HD-MPC

Hierarchical and Distributed Model Predictive Control for Hydro-Power Valleys

Providing almost 17 % of the world's electricity, hydro-power is the most important renewable power resource in the world. To increase the proportion of renewable resources in the future even more, in particular intermittent installations like solar and wind power plants, the grid will require more flexibility from traditional "controllable" generation facilities such as fossil, nuclear, and hydro-power plants. Advanced control methods can be applied at these power plants at the local level to improve the power response to frequency variations. Further, the maneuverability of hydro-power valleys can be enhanced by implicitly considering interactions between individual plants and avoiding that commands applied to a given plant lead to a limitation on a downstream or upstream plant of the valley.
One-day-ahead prediction of the electricity production is usually done by experienced operators with simulation or optimization tools. This is a difficult task, in particular when water levels are near their boundaries or when water inflows are extremely high or low. Optimization tools for cascaded run-of-river plants include classical feed-forward and model predictive control. However, the size of the problem, in case of a large hydro-power valley, is huge and can lead to implementation problems.
Robustness towards communication failures with distributed control is important to guarantee safe operation. For this reason, each plant needs to be controlled at the local level.

Main Challenges

Hydro-power valleys are common and important industrial systems, where safe operation, expressed by constraints, is an absolute necessity to run. Even in case of communication failures, the operation must be safe and robust, thus the local controllers in the plant must have a certain degree of autonomy. At the same time, it is challenging to take advantage of their particular properties to optimize them economically.
There are many difficulties to optimize hydro-power valleys. The multiple interconnected plants have many interactions and strong mutual influences among them. Due to this inter-dependence the transients of one subsystem perturb the water levels of the other plants; therefore subsystems cannot be optimized individually without de-optimizing the rest of the system.

FP7 STREP project

HD-MPC - Hierarchical and distributed model predictive control of large-scale systems

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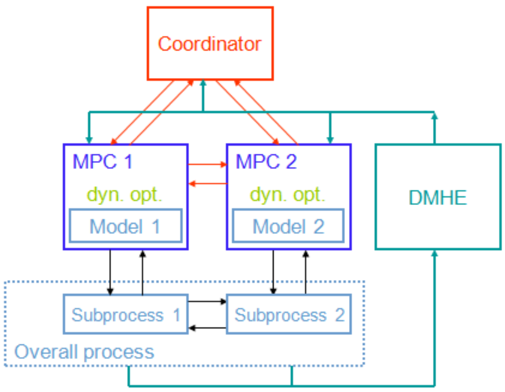
How to ...?

Coordinate a complex and strongly linked set of hydro-power plants, with constraints and multi-time-scale objectives.



Highly complex and detailed models become more and more available, and the integration of these models in the optimization and control methods is essential to improve the performance of the overall system. However, the tractability of such large models reaches the current computational limits.

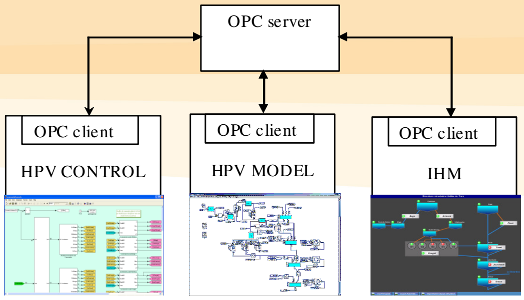
HD-MPC Solutions for Hydro-Power Valleys

The control of hydro-power valleys needs a central brain that coordinates the smaller entities and it needs a dynamical representation of the overall system in order to look ahead into the future. The coordinated entities, guided in this way, can be optimized locally with a precise model and on a smaller time scale.

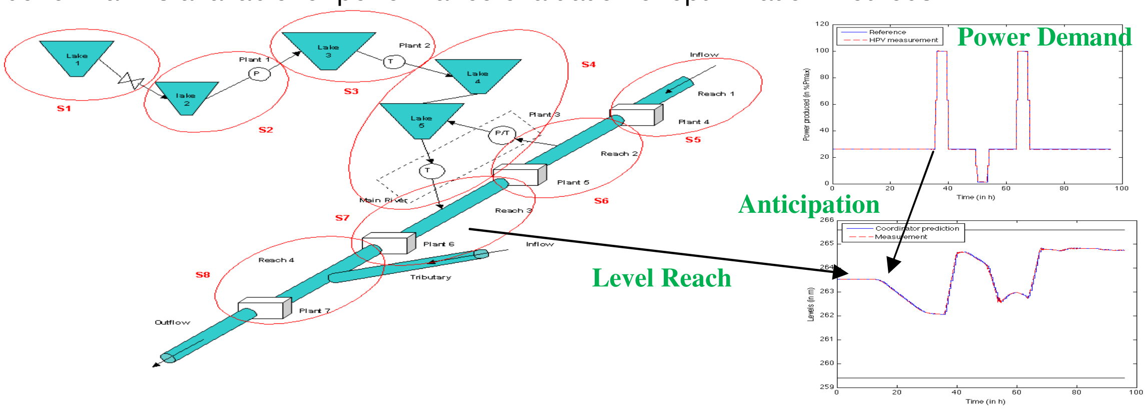
New hierarchical and distributed model predictive control methods have been developed in the HD-MPC project, in order to cope with the challenges arising in large-scale distributed plants.

The two most promising methods to optimize hydro-power valleys are:

- Distributed multiple shooting, which is an extension of the single shooting method. To speed up the optimization it makes use of inexact gradients and, now easily available, parallel computing.
- Fast gradient-based distributed model predictive control (DMPC), where only communications between direct neighbors are needed. This method solves dual optimization problems with a fast convergence rate, which makes it suitable for real-time implementation.



A flexible platform is created by connecting a detailed process model, interchangeable controllers and a human machine interface for visualization. In addition, a public benchmark is available for performance evaluation of optimization methods.



Impact and Benefits

Simulations and HD-MPC control on the platform with the detailed process model show that the controller anticipates important water flows and respects constraints on levels, flows, and power demand. With this advantage, the hydro-power valley can help actively to achieve a good level of ancillary services and prepare for supplementary intermittent renewable power sources in the future.

The newly developed hierarchical and distributed control methods provide good performance and an efficient way for scheduling. Evaluations on the public hydro-power valley benchmark show that the mean average tracking error of the distributed multiple shooting method is too low to be measured on a real plant and that the fast gradient-based DMPC approach has an tracking error less than 1%.

Main achievements

New methods to optimize and to control multiple time-scale and interconnected processes are now available and their efficiency is evaluated on a benchmark.

An application on hydro power valley illustrates the anticipation and coordination of water levels in order to guarantee future power demand.