Optimizing the Entire Enterprise: A Case Study in Advanced Dispatch Control

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ABSTRACT

This case study explores the challenges encountered while designing an advanced dispatch control system that optimizes an international oil field enterprise for a major global oil company. Because operations are isolated from the host nation's power grid, the company runs multiple steam and power generation facilities fueled by natural gas captured from the field and imported from outside sources. Power and steam are generated and transmitted to numerous consumers throughout the enterprise micro-grid for pumping, steam injection, and crude recovery operations.

Operations management wished to implement an advanced dispatch control system interfaced with Supervisory Control and Data Acquisition (SCADA), a Distributed Control System (DCS), and remote I/Os to (1) centralize decision making and control for complete enterprise symbiosis of fuel, water, power, and steam production and transportation and (2) optimize load sharing and transmission efficiency to reduce energy costs.

The solution includes hydraulic and electrical models that track all mass and energy from production input to consumption output and all transportation losses in between. Models include compressors, simple boilers, heat recovery steam generators (HRSGs), gas turbines, electrical generators, electrical transmission and associated equipment, pipelines and associated equipment, and consumers of steam and electrical energy. Equipment performance is tracked to determine real-time performance curves for calculating load sharing optimization based on equipment state, ambient and process conditions, and current production levels.

ENTERPRISE SCOPE

The crude oil being recovered at the oil field is classified as heavy crude. In order to facilitate recovery and pumping, steam is injected into the ground to heat the crude and lower viscosity. This steam is produced by approximately 300 simple "once-through" steam generators and is piped to approximately 40 separate injection areas.

Because all operations are isolated from the national grid, 24 gas-fired turbine/generator sets produce approximately 600 megawatts of total electrical power. This electricity powers thousands of consumers, including oil pumps and multiple processing facilities. It also powers living quarters, operations infrastructure, and offices for the operation personnel.

Heat recovery steam generators (HRSGs) use heat from the gas-fired turbine exhaust stream to produce additional steam for the injection.

Approximately 15 percent of the fuel gas needed for steam and electrical production is captured from the oil field; the remainder is purchased from outside sources. Eight separate compressor stations and processing facilities refine and supply the gas. Each compressor station has multiple reciprocating compressors operating in parallel to generate the pressure necessary to deliver the fuel gas to the steam and power production facilities.

OBJECTIVES

The enterprise is scattered across thousands of square miles. Daily operations were hampered by logistical difficulties associated with isolation due to distance and operational function. In order to facilitate better symbiosis between all operations, a central decision support center was commissioned to realize the following goals and benefits:

- Standardize and centralize analyses and decision making.
- Use real-time or near real-time data in decision making.
- Achieve optimal operation by accurately responding to real-time demands and limitations.
- Manage by exception, allowing routine work to be done automatically.
- Reduce energy consumption while meeting delivery commitments.
- Improve process stability, allowing operation closer to target, constraint, and optimum values.
- Provide a tool for forecasting, process simulating, and determining the ability to meet obligations.
- Improve collaboration across distance and operational function.

OPERATIONAL TRANSFORMATION

In addition to needing advanced process control software solutions to accomplish the stated objectives, three sequential steps needed to be implemented before a corporate shift to centralized decision making could occur.

1) Surveillance—Install missing field instrumentation, especially instrumentation necessary for measuring high-value process streams that are key to mass and energy balances. Also install equipment/methods for reliable and continuous communication with the instrumentation. Finally, ensure that centralized and standardized hardware architecture is in place to collect, transmit, store, and access real-time data.
2) Analysis—With the objective of standardizing and centralizing decision making as much as possible, ensure that the right people are doing the analysis and decision making. Make changes to corporate workflows as necessary.
3) Optimization—Use analyzed data, make calculations, model key elements, and implement optimization algorithms. Analyzed data can be used to calculate optimal operating set points for balancing production between parallel producers. In addition to balancing production,

transportation losses of process streams and optimal operating levels of end consumers need to be considered. All producers, transporters, and consumers of mass and energy need to be modeled in their respective electrical and hydraulic process models. In turn, optimization algorithms can perform real-time, continuous optimization.

Once all of these steps were implemented, centralized decision making could occur.

BACKGROUND AND CHALLENGES

Advanced process control solutions have become commonplace in many industries that have complex processes. Distillation columns and process reactors are two examples where multivariable predictive control models are commonly used. The unusual aspect of this case study is that instead of focusing on a specific process segment or a particular piece of equipment, this solution is applied across an entire enterprise.

Numerous challenges appeared while implementing the steps outlined in the previous section. The following represent significant challenges:

1) Lack of real-time data. Although considerable measures were taken to install field instrumentation and communication, process measurements are often absent.
2) Discrepancies. When tracking mass and energy from fuel to final consumption or loss, a certain amount of measurement error occurs. Effective methods for dealing with the measurement error are needed.
3) Dynamic processes. If operations were continuously performing at static levels, optimization could also be static; however, production levels are dynamic—they continuously change. Responses to those changes must typically take place minutes or hours before the change occurs. The process model and optimization schedules must both be transient in nature.
4) Calibration and tuning. Multivariable predictive models are commonly calibrated using step-change iterations that record and establish relationships within large relational data sets. Because this study is a brownfield operation and because the model is across an entire enterprise, performing step changes is impractical and carries high lost production costs.
5) Staying current. With a large-scale enterprise, two specific challenges are present: (1) equipment degrades over time, so process responses and rates change accordingly, and (2) the process is continually being changed by the company, i.e., new equipment is being installed and old equipment is being removed. For the model to be effective and useful, it must be frequently modified to represent the current enterprise. As a result, users need to have the capability of making model changes themselves.

METHODOLOGY AND SOLUTIONS

A process model is a set of differential and algebraic equations that describe and solve representations of large-scale technological processes. The model identifies functional dependencies between various inputs, outputs, and losses so that optimization applications may find opportunities for improvement.

All functions, such as forecasting, simulation, control, and optimization, rely on the accuracy of the process model.

Constructing the process model involves very complex mathematical design and programming submodels that represent complex process components. The submodels must then be configured to represent entire subprocesses, which are configured into the complete enterprise process. For example, within an electrical micro-grid, numerous components exist (i.e., generators, transformers, bus bars, breakers, transmission lines, etc.) that function together so that energy can be tracked from producer to consumer. Energy input can be measured in BTUs contained in fuel, feed water, forced air, and the ambient environment. That energy is converted into electricity, which can be measured at various points to calculate production and losses and to ultimately be converted to work. The same methodology is employed in a hydraulic model for steam production and transmission as well as for fuel gas capture, compression, and transmission.

Once the process model has been constructed and configured, process tags are assigned to interface the model with instrumentation to receive real-time measurement data. This interface is usually performed through OPC or ODBC with Supervisory Control and Data Acquisition (SCADA) systems and historical program servers. The process model resides on a PC-based server or a combination of servers with the appropriate processing capability. Parallel processing methods are employed to accelerate computation.

In order to facilitate calibration, the model is originally constructed based on first principles (laws of physics) to calculate the flow and conservation of mass and energy, thermodynamic relationships, etc. After construction, hybrid modeling methods are employed to automate model parameter tuning. Historical or real-time empirical information is used to recalibrate the model so that calibration becomes current. This process always runs in the background, negating the need for step change iterations during initial calibration and periodic updating. (For a detailed discussion regarding model construction, noise handling, self-learning, and respective mathematical expressions, see the *OptiRamp Modeling Module* white paper (http://www.stctrl.com/sites/default/files/Modeling_Module.pdf).

A user-friendly interface was developed to allow both service provider and end-user engineers to perform configuration. High-level programming skills are not needed for process model assembly and tag assignment. As physical modifications are made to the process equipment, users can perform respective model modifications. Additionally, the model can be run off-line so that proposed changes can be studied to see how they affect overall process performance.

Whenever possible, real-time process measurements are best for understanding mass and energy flow; however, these measurements are often absent, especially with large-scale operations. To deal with this challenge, the model can predict process conditions based on first principles. Conversely, when data are present, the model must be able to identify and recognize errant information so that (1) the model does not use the measurement to self-tune, (2) the model does not provide optimization based on false measurements, and (3) an alarm is given to prompt investigation for the cause of the errant data. By nature, a certain amount of error is always present, so methods were developed for reconciling these errors from a management perspective. (For more discussion of methods employed, see the *Material*

Balance Reconciliation Module white paper (http://www.stctrl.com/sites/default/files/Material_Balance_Reconciliation_Module.pdf).

Processes are rarely in a steady state, especially in a large enterprise. Production rates are usually in flux, and equipment is continually coming off-line and online for various reasons. If the model cannot accommodate these changes, optimization solutions are of little value. Both the model and the optimization algorithms need to account for a changing process as a function of time. A scheduling routine to accommodate transient conditions was developed to work with the optimization algorithm so that optimal transient solutions can be computed.

CONCLUSION

SCADA- and DCS-interfaced process models can be of great benefit to enterprises by dynamically computing cost-saving measures in a real-time environment. Multidimensional analysis can be performed in a small fraction of the time needed for manual calculations. It must be recognized that using this solution as an enterprise-wide application carries new challenges that are usually unaddressed by traditional APC.

New mathematical methods have been developed to ensure a robust, sustainable solution. A predictive, transient model can compensate for missing field data and delayed responses inherent to certain processes. Special algorithms can identify errant field data. The ability to self-tune and user-friendly interfaces for reconfiguration provide practical methods for staying current and applicable.