TIP 259: *Short-Term Hydropower Production and Marketing Optimization (HyProM)*

Context

Short-term reservoir planning is difficult because future load and production are highly uncertain. Wind power supply in the Federal Columbia River Power System (FCRPS) is uncertain because it depends upon uncertain wind forecasts. Hydropower production is also uncertain as it depends upon precipitation and temperature. Load also depends upon the meteorology as well as numerous non-meteorological factors, like electricity prices. One effective method for quantifying uncertainty is to use ensemble forecasts. By using ensembles, forecasters can assess the impacts of high wind/low wind scenarios and high temperature /low temperature scenarios upon the reservoir operations. While ensembles can help provide users with a range of likely outcomes, they can also offer too much and conflicting information.

The BPA's current short-term planning modeling software relies on deterministic optimization techniques that do not adequately account for these uncertainties. The increasing numbers of constraints on hydro management, for example; balancing renewable energy such as wind generation, are not well described within the BPA's business processes. In order to meet physical constraints, legal operating requirements and to realize business opportunities in this increasingly complex management puzzle, the BPA needs to adopt more sophisticated optimization techniques.

Description

The BPA needs a reliable predictive model that integrates the meteorological uncertainty of wind power, water flow, and load demand to support more predictable power marketing.

This project focused on the integrated short-term management of hydropower production and marketing over a period of up to 20 days ahead. It developed a robust and computationally efficient framework for the real-time operation of multi-objective and multi-reservoir systems that accounts for uncertainty and operational flexibility.

That included devising a novel methodology for the incorporation of uncertainty into the FCRPS computational system, investigating hybrid optimization approaches, allowing for scalable parallelization in numerical methods and combining all components into an integrated platform with a user-friendly graphical interface. Given a forecast horizon of up to 20 days, one major source of uncertainty in the management strategy has been meteorological. Therefore, the BPA required intensified, restructured focus on forecasting procedures for transforming probabilistic meteorological predictions into optimized reservoir operations.

Benefits

The project addressed the need for more precise knowledge of future stream flow, wind reserve, and power load, with a user-friendly tool to integrate those entities. This was vital to solving the multi-objective problem of reservoir management. Among the benefits this project confers to the BPA are:

- Improved ability to manage high-priority objectives (e.g. environmental obligations, flood control, reliability and safety)
- Improved ability to assess potential Over-Generation Supply conditions and assist in the refinement of mitigation strategies
- Improved ability to maximize the value of FCRPS through Net Secondary Revenue sales in the short-term planning horizon
- And it prepares BPA for changes in the current energy market landscape and/or requirements for emerging markets

Accomplishments

This project advanced a state-of-the-art software infrastructure for short-term management of the FCRPS. It included multi-objective deterministic and stochastic optimization techniques with a modular, open-source, computationally efficient and multithreaded IT design.

The following project objectives were achieved:

1. Model Library: Development and integration of a model library for the process description of hydro power production (including routing in the downstream river reaches), marketing, and energy networks.
2. Representation of Uncertainty: Analysis of the system's uncertainty and its description by non-parametric scenario tree methods in particular for describing the meteorological uncertainty derived from ensemble forecasts.
3. Stochastic Optimization: Design and implementation of online optimization algorithms, i.e. algorithms which run in an operational setting, both in

deterministic and multi-stage stochastic mode for supporting the short-term management of the short-term planning group.

4. Operational Flexibility: Online assessment of the operational flexibility of the system by analyzing its sensitivity to constraints and related to different stream flow and load scenarios.
5. Advanced Visualization: Setup of demonstrations with a phased integration of all developed components and a focus on the proper data visualization to the operator.

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Project Start Date: October 1, 2012

Project End Date: April 30, 2015

Deliverables

- Technical integration of both Power Production and Market Trading optimization models;
- Technical integration of deterministic and stochastic models;
- Ongoing application of BPA test cases and evaluation of results;
- Development of final results, reports and scientific papers

Project Cost

Total Project Cost: $1,166,100

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Fraunhofer IOSB-AST, Germany

Related Projects

TIP 258: Development of a State-of-the-Art Computational Framework and Platform for the Optimal Control of Multi-reservoir Systems under Uncertainty

TIP 265: Computationally Efficient, Flexible, Short-Term Hydropower Optimization and Uncertainty Analysis (SHOA) for the BPA System

Conclusions of the Project Manager:

In this TI project, novel tools were developed for the combined short-term management of hydropower production and marketing and implemented in a system demonstration for the FCRPS. Results indicate the significant added value of probabilistic over deterministic forecast products such as their better skill, longer forecast time and higher stability. Although this better input already leads to better decisions in a deterministic optimization framework in a first step, the use of a multi-stage stochastic optimization approach also propagates and visualizes the forecast uncertainty through the hydro system and provides more robust decisions by the consideration of multiple future trajectories.

From the BPA point of view, all novel components are either already in use at BPA or compatible with available systems. Since some of the components are still in a prototype status, moderate investments could make them ready for a production environment.

The main challenge in the next years will be the consistent and organization-wide introduction of short-term probabilistic forecast products and its use in stochastic decision-making tools. Note that the maximum benefit can only be achieved, if all upstream products are in place and properly represent the forecast uncertainty. The main focus in this project has been the most relevant meteorological forecast uncertainty, but other non-meteorological sources such as from non-federal upstream reservoirs will also contribute to uncertainty.

Published Papers and Conferences

Publications in peer-reviewed journals

Reference	Deliverable	Comments
Schwanenberg, D., Xu, M., Ochterbeck, T., Allen, C., Karimanzira, D., "Short-Term Management of Hydropower Assets of the Federal Columbia River Power System", IAHR J. **Applied Water Engineering and Research** 2(1), 25-32, May 2014	D3.1 Deterministic Optimization	Description of the deterministic optimization of the FCRPS and outlook to upcoming work
Karimanzira, D., Schwanenberg, D., Allen, C., Barton, S., "Short-Term Hydropower Optimization and Assessment of Operational Flexibility", accepted by ASCE J. **Water Resources Planning and Management**	D3.2 Assessment of Operational Flexibility	Assessment of operational flexibility of the FCRPS with the deterministic optimization model
Schwanenberg, D., Mainardi Fan, F., Naumann, S., Kuwajima, J.I., Alvarado Montero, R., Assis dos Reis, A., "Short-Term Reservoir Optimization for Flood Mitigation under Meteorological and Hydrological Forecast Uncertainty, Application to the Tres Marias Reservoir in Brazil ", J. **Water Resources Management** 29(5), 1635-1651, March 2015	D3.3A Multi-Stage Stochastic Optimization	First version of the stochastic optimization approach in application to the Brazilian reservoir system
Naumann, S., Schwanenberg, D., Karimanzira, D., Allen, C., "Short-term management of hydropower reservoirs under meteorological uncertainty by means of multi-stage optimization ", accepted by J. **at - Automatisierungstechnik**	D3.3A Multi-Stage Stochastic Optimization	First version of the stochastic optimization approach in application to hydropower production of the FCRPS
Schwanenberg, D., Naumann, S., Warweg, O., Allen, C., Karimanzira, D., "Integrated Short-Term Management of Hydropower Production and Marketing - Application to the Federal Columbia River Power System in the Pacific Northwest of the USA", manuscript	D3.3C Multi-Stage Stochastic Optimization	Final version of the stochastic optimization in application to hydropower production and marketing of the FCRPS

Conferences: European Water Resource Association (EWRA) 2013, International Association for Hydro-Environmental Engineering and Research (IAHR) 2013, International Conference of Hydroinformatics (HIC) 2014, European Geosciences Union (EGU) 2014 (x2), American Geophysical Union (AGU) Fall Meeting 2014