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OPERA:

Improving Operations on the Columbia: The Power of Optimization

A plant optimization program being implemented for the Federal Columbia River Power System should boost efficiency by 1 to 2 percent — which could mean an increase in revenues of as much as $80 million a year. The goal is to operate the correct number of turbine-generating units at the right time, providing more electrical capacity using the same amount of water.

By Thomas R. Murphy

With average annual generating capacity of 9,000 MW, the 31 hydroelectric plants and one nuclear facility that make up the Federal Columbia River Power System (FCRPS) are a vital regional resource. And thanks to a $25 million hydro optimization program being implemented, the FCRPS soon will be able to increase revenue by as much as $80 million a year with the same amount of water going through the turbines. Begun in 2000, this system-wide hydro optimization program will be substantially completed in 2009.

The FCRPS is operated jointly by the U.S. Army Corps of Engineers, U.S. Department of the Interior's Bureau of Reclamation, and Bonneville Power Administration (BPA). BPA markets the power, operates the transmission system, and funds hydro plant construction and operation. The Corps and Reclamation design and operate the dams and powerhouses.

Included in the optimization project are many efforts, ranging from improving efficiencies of existing generating units to implementing computer programs that will help operators optimize system operations. When completed and implemented together, these changes will increase the efficiency of the entire generation system, boosting power output by 1 to 2 percent.

Tom Murphy is project manager for the Bonneville Power Administration. He provided technical assistance and was the project manager for part of the optimization described in this article.

Goals of the optimization program

The hydro optimization program underway for the FCRPS is designed to use water more efficiently and to maximize revenue generated. This program consists of four elements:

1) Implementing Type III optimization. This type of optimization makes the best use of water to maximize revenue subject to system constraints and market conditions in the near term (daily) through long term (yearly).

2) Implementing Type II optimization. This type of optimization minimizes the amount of water needed to produce a given amount of megawatts and other generation products. This is accomplished in two ways: committing an efficient number of units on-line to produce the generation requirements and loading the units to their most efficient collective operating points, taking into account individual unit characteristics.

3) Implementing Type I optimization. This type of optimization is possible only for Kaplan units. It is necessary to conduct performance tests to determine improved turbine operating data and more accurate wicket gate and blade relationships at a specific head and level of generation. This strategy reduces the water needed to produce a given amount of megawatts.

4) Building an integrated system where all three types of optimization work together to improve overall operations. This system is required to recognize and deal with changes on a real-time basis. Optimization of a river system or plant relies on forecasts, and any changes will decrease the accuracy of the forecasts. To help minimize the effects of changes occurring after optimization, a hydro system must have real-time controls that use the new modified optimization results to adjust ongoing operations and gain back some of the losses.

Setting up the program

In 2000, BPA began by funding project improvements that gave some immediate benefits and will eventually contribute to successful implementation of Type I and Type II optimization. This work, performed by the Corps and Reclamation, included updating performance testing on all generating units and updating some of the plant control systems. Later, head measurement systems were improved. We are currently trying to develop better flow measurement systems.

At the same time we were starting these improvements, BPA began planning to replace its current river planning models with modern optimization models of the FCRPS. The FCRPS is a large, complex system that is more constrained than most hydro systems because of the multiple uses of the river, including salmon operations, flood control, irrigation, and recreation. Other challenges — such as integration of wind generation, Mid-Columbia coordination, and unique load contracts — add to the complexity of the calculations.

After conducting a search, BPA contracted with Synexus Global in Montreal, Québec, Canada, to provide a suite of optimization tools. Synexus' programs covered both long- and short-term planning of the hydro system

(Type III optimization), but did not handle the operation and adjustments of the hydro system with a real-time hybrid Type III/Type II optimization.

We estimated that benefits from a hybrid Type III/Type II optimization would be about 0.5 percent of revenue, or about $21 million per year. We found that no Type III optimization programs were simple or fast enough to run in real time. We also found that many Type II programs are capable of optimization and suggesting the most efficient operation, but the solution is only valid for static or base loaded conditions. This turns out to be a limiting assumption on the FCRPS because our system needs to handle forecast errors, load following, reserves, and dynamic power contracts, and provide support for wind generation.

Because the generation requirement changes so frequently, we needed a way to re-optimize in real time. BPA wanted a real-time optimization program to consider the costs of starting additional units, forecasts for future generation requirements, and costs of generating a little less at one plant and more at another. In addition, we wanted the effects of any changes on our short-term Type III river planning model to be optimized. BPA decided to contract with Synexus to design this real-time hybrid optimization software.

Implementing the program

Synexus was successful in designing the first stage of this hybrid Type III/Type II software (named Near Real Time Optimizer, NRTO). This NRTO is only the first step in implementing a final system operating scheme.

In the interim, before this operating scheme is fully functional, the hydro schedulers and plant operators are key to manually implementing the first stage of the hybrid Type III/Type II optimization. The hydro schedulers will try their best to minimize plant setpoint changes outside of some dead bands. This should reduce the number of generator starts and stops. The duty schedulers also will try to provide as much setpoint forecasting as possible to the hydro plants. The ability to forecast future setpoints will vary greatly, depending on plant, time of day, day of the week, system demand, and market conditions. The forecast will range from zero to 24 hours in advance. The plant operators will use any future hour forecasts available to fine tune unit commitment. For example, if the present hour benefits from changing unit commitment are small, the operator can use the forecasted change in generation to determine the most economical number of units to have on line.

We have a preliminary plan for an ultimate system operating scheme that incorporates a real-time hybrid optimization. In this plan, the hybrid Type III/Type II software will combine the hourly targets from the short-term planning model with real-time loads and generation requirements, then use this to determine optimized plant setpoints and future hour forecasts. This software will send new setpoints to be dispatched to the hydro projects at a fixed interval. These setpoints will account for most of the load changes during the hour. Information also will be sent to the projects that includes a suggested unit commitment based on current loading and future hour forecasts. The plant optimization software will use this information to perform a detailed plant optimization and instruct both the plant operators and the supervisory control and data acquisition (SCADA) systems how best to operate the plant. Some operating decisions will be made by the plant operators, and others will be made automatically by the plant control systems.

In this ultimate operating scheme, the goal is to use future forecasts to limit unnecessary generating unit starts and stops while still operating the plant efficiently. We want to send setpoint changes to the plants in calculated amounts so that the change in plant capacity from adding or subtracting a unit matches the change in the setpoint. The remainder of the load changes will be handled by movement of generating units on automatic generation control (AGC).

Figure 1 shows this planned operating scheme. Key elements are:

— The timely aggregate of all inputs comprising real-time generation requirements (yellow). This includes both real-time and forecasted requirements.

— Forecasts and targets from our short-term planning model (blue).

— A centralized basin control system capable of sending coordinated operations to all projects on system response (green).

— A centralized basin communication system capable of sending a frequent information array to all projects on system response (red).

Other elements of the scheme include:

— A generation management system that contains software capable of optimizing frequently. The system needs to consider planning inputs and real-time changes, transmission constraints, and project operations and capabilities.

— Compatible operating controls and software at the hydro plants, including an operators information system that suggests how to operate the hydro plant more efficiently.

— Hydro schedulers, transmission dispatchers, and project operators committed to hydro system optimization.

Once this system operating scheme becomes more automated, the next

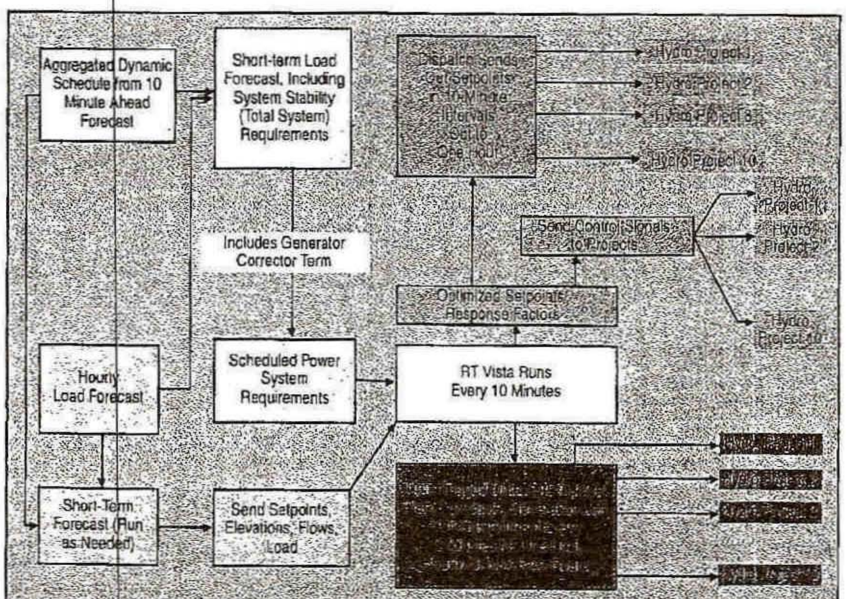

Figure 1: The hydro optimization program currently underway for the Federal Columbia River Power System is designed to maximize electricity generated from the water available.

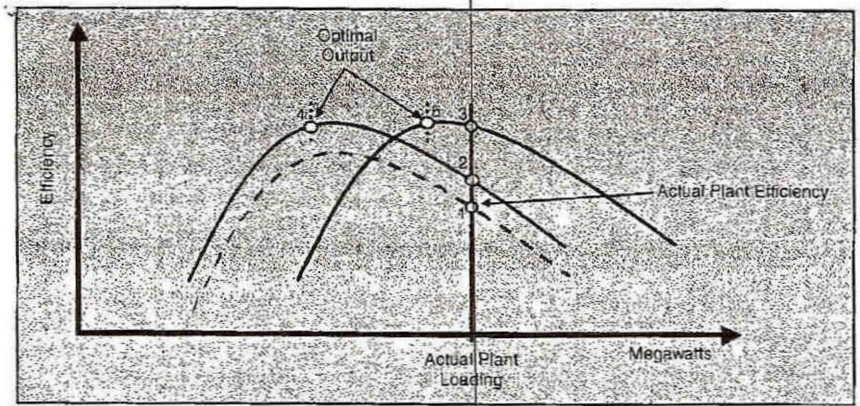

Figure 2: Plant efficiency with 12 units optimally loaded (purple) is much higher than with ten units optimally loaded (green) or ten units not optimally loaded (dotted). The benefits that can be realized from Type II optimization include better unit loading (from point 1 to 2), better unit commitment (from point 2 to 3), and better setpoint (from point 2 to 4).

problem will be how to best communicate optimized operating instructions to the hydro plants. To handle this, BPA is upgrading its control systems. BPA also initiated parallel projects with the Corps and Reclamation to develop real-time optimization programs at each plant that can interpret and display these optimized operating instructions. The optimization software will reside in the plant SCADA system and receive optimized instructions from BPA. But it will perform independent plant optimizations.

Benefit determination

The benefits from most improvements will have to be calculated. The FCRPS has and will realize several benefits from this optimization project. First, we will determine the benefits from updating and correcting Kaplan unit performance curves (Type I optimization) by calculating a megawatt savings due to reduction in flows on a generating unit. Ideally, we would like to measure absolute flows in real time, but because of the expense of installing equipment on 160 units, we will begin by using flows from our updated performance curves to calculate the benefits. We also are funding the Corps to develop a real-time relative flow measuring device that uses existing Winter-Kennedy taps, which will be completed in 2008. Because optimum gate and blade relationships can be determined by using relative flows, this will allow us to account and tune for differences during the operation of individual units. This should give additional Type I optimization benefits.

Second, to determine the benefits of hybrid Type III/Type II optimization, we plan to run extensive simulations of our improved operations and compare these to historical data. Figure 2 illustrates the benefits we will measure from real-time hybrid optimization. Benefits between points 1 and 2 are realized when the units are collectively loaded to the most efficient levels possible given the required generation level, or optimally loaded. Benefits between points 2 and 3 are realized when the plant has put the optimum number of units on line. Benefits between points 3 and 5 and between points 2 and 4 (included in Type III optimization) are realized by recognizing that a plant has "sweet" spots that vary with head and the number of units on line. Generating at points 4 or 5 would increase plant efficiency (the amount of benefit gained varies depending on the unit). In the case shown in Figure 2, we would put two more units online and try to move our required plant generation level close to point 5. This would allow us to generate the greatest number of megawatts per unit of water passing through the turbines.

Third, one of the biggest benefits of this optimization project is that it provides the framework and funds to help investigate other efficiency improvements. These improvements can be grouped into two categories. First is improvements that will be or are inputs into our overall system, such as updating the performance curves that input into the optimization software. We updated these curves to improve the accuracy of the optimization. We also used some of this information to update the unit cam curves. This will make our Kaplan units operate more efficiently. Our engineers also noticed that plant head readings taken from single forebay and tailrace sensors did not accurately represent actual heads at individual units. This meant the wrong cam curves were being used to operate the generating units, resulting in decreased efficiency. To correct this, we installed radar head sensors at the forebay and tailrace of every unit to generate the right cam curves.

The second category of improvements results when system operators, engineers, and managers become aware that increasing efficiency of the FCRPS is important, and start suggesting ideas. Examples include smoothing hydraulic surfaces to improve efficiencies, reviewing operating practices, and fine tuning equipment.

Implementation and assessment

We have only begun to implement this vision on the FCRPS. What started as a collection of ideas and hazy goals is now a much clearer vision that is partly designed and implemented. During the initial design period, we found that addressing cultural changes is as important as solving technical challenges. Because we are implementing these systems in stages, we have the unique opportunity to involve the users in a meaningful way. None of the plans for the future operating scheme is written in stone. The plan for the final operating scheme will change during the project, reflecting new information and user inputs. The response has been encouraging and valuable. The subsequent stages and overall operating scheme have already benefited from our users' hands-on experience and suggestions.

The main systems will be substantially completed by 2009. Until then, we will gain partial benefits based on the staged implementation. We have already redesigned some of our processes based on what we have learned so far and have begun manual implementation. Because the accuracy and benefits of optimization are tied to the quality of the inputs, improvements will continue for many years after the main installation. When complete, we will be able to perform Type I, II, and III optimizations using a single interconnected operating system.

Implementing Type I and real-time hybrid optimization is estimated to cost $25 million. We estimate the benefits of implementing this optimization to be between 1 to 2 percent of our power revenue. This equates to an annual benefit between $40 million and $80 million. ■

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