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A standard method for specifying the response of hydroelectric plant in frequency-control mode

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Abstract

The paper proposes a specification for the transient and steady-state responses of a hydroelectric power station operating in frequency-control mode. It can be used during design, testing and commissioning as well as forming the basis for contractual agreement on performance during normal operation. The specification gives a generic definition of how the electrical power should respond to step, ramp and random changes in frequency. The rationale for the proposed specification is discussed. A prototype transfer function is proposed as an aid to formulating a step response specification. The length of record required during random testing is discussed. The use of the specification is illustrated by considering the response of the Dinorwig pumped-storage hydroelectric station.

Keywords: Design; Hydroelectric plant; Frequency-control

1. Introduction

The role of a hydroelectric station in frequency-control mode is to provide accurate and timely supply of its target power contribution to the power system. Typically, there will be several regulators, of varying capacity and speed of response, connected to the power system at any given time. Stable sharing of the load between multiple generators is achieved by including in their governors a characteristic that causes generated power to increase as power system frequency falls. This is known as the speed regulation or 'droop' characteristic [1]. Almost all current-day governors for hydroelectric plant have a PI or PID structure [2] although the application of multivariable techniques [3], predictive control [4] and fuzzy-logic methods [5] are under active consideration. Regardless of the control method in use, there is a need to specify the response of the plant in a meaningful way that reflects its role during normal operation. The specification must be:

- simple and intuitive so that requirements may be expressed during the planning and design stages,
- easily tested during commissioning, and
- verifiable during day-to-day operation under contract.

To the best of the authors' knowledge, no such specification currently exists. Yet the recent development of electricity markets means that the need for one has never been greater. In England and Wales, the quality of system frequency is the responsibility of the National Grid Company (NGC), which procures and dispatches the required power provided by private generators by means of a mechanism known as Ancillary Services. The legal foundation for operating the Grid is provided by the electricity regulations [6] and the functional requirements are set out in the Grid Code [7], with which all generators must comply. NGC has also worked with generators to develop a strategy for improving frequency response services as described by Erinmez et al. [8]. Privatisation of the electricity industry

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has led to a closer link between the commercial and technical aspects of power generation, linking profit to performance and providing a stimulus to the development of better operating strategies. This trend has continued with the recent introduction of the New Electricity Trading Arrangements. Of particular relevance to this work are the descriptions in [8] of how the *primary* and *secondary* response characteristics of generating plant form the basis for benchmarking frequency-control services. Similarly the authors emphasise the commercial importance of frequency response monitoring and describe the development of frequency service monitoring equipment to be sited at major power stations in order to record electrical output on a second-by-second basis for comparison with expected contract deliveries. Erinmez et al. [8] also consider frequency response testing and outline a set of typical plant response profiles involving injection of simulated frequency changes into the plant governor.

The tests described in Ref. [8] are rather general, of necessity as they must be applicable to a number of different types of plant. This paper considers hydroelectric plant in more detail and offers a simple set of conditions to complement and enhance the basic NGC requirements. The specification is intended to act as a standard method for specifying the dynamic characteristics of hydroelectric plant and to serve as a consistent basis of comparison. The proposed specification is stated in Table 1 and illustrated in Figs. 4 and 8 It consists of three types of signal (step, ramp and random) which are injected at the frequency-error input to the governor, as demanded or 'target' powers. Compliance with the specification depends on the power output satisfying a small number of criteria on speed and accuracy of the response. The basis for these criteria is discussed in the next section by reference to the frequency variation expected on a power system. Sections 3–5 discuss the step, ramp and random tests, respectively. For the step input case, a prototype transfer function is developed as an aid to formulating the specification and ensuring consistency of the individual tests. For the random input case, the length of record needed to achieve a given accuracy of the estimate of mean square power error is analysed. In each case, there is an example of how the specification is being used to guide the design of a better control system for the Dinorwig power station.

2. Basis for the specification

Power generation in a hydroelectric plant depends on the hydrodynamics of the water supply, the turbine/generator characteristics and the control system, which includes the governor (usually a digital electronic unit) and the guide vane dynamics. Automatic frequency-control mode is described generically by the block diagram of Fig. 1 (although there are governors which

Table 1
The proposed specification

Test	Criterion	Parameters
Step of amplitude A_s (MW)		
P1	The time at which at least P_1 (%) of the step amplitude A_s is achieved shall be no more than t_{p1} (s) after the time at which the step was applied	P_1, t_{p1}
P2	The output power shall not exceed the target power by more than P_2 (%) of the step amplitude A_s and the time at which the peak power output occurs shall not be more than t_{p2} (s) after the time at which the step was applied	P_2, t_{p2}
P3	The output power shall enter and remain within a band of $\pm P_3$ (MW) of the target power within t_{p3} (s) of the time at which the step was applied (*settling time*). The value of P_3 shall be taken as $\pm X$ (%) of the step amplitude A_s	P_3, t_{p3}
P4	The output power shall enter and remain within a band of $\pm P_4$ (MW) of the target power within t_{p4} (s) of the time at which the step was applied (*steady-state accuracy*). The value of P_4 shall be taken as $\pm X$ (%) of the step amplitude A_s	P_4, t_{p4}
P5	The output power shall take no longer than t_{p5} (s) to increase from 10 to 90% of the step amplitude A_s (*rise time*)	t_{p5}
P6	The negative power excursion shall be no more than P_6 (%) of the step amplitude A_s	P_6
P7	The time at which positive power generation begins shall be no more than t_{p7} (s) after the time at which the step was applied	t_{p7}
Ramp of amplitude A_r (MW) and period T_r (s)		
Q1	The power output at the end of the period t_{q1} shall be at least Q_1, t_{q1} (%) of the ramp amplitude A_r	Q_1
Q2	The maximum rate of increase of the power output shall not be less than Q_2 (%) of the ramp rate	Q_2
Q3	The output power shall enter and remain within a band of $\pm Q_3$ (MW) of the target power within t_{q3} (s) of the time at which the ramp was applied (*steady-state accuracy*). The value of Q_3 shall be taken as $\pm X$ (%) of the ramp amplitude A_r	Q_3, t_{q3}
Q4	The RMS error between the output power and the target power, calculated over a period of t_{q4} (s), shall not differ by more than Q_4 (%)	Q_4, t_{q4}
Gaussian distributed random signal of mean square value $\overline{\Delta P^2_{\text{targ}}}$ (MW^2) band-limited at ω_0 (r s^{-1})		
R1	The mean square error between the output power and the target power $(\overline{E^2})$, calculated over a period of t_{r1} (s), shall not be more than R_1 (%) of the mean square value of the target power, $\overline{\Delta P^2_{\text{targ}}}$	R_1, t_{r1}