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Hierarchical hydro power valley control: Validation on simulation platform

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ABSTRACT

Hydro power valleys (HPV) are large scale interconnected systems. All plant operations have to comply with technical and environmental requirements concerning level, flow rate and power variations. A two-layer hierarchical MPC solution, designed to manage the large scale constrained and time delayed HPV, is tested on a simulation platform. The upper layer optimizes the power profiles on a one-day horizon with a coarse step size. The lower level refines the control for a shorter horizon and step size. Simulations show that the coordination is able to improve the maneuverability of the HPV.

1. Introduction

Hydro power is the most important means of renewable power generation in the world. According to IEA statistics, around 16% of electricity in the world was generated by hydro power plants in 2008. Hydro power does not produce any CO_2 and is independent of fuel prices. Compared to other renewable resources like wind power, hydro power plants are maneuverable and can modify their load easily, their production is rather well predictable and depends on the reservoir capacity.

To increase in the future the proportion of the intermittent and non-dispatchable renewable resources (solar and wind), more flexibility will be required for the "controllable" generation facilities (fossil, nuclear and hydro power plants). For hydro power plants, the flexibility improvement can be obtained at different levels. Advanced control can be implemented at local level to improve the power response of the power plants for frequency response (Treuer et al., 2007; Weber et al., 2002). On the other hand, maneuverability can be enhanced in the case of a hydro power valley by considering interactions between the units and avoiding for instance that a command applied to a given unit leads to a limitation on another plant located downstream or upstream in the valley. The optimization of cascade run-of-river power plants has already been addressed in several papers using classical feed-forward (Van Mien & Klein, 1992) or MPC control (Dumur, Libaux, & Boucher, 2001; Setz et al., 2008). The latter considers the control of the power plants as a constrained optimization problem that is solved with a receding horizon approach. The size of the problem in the case of a large hydro power valley is however huge and can lead to implementation problems. For this particular reason and other reasons corresponding to robustness issues in case of communication failure, distributed control setups have been considered in recent publications. An overview of the different possible structures for hierarchical and distributed model predictive control (HD-MPC) architectures can be found in Scattolini (2009).

Distributed MPC solutions for hydro power valleys with explicit solutions are proposed for instance by Zarate et al. (2011a, 2011b, 2013). The solution is based on dual decomposition also known as price coordination mechanism as described by Mesarovic, Macko and Takahara (1970), where each local controller optimizes a part of the objective function and where the coordinator iterates with Lagrangian parameters associated with coupling constraints. This decomposition is possible when the objective function is additive i.e., when the global objective function is the sum of the objective functions optimized by the local controllers. Unfortunately, this approach cannot be easily applied when considering the problem of dispatching the global power of a hydro power valley on each plant.

Another solution to simplify the optimization of large scale systems consists in hierarchical MPC with different time scales. The upper-level control finds the set points for the local controllers considering the whole system on a slow sample rate and a long prediction horizon. The local lower-level controllers regulate, on a fast time scale, the controlled variables at the references defined

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by the upper level. In this paper an advanced control solution is proposed to improve the power response of a hydro power valley by applying this HD-MPC architecture.

Fig. 1 shows the structure of the paper. Section 2 describes the hydro power valley (HPV). This valley is composed of lakes, pumps, turbines and river reaches. This section examines also nonlinear and linear control models. Section 3 formulates the control problem. Centralized MPC and HD-MPC solutions are detailed in the same section. Section 4 describes the validation platform which consists of a detailed model developed with the hydraulic code Mascaret (http://www.openmascaret.org), the HPV control in Matlab™ (http://www.mathworks.com/) and a HMI. Section 5 gives the simulation results obtained with the two control structures in order to compare their performance and robustness. The results of the validation tests achieved on the platform are shown in Section 6 before the conclusion which includes the perspectives and future developments.

The proposed paper is an extended version of the published work (Faille, Davelaar, Murgey, & Dumur, 2012) with a more detailed presentation of the simulation platform and of the mathematical solutions (coming from reports developed during the European project HD-MPC).

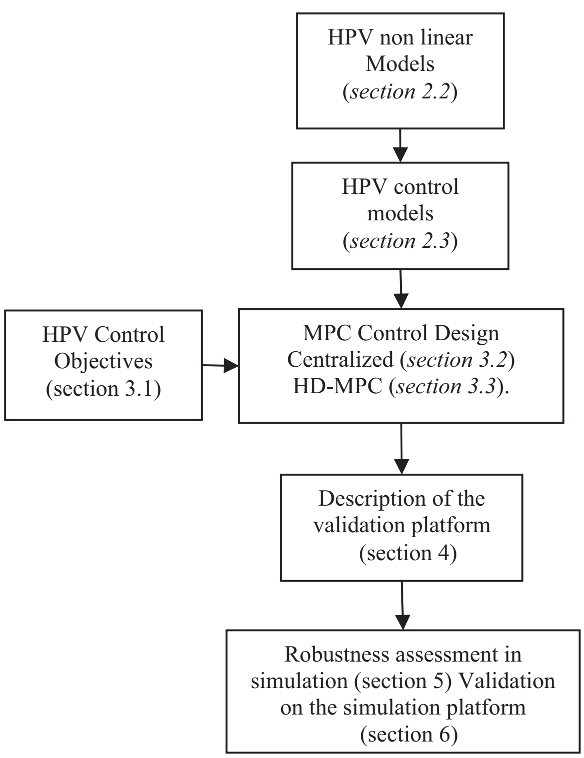

Fig. 1. Organization of the paper.

2. HPV modeling

2.1. HPV description

Fig. 2 presents the different power units that are considered in the hydro power valley of this paper. High head power plants (see Fig. 2a) are flexible plants which use the water stored in the reservoir to produce electricity. A detailed description of such plants can be found in Weber et al. (2002). The other units of the hydro power valley are run-of-river power plants (Fig. 2b). Generally, they are characterized by a small storage capacity and strict level constraints. Fig. 2b shows a river reach (the portion of the river between two power generating units) with a dam on both sides to store the water and a plant to produce electricity. Each plant is equipped with a level and a power/speed controller that imposes the flow rate through the turbine in order to control the upstream level of the dam and the turbine speed. Locks are also installed to ease navigation.

Fig. 3 shows the structure of the valley considered in the paper. It consists of a river and a lake network. The five lakes are interconnected by ducts, pumps (denoted by the letter P in the figure) and turbines (denoted by the letter T in the figure). The water can be pumped from, or passed through the turbine to the river, which is composed of three reaches separated by hydro power plants. Plant 3 is a reversible system able to pump water from reach 1 into lake 5, or conversely to turbine water from the lake to the river. This possibility allows the production optimization algorithm to take advantage of the low price during off-peak hours.

The two main inputs of the HPV are the river and the tributary inflows. Other perturbations (due to rain or small creeks for instance) on the lakes and the river reaches are supposed to be small.

The HPV is decomposed into eight subsystems corresponding to the dashed circles in Fig. 3 and noted S1–S8. Each subsystem contains a lake or a reach and a plant and has its own manipulated (the flowrate through the turbine, pump or valve) and controlled variables (level and power).

2.2. HPV simulation model

The dynamics of the river are slow and on-site tests are time consuming and expensive. Therefore, in order to shorten the on-site commitment of the HPV optimization, a platform has been set up. This platform, which is described in Section 4, uses detailed simulation models of the reaches, as a replacement for the real process, to test the robustness and the performance of the solution in different configurations. Hereafter follows the description of the model.

The lakes are modeled as simple integrators calculating the water storage volume as a function of the water inflow and outflow. Tables are used to determine the levels from the volume.

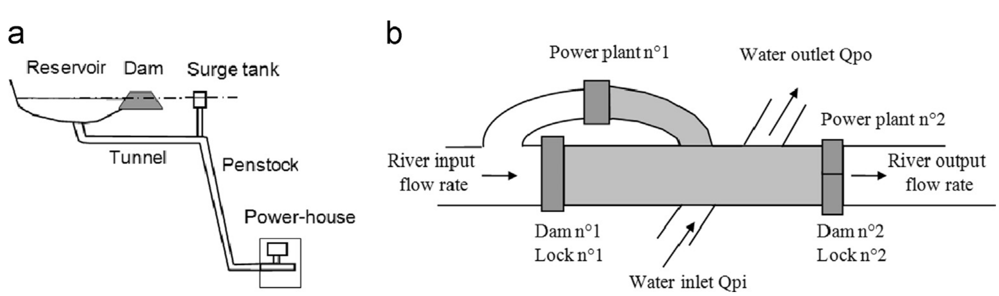

Fig. 2. (a) High-head power plants and (b) run of river plants.