant increasingly competitive. Genoa has a sophisticated plant data highway already in place, so that all of the necessary on-line data needed for PECOS is readily available, although some data from separate subsystems has had to be routed to the selected PECOS data source

Genoa blends an inexpensive low-Btu PRB coal with a more expensive high-Btu Eastern coal. The coals are currently blended to provide a sufficient heating value for the maximum predicted weekly load. However, Genoa experiences fairly regular daily load shifts.

The goal of CBAS at Genoa is to maximize the use of cheaper PRB coal in its fuel blend and minimize the use of more expensive high-Btu eastern coal. The strategy in this case is to always match the blend quality to the load requirements and use the higher-Btu blends only at higher loads. CBAS recommends coal handling and blending strategies that deliver the right blend to the boilers at the right time. CBAS is capable of shifting blends to track load requirements on short notice, as well.

BANCS will be used at Genoa to lower operational costs and improve heat rate. In addition, BANCS will help remediate NO_x emissions to below the impending 0.45 lb/mmBtu limit. BANCS will also provide a detailed on-line cost analysis that could be used in the future to aid dispatch decisions.

Use of the PEPSE Model for Genoa

In an effort to improve the computational speed of PECOS at Genoa without unduly sacrificing accuracy, the modeling software PEPSE™ Version 60H was used to create a computational model of both the steam and boiler systems, in order to generate data for the calibration of PECOS. The model was originally created to assist engineers in testing plant performance to varying conditions, including changes in coal blend. It has garnered extensive use at Genoa and is accepted as a reliable tool for simulating the operational performance of the plant. The model is meticulously detailed, including the myriad steam leakages in the steam cycle and all of the heat transfer sections in the boiler, providing good predictive accuracy in comparison to actual measured plant data.

The PEPSE modeling was used as a basis for comparison for the internal modeling contained in PECOS. Because the PEPSE model is so detailed, it is capable of providing accurate data for quantities that are not directly measured at the plant. Also, PEPSE is capable of providing data for load conditions which are not contained in the stored measured data history. This can be particularly useful for filling in data for missing operational regions required to make neural models more robust and comprehensive without requiring special boiler tests.

In addition, the PEPSE modeling has been used to generate data to speed up and simplify calibration and modeling on the steam side. A set of PEPSE runs was performed over a range of loads to provide data for:

- Turbine leakage flowrates, including gland, bushing, and seal leakages
- Turbine steam extraction flowrates for the feedwater heaters
- Turbine efficiencies

Turbine leakage flows are not measured at Genoa, hence no existing data could be used. For BANCS, a curvefit of leakage flow as a function of input pressure, temperature, and flowrate to the particular turbine stage was calculated from the PEPSE data. This step does not significantly degrade the accuracy of the PECOS model and eliminates backcalculations.

A similar methodology was used for curvefitting turbine steam extraction flowrates to the feedwater heaters. Although this can be readily modeled analytically, numerous iterations are necessary to insure that both mass and energy are conserved locally and throughout the entire system, greatly increasing the necessary computational time. The degradation in accuracy for the calculation in turbine heat rate using this method in comparison to the detailed calculations made by PEPSE is less than 5%.

For the case of turbine efficiencies, on-line data exists that can be used for neural models. However, care must be taken in using this data, as most of it is invalid during unsteady operation when equilibrium has not been achieved. The PEPSE data was used only for the preliminary curvefitting, but may also prove useful in assisting data validation routines that assess the usefulness of the measured on-line data.

Conclusions

The optimization software, PECOS, provides plant operators with optimal, least-cost settings based on an analysis of all factors in real-time. PECOS is capable of optimizing the entire plant, from providing optimal coal blends using CBAS, to recommending least-cost setpoints for the boiler and steam cycle using BANCS and SCYLOPS. This leads to the "best possible" operation under all conditions, improves shift-to-shift consistency of operation, and results in lower emissions.

This paper detailed the status of the customization of PECOS for the Genoa Thermal Station. PECOS will provide real-time advice on how to blend low-Btu and low cost coal with high-Btu and high cost coal to insure the right heating value at the lowest cost, while also recommending optimal boiler setpoints designed to improve heat rate and further reduce overall costs.

The PEPSE modeling software was used to generate data sets to improve the computational speed of PECOS without unduly sacrificing accuracy.