Optimization Applications in the Energy and Power Industries

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Introduction: Energy and Power Today

Few industries have as great an impact on the daily lives of so many the world over as the energy and power industries. Without them, necessities as we know them today, including central heating, electric lighting and cooking appliances, as well as modern conveniences such as televisions, computers and cell phones, would not be possible. It would be no exaggeration to say that all the other major industries, including manufacturing, transportation and telecommunications, greatly depend on the energy and power industries.

Even so, many have come to associate these industries with waste and pollution. Collectively, they are among the leading sources of greenhouse emissions, and consume more fossil and nuclear fuel than any other industry. Clean, renewable forms of power generation are rapidly coming online, but they amount to a small percentage of the energy generated today and decades will likely pass before they hold a dominate position in these industries.

No one knows these issues better than the energy and power companies. They have an impressive record of constantly searching for ways to cost-effectively meet the world's energy needs with cleaner, more efficient and reliable technologies.

The role of IBM® ILOG optimization has been primarily in delivering software that helps these companies make better decisions faster. As this white paper shows, the IBM ILOG CPLEX and IBM ILOG OPL Development Studio enables rapid development and deployment of applications that address the energy and power industries' most pressing issues.

Hot Button Issues

Long major users of optimization technologies, the energy and power industries face a number of hot-button issues:

- **Climate Change:** These industries are among the largest sources of carbon emissions worldwide, and any strategy for reducing emissions will heavily impact them. Many large energy companies are positioning themselves as part of the solution rather than part of the problem. Their responses include more investment in renewable energy, especially wind and solar; more investment in energy efficiency by electricity users; development of low-emission generation, especially nuclear and "clean coal"; and shifting transportation from fossil fuels to electricity, for example, plug-in hybrid vehicles.
- **Grid Utilization and Reliability:** Many gas and power systems are overtaxed as capacity investments have not kept pace with demand. Market restructuring has opened access to these networks, with novel contracts and pricing policies, increasing the volume of transactions and altering flows in ways not envisioned when they were designed. Overuse and aging equipment have resulted in deteriorating reliability in many power systems, leading to frustrated customers and regulators. As a result, the industries face challenges that include performance penalties for failing to meet reliability goals, increasing attention to and expenditures on maintenance, and increasing needs for investment in gas and electric transmission and distribution systems.
- **Market Restructuring:** Market reforms in many countries have opened utility monopolies to new competition. Central planning and control of energy and power systems has yielded to more decentralized, market-based processes and institutions. As gas has become a preferred fuel for power generation, gas and electricity markets have converged. As a result of these trends, the market operators and regulators in these industries face challenges that include designing efficient and equitable markets, assuring adequate investment in new generation and transmission capacity, and controlling market power, price spikes and gaming. Likewise, companies in these industries need to optimize their bidding strategies and manage price volatility and volume risks in their business.

- **Enterprise IT**: Energy companies are spending large amounts of money on their information technology infrastructures, using systems from IBM, SAP and Oracle, among others. The focus has moved beyond streamlining financial control and ensuring regulatory compliance toward managing risks and improving physical asset management. Issues for energy and power companies include moving from better information to better decisions, empowering business and technical users, and catching up on data collection as data management capabilities improve.

Better Decisions Faster

As illustrated in *Table 1*, optimization helps energy and power companies address these issues by enabling them to make better decisions faster:

- **Resource Planning Models** address the supply and demand side investment decisions an energy supplier makes to ensure that it can satisfy customer demand. The objective is to minimize the total present-value cost of building and operating production facilities and customer demand-side management programs to serve or reduce forecasted loads over a multiyear planning period. The decision variables include the amount of capacity of each resource type to be installed in each year of the planning period and the utilization of those resources (and existing resources) to serve annual customer loads. The constraints include the requirement that customer loads be served at all times, that sufficient reserves exist to serve the annual peak demands, and various restrictions reflecting operating constraints such as emission and fuel limits.
- **Unit Commitment/Economic Dispatch Models** are used to schedule hourly production of thermal power stations for periods up to about a week in advance. The objective is to minimize the short-term costs of operating the generators to serve forecasted customer loads. The costs include both fuel costs and start-up costs. The constraints represent the requirement to serve hourly customer loads, various reserve requirements, minimum uptimes and downtimes for generators, and ramping limits for generators. Fuel costs represent the nonlinear operating characteristics of the generators. Unit commitment models are increasingly used in the bidding process in restructured power markets.

- **Hydro/Thermal Scheduling Models** are used to determine the use of water resources in power systems with a lot of hydroelectric generation. In these systems, the cheap hydro offloads more expensive thermal generation, but the amount of energy that can be produced by the hydroelectric generators is limited by inflows to the reservoirs, which typically have large seasonal variations. The objective is to minimize the short-term costs of operating the power plants to serve forecasted customer loads. The costs include thermal power plants' fuel costs, since hydro generation typically has negligible direct costs. The constraints represent the requirement to serve customer load per hour, the availability and flow of water through the supporting river network, various reserve requirements, various restrictions on water flows and reservoir volumes reflecting environmental regulations and other water uses, for example, agricultural or recreational. The operating characteristics of the thermal and hydro generators may be represented nonlinearly.
- **Optimal Power Flow/Security Constrained Dispatch Models** are extensions of the load flow model, which is used to determine the flows of power along the various transmission paths in a power network for the purpose of evaluating the feasibility, reliability and security of the power system. The Optimal Power Flow (OPF) includes the economics of the generating units and determines an optimal dispatch that satisfies demand and the transmission limits in the network. OPF is currently used by many power system operators to clear their power markets and establish prices. The objective is to minimize the operating cost of serving the load. The constraints represent the requirement to serve instantaneous customer load at all nodes of the network, the generator capacity limits, conservation of power flow and voltage laws governing the physical power flows (which may be represented nonlinearly), and various reserve, security and reliability criteria.
- **Network Planning Models** are used to plan investments in gas pipelines, storage fields and compressor stations to assure there will be adequate capacity to meet the needs of multiple shippers at numerous delivery points. The objective is to minimize the cost to build and operate pipelines, storage facilities and compressor stations to serve forecasted demands over a multiyear planning period. The constraints represent the requirement to serve projected shipper and customer demands at all times, with sufficient capacity to serve daily and annual peak demands. There may be nonlinear representation of pressure/flow relationships and compressor operating characteristics.

- **Contract and Risk Management Models** enable energy and power companies to implement profitable bidding strategies while limiting price and volume risks to acceptable levels. The objective is to determine volume and price for possible energy transactions and emission credits bought or sold in order to maximize expected net returns. The constraints represent forward price curve uncertainty and volatility, and impose limits on value at risk and conditional value at risk (stochastic programming may be used to capture these risks). There may also be requirements to hold adequate emission credits to comply with environmental regulations.
- **Power Market Simulation Modeling** is a very new field that addresses the performance of new market constructs and rules now being implemented as part of the ongoing restructuring of the power industry worldwide. The purpose is to use simulation to estimate the effects of proposed market rules to determine their efficiency, fairness and conformance to legal and regulatory objectives and requirements, such as reliability and mitigation of market power. The results are used to inform policymakers and identify anomalous behavior among market participants. Power market simulation models are similar to unit commitment and optimal power flow models, but in addition, they incorporate behavioral assumptions about the market participants. Game theory is often used to model behavior.
- **Maintenance Scheduling** is a highly complex process, especially for nuclear power plants, where much of the plants are inaccessible to workers during operation because of high levels of radiation. A nuclear plant must be shut down for refueling approximately every 18 months, and while undergoing refueling, many other maintenance tasks are performed. The tasks themselves are highly interdependent and must be scheduled to adhere to complicated precedence constraints, as well as safety and environmental regulations. Specialized skills and equipment are required for individual tasks, and the availability of contractors is often an issue. Furthermore, time is of the essence due to the value of the plant and the cost of alternative power sources when the plant is not generating.

Table 1: How Optimization Addresses the Hot-Button Issues in the Energy and Power Industries

	Climate Change Regulations	Grid Reliability	Market Restructuring	Enterprise IT
Generation/ Resource Planning	Optimal mix of conventional generation, renewables, demand-side programs	Better transmission utilization	More coordinated planning	Quicker planning cycle Lower data preparation effort
Unit Commitment/ Economic Dispatch	Lower emissions		Improved bidding	Quicker, more flexible response
Hydro/ Thermal Scheduling	Lower emissions		Improved bidding	Quicker, more flexible response
Optimal Power Flow/Security Constrained Dispatch		Better transmission utilization Lower outage risks	Better transmission utilization Improved bidding	Improved system operation Lower data maintenance effort

	Climate Change Regulations	Grid Reliability	Market Restructuring	Enterprise IT
Network Planning	Better compliance with emissions regulations	Better network utilization	More responsive to market needs	Quicker planning cycle Lower data preparation effort
Contract and Risk Management	Better compliance with emissions regulations		Improved bidding	Quicker, more flexible response
Power Market Simulation			Better resource adequacy Lower risk of price spikes and gaming	Quicker adoption cycle Lower data preparation effort
Nuclear Power Outage Scheduling	Greater utilization		Greater utilization	Better reliability

Highlights

Red Eléctrica de España, the company in charge of managing the Spanish national power grid, recently used IBM ILOG optimization technology to upgrade the software it uses to regulate its power supply

Case Studies: IBM ILOG Optimization at Work

Among the many uses of IBM ILOG products, these four recent applications illustrate the benefits of using IBM ILOG optimization technologies in the energy and power industries:

1. Red Eléctrica de España, the company in charge of managing the Spanish national power grid, recently used IBM ILOG optimization technology to upgrade the software it uses to regulate its power supply. Red Eléctrica implemented a new unit commitment model that uses exact mathematical methods (dynamic programming and mixed-integer programming) to replace the approximate, heuristic methods it had used for 20 years.

   According to Mustafa Pezic, director of the project, *"The methodology applied until now . . . was an interactive methodology, which did not guarantee an optimum solution. There were many difficulties in the smaller systems and it was hard to find the most viable solution. Thanks to the new methodology, we have resolved this type of problem."* From an IT viewpoint, *"the new tool allows us to simplify all maintenance tasks and any changes made to the model, which in our particular case, are very frequent."*

   The implementation of an IBM ILOG ODM (Optimization Decision Manager)-based solution through the CPLEX and OPL Development Studio has provided great operational advantages to the company's managers and engineers. *"From a user viewpoint, it has brought greater trust in the solution and a significant reduction in planning time required by users. In parallel with this, from a development and maintenance viewpoint, there has been a significant reduction in associated costs, as well as in the duration of the processes."*

   Red Eléctrica has reduced its production costs by one to two percent, a savings of between €50,000 and €100,000 per day. In addition, the company has reduced its carbon emissions by 2.5 percent, approximately 100,000 tons of CO_2 annually.

Highlights

A large power utility with a service area in the Midwestern United States, uses IBM ILOG optimization technology to maximize the market impact of its pumped storage plant by optimizing its operating schedule to the Midwest Independent Transmission System Operator (Midwest ISO) market signals

2. A large power utility with a service area in the Midwestern United States uses IBM ILOG optimization technology to maximize the market impact of its pumped storage plant by optimizing its operating schedule to the Midwest Independent Transmission System Operator (Midwest ISO) market signals.

   Pumped storage hydroelectricity is a type of hydroelectric power generation used by some power companies for load balancing. The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines. The pumped storage unit stores energy when electric demand and prices are low and generates power when demand and prices are high.

   Prior to implementing the new optimization application, the utility's plant operators created operating schedules based on their past experience. However, there was no model to support their decisions, and when Midwest ISO asked the company to deviate from the original schedule, there was no tool to validate costs. The utility believed it was accepting suboptimal courses of action and foregoing the benefits of optimal actions because the company did not know the true value of the energy in storage.

   The new optimization-based application standardizes the business process, providing mathematically validated schedules. The model finds opportunities that may not be obvious and helps operators value the water in the reservoir and make decisions that deviate from the schedule in real time. Furthermore, when asked to deviate from the original schedule, the model gives the utility an assessment of the lost opportunity so that the operator knows the deviation cost.

   Ultimately, the optimization model has increased utilization of the pumped storage plant. CPLEX gives the power company the performance it needs, and OPL Development Studio makes it easy to code, test and embed changes into their business process. The bottom line is an expected improvement opportunity of as much as U.S.$8 million annually, with an initial goal to achieve at least 10 percent of that opportunity.

Highlights

3. Overseeing a major wholesale electricity market, a power management company in Asia serves as an intermediary between electricity retailers and local power companies by providing market governance and a central trading environment. Every half-hour, the power companies update their rates for selling electricity to the exchange. The management company must assemble these rates into a mix of prices and generation schedules that will satisfy consumer demand at the lowest cost possible.

   A crucial part of the company's operation is an application that uses CPLEX to form solutions for buying power to provide affordable electricity. CPLEX solves the problem within 30 seconds, addressing more than 15,000 constraints and bounds with each trade. Furthermore, by using IBM ILOG Concert Technology in developing and maintaining the optimization models applied by CPLEX, the company's IT team is more efficient in maintaining the application. Using CPLEX has helped the company:

   - Consider all possible constraints with each trade
   - Achieve the lowest generation cost for electricity offered to the Singapore wholesale electricity market while considering system security and reliability requirements
   - Improve the performance of the electricity market
   - Reduce the maintenance time for the trading system

CPLEX delivers breakthrough performance on unit commitment, historically one of the toughest optimization problems to solve

4. CPLEX delivers breakthrough performance on unit commitment, historically one of the toughest optimization problems to solve. With potential savings of hundreds of millions of dollars annually for a sizable power system, unit commitment is also one of the most economically important optimization problems.

   Sparked by CPLEX, the last 10 years have seen a revolution in solving unit commitment problems. Before then, unit commitment stretched the capabilities of computer hardware and optimization algorithms. As a result, most automated unit commitment applications relied on a combination of human judgment and heuristics based on dynamic programming and Lagrangian relaxation.

Highlights

Until the release of CPLEX, no mixed-integer programming (MIP) solver had the power to handle real-world unit commitment. CPLEX provides:

- Provable optimality bounds
- Robust optimization algorithms, used in multiple applications across many industries
- Flexible model formulations that can accommodate many new market features
- High-level modeling tools that make it easy and reliable to develop, modify and maintain your optimization applications

Unit commitment applications made with CPLEX are widely deployed. For instance, an eastern United States system operator saves US$200 million annually on unit commitment with IBM ILOG CPLEX Mixed Integer Optimizer.

Conclusion: Proven Benefits of IBM ILOG Optimization Technologies

IBM offers the most advanced optimization technologies on the market today

IBM offers the most advanced optimization technologies on the market today. They have been broadly used in virtually every industry where optimized planning and scheduling makes a difference. In the energy and power industries, IBM ILOG optimization has an established place as a key contributor to cutting costs and improving operational efficiency.

The value IBM ILOG optimization can bring to your company includes:

- **Better decisions**: True optimization finds the non-obvious solutions that maximize your value or minimize your costs while observing the many complex requirements and limitations of modern power system operations. Optimization shifts the cost-performance frontier for your system, enabling you to get better performance at lower cost. And optimization produces quantifiable bottom-line benefits, often with payback in less than a year.

- **Faster decisions:** Automating decision processes increases the speed at which you respond in today's accelerating markets, and allows your operators and planners to focus on critical complexities rather than routine issues.
- **Faster, lower cost development and maintenance:** Using the high-level modeling tools in CPLEX and OPL Development Studio enables your engineers to code and validate your optimization model with less time and effort than traditional programming languages, and by increasing the transparency of your model, makes maintaining and upgrading your system easier and more reliable.
- **Turn information into action:** IBM ILOG optimization leverages your investment in enterprise information technology.

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