Performance Modeling of a Legacy Cogeneration Plant

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ABSTRACT

This article will discuss the derivation and use of a performance model, which represents both steam and electric thermal plant cycles of a cogeneration plant. The plant is rated at 58.2 MW electric and 350 kpph steam output; it utilizes four boilers and six back pressure turbines and was commissioned in 1950. The host site is a legacy Department of Energy (DOE) complex facility located in the Southeast United States. This complex, which covers an area of 310 square miles, serves as a nuclear materials processing center for the DOE and employs over 10,000 people.

The primary focus is OPTIM, a spreadsheet based economic model that incorporates a detailed thermal performance map, fixed and variable operating costs and electrical purchase contract costs. It can be used to estimate as well as optimize plant running costs accrued by serving the site's steam and electrical demands. This ability allows OPTIM to be used for the analysis of daily economic dispatch or to evaluate various operating strategies for providing future steam and electrical demands. A sample application of OPTIM related to operating strategies is discussed.

OVERVIEW OF OPTIM SOFTWARE

The problem of accurately characterizing cogeneration plant performance is well understood (Reference. 1, 2). However, additional problems arise when these methods are implemented in an operating plant

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environment. OPTIM was designed to meet the needs of plant operators while providing a role for robust analytic methods.

A detailed performance map is required to initialize the OPTIM software. It can be extracted analytically from the plant's operating heat balance and quantitatively describes the amount of fuel (heat) required to support the export of various combinations of plant products. Typically, the map consists of 100 operating points (using 10% intervals) to specify fuel required to produce 0-100% steam and electric power.

The performance map is used by OPTIM to estimate fuel costs incurred by each operating strategy modeled. In its current configuration, OPTIM can model either a fixed electrical output strategy or an electrical load-following strategy. OPTIM was originally applied to a plant, which serves as the host facility's sole steam source. Therefore steam output is always assumed to match steam demand (must-run strategy).

OPTIM can be used to guide operators in their daily decisions affecting dispatch of both steam and electric capacity. Its main benefit accrues from avoiding lengthy data preparation and awkward calculations, relying instead on a small set of readily available aggregate quantities such as the previous week's generation, plant load and standby energy costs. After initialization, OPTIM is used to set a monthly generation "target" for steam and electricity production. The overriding objective is to satisfy monthly targets with adjustments being made weekly to meet this goal. Figure 1 shows the overall program flow.

Numbered features shown in Figure 1 are discussed next. Steps 2, 3 and 4 yield intermediate results. Values from the performance map are selected in Step 2. OPTIM establishes a synthetic week in Step 3 by pro-

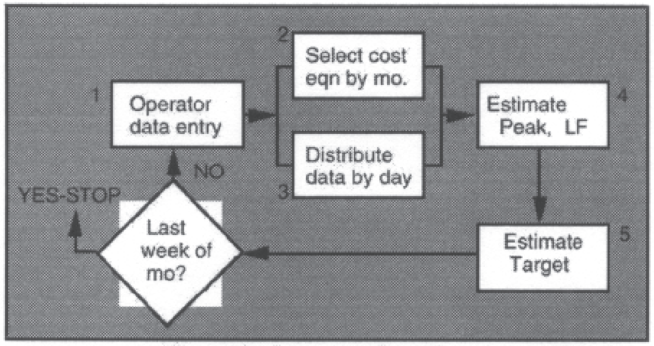

Figure 1. OPTIM Program Flow

portioning weekly energy over a unitized demand curve. The weekly peaks and load factor observed to date are compared to forecasted quantities. If there is a deviation, then a residual error is calculated and used in the target interpolation.

USE OF OPTIM FOR PERFORMANCE MODELING

To illustrate results of performance modeling, refer to Figure 2, which displays a sample plant operating strategy derived from OPTIM. It assumes operators attempt to follow weekly targets, avoiding forced outages and ramping boiler output as required.

Typical site electric demand for June is shown in the upper plotline, while cogenerated electricity is allowed to vary. Also plotted are the weekly series of targets needed to optimize plant output. Four numbered features are highlighted in Figure 2 to illustrate salient features of OPTIM's logic; they are discussed next.

A "must-run" target opens the month (# 1). In this strategy, electric output is dispatched to the level necessary to meet steam demand. Although it minimizes fuel costs, it does not yield a least cost solution for

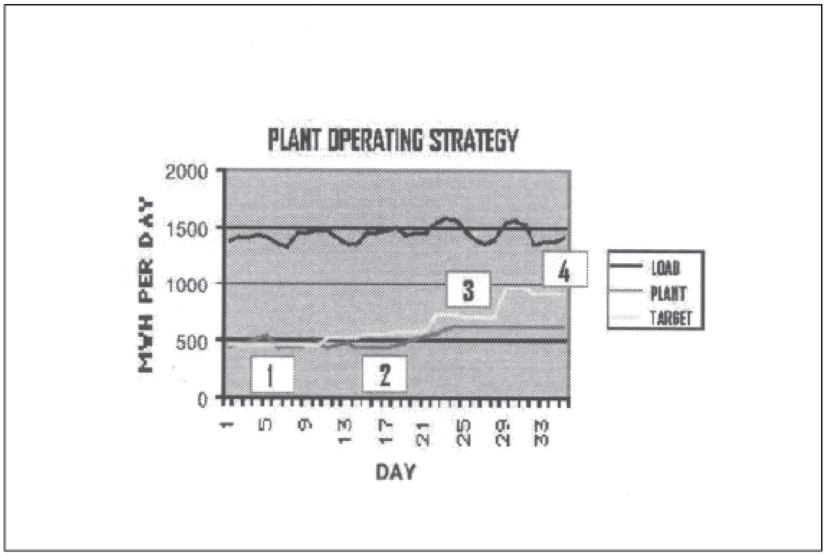

Figure 2. Sample Plant Operating Strategy

all factors involved (site steam, site electricity and off-site purchased electricity). This is the most conservative opening position to assume, lacking a trending history, which reliably predicts timing of the month's peak demand. It allows maximum ramping flexibility but does incur financial risks if peak demand develops early.

Boiler ramping and target may conflict (#2). Our plant is more easily managed if limited ramping over five to seven day intervals occurs with no significant loss of capacity from forced outages. As shown, the target series may deviate from this condition during some intervals.

Targeting and load forecasting logic are linked (#3). OPTIM is designed to anticipate a month's peak that could develop on short notice. After observing three weekly load cycles, the target is finally ramped to meet an expected peak and then converges on the ending target

Target series often end with "trim" days (#4) This feature typically results in lowered plant output as the month ends. The trim is proportional to the accuracy of our load factor and demand forecast as well as the degree to which generation tracked the target. If peak demand occurs in the third or fourth week, then trimming may not be needed.

See Table 1, which summarizes three alternative operating strategies analyzed with OPTIM and their respective costs and savings.

Table 1. Potential Monthly Savings Realized by OPTIM

MWh/day	*Cost 000's*	*Savings 000's*	*+/-Target MWh*
430	2,378.4	0	-6,028
527	2,227.8	-150.6	-3,896
555	2,157.8	-220.6	0

The column titled "MWh/day" tabulates average plant electric output. The column titled "+/- Target" tabulates deviations from OPTIM's recommended electric strategy, summed over the month. Figure 2's operating strategy corresponds to the 527 MWh per day case, which fails to achieve highest savings. This analysis indicates over $220,000 per month, or approximately 10% savings, are achievable if OPTIM's target profile is closely followed.

ADAPTING OPTIM TO PLANT ADVISORY MODE

OPTIM is particularly suited for use in older plants, which have sparse or outdated instrumentation and control (I&C) systems and no immediate plans to retrofit with state-of-the-art controls. (Reference 3)

Plant operators justifiably expect modern I&C but it is often not economic for cogeneration plants with five or more decades of continuous service. However, from an engineering perspective, it is necessary to determine if the current plant controls provide sufficient information to support cost effective operating decisions on a daily basis. One strategy would be to replace or retrofit outmoded pneumatic control systems, which are reaching the end of their life cycle. Replacing analog components with a digital equivalent may be expensive because the system is difficult to modify or replace to meet modern standards. In addition, many instrument cables must be moved in some cases from the old system to the new system.

I&C retrofitting includes the installing of sensors, meters, conduit, and networks. In more modern plants, real-time processing is accomplished with a distributed control system (DCS). In comparison, OPTIM offers a less expensive upgrade option, which combines limited replacement of I&C with on-line advisory control functions requiring operator interaction. In effect OPTIM fills the role of a semi-automated supervisory control processor or DCS. It must be capable of receiving automatically logged data from various plant meters to allow the software to operate efficiently.

Ideally, OPTIM would be linked to a group of operator consoles and an engineer workstation by redundant data highways. In most plants, interfaces with the control systems furnished by the combustion turbine and steam turbine suppliers provide remote control capabilities, as well as data acquisition, annunciation, and historical storage of turbine and generator operating information.

Plant operation continues to be the responsibility of shift operators who base their decisions on information provided by OPTIM's advisory displays. This capability can be installed relatively cheaply, in comparison to wholesale upgrades of the entire I&C system. One 1950's vintage steam plant located at the host facility included in its original design, two boilers and outdated pneumatic controls. This system was upgraded to a digital standard adequate for seamless integration with OPTIM at a total hardware cost of $40,000. Four I&C systems were installed, providing LCD display and bi-directional control capability for efficient plant operation.

SUMMARY

While the primary goal of OPTIM is to improve cogeneration plant economy, it offers significant benefits for plant operators. The OPTIM software was designed to be simple to use in routine plant conditions. Further it is capable of guiding operators towards general cost reduction goals in a flexible manner. In its intended application OPTIM is primarily used to dispatch electric plant with steam as a byproduct.

The process of characterizing production costs based on a pre-existing plant model was described. Our estimated savings outlined in Table 1 suggest that costs associated with maintaining the software (primarily data entry and recalibration) can be easily offset by "targeting" more efficient plant operation. The authors believe this method can be readily adapted to other plants, if operating performance can be accurately mapped for steam and electricity.

References

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