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Dynamic analysis of a pumped-storage hydropower plant with random power load

Hao Zhang [a], Diyi Chen [a,*], Beibei Xu [a], Edoardo Patelli [b], Silvia Tolo [b]

[a] Institute of Water Resources and Hydropower Research, Northwest A&F University, Shaanxi, Yangling 712100, China
[b] Institute of Risk and Uncertainty, University of Liverpool, Liverpool, United Kingdom

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ABSTRACT

This paper analyzes the dynamic response of a pumped-storage hydropower plant in generating mode. Considering the elastic water column effects in the penstock, a linearized reduced order dynamic model of the pumped-storage hydropower plant is used in this paper. As the power load is always random, a set of random generator electric power output is introduced to research the dynamic behaviors of the pumped-storage hydropower plant. Then, the influences of the PI gains on the dynamic characteristics of the pumped-storage hydropower plant with the random power load are analyzed. In addition, the effects of initial power load and PI parameters on the stability of the pumped-storage hydropower plant are studied in depth. All of the above results will provide theoretical guidance for the study and analysis of the pumped-storage hydropower plant.

1. Introduction

Pumped-storage hydropower plants (PSHP) play an important role in the peak regulation and frequency control of a power grid. They pump water with the power consumption at valley hours and generate electricity with the power consumption at peak hours to balance energy production and consumption levels [1–5]. As the PSHP can assume advantageously the power-frequency regulation, they allow power plant owners to improve the power supply quality effectively [6–10]. Therefore, the research on dynamic analysis and stability of the PSHP is of great importance.

Many studies focus on the modeling and dynamic analysis of the PSHP [11–16]. It is worth mentioning the work presented in Ref. [17] where the dynamic characteristics of a pump-turbine were studied. The dynamic method was proposed to simulate the critical transient parameters. In Ref. [18], the authors explored the nonlinear dynamic behaviors of a hydro-turbine governing system in the process of sudden load increase transient. In Ref. [19], a one-dimensional numerical code estimating the performances of centrifugal PATs (pumps used as turbines) was presented. The work of [20] is aimed to analyze the different guide-vane closing schemes for reducing the maximum transient pressures in the S-shaped region. A series of model tests were conducted on a pumped-storage station model and the measured data fully validated the correctness of the analyses.

In practical situations, it is difficult to regulate and control perfectly the dynamic characteristics of the PSHP because of the random power load [21–25]. In addition, the lack of the accurate model of the PSHP and the qualitative analysis of control parameters also make it hard to ensure the stable operation of the PSHP [26–28]. However, few researchers have focused

* Corresponding author.
E-mail address: diyichen@nwsuaf.edu.cn (D. Chen).

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on the dynamic characteristics of the PSHP with random power load. Therefore, to overcome the above situations, this paper tries to investigate the influences of the PI gains on the PSHP with the random load from the view point of dynamics. In addition, the effects of the initial load on the dynamic characteristic of the PSHP with random power load are analyzed deeply by means of simulations.

The remaining content of this paper is organized as follows. Section 2 introduces the PSHP. Section 3 presents the linear reduced order model of the PSHP. In Section 4, the system dynamic response is analyzed by means of simulations. The effects of the PI gains and initial power load on the dynamic characteristics of PSHP are discussed. Finally, Section 5 condenses the conclusions.

2. Dynamical model of the PSHP

The scheme of the considered system, corresponding to the mechanical and hydraulic components of the hydropower plant, is represented in Fig. 1. The main model blocks are described in the following subsections.

Notation	
b_{11}, b_{12}, b_{13}	partial derivatives of the flow with respect to the head, speed and wicket gate position (p.u.)
b_{21}, b_{22}, b_{23}	partial derivatives of the turbine torque with respect to the head, speed and wicket gate position (p.u.)
c	turbine mechanical torque (p.u.)
h	net head (p.u.)
h_c	reservoir water level (p.u.)
Δh	relative deviation of the net head (p.u.)
k_{loc}	local head losses coefficient (p.u.)
k_p	proportional adjustment coefficient (p.u.)
k_i	integral adjustment coefficient (s^{-1})
Δn	relative deviation of the unit speed (p.u.)
p_g	generator electric power output (p.u.)
Δp_g	relative deviation of the generator electric power output (p.u.)
p_t	mechanical power (p.u.)
Δp_t	relative deviation of the mechanical power (p.u.)
q	flow through the turbine (p.u.)
Δq	relative deviation of the flow through the turbine (p.u.)
q_t	flow in the penstock (p.u.)
Δq_t	relative deviation of the flow in the penstock (p.u.)
z	wicket gate position (p.u.)
Δz	relative deviation of the wicket gate position (p.u.)
$r/2$	continuous head loses coefficient (p.u.)
T_m	mechanical starting time (s)
T_w	water starting time in the penstock (s)
T_e	water elastic time (s)
T_r	dashpot time constant (s)
δ	transient speed droop
p.u.	per unit

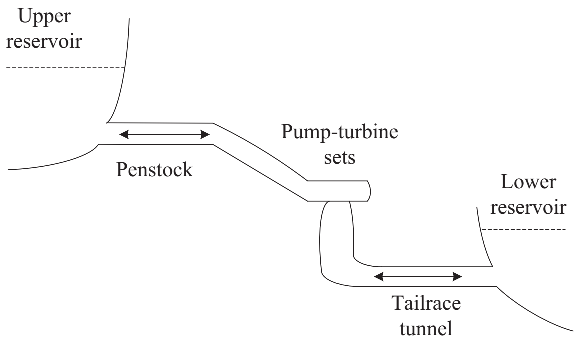

Fig. 1. Scheme of the dynamic model.