The Hydropower Flexibility Framework Tool: A Water-based Approach for Quantifying Hydropower Flexibility

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The resource mix across the globe is changing as renewable technologies become more cost-effective and as part of efforts to reduce the world's dependence on carbon-based generation technologies. Increasing amounts of variable renewable energy (VRE) resources, primarily wind and solar, are interconnecting with the grid. Worldwide pumped storage hydro currently provides regulation, spinning reserve, and approximately 96% of utility scale energy storage, and significant utility effort is focusing on increasing capacity at existing pumped storage facilities. Further, conventional hydroelectric power plants can, and often do, provide flexibility services for grid reliability and stability and for integrating VRE resources; they may have limited ability to store water and to provide regulation, and spinning reserve in addition to energy, such as for run-of-river plants.

The U. S. Department of Energy's (DOE's) Water Power Technologies Office (WPTO) under DE-EE0008941 is sponsoring the Electric Power Research Institute's (EPRI's) Hydropower Flexibility Framework (HFF) Project to develop a publicly available tool capable of integrating detailed hydropower plant characteristics with water availability through various Use Cases. This public tool uses an innovative, water-based methodology for analyzing and evaluating energy and flexibility services and a cloud-based calculation engine that co-optimizes unit-level dispatch for energy generation, regulation, and spinning reserve, subject to water availability. A hydropower plant's abilities to provide flexibility services, like regulation and other reserves, depends on its fuel (water availability and water-specific constraints), the plant-specific electrical and mechanical capabilities and constraints, and the environmental and regulatory constraints.

The HFF Tool's components are a plant model, an associated reservoir curve, and the minimum/environmental flow characteristics. The plant model includes optimized plant efficiency matrices, optimized regulation matrices, and a spin deployment probability to account for water use with spinning reserve commitments[2]. **Figure 1** shows optimized plant performance curves for a three-unit plant with varying amounts of regulation (i.e., regulation "swing" from the setpoint), using fixed dispatch.

Hydropower Flexibility Framework Applications

The HFF Tool employs multiple user-provided datasets, as outlined below, to perform the co-optimization and to provide the user with dispatches for various electricity market products, the revenue associated with these products, and the corresponding water flow schedules.

Data Requirements for the HFF Tool

- Unit Efficiency Characteristics
- Regulation Parameters (minimum and maximum swing for regulation)
- Reservoir and Tailwater Elevation Curves
- Minimum/Environmental Flow Requirements
- Initial Reservoir Elevation and Inflow Data
- Energy Market Price Data

By varying the data inputs, the user of the HFF Tool can explore a range of interesting topics, including assessing opportunities to support the dispatch decision process, provide valuable information when participating in electricity markets, assessing the potential benefits from participating in additional electricity markets, quantifying the impact of water passage regulations, understanding the impact of future hydrologic conditions, and estimating the benefits from future plant efficiency improvements. To aid in these assessments, the HFF Tool contains comparison capabilities that allow the user to view both an aggregated change in dispatch for various market products, total energy production, and revenue. While there are a host of different applications for the HFF Tool, the following seven Use Cases have been identified.

Improve the Dispatch Process

The first Use Case is an assessment of the decision-making process for hydropower dispatch to identify any opportunities for improvement. It is valuable to plant operators because any significant deviation between historic plant dispatch and the results from the HFF Tool may indicate areas where additional performance could potentially be gained, or additional tool calibration is needed. To perform this assessment, the HFF user uses historic reservoir inflows and market price data along with existing unit efficiency curves, minimum flow requirements, and reservoir curves. The HFF user can also examine improvements to multi-day dispatch planning by using expected reservoir inflows and expected market prices along with existing unit efficiency curves, minimum flow requirements, and reservoir curves. This Use Case allows the examination of current operations and also has the benefit of highlighting the value of increased accuracy of inflow and market forecasts.

Improve Existing Market Participation

The second Use Case focuses on improving future participation in electricity markets with which the plant owner is engaged. For this application, the user provides the HFF Tool with anticipated reservoir inflows and expected market prices along with known unit efficiency characteristics, constraints, and reservoir curves. The results of the HFF Tool may be integrating into existing market participation processes to enhance plant value and efficiency.

Assess Additional Market Engagement Benefit

The third Use Case explores the benefits from, and the implica-

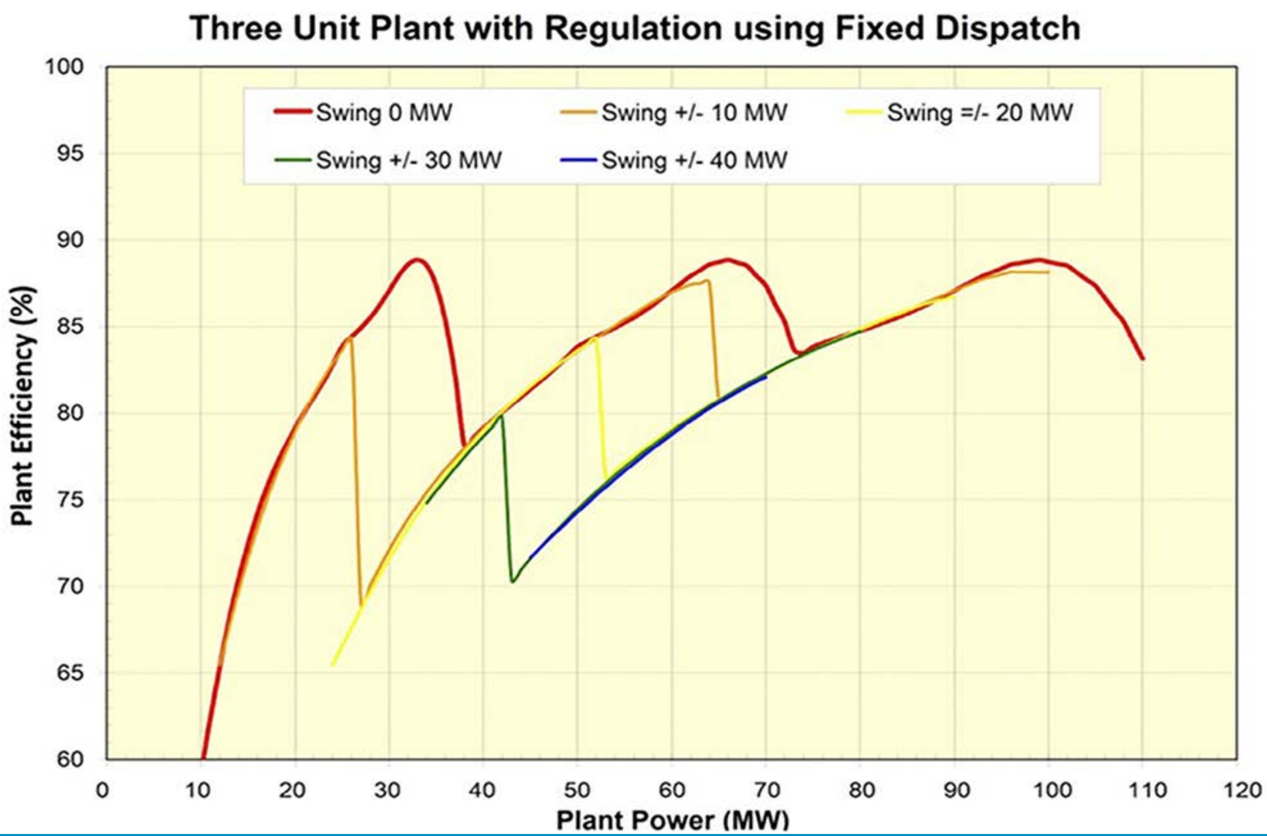

Figure 1 | Three-Unit Plant Performance Curves with Regulation using Fixed Dispatch.

tions of, engaging in additional flexibility services or of limiting engagement in them. Generally, there are four types of products offered by generation owners in a typical electricity market: energy, regulation, spinning reserve, and non-spinning reserve. As the share of variable wind and solar energy resources increases, the need for flexible resources, particularly those that can provide regulation and spinning reserve, also increases. However, predicting the impacts from market participation on overall revenue and on plant dynamics is challenging. Increased unit start-stops, off-design operation, and increased ramping has shown to have a negative impact on the remaining useful life of hydropower plant components[1]. To perform analyses within this Use Case, electricity market prices are gathered for representative locations and time periods and alternative market engagement scenarios are be developed and evaluated with the HFF Tool.

Calculate the Impact of Water Passage Requirements

As the understanding of social or environmental needs evolves, hydropower plants may be required to alter their minimum flow requirements. This stewardship of water resources is important but has potential implications on the ability of the hydropower plant to support the requirements of the electric grid. The fourth Use Case for the HFF Tool is focused on quantifying the impacts of evolving minimum flow requirements. For this Use Case, the user enters the existing minimum flow requirements in one simulation and the modified minimum flow requirements in another simulation using the same representative market price signals and water inflows. Analyses using the HFF Tool provide a comparison of the scenarios in terms of revenue, energy generation, and flexibility services (i.e., regulation and spinning reserve) to support the grid.

Evaluate the Impact of Future Hydrologic Conditions

The fifth Use Case estimates the impact of climate change on a hydropower plant's ability to provide grid flexibility services. The user performs a simulation with the HFF Tool using existing hydrologic conditions and then performs additional simulations using predicted stream flows, based on varying climate scenarios. The ability of the HFF Tool to assess numerous simulations is valuable, because the Tool can quickly produce results for numerous climatological scenarios. Such scenarios may include different Representative Concentration Pathways for varying levels of greenhouse gases in climate scenarios, different General Circulation Models used to predict large scale climatological effects, and different downscaling methodologies which take large-scale model results and convert them into local effects.

Assess the Flexibility Potential for Non-Powered Dams and Greenfield Development

While recent development of new domestic hydropower has been limited, there is significant potential for both non-powered dam (NPD) conversion and for new site development (Greenfield). Assessments from Oak Ridge National Laboratory have estimated the potential for new development at 12 GW for NPD and at 84.7 GW for new sites[3,4]. The sixth Use Case focuses on quantifying the potential role that new hydropower could have in providing flexibility services, where the user enters data from a representative market prices, reservoir inflows based on stream gauge data, minimum flow obligations based on other facilities within the same basin or other prior knowledge, and reservoir elevation curves based on the existing asset for NPDs or planned inundation levels for a greenfield development. This Use Case serves as a valuable screening tool for site developers interested in quickly assessing the viability of a new development and the role that the new development could play in supporting the grid.

Predict the Flexibility Benefits from Efficiency Improvements

The seventh Use Case assesses the impacts of improvements to unit efficiency may have on hydropower plant grid support and value. The user performs one simulation using existing plant efficiency characteristics with a representative set of reservoir inflows and market signals and then performs an additional simulation using predicted plant efficiency using the same inflows and market signals. These results help improve predictions of the impact of system upgrades by including both energy and flexibility services. This application of the HFF Tool is particularly valuable as the hydropower industry continues to age, grid requirements for flexibility increase, and the Federal government is providing support for improvements to hydropower plant efficiencies.

Getting Involved

The HFF Tool will be launched online in the Summer of 2023, and it will be available to qualified users. Users of the HFF Tool will be required to register for accounts, users' data will be secured, and no secondary uses of the data will be allowed. The authors are highlighting the performance and use of the HFF Tool in a variety of hydropower community venues, including engagement with a Technical Review Committee, presentations to individual organizations, industry case studies, and industry conferences. If you are interested in using the HFF Tool, please contact Dr Mark Christian at mchristian@epri.com.

Acknowledgements

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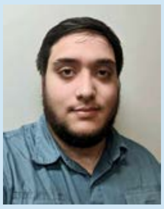

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