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Application of adaptive time delay model in optimal control of a hydropower cascade

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Abstract

Small hydropower plants (SHP) are increasingly constructed in recent years as a substitution of the use of conventional energy materials such as wood and fossil fuel in remote rural regions. Besides new constructed plants, upgrading operational strategies of existed systems for increasing electricity productivity is also significant. Motivated by this issue, a combination of two techniques, simulation and optimization based on models is frequently used to improve the operation regimes of coordinated reservoir cascades. However, the application of a complex hydraulic model consumes a huge computation time. Hence, this paper proposes a replacement for the complex hydraulic model by an adaptive time delay (ATD) model. The cutting- edge point is that the ATD model is able to quickly predict the system dynamics both in simulation and optimization. This ATD model consists of only two parameters: time constant and time delay which are functions of unsteady flow and can be easily derived from complex hydraulic models (HECRAS, MIKE11), or from physical parameters of rivers (flow rate, roughness, bed slope, cross section). The integration of the ATD model into the simulation and optimization techniques will be demonstrated by a case study of a cascade of SHPs. In terms of optimization, a non-linear constrainted optimization algorithm is applied to improve electricity production to meet the scheduled demand.

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Keywords: small hydropower plant; water storage; adaptive time delay model; simulation; optimization

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1. Introduction

Over the past decade, a tendency for supplementing and replacing conventional fossil sources for electricity generation by renewable sources has been substantially exerted because of the scarcity and limitation of fossil energy. Although the natural replenishment of these sources for renewable electricity is well known, an efficient manner in using this energy is always essential. Hydropower is one of the viable option for sustainable energy production. However, operation and management of hydropower systems is a challenging issue for decision makers and operators. The reasons are conflicts among stakeholders (electricity, flood protection, agriculture, industry, and others) as well as the uncertain nature of reservoir inflow that adds considerably to complexity of the system [1-3]. Popular powerful techniques for hydropower analysis are simulation and optimization. Models represent the system attributes and predict the system responses under different conditions. A set of operating rules are developed and continuously improved in order to determine an acceptable release of reservoirs. On the other hand, the optimization that focuses on identifying optimal decision variables is based on mathematical formulation for maximizing or minimizing an objective function subject to constraints [4]. In fact, the optimization models for hydropower systems are applied for different operation period such as seasonal operation, daily, hourly, or event-based real-time regulation. Moreover, its applicability is not only for an individual hydropower plant, but also for cascade of hydropower plants that improves significantly electrical productivity. A large number of optimization approaches for dam optimal control exists, e.g., linear programming (LP), nonlinear programming (NLP), dynamic programming (DP), genetic algorithm (GA), and have been applied since years [5-9].

The paper introduces a new approach that combines an adaptive time delay model and reservoir model for simulation, and then applies nonlinear constrainted programming to achieve an optimal regulation for enhancing the electricity generation of a cascade of hydropower plants. The integration of adaptive time delay river dynamics into the optimization is considered as an innovation in this paper.

2. Methodology

The method consists of two components: simulation and optimization. In terms of simulation, the dynamic of system is shown by reservoir model and flow routing model (ATD). In which, the ATD model transfers the releases from upstream reservoir to downstream reservoir while reservoir model simulates behaviours of dams. Regarding optimization, nonlinear programming technique is applied to determine the best release of the cascade by which the electricity production will meet the objective. For illustration, a case study of a cascade with two hydropower plants is selected in order to compare an energy production of an optimized operation and existing operation. The objective of this study is to present a new method that may be applied to improve the electricity production of hydropower cascades. The system is a combination of an ATD model and a reservoir model and is presented in Fig. 1 and Equation 1, 2, and 3.

$$\frac{dV^u}{dt} = Q^u_{in} - Q^u_{out} \tag{1}$$

$$\begin{cases} T_c \dfrac{dq}{dt} + q(t) = Q^u_{out}(t) \\ Q^d_{in}(t) = q(t - T_d) \end{cases} \tag{2}$$

$$\frac{dV^d}{dt} = Q^d_{in} - Q^d_{out} \tag{3}$$

Where $Q^u_{in}(t)$ is inflow of upstream reservoir, $Q^u_{out}(t)$ is discharge of upstream reservoir, $Q^d_{in}(t)$ is inflow of downstream reservoir, is discharge of downstream reservoir, $V^u(t)$ is storage of upstream reservoir, $V^d(t)$ is storage of downstream reservoir, T_c is the time constant, T_d is the time delay.