# Black Boxes Broken Open
# An Open Web-Based Economic Optimization Tool

Jeff Williams
Emerson Process Management Power and Water Solutions
200 Beta Drive
Pittsburgh, PA 15238
Jeffery.Williams@EmersonProcess.com

**KEYWORDS**

Browsers, Linear models, Neural Network models, optimization

## ABSTRACT

It is possible to think of the word optimize as being composed of two ideas: that of options or choice and the idea of maximizing or minimizing the operating situation by selecting the most appropriate choice. Thus, whenever there is a situation where two or more pieces of equipment make a common commodity, optimization is always possible. In a power plant there can be multiple steam and power producers with varying efficiency making it possible to economically assign loads among them based on their efficiency. An optimization program that can communicate to the plant's distributed control system (DCS) can perform this, because it has access to all of the data monitored by the DCS necessary for the calculation.

The ideal Optimizer provides this capability. It would be essentially a generic solver for the mixed integer linear/nonlinear optimization problems raised from power plant operations. Software that can provide the user with abilities to find a solution of x (a.k.a. a vector of independent decision variables) in the feasible regions (which are determined by a set of equality/inequality constraints), such that the local/global minimum (or maximum) value of the objective function J is obtained.

## BACKGROUND

Operation of power generation facilities has the responsibility to meet grid demands with a high degree of quality. This can be considered as dependable power supply produced efficiently while meeting all the environmental mandates in effect.

Deregulation may cause grid demands to change rapidly based on market conditions, and the production facility that has the capacity to deliver will receive first consideration. Cost per megawatt is equally as important since the dispatcher has several facilities from which to choose. Other factors such as NOx and $SO_2$ production have economic impacts, as well as the ability to ramp to meet new demands targets. Therefore, operation management has a need to know how to be able to dispatch the power demands among the available facilities so that the power demand is satisfied at minimum cost. Traditionally, minimum cost could be thought of as economic dispatch among units based on heat rate, however, these economic circumstances are forcing the electric utility industry to take sophisticated steps to not only improve unit heat rate, but to also look at methods for optimizing generation profiles with considerations for ramp rate, emissions, and dynamic heat rate factors.

Likewise, industrial captive power plants that buy and generate power often have multiple pieces of equipment producing power and steam. In many cases not only are there multiple power and steam generators but there can be multiple fuel considerations with varying costs and heating values which can be utilized. Such systems with many interacting energy resources each with its own cost profiles can be optimized to provide cost reductions. Managing these economic tradeoffs to determine the most profitable operating conditions at any given time can be a daunting task
The key aspects for an optimization routine to evaluate are the dynamically characterized heat rate curves for each generating unit, determining optimum operating zones and produce advice accordingly, and predicted future load profiles based on past unit operating information.

**Potential Optimization areas for Power and Utility Plants**

Application possibilities:

- Fleet-wide emission optimization (NOx, $SO_2$ or both)
- Industrial captive power plant optimization
- Multiple boilers feeding a common steam turbine
- Combined cycle plants where several gas turbines/ HRSGs feed a steam turbine
- Several condensing units operating in dispatch mode a single load demand signal or in a common steam header configuration
- Several boilers in a cogeneration utility or Combined Heating and Power (CHP) plant operating with one or more steam generators
- Several plants generating the demanded load level in a networked region
- Hydro power plant optimization

**Functional Aspects**

An equation derived model-based approach to economic optimization would provide advanced control capabilities unattainable by traditional control systems. Variables such as fuel, power, and emissions can have a cost or credit (negative cost) associated with it. These costs along with power demands and equipment availability that can be constantly updated would reflect the current conditions in the models. A cost-based target function can be used for the optimization and this function can consider efficiency, emissions, ramp rates, and maintenance costs (where applicable). This makes it possible to optimize for lowest cost, best heat rate or lowest emissions. The ideal economic optimizer would have both offline and online modes of operation.

**Software and Hardware Requirements**:
The ideal Economic Optimizer tool would execute on a PC with the current operating systems (Windows 2000-XP) or later operating systems. The only software required for the user of the ideal optimizer would be a common web browser.

**Web-based GUI**
Equipped with a web based user interface, the ideal economic optimizer would offer a number of features, including:

- Multiple users could access and perform what-if scenarios at the same time.
- Users could easily create new models and modify existing models. It would also permit configuration and online start/stop optimization process initiation from the user interface.
- A highly flexible online advisory program for utilization of recommended changes to the operating process status.
- Closed-loop control constraints of the plant model to actual plant capability for the current conditions.

**Model Capability**

Theoretically, the models involved in reflecting the plant and equipment arrangements to support the decision making process possess one or more of the following features:

Nonlinear --- Most plants' heat rate characteristics have a nonlinear aspect in that they have a high value at the low load and flatten out at the higher end. The mid load level change is usually quite dramatic. This is especially true for a combined cycle unit when different combinations of CTG and HRSG (Heat Recovery Steam Generator) are involved. The traditional regression strategy does not fit these curves accurately, so a feedforward neural network models can be used instead.

Time varying --- Many models considered have more or less slow time-varying characteristics. For example, the heat rate models are normally obtained from the lower level plants. Due to equipment aging, pump performance degradation and process drift, these models need to be updated constantly. Fuel price and regulatory policy change also introduce variations to the models. Fortunately, the state-of-the-art networking technology easily allows any of the models to be updated in an on-line setting.

Dynamic --- Many of the technical, economic, and regulatory processes involved in the optimization decision making have a dynamic aspect. The dynamics can be slow or fast. For example, when an optimal emissions profile is calculated and sent out from the operations center, it often takes hours for the lower level plants to reach their desired emissions rates levels due to inherent process dynamics. Emission credit generation also takes time to realize, since the trading process has its own time-delay and dynamics. Regulatory constraints are getting tightened each year according to schedules that may be revised in a non linear process, and the impact on generation pattern may take time to be fully recognized due to different O&M performance from plant to plant

**Optimization Problem Mathematical Form**

$$\underset{x}{Min} \quad J = f(x)$$

$$s.t. \quad \begin{cases} g(x) \le 0 \\ h(x) = 0 \\ x_{i,min} \le x_i \le x_{i,max} \end{cases}$$

The ideal optimization software that can provide the user a method to find a solution of x (a.k.a. a vector of independent decision variables) in the feasible regions (which are determined by a set of equality/inequality constraints), such that the local/global minimum (or maximum) value of the objective function J is obtained would be a great benefit to the optimization engineer.
The optimization function should use state-of-the-art methods (e.g. genetic algorithms, mixed integer programming, LP/Quadratic, GRG Nonlinear, and Evolutionary solvers) and allows the user to define manipulated variables, define coefficient or constant variables, define dependent variables, and define constraints. The different values of the coefficients determine different cases or scenarios of the same problem for optimization "what-if" scenarios

The user must be able to define the manipulated variables (MV's). They should also be able to define coefficient or constant variables (CV's) as well as define the dependent variables affecting the models. The constraints need definition when there are physical, operational or economic limits of the plant equipment. The different values of the coefficients can determine the different cases or scenarios of the same problem for analysis.

**CONCLUSIONS**

Combining a state of the art performance monitor with an ideal heat rate optimizer can benefit power generation facilities at the multi-unit facility level as well as at the fleet management level. New possibilities arise for examining the operational aspects against known and observed economic factors. The plant equipment and unit operation characteristics can now be evaluated easily for optimum economic benefit..

## REFERENCES


1. Huff, Frederick & Gianamore, David, "A Reduced Emissions and Optimal Production Balance", in Proc. ISA Conference - Chicago, October 1995
2. Huff, Frederick, "Production Optimization of a Combined Cycle Plant", in Proc POWER-GEN Conference - Orlando, December 1996
3. Cheng, Xu & Huff, Frederick, "Model Based Simulation Study on Corporate-wide Load Dispatch Optimization with Pollution Control", ISA Conference - Houston, October 2003