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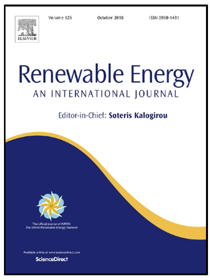

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Dynamic performance analysis of hydro-turbine governing system considering combined effect of downstream surge tank and sloping ceiling tailrace tunnel

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Abstract: This paper aims to analyze the nonlinear dynamic characteristics of hydro-turbine governing system with downstream surge tank and sloping ceiling tailrace tunnel and reveal their combined effect mechanism on stability. First, the nonlinear mathematical model of hydro-turbine governing system is presented. Second, the Hopf bifurcation theory is adopted, and the stability performances of hydro-turbine governing system under different sectional areas of downstream surge tank are analyzed and verified. Finally, the combined effect of downstream surge tank and sloping ceiling tailrace tunnel on stability is investigated and the design methods are proposed. The results indicate that: The dynamic response process of hydro-turbine governing system shows an obvious characteristic of wave superposition. Two types of bifurcation lines reflect the critical stability characteristics of the two subsystems and constitute the boundaries of the stable domain. The sloping ceiling tailrace tunnel cannot make an obvious change of the stability performances of the subsystem of penstock - hydro-turbine unit, but it has significant effect on the stability performances of the subsystem of downstream surge tank - sloping ceiling tailrace tunnel. The larger aspect ratio or smaller ceiling slope gradient results in better stability of the subsystem of downstream surge tank - sloping ceiling tailrace tunnel.

Keywords: downstream surge tank; sloping ceiling tailrace tunnel; hydro-turbine governing system; nonlinear dynamics; stability; combined effect.

1. Introduction

The combined layout of downstream surge tank and sloping ceiling tailrace tunnel is usually applied to the diversion-type and header-development underground hydropower stations. This type of hydropower station has the following features: (a) long tailrace tunnel, (b) large discharge of hydro-turbine unit, (c) low working head and (d) large amplitude of downstream water level change. Because of the features (a), (b) and (c), the downstream surge tank must be set to satisfy the requirements of the regulation assurance calculations and stable operations of hydropower station [1,2]. Moreover, according to the design specifications of surge tank [3], the sectional area of downstream surge tank of this kind hydropower station is generally extremely large. In the design processes, the downstream surge tank is usually located near the powerhouse in order to reduce the flow inertia between hydro-turbine unit and downstream surge tank [4]. The extremely large downstream surge tank, underground powerhouse and main transformer cave are parallel located in a narrow area. Meanwhile, there are some other tunnels in the neighborhood of downstream surge tank. As a result, the surrounding rock stability, hydraulic arrangement and excavation of underground cavern group would exist severe difficulties.

In order to overcome the difficulties of the arrangements and constructions of underground cavern group caused by the extremely large downstream surge tank, reducing the sectional area of downstream surge tank by adopting new types of tailrace tunnel is a possible method. Nowadays, the application of sloping ceiling tailrace tunnel into the design of the tailrace tunnel of this kind hydropower station is being explored. The working principle of sloping ceiling tailrace tunnel is as follows [5,6]: the length of the pressurized flow section in tailrace tunnel is shortened through the change of downstream water level. The larger the amplitude of downstream water level change, the more obvious of the favorable effect on shortening the length of the pressurized flow section. However, the combined layout of downstream surge tank and sloping ceiling tailrace tunnel is a completely new layout pattern of pipelines of hydropower station. The knowledge of the working characteristics and design methods of the hydropower station with downstream surge tank and sloping ceiling tailrace tunnel is extremely limited. What are the dynamic characteristics of the hydro-turbine governing system of this kind hydropower station? How do the downstream surge tank and sloping ceiling tailrace tunnel interact with each other? What are the effects of the interaction between downstream surge tank and sloping ceiling tailrace tunnel on the stability of the hydro-turbine governing system? How to design the downstream surge tank and sloping ceiling tailrace tunnel to improve the system stability? All the above questions are the most concerned and urgent issues in the practical applications. Aiming at solving the above questions, this paper attempts to establish the mathematical model of hydro-turbine governing system with downstream surge tank and sloping ceiling tailrace tunnel. Then, the suitable mathematical analysis theory is chosen to investigate the dynamic characteristics during the transient processes. Finally, based on the research results, the theoretical basis and technical guidance on the design and operation of

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