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IFAC-PapersOnLine 49-27 (2016) 188–194

Real-Time hardware-in-the-loop grid simulator to test generating units' speed governors under islanding operating conditions

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Abstract: This paper describes a hardware-in-the-loop simulator for the real-time testing of on-field speed governors within generating units. The simulator is designed to be inserted within the speed measurement loop of speed governors and to emulate a speed signal which represents the generating unit's speed as if the unit were operating on a small and weak network. The equipment is used for testing the behavior of generating units during large frequency transients while taking account of possible non-linearity of actuators, which can drastically affect this transient. This system also provides power plant simulation, which can be used for Factory Acceptance Testing of speed governors in order to assess their functionality and to confirm parameter settings. The whole system has been rigorously tested in the field on hydro and thermal power plants and some of the more significant results are presented in this paper.

Keywords**:** Real-Time simulator, speed governor, islanding operation, hardware-in-the-loop

1. INTRODUCTION

Traditionally there are two approaches to assess speed governors and their behavior during large frequency transients. These are numerical PC-based simulations with a modeling of the physical components that effectively contribute to speed control, and actual field tests. The first approach is very useful but requires the implementation of complex mathematical models of electrical and mechanical components and normally does not take into account time-variant aspects, which compromises the quality of the numerical simulation. The second approach is more effective and meaningful but requires a lot of preparatory work and coordination between the different stakeholders as it can directly affect the customer base. Such field tests must be coordinated by the network operator who has to identify and separate a portion of the network for the purpose of the test. These tests are therefore time-consuming and expensive and require the involvement of many parties; i.e. power plant operator, transmission network operator, distribution network operator as well as industrial consumers whose power requirements must continue to be met which will mean using and potentially overloading other grid sections.

Towards this end CESI has designed and developed a hardware-in-the-loop simulator that simplifies the measurement and monitoring of the performance of speed governors either during Factory Acceptance Testing (FAT) or with on grid-connected generating units while precluding the need for major disturbances of the power system or of customers. FAT is based on numerical simulation of the most meaningful parts of the power plant (i.e. alternators, turbines, actuators, other process devices…). The main purpose of FAT is to assess the primary functions of the speed governor under test and/or to define an initial set of acceptable parameters which can later be further refined during the commissioning of the power plant. On the other hand, field tests on grid-connected units are performed with a hardware-in-the-loop simulator where only the grid and the generator behavior is emulated (especially during local network islanding operations), whereas all the other real-world power plant components which affect the frequency control (turbine, valves, supply systems etc.) are actually involved in the tests. During the tests the generator is always grid-connected, running commensurate with the actual frequency of the grid, but behaving as if the frequency were completely different. Such test methods allow the actual non-linear and time-variant parameters of the power plant to be factored in which is usually something that is difficult to represent and to simulate.

2. MODELLING ASPECTS

CESI's Grid Simulator is physically linked to the system under test and is used as a substitution of the real speed signal generated by the speed governor measurement loop.

The block diagram of the Grid Simulator is shown in Fig. 1 (IEC60308 (2005)), where the $\Delta\omega$ variable represents the simulated speed variation, Y the opening request command from the speed governor and Pm the mechanical power.

The Grid Simulator can be operated and used in different modes. The user can choose either to perform tests in open or closed loop configurations depending on the speed governor's functions that are being tested. The selection of the switch position in Fig. 1 changes the operating mode from simulated power plant to actual power plant.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.681

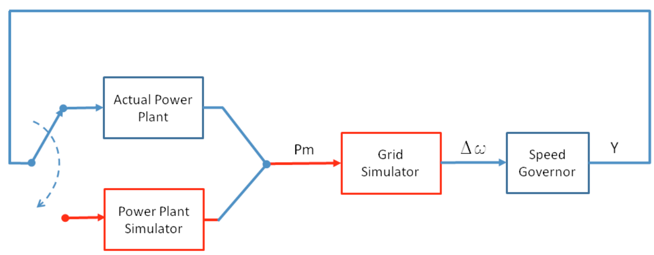

Fig. 1. Grid Simulator Block Diagram

1. Power Plant Simulator Mode

This operating mode has been specifically designed for hydropower plants as these generating units have unique and critical features to be accounted for when they operate on weak power systems (and even more so during islanding operations). In fact, large frequency transients and islanding operations can cause sudden and large penstock flow variations which lead to big pressure oscillations (i.e. water hammer effect). These oscillations can be correctly damped by the speed governor, however incorrect settings can magnify these oscillations often resulting in significant damage to the penstock or even posing potential risk to human life. Thus it is strongly recommended for hydropower plants to accurately test the speed governor functions and settings in all operating conditions and to verify that the parameters are well-tuned to avoid any possible catastrophic situations. The best way to perform these checks is by using a tool like CESI's Grid Simulator.

During speed governor FAT the Power Plant Simulator (a subset of the Grid Simulator) measures the output of the speed governor under test (i.e. reference value of the turbine's gate), emulates the speed of the shaft on the basis of this signal and models a number of additional components including the servo-positioner, water supply system, nozzle and/or deflector, turbine (Francis or Pelton) and power system itself. In particular, the modeling of the servo-positioners, gates, hydraulic system and turbine are used to calculate the mechanical power transmitted to the shaft of the generator. Then a simplified model of the generator calculates the resultant speed for the governor under test.

1.1. Power plant modeling

The components of the power plant such as water supply system, penstock, servo-positioner, distributor, deflector, and turbine are represented by transfer functions that are factored into the typical static and dynamic behaviour of these systems. The models can be configured through selectable parameters that allow the operator to model different types of power plants and/or to represent different operating conditions. With respect to Fig. 2 (IEC61362 (1998)), the main characteristics of the different components modelled in the Grid Simulator are as follow:

- The model of the servo-positioner dynamically computes the stroke of the actuator (*c*) as a function of the position command required by the speed governor (set point value *Y*). Specifically, the servo-positioner implements a first order transfer function with a gradient saturation parameter.
- The model of the gate (nozzle or guide vane) calculates the water outflow cross-section (*S*) based on the position of the actuator signal coming from the servo-positioner. The position-section characteristic is non-linear.
- The model of the feed water system takes into account the inelastic phenomena of water in the penstock (Kundur P. (1994)) and outputs the mechanical power (*Pm*) and the base penstock pressure (*H*).

In all cases the mathematical models can be modified and adapted to the needs of the customer.

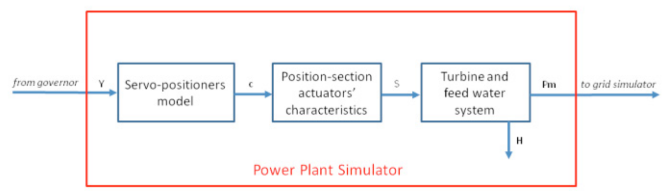

Fig. 2. Power plant simulator block diagram

1.2. Power system and generator modeling

The power system and the generator are represented by a simplified model which is presented in Fig. 3. Such a model implements the torque equation on the shaft of the generator where the mechanical torque is the output of the turbine model whereas the electric torque is represented by the electricity demand of the power system being simulated. The integral function of the equation is therefore the frequency of the power system and the speed of the generator shaft (Kundur P. (1994)).

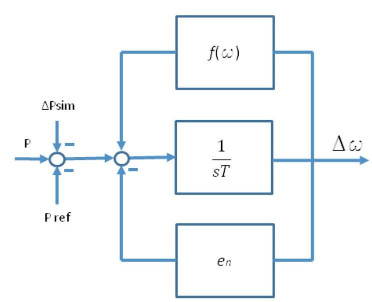

Fig. 3. Generator and power system model

In Fig. 3 *P* is the power measured from the CTs and VTs (current and voltage transformers) at the terminals of the generator, *Pref* is the power at the start of the simulation and Δ*Psim* the electrical load variation input by the user. The parameter *T* is the acceleration time (in seconds) and represents the inertia of the generating unit. It is calculated as (IEC60034 (1998)):

$$T = J\omega_0^2 / P_0 \qquad (1)$$