International Journal Of Engineering Research & Management Technology
ISSN: 2348-4039
Email: editor@ijermt.org May- 2014 Volume 1, Issue 3 Website: ijermt.org

Load Frequency Control in Two Area Control in Restructured Power System

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ABSTRACT

This paper is mainly focused on technical issues associated with load-frequency control (LFC) in restructured power systems. The main goal of this paper is to develop the robust decentralized LFC synthesis methodologies for two-area power systems based on the fundamental LFC concepts and generalized well-tested traditional LFC scheme to meet the specified LFC objectives. A realistic situation may arise where an area regulated by Hydro generation is interconnected to another area regulated by Thermal generation. Hydro area or units is differ from Thermal units in the sense a relatively large inertia of water is used as a source of energy that causes a considerably greater time lag in the response of the change in prime mover torque to change in gate position and also there is an initial tendency for the torque to change in a direction opposite to that finally produced. The operational performance of hydroelectric units is quite different from that of Thermal units. Hydro-thermal systems are operated by economical scheduling to produce minimum cost for Thermal generation, subject to Hydraulic and Thermal constraints, and the demand for electrical energy. Hydraulic and thermal constraints may include operational limits on Hydro and Thermal generation, reservoir storage, water discharge and spillage. The short-term scheduling horizon is normally one day to one week, and the time unit is one hour, with complete river flows and load demand generally assumed.

Keywords— load frequency control, restructured power system, system security.

I. INTRODUCTION

The main objective of power system operation and control is to maintain continuous supply of power with an acceptable quality, to all the consumers in the system. The system will be in equilibrium, when there is a balance between the power demand and the power generated. As the power in AC form has real and reactive components: the real power balance; as well as the reactive power balance is to be achieved. There are two basic control mechanisms used to achieve reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). The former is called the automatic voltage regulator (AVR) and the latter is called the automatic load frequency control (ALFC) or automatic generation control (AGC). In a single area system, there is no tie-line schedule to be maintained. Thus the function of the AGC is only to bring the frequency to the nominal value. This will be achieved using the supplementary loop which uses the integral controller to change the reference power setting so as to change the speed set point. The integral controller gain KI needs to be adjusted for satisfactory response (in terms of overshoot, settling time) of the system. Although each generator will be having a separate speed governor, all the generators in the control area are replaced by a single equivalent generator, and the ALFC for the area corresponds to this equivalent generator.

Generation in a large interconnected power system usually comprises of a suitable mix of Thermal, Hydro, and Nuclear and Gas units. In case of nuclear units, due to their high efficiency, they are usually kept at base load close to their maximum output with no participation in Automatic Generation Control (AGC). The Gas power generation is ideal for meeting varying load demand. However, such plants do not play very

significant role in AGC of a large power system, since these plants form a very small percentage of total system generation. Gas plants are used to meet peak demands only. Thus the natural choice for AGC lies either on Thermal or Hydro generating units. The determination of optimal number of operating units and their combination are taken into the consideration. To guarantee the safety of the operation is the major goal of the plant. In the moment of determining which unit ought to operate, besides economic requirements, the safety requirements must be considered.
Hydro-thermal systems are operated by economical scheduling to produce minimum cost for Thermal generation, subject to Hydraulic and Thermal constraints, and the demand for electrical energy. Hydraulic and thermal constraints may include operational limits on Hydro and Thermal generation, reservoir storage, water discharge and spillage. The short-term scheduling horizon is normally one day to one week, and the time unit is one hour, with complete river flows and load demand generally assumed.

II. EXISTING TECHNIQUES FOR POWER SYSTEM CONTROL

The overall control task in an electric power system is to maintain the balance between the electric power produced by the generators and the power consumed by the loads, including the network losses, at all time instants. If this balance is not kept, this will lead to frequency deviations that if too large will have serious impacts on the system operation.
A complication is that the electric power consumption varies both in the short and in the long time scales. In the long time scale, over the year, the peak loads of a day are in countries with cold and dark winters higher in the winter, so called winter peak, while countries with very hot summers usually have their peak loads in summer time, summer peak. In addition to keeping the above mentioned balance, the delivered electricity must conform to certain quality criteria. This means that the voltage magnitude, frequency, and wave shape must be controlled within specified limits. If a change in the load occurs, this is in the first step compensated by the kinetic energy stored in the rotating parts, rotor and turbines, of the generators resulting in a frequency change. If this frequency change is too large, the power supplied from the generators must be changed, which is done through the frequency control of the generators in operation. An unbalance in the generated and consumed power could also occur as a consequence of that a generating unit is tripped due to a fault. The task of the frequency control is to keep the frequency deviations within acceptable limits during these events. To cope with the larger variations over the day and over the year generating units must be switched in and off according to needs. Plans regarding which units should be on line during a day are done beforehand based on load forecasts. Such a plan is called unit commitment. When making such a plan, economic factors are essential, but also the time it takes to bring a generator on-line from a state of standstill. For hydro units and gas turbines this time is typically of the order of some minutes, while for thermal power plants, conventional or nuclear, it usually takes several hours to get the unit operational. Apart from this the voltage magnitude in a power system maintained using Automatic voltage regulator (AVR). AVR maintains the voltage by adjusting the field excitation to the generator according to the variations. This is also called as reactive power control method.
The load frequency control (LFC) or automatic generation control can be done in two ways.

- Input side control
- Output side control

Where first one defines the normal LFC using a respective controller in input side to reduce the area control error (ACE) and the second one can be done using frequency control devices like SMES (super conducting magnetic energy storage), CES (capacitive energy storage) and BES (battery energy storage) etc., this method of LFC limited to minimum sudden change of load demands.

III. MATHEMATICAL MODELING IN AUTOMATIC GENERATION CONTROL

A. Mathematical Modeling of Governor

The first step for modeling an AGC model is to model the prime-mover of the generators. To simplify this model, the non-reheat turbine is used. Each generator unit has multiple valves to control the flow of steam into the turbine. The prime mover has a charging time constant associated with it. The transfer function of the prime mover model is shown on the next page in Fig 1 T_{CH} is the prime mover charging constant and ΔP_{Valve} is the per unit change in valve position. ΔP_{Mech} is the change in mechanical output of the prime mover in per unit.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

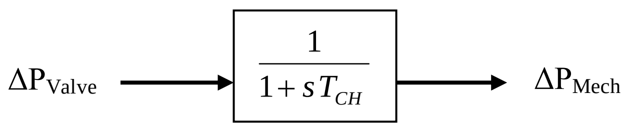

Fig. 1 Transfer function model of Prime mover

Governors also differ by a governor time constant, T_G. The final piece in the governor model is the load reference set point. This set point is determined so each unit can maintain its dispatch. In the case of a two unit system, if unit 1 is generating 65% of the power and unit 2 is supplying 35%, then unit 1 will supply 65% of the load change and unit 2 will supply 35% of the load change. The block diagram for the governor is shown below in Fig 2.

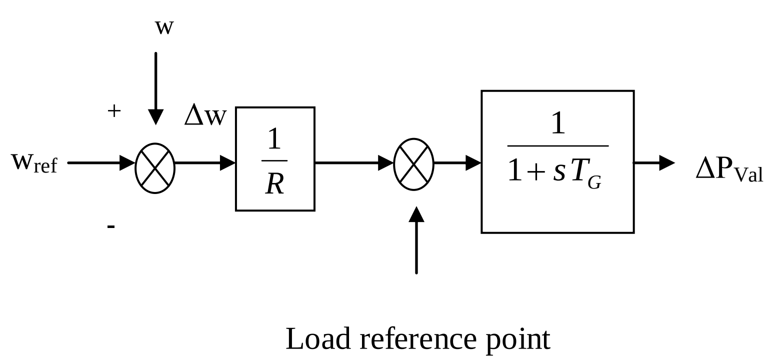

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Fig. 2 Transfer function model of Governor

B. Turbine Model

All compound steam turbine system utilize governor controlled valves at the inlet to the high pressure (or very high pressure) turbine to control steam flow. The steam chest and inlet piping to the steam turbine cylinder and re-heaters and crossover piping down steam all introduce delays between the valve movement and change in steam flow. The transfer function model for single reheat turbine is shown below in Fig. 3

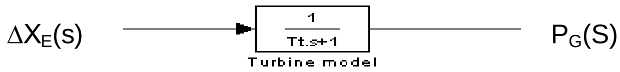

Fig. 3 Transfer function model of turbine

C. Mathematical Modeling of Generator

A generator-load model is formulated. While the turbine is outputting mechanical power, the generator is outputting electrical power. If there is a change in electrical power demanded, the mechanical power of the prime mover will have to make up for the difference.

This will slow down the rotation of the turbine since more work has to be done by the turbine. This slowdown results in a reduction of generator frequency. The block diagram for the generator-load model is shown below in Fig 4.

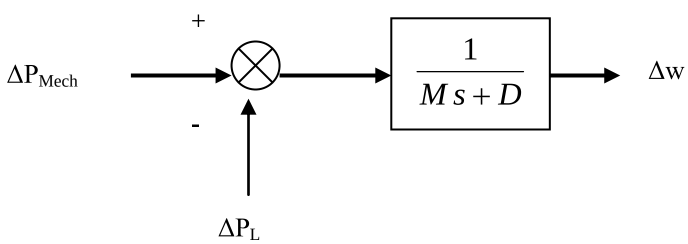

Fig. 4 Transfer function model of Generator-load

M is defined as the angular momentum of the machine. D is the percent change in load divided by the percent change in frequency. D is defined by the equation below.

$$D = \frac{\Delta P_{L(freq)}}{\Delta \omega}$$

All turbines in a system are required to have a governor. This governor limits the prime mover to rotate at a certain speed. The governor compares system frequency with a reference frequency of 60 Hz to determine if more steam is needed to be input to keep the prime mover rotating at a constant speed. All turbines are not alike however. To resolve this issue, a droop characteristic keeps a unit's output proportional to its rated output.

Thus a generator with a rating of 700 MW, will output twice as much to compensate for the load change as a 350 MW unit. This droop characteristic is determined with the following equation.

$$R = \frac{\Delta \omega}{\Delta P} \; per\ unit$$

Now the tie-line model is introduced. Using the DC load flow method, the tie-flow power is defined by the admittance in the tie-line multiplied by the difference in angles between area 1 and area 2. This equation is shown below.

$$P_{tie-flow} = \frac{1}{X_{tie}}\left(\theta_1 - \theta_2\right)$$

Since we are concerned with how the tie flow changes,

$$\Delta P_{tie-flow} = \frac{1}{X_{tie}}\left(\Delta\theta_1 - \Delta\theta_2\right)$$

In terms of frequency, this equation resolves to,

$$\Delta P_{tie-flow} = \frac{T}{s}\left(\Delta\omega_1 - \Delta\omega_2\right)$$

Here, T is considered the tie-line stiffness. It is defined by the below equation.

$$T = 377 * \frac{1}{X_{tie}}$$

Equations relating this model are given below.

$$\Delta\omega = \frac{-\Delta P_{L1}}{\frac{1}{R_1} + \frac{1}{R_2} + D_1 + D_2}$$

$$\Delta P_{tie} = \frac{-\Delta P_{L1}\left(\frac{1}{R_2} + D_2\right)}{\frac{1}{R_1} + \frac{1}{R_2} + D_1 + D_2}$$

Considering there are two interconnected systems and that a change in demand in one area will result in both areas' generation changing, a control system must be included in the model to return the tie line flow to its pre-change value. This is because a power system that sells or buys power is by contract and any change in that flow will be costly. This is why the area control error (ACE) is added. The ACE represents the shift in an area's generation to meet the load change in another area. The ACE is defined below.

$$ACE = -\Delta P_{net\,\mathrm{int}} - B\Delta\omega$$

$$B = \frac{1}{R} + D$$

while the above model does a good job of returning a change in frequency and a change in tie flows to zero, given a load change.

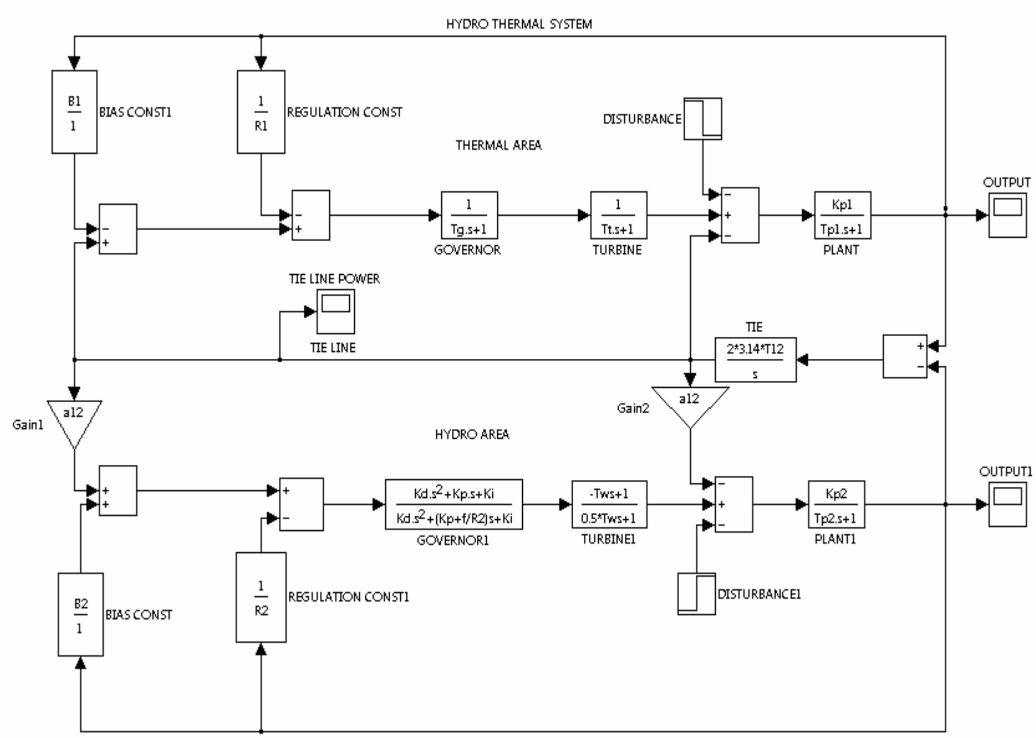

Fig. 5, Mathematical model of Hydro-Thermal System

IV. Result and Discussion

The proposed DE based approach for solving the LFC problem was applied to two area Hydro-Thermal systems with different cases (Hydro with Electrical/Mechanical governor, Thermal with Double reheat/Single reheat). The results of the Simulations are presented below. For the optimum AGC controller gain value, the corresponding results of optimum generators participations in generations, tie line exchanges obtained by computed values using formulae and MATLAB/ SIMULINK based results are computed. For the first case study considered with Hydro-Thermal system, the different computed values are compared with the SIMULINK values obtained with and without GRC. From figure 6, the optimal transient performance of the power system for thermal unit with single stage reheat/double stage reheat turbine in the LFC loop with different loads are tested. From this figure, it is clearly observed that while comparing the transient response profile of the power system for single stage/double stage reheat turbine, for both the turbine models yield the same performance .Thus, it may be inferred that a double stage turbine can be modeled as a single stage one.

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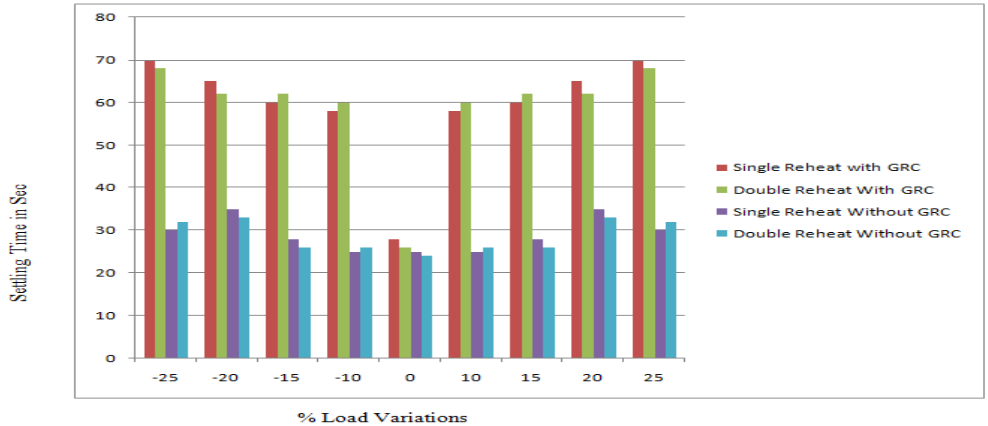

Fig. 6 Comparative performance analysis of Single and Double Reheat Thermal system for two area H-T under Deregulated environment with and without GRC

V. Conclusion

LFC as an ancillary service acquires a fundamental role to maintain the electrical system reliability at an adequate level. That is why there has been increasing interest for designing load frequency controllers with better performance according to the changing environment of power system operation under deregulation. The proposed approach for solving the LFC problem was applied to two area Hydro-Thermal systems with different cases (Hydro with Electrical/Mechanical governor, Thermal with Double reheat/Single reheat). For the optimum AGC controller gain value, the corresponding results of optimum generators participations in generations, tie line exchanges obtained by computed values using formulae and MATLAB/ SIMULINK based results are computed. For the first case study considered with Hydro-Thermal system, the different computed values are compared with the SIMULINK values obtained with and without GRC. The optimal transient performances of the power system for Thermal unit with Single Stage Reheat/Double Stage Reheat turbine in the LFC loop with different loads are tested. It is clearly observed that while comparing the transient response profile of the power system for single stage/double stage reheat turbine, for both the turbine models yield the same performance .Thus, it may be inferred that a double stage turbine can be modeled as a single stage one.

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