Dynamic Optimization Improves Profits in Batch & Continuous Applications

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Dynamic Optimization, Process Optimization, Batch, Semi-batch

Summary

Process optimization is one of the fastest growing technologies in the automation industry because of its ability to tightly link a company's business and economic objectives to its operations. Most optimization projects are implemented with steady state simulators. Unfortunately, most industrial processes are not steady state. Dynamic optimization is the only technology that can truly optimize state changes in continuous processes and is equally applicable to batch and semi-batch processes. Most batch process industries, however, have not implemented optimization software to the extent of the traditional continuous process industries. Companies that successfully implement optimization are significantly improving their bottom line. Shell Chemicals, for example, is using gPROMS from PSE to optimize its catalytic reactors. Implementation of dynamic optimization does not come without a cost, however. It requires a thorough understanding of the process to implement and maintain.

> Process Optimization is one of the best ways for organizations to achieve optimal asset utilization and performance. In the past, optimization focused on steady state operations. Dynamic optimization is the only technology that can truly optimize state changes in continuous processes and is equally applicable to batch and semi-batch processes.

Analysis

Process optimization is one of the best ways for technically adept organizations operating complex processes to achieve optimal asset utilization and performance. To date, most rigorous optimization implementations have been for the design and operation of continuous processes using steady state simulation and optimization. Unfortunately, the majority of industrial processes either do not operate at steady state or have important transients between steady state operating points. To optimize these batch processes and transition states of continuous processes, a dynamic simulator is often used.

Until recently, dynamic process modeling tools have been used primarily for process simulation, which involves setting up and executing a model of the plant to investigate a particular aspect of the design or operation. Typically, such simulations are used in a trial-and-error fashion to verify control system design, operating parameters, and equipment sizing. This method is time consuming and is highly unlikely to produce the optimal results. Dynamic simulation alone does not directly solve many of the real issues confronted by design engineers or operations personnel.

Dynamic Optimization Breaks Steady-State Barrier

Recently, true dynamic optimization has become available that goes beyond the design phase to help you optimize plant performance and eliminate waste. Dynamic optimization is the only method that truly optimizes batch and semi-batch processes and state changes in continuous processes. Dynamic optimization allows the problem to be formulated directly and solved in a single run to come up with the optimal answer, saving valuable time and effort. In contrast to steady state optimization, dynamic optimization also permits operability considerations to be taken into account at the design stage.

Optimize startup and shutdown procedures
Optimize design and operation of batch reactors
Establish optimal grade switching policies for continuous processes such as polymerization reactors
Determine optimal tuning of PI & PID controllers
Optimize the dynamic performance of utility plants
Determine optimal trajectory of MPC applications
Simultaneously optimize process and control design

Typical Applications of Dynamic Optimization

A typical dynamic optimization setup requires a dynamic process model, definition of existing operating procedures, an objective function, operating constraints, and a set of optimization variables. During execution of the optimization procedure, the optimization engine searches for the values of the optimization variables that maximize or minimize the specified objective function while ensuring that all the constraints are satisfied. A typical objective function is the calculation of operating revenue, taking into account feed and product flow rates and cost, energy costs, and any other economic factors, or the amount of a high-value component lost through a waste stream.

Building the underlying dynamic model for optimization requires a true dynamic modeling tool, i.e. one that works with a mathematical representation – not just a simulation model - of the process. Such tools usually take an equation-oriented approach, where the underlying relationships are described by equations representing the process physics and chemistry. The resulting set of equations is solved transparent to the user.

Dynamic modeling tools can make use of the same underlying mathematical model to perform many diverse activities beyond simulation and optimization, including parameter estimation and data reconciliation. Parameter estimation permits the model to be fitted to plant or experimental data to produce a more accurate model so that the optimization will be closer to reality.

Optimization Offers Rapid Return on Investment

Virtually all optimization applications have one thing in common – they are aimed directly at improving plant profitability or return-on-investment in an immediately quantifiable way. Almost all processes can benefit from dynamic optimization in some way – by increasing yield and throughput, limiting off-spec production, reducing downtime, and lowering energy costs. If performing a design-phase optimization, dynamic optimization can reduce capital cost and improve process operability and reliability. Even a 1 percent increase in plant operating profit can justify the typical 3-9 man-months spent building a dynamic model of the process from scratch and applying dynamic optimization to it. Most dynamic optimization projects can offer a return on investment well within a year of their implementation.

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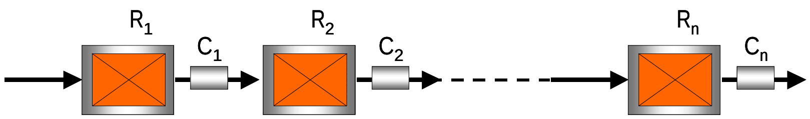
Once the investment has been made in building a rigorous dynamic simulation model it requires very little additional effort. With the current technology available, all that is normally required is determining an appropriate objective function that truly reflects the business objectives, identifying the key operational, safety and environmental constraints that need to be observed, and deciding on the variables to be manipulated.

Shell Maximizes Profit of Catalytic Reactors

One example of a major manufacturer who has deployed a dynamic optimization solution to a batch or semi-batch process is Shell Chemicals. Shell is using gPROMS from Process System Enterprise (PSE) to model a complex reaction system involving a series of catalytic reactors. Shell is then using gPROMS to dynamically optimize the catalyst changing sequences and frequencies for the large-scale production unit.

PSE, the gPROMs developer, is a spin-out from London's Imperial College where many of the major advances in equation-based modeling systems originated. PSE's gPROMS is a flexible, robust general-purpose equation-oriented dynamic modeling and dynamic optimization environment used to enhance design and operation of continuous and batch processes.



Shell Optimizes Its Plant, Which Consists of a Series of Catalytic Reactors Each Followed by a Cooler

Shell's plant consists of a number of catalytic reactors in series along with interstage coolers. The main reaction is exothermic, and there are a number of side reactions. Both catalyst activity and catalyst selectivity decline over time, and the operating conditions have to be changed periodically and an optimal timing for catalyst change established. The answer involves a trade-off between, on one hand, running the reactor for as long as possible (thus delaying down time) and, on the other hand, increasing reactor yield and selectivity as soon as possible by providing new catalyst. It is a classic dynamic optimization problem that cannot be solved without taking into account the time-varying behavior of the system.

Developing a Good Model Is Crucial to Success

The project involved four basic stages: developing the dynamic model of the physics and chemistry of the reaction process, developing a catalyst deactivation model, assembling an overall plant model, and performing the dynamic optimization. The greatest effort was expended during the first couple of stages to understand the physics and chemistry of the process.

For dynamic optimization to be successful, the underlying dynamic model of the process should represent reality as closely as possible and be robust over the required frame of operation. This is done by creating a model of the process to describe the underlying physical and chemical phenomena in mathematical form, then fitting the model to laboratory and plant data to tune the model parameters to the actual observed process behavior.

Shell used gPROMS to optimize the inherently dynamic operation of the reactor. The objective was to maximize profit from the operation by maximizing the average yield against operating cost. The optimization variables in the process included time-varying reactor temperatures, the catalyst charge for each reactor, the time at which to place a reactor in operation, the time at which to replace the catalyst in a reactor, and the total cycle time.

Shell studied different cases with different optimization variables to find the optimum cycle. This resulted in an optimized model that determined 20 optimum control intervals of varying duration to maximize the profitability of the reactor operation. The model clearly demonstrated significant benefits that justified the investment of the six man-month modeling effort. Shell carried out tests by applying the optimized temperatures to the plant to verify the results. The analysis showed that 70 percent of the yield increase predicted by the model was achieved. The level of detail encapsulated in the model can explain the discrepancy between the actual results and those predicted by the model. Subsequently, Shell has translated the results into a set of operating guidelines that contains quantitative information on how to optimize their reactor operation.

Recommendations

- Identify processes in your plant that can benefit from using dynamic optimization. Consider applying dynamic optimization to the processes likely to have the greatest impact on the bottom line, product quality, product yield, or other important objectives that fit into your corporate strategy.

- Dynamic optimization does not come without a cost; for proper implementation it requires considerable process domain expertise to develop a dynamic model of the process. Keep in mind that your dynamic optimization supplier can help with the development of process models.

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