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Wear and tear on hydro power turbines – Influence from primary frequency control

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ABSTRACT

Nowadays the importance and need of primary frequency control of hydro power units are significantly increasing, because of the greater proportion of intermittent renewable energy sources and more complex structure of power systems. It brings a problem of increasing wear and tear of turbines. This paper studies this problem by applying numerical simulation and concise theoretical derivation, from the point view of regulation and control. Governor models under opening and power feedback mode are built and validated by measurement data. The core index, guide vane movement, is analyzed based on ideal sinusoidal frequency input and real frequency records. The results show the influences on wear and tear of different factors, e.g. governor parameters, power feedback mode and nonlinear governor factors.

1. Introduction

Primary frequency control (PFC) of the electrical power grid frequency is commonly performed by units in hydro power plants (HPP). In some countries, as in Sweden, PFC is a service that the transmission system operator buys from the power producers. In other countries, as in Norway and China, there is also an obligation for the producers to deliver this service, free of charge. However, there are costs related to primary control, e.g. due to design constraints and auxiliary equipment when purchasing a new unit or system, due to personal costs for decision making during operation, and due to wear and tear which affects the expected life time and maintenance intervals. Nowadays the importance and need of PFC is constantly increasing, because of the more complex structure of the power system and a greater proportion of intermittent renewable energy sources. This leads to more actuator movement, which implies a risk of more wear and tear on turbines and systems. This paper will discuss how the PFC structure and parameterization affects the wear and tear of hydro power turbines. The aim is to decrease the power regulation cost as more intermittent renewable energy sources are connected to the grid.

To the best of the authors' knowledge, no specific research on wear and tear of hydro units with respect to primary control and regulation exists currently. From the point of view of tribology and hydraulics, references [1–3] researched the wear on bearing materials of guide vanes of hydro turbines, and several studies were conducted on fatigue design and life of Francis turbine runners [4–6]. Reference [7] mainly investigated the life time of high head runners and low head runners, and discussed the pressure at discharge control and frequency control. Reference [8] also studied the consequences of primary control to the residual service life of Kaplan runners. Based on the analysis method of scheduling and financial feasibility, references [9–11] investigated the hydro power unit start-up cost, and references [12–15] studied the costs and financial impacts of operation, production and maintenance of HPP. Meanwhile, there are other related researches [16–25] which focus on the hydro power control and electromechanical theory, but in these studies, the wear and tear of units is just regarded as a

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fraction of discussion, instead of the main research object. All in all, these papers lay a solid foundation of this study, from different fields and views. However specific research on hydro unit wear and tear due to primary control is still needed.

In this study, two very important indices, guide vane movement and its distance are illustrated in Fig. 1, and each movement corresponds to a direction change. There is a balance to strike between the movement and power output, since a minimization of movement, and hence a minimization of cost for the owner of the unit, also implies a possible decrease of power response. Hence, blindly decreasing the movement is obviously not advisable. The balance is especially essential for large-distance movements, since each relative large movement affects the regulation power needed by the power grid. However, the problem happens on the small-distance movements: Reference [26] found that during 4 months of observations in HPPs, between 75 and 90% of all opening movements are less than 0.2% of full stroke. A simulation conducted in this study also demonstrates the similar result, as shown in Fig. 2. More importantly, from the engineering experience, the wear and tear on the materials from small movements is believed to be more serious than from large movements. On the other hand, the regulation value from the small movements is not very obvious. Therefore another question is raised: how to specially decrease the small movements which is more “harmful”? This question will be investigated in this paper.

The content of this paper is organized as follows: Section 1 introduces the research background, the motivations and objectives of this study. Section 2 describes the method and model applied in the study. Section 3 shows the main results, and discusses different influent factors on wear and tear. Section 4 condenses the conclusions and also introduces the future work.

2. Method and model

This section introduces the method and model for treating the wear and tear caused by primary control actions. We perform numerical simulations of both governor and power plant behavior during primary control, and extract the distance of the traversed guide vane movement (accumulated movement distance), as well as the number of direction changes, and the distribution of amplitude between direction changes. A tribology formula [2]

$$\omega_{wear} = k \cdot P \cdot D_y \quad (1)$$

shows the relation between movement distance and material deterioration. Here ω_{wear} stands for the linear wear [m]; D_y is the

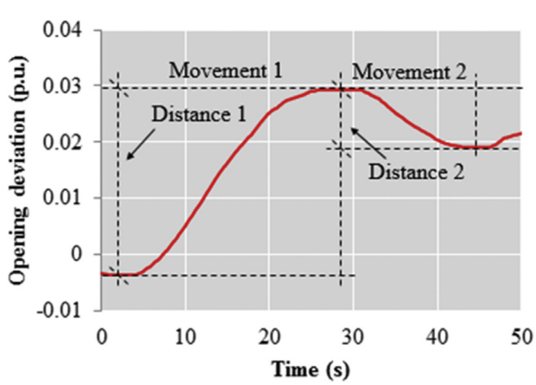

Fig. 1. Illustration of two very important indices: guide vane movement and its distance.

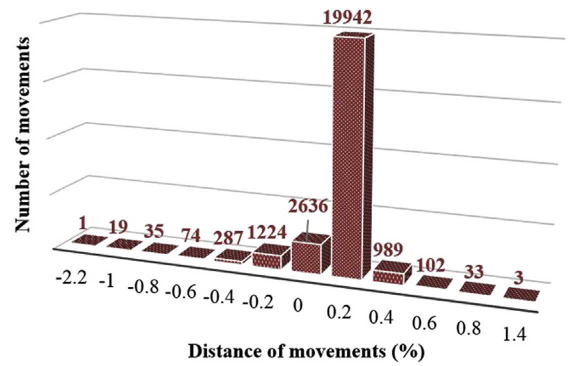

Fig. 2. Histogram of simulated opening movements for real frequency record of a week in March, 2012 (19942 is the number of movements with the distance from 0 to 0.2%).

real accumulated movement distance [m], which is the core index in this paper; k is the wear rate [m^2/N]; P represents the specific load [N/m^2]. Some basic analytical results for idealized frequency deviation signals are also derived and presented.

The simulation and analysis in this study are based on the following scope and assumptions. (1) The perspective adopted in this paper is that of a single unit that is part of a power system of considerable size. The grid frequency is assumed not to be influenced by alterations of parameters related to this single unit. Hence, grid frequency is here considered as input only, not as a feedback signal. Both idealized periodic frequency deviation data, and frequency measurements, are used as input in this study. (2) The model is based on the Francis turbine, therefore there is only one type of actuator, which refers to a single output governor system. This could simplify the study at this stage, and could lay a foundation for the research on other types of turbines, for example Kaplan turbines which are doubly regulated units. (3) In order to obtain estimates of related costs, one would also need to know the subsequent consequences for maintenance demands, and of course the costs of equipment, labor, and down time. These factors are not treated in the paper. (4) Other parameters regarding materials and tribology properties are not discussed in this study.

2.1. Numerical simulation

Numerical simulations of PFC in this study are conducted under both opening feedback and power feedback. The modeling described in this section is based on the software TOPSYS [24,27], which is developed for analyzing transient processes of HPP based on VC++.

2.1.1. Model for opening feedback

Primary frequency control under opening feedback is not affected by other components of the power plant, therefore the simulation could be conducted with an isolated governor model. The PID (proportional-integral-derivative) governor under opening feedback is shown in Fig. 3. Different non-linear factors are contained in the model. The dead zone, floating dead zone and backlash will be discussed in Section 3.

2.1.2. Model for power feedback

Primary frequency control under power feedback is based on the dynamic process of the whole HPP. A governor model with power feedback was built in this study, as shown in Fig. 4. The engineering case in this paper is a Swedish HPP which is owned by Vattenfall AB (the largest hydro power owner in Sweden), with a