A Real-Time Regulator, Turbine and Alternator Test Bench for Ensuring Generators Under Test Contribute to Whole System Stability

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Abstract: A new Test Bench for speed governors has been developed and successfully tested in a simulation laboratory and in a Hydro-Québec hydroelectric powerhouse. Equipped with a Real-Time Simulator, the RT-LAB BERTA Test Bench makes it possible to cause the speed governor and turbine to react as though they are operating in an islanded power system, while remaining connected to the main grid. This ensures that the generating unit under test actually contributes to the stability of the whole power system. On-site testing has demonstrated that previous speed governor settings which were thought to be very stable were in fact generating undesirable power oscillations. Through the use of the proposed Test Bench, more accurate settings can be made on-site without the need to conduct laborious analyses.

Keywords: Speed Governor, Islanded Operation, Frequency Stability, Power System Stability, Speed Regulation, Frequency Regulation, Test Bench, Real-Time Simulation.

1. INTRODUCTION

Digital models of speed governors and turbines are necessary to carry out stability studies of an AC generator in an islanded power system, as well as general stability studies of a large power system. Such models were developed many years ago and have improved as knowledge, requirements and computer simulation technologies have evolved. These models are not individually validated on-site, since it is impossible to ensure that only one generating unit will react to a power system disturbance. Even a load trip or a generating unit trip in the proximity of a unit under test will lead to a general reaction of the power system. Identifying modeling parameters requires either highly accurate calculations, using data that manufacturers are reluctant to provide, or very costly and arduous on-site tests.

Speed control parameters must be set following the principles listed in Section 3. To do so, the engineer must conduct stability studies using available digital models. On-site settings are usually unusable since in practice it is impossible to perform tests representing the real stability of the speed setting.

By designing a Test Bench for speed governors and turbines with a Real-Time Simulator, it is possible to cause the governor and turbine react as though they were operating in an islanded power system. It is then possible to adjust the speed governor and validate the governor and turbine models in the same test session.

The proposed Test Bench, called RT-LAB BERTA, is equipped with such an islanded operation Real-Time Simulator, which enables high-fidelity simulation and testing to be conducted with physical Hardware-in-the-Loop (HIL). This capability enables the Real-Time Simulator to interface with a real synchronous generator in a real large power system. The Real-Time Simulator achieves this by generating simulated signals which are ready to be injected into the real speed governor of the generating unit under test.

2. BASIC CONCEPT OF SPEED REGULATION

The frequency of a large power system acts as the speed of a single AC generator supplying a load. When a large disturbance causes an observable variation in the power system load, (for example, when many loads or a significant load are tripped, or when generating units are tripped) the power system reacts as if it were a single large generator whose inertia equals the sum of all the inertias of the rotating masses in the system. When a load is tripped, the rotating masses accelerate and when a generator is tripped, they decelerate. To reset the frequency to its rated value, the speed governors of all the generators in the power system correct the operating point of the turbines. Their control settings must be such that this correction does not create any instability in the power system, while bringing back the frequency to its rated value as quickly as possible.

2.1 Operating in Islanded Mode

Figure 1 illustrates the frequency behavior of an AC hydro-generator operating in an islanded power system. The initial load being 0.875 p.u. on the generator MVA base, an additional load of 0.05 p.u. is applied at time T = 5 seconds. The inertia constant H equals 3.2 MJ/MVA and the water starting time of the unit is 2.67 seconds at rated water head and full turbine power (0.95 p.u. on the MVA base).

The speed governor model is shown in Figure 2. Its parameters are listed in Table 1

Table 1 : Speed governor settings

Test no	B_p	K_d	K_p	K_i	K_{sm}	T_{act}
E1	0.05	0	1.163	0.105	3.333	0.07
E2	0.05	0	1.163	0.25	3.333	0.07

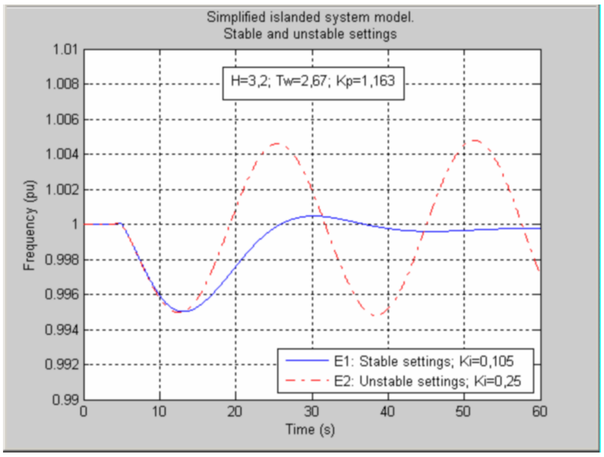

Figure 1 : Frequency behavior of an AC generator in an islanded mode of operation

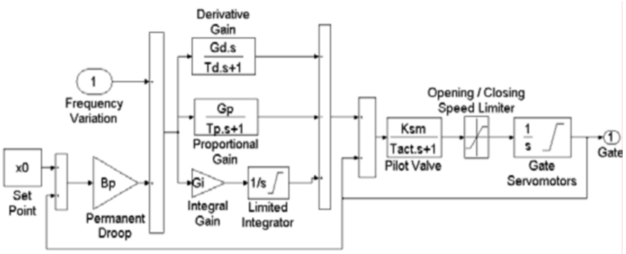

Figure 2 : PID speed governor block diagram

Test E1 shows that the system is well stabilized with the appropriate integral gain $K_i = 0.105$. However, Test E2 shows that using a value $K_i = 0.25$ will destabilize the isolated system.

2.2 *Operating in Multi-machine Power System*

The simulation of a similar disturbance on a multi-machine power system model of an actual large power system (Figure 3) illustrates the validity of this basic concept. This explains why, although rarely operating in an islanded power system, each generator should be set to ensure its stable operation in such an islanded system According to F.R. Schleif and A.B. Wilbor, "The basis for coordination of the interconnected system is that the governor of each prime mover would yield good speed regulation for isolated loads." The principle is based on the fact that a unstable synchronous generator stabilized owing to its interconnection to a large power system reduces the stability margin of this system.

In a multi-machine power system, the synchronous interconnection of an AC generator with other generators will only stabilize a generator to the extent that the other generators will stabilize the system owing to their inertia. However, the other generators may not contribute to the frequency regulation of the system. In such cases, the accuracy of the setting is affected and large frequency deviations can degrade the quality of the voltage wave and trip loads or generators, ultimately jeopardizing the stability of the power system.

There is a limit to the number of generating units that would be unstable in an islanded power system, beyond which the whole system would become unstable. Figure 3 shows clearly that increasing the proportion of badly tuned speed governors will eventually lead to the instability of the whole power system. A well-adjusted speed governor is therefore an absolute requirement, regardless of the operating mode of the generator.

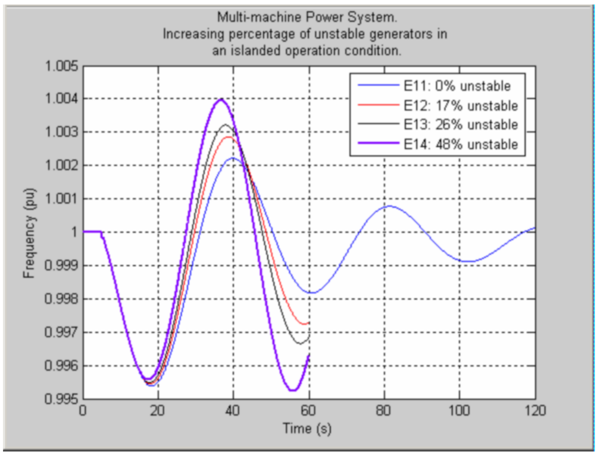

Figure 3 : Frequency behavior of a multi-machine power system, using different speed governor settings

3. MAIN PRINCIPLES TO CONSIDER WHEN ADJUSTING A SPEED GOVERNOR

Following the basic concept discussed in the preceding section, basic principles can be derived that must be observed when optimizing speed governor parameters.

The **first principle** to follow when setting the speed governor of a synchronous generator is that the speed governor must be set to ensure operating stability in an islanded power system, regardless of its actual operating mode, as demonstrated in the preceding section.