AUTOMATIC POWER GENERATION CONTROL AND SIMULATION

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Abstract— In the presented work the role of automatic generation control (AGC) in power system operation with reference to the tie line control under normal operating conditions is first analyzed. Typical responses to real power demand are illustrated using the latest simulation technique available by the MATLAB SIMULINK package. Finally the requirement of reactive power and voltage regulation and the influence on stability of both speed and excitation controls with suitable feedback signals are examined. An isolated power system and two-area system were simulated using LFC and AGC.

Index Term*s*— LFC, AGC, automatic voltage regulator (AVR), control loop.

I. INTRODUCTION

The control of active and reactive power is necessary in order to keep the power system in the steady state. The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits. Change in real power affect mainly the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes in voltage magnitude. Thus, real and reactive powers are controlled separately. The load frequency control (LFC) loop controls the real power and frequency and the automatic voltage regulator (AVR) loop regulates the reactive power and voltage magnitude. LFC has made the operation of interconnected system possible. Modern energy control centers (ECC) are equipped with on-line computers performing all signal processing through the remote acquisition systems known as “supervisory control and data acquisition (SCADA) systems”.

2. BASIC GENERATOR CONTROL LOOPS

In an interconnected power system, LFC and AVR equipment are installed for each generator. Figure 1 represents the schematic diagram for the LFC and AVR loop. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle δ and thus the frequency. The reactive power is mainly dependent on the voltage magnitude (i.e. on the generator excitation). The excitation system time constant in much smaller than the prime mover time constant and its transient decay much faster and does not affect the LFC dynamics. Thus the cross coupling between the LFC loop and the AVR loop is negligible and the load frequency and excitation voltage control are analyzed independently.

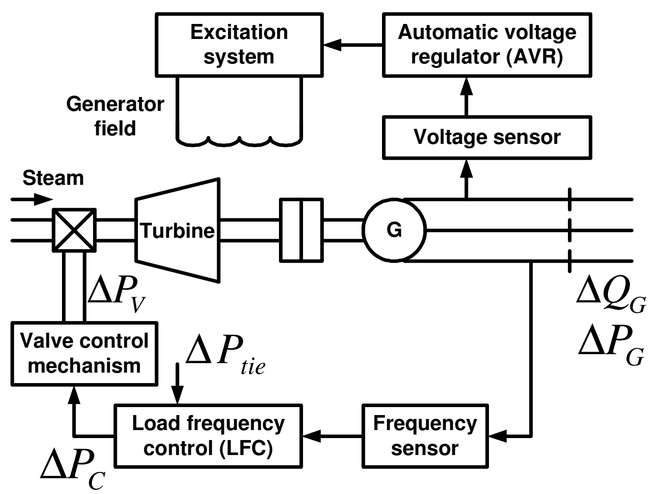

Fig. 1. Schematic diagram of LFC and AVR of a synchronous generator.

3. LOAD FREQUENCY CONTROL

The operation objectives of the LFC are to maintain reasonably uniform frequency to divide the load between generators and to control the tie-line interchange schedules. The change in frequency is sensed as $\Delta\delta$ which is the change in rotor angle and the error to be corrected. The error signal Δf and ΔP_{tie} are amplified, mixed and transformed into real power command signal ΔP_V, which is sent to the prime mover to increment the torque. The prime mover therefore changes the generator output by ΔP_g, which will change the value of Δf and ΔP_{tie} within the specified tolerance. The first step in the analysis and design of a control system is mathematical modeling of the system for which transfer function for following components is obtained.

Generator Model:

Applying the swing equation of a synchronous machine to small perturbation, we have

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \text{ ....(1)}$$

or in terms of small deviation in speed

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \text{ ....(2)}$$

With speed expressed in per unit

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \text{ ....(3)}$$

Taking the Laplace transform of above equation we get

$$\Delta\omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \text{ ....(4)}$$

Load Model:

The load on a power system consists of variety of electrical devices. For resistive loads, such as lighting and heating loads; the electrical power is independent of frequency. Motor loads are sensitive to changes in frequency. The degree of sensitivity depends on the composite of the speed-load characteristics of all the driven devices. The speed load characteristics of a composite load is given by

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad \text{.................(5)}$$

Prime mover model:

The source of mechanical power is known as prime mover. The model for the turbine relates the changes in mechanical power output ΔP_m to changes in the steam valve position ΔP_V. There can be different types of turbines with different characteristics. The simples prime mover model for the non-reheat steam turbine can be approximated with a single time constant τ_T, resulting in the following transfer function

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \qquad \text{.......................(6)}$$

Governor Model:

When the electrical load is suddenly increased, the electrical power exceeds the mechanical power input. This power deficiency is supplied by the kinetic energy stored in the rotating system. This reduction in kinetic energy causes the turbine speed to fall and hence the generator frequency falls. The governor has speed regulation R ($\Theta\ R = \Delta\omega/\Delta P$) of 5-6% from zero to full load. The speed governor mechanism acts as a comparator whose output ΔP_g is the difference between the reference set power ΔP_{ref} and the power $\Delta\omega/R$ as given by governor speed characteristics:

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(s) \text{ ....(7)}$$

The ΔP_g is transformed through hydraulic amplifier to the steam valve position command ΔP_V. If a linear relationship is assumed with a simple time constant τ_g, we have

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \text{ ......(8)}$$

4. BLOCK DIAGRAM

The LFC of an isolated power station can be obtained by combining eq(1) to eq(8).
The open loop transfer function can be given as

$$KG(s)H(s) = \frac{1}{R}\frac{1}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)} \text{ ...(9)}$$

and the closed loop transfer function relating load ΔP_L to the frequency deviation $\Delta\omega$ is

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)+1/R} \quad (10)$$

The block diagram is as shown in figure 2 below.

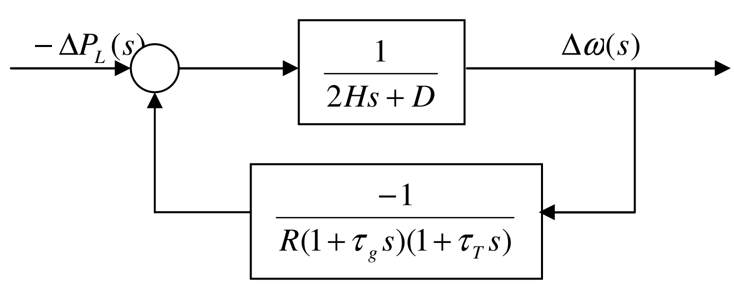

Fig. 2. Block diagram of LFC

5. AUTOMATIC GENERATION CONTROL

If the load on the system is increased, the turbine speed drops before the governor can adjust the input of the steam to the new load. The speed of the rotor can be maintained constant by adding an integrator. The integral unit monitors the average error over a period of time and will overcome the offset. Thus, as the system load changes continuously, the generation is adjusted automatically to restore the frequency to its nominal value. This scheme is known as automatic generation control (AGC). In an interconnected system consisting of several pools, the role of AGC is to divide the loads among system, stations, and generators so as to achieve maximum economy and correctly control the scheduled interchanges of tie-line power while maintaining a uniform frequency. With the primary LFC loop, a change in the system load will result in a steady state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero, a reset action should be provided. The reset action is achieved by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1, which forces the final frequency deviation to zero. The LFC system with addition of the secondary loop is as shown in figure 3. The integral controller gain K_I must be adjusted for a satisfactory transient response. The closed loop transfer function of the control system is given as:

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_g s)(1+\tau_T s)+K_I+s/R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

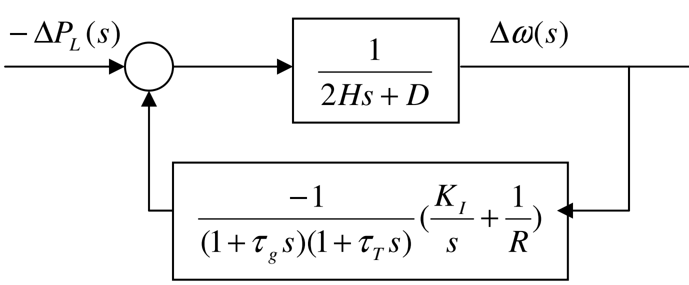

Fig. 3. Block diagram of AGC

If a two-area system is considered then the real power transfer during normal operation is given as

$$P_{12} = \frac{|E_1||E_2|}{X_{12}}\sin\delta_{12} \quad \ldots\ldots\ldots\ldots\ldots(12)$$

where $X_{12} = X_1 + X_{tie} + X_2$ and $\delta_{12} = \delta_1 - \delta_2$

the tie line power deviation is

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \quad \ldots\ldots\ldots(13)$$

ΔP_{L1} is the load change and in steady state both areas are assumed to have the same steady state frequency deviation i.e.

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \quad \ldots\ldots\ldots\ldots\ldots(14)$$

and $\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1$

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2 \quad \ldots\ldots\ldots\ldots(15)$$

the change in mechanical power is determined by the governor speed characteristics, given by

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2} \quad \ldots\ldots\ldots(16)$$

and hence change is frequency deviation can be given as

$$\Delta\omega = \frac{-\Delta P_{L1}}{(\frac{1}{R_1}+D_1)+(\frac{1}{R_2}+D_2)} \quad \ldots\ldots(17)$$

6. CASE STUDY

A. Isolated power station: An isolated power station with following parameters is studied and simulated with LFC and AGC:

Turbine time constant τ_T =0.4 sec,
Governor time constant τ_g = 0.3,
Governor inertia constant H = 5 sec,
R = 0.05 pu,
The load varies by 0.8% for a 1% change in frequency, i.e. D = 0.8.
The turbine rated output is 250 MW at nominal frequency of 50 Hz.
A sudden load change of 50 MW occurs. The above system is modeled as shown in figure 4.

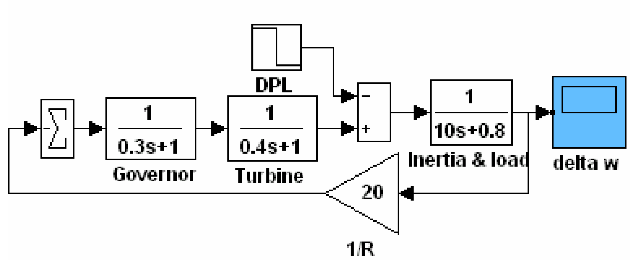

Fig. 4. Simulation block diagram for an isolated power station with LFC

The above system is now equipped with the secondary integral control loop of AGC with controller gain K_I = 7. Figure 5 shows the modified simulation block for power station with AGC. Figure 6 shows the simulation result for single power station with LFC and AGC.

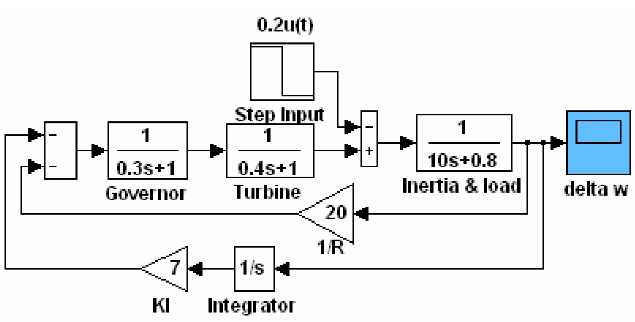

Fig. 5. Simulation block diagram for an isolated power station with AGC

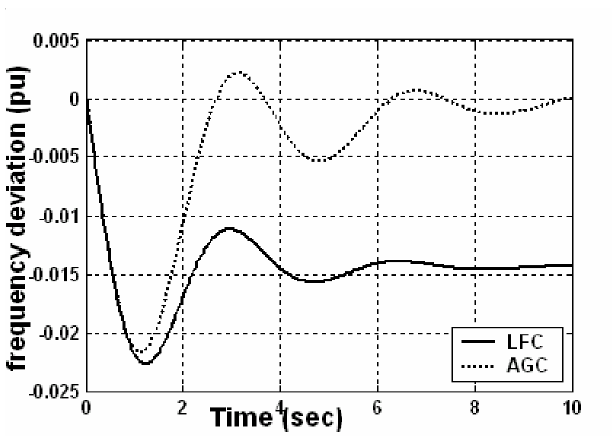

Fig. 6. Frequency deviation step response of isolated power station

B. Two-area system: A two-area system connected by a tie line has the following parameters on a 1000MVA common base:

Area	1	2
Speed regulation	$R_1 = 0.05$	$R_2 = 0.0625$
Frequency sensitivity load coefficient	$D_1 = 0.6$	$D_2 = 0.9$
Inertia constant	$H_1 = 5$	$H_2 = 4$
Base power	1000MVA	1000MVA
Governor time constant	$\tau_{g1} = 0.2$ sec	$\tau_{g2} = 0.3$ sec
Turbine time constant	$\tau_{T1} = 0.6$ sec	$\tau_{T2} = 0.8$ sec

The above system is modeled in similar manner as an isolated system is modeled. Following are the simulation results with LFC and AGC respectively for frequency deviation and power deviation.

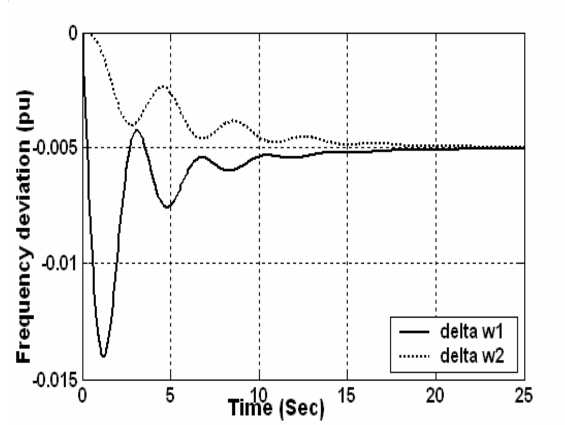

Fig. 7. Frequency deviation for two-area system with LFC

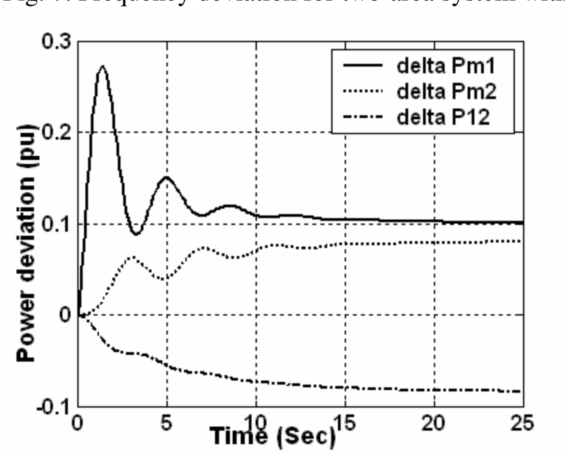

Fig. 8. Power deviation step response for two-area system with LFC

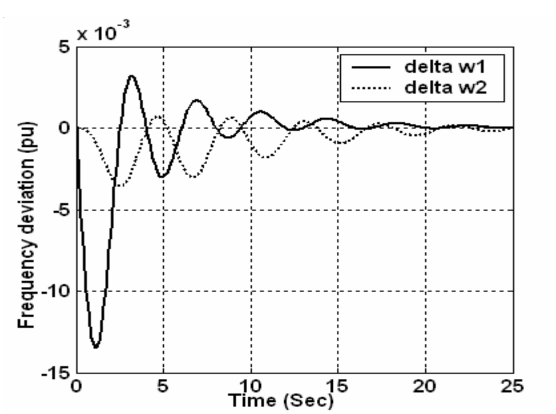

Fig. 9. Frequency deviation for two-area system with AGC

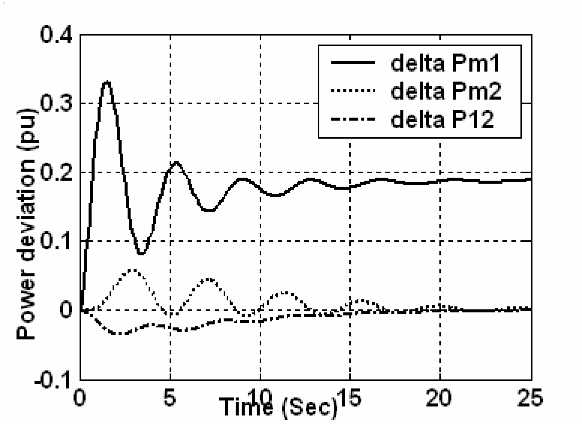

Fig. 10. Power deviation step response for two-area system with AGC

7. CONCLUSIONS

The simulation results shows that if AGC is used along with LFC then system performance improves for single area as well as for two-area system. The system with AGC settles to the minimum change i.e. error is reduced significantly. For an isolated power station the system settles early with LFC but if an integrator is added then system settles a bit late with error limit almost negligible. Similarly for two-area case also the system with AGC has minimum error. In two-area system AGC reduces the mechanical power difference.

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