PERFORMANCE ANALYSIS OF AUTOMATIC GENERATION CONTROL IN TWO AREA POWER SYSTEM USING INTEGRAL CONTROLLER

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Abstract—This paper describes an application of automatic generation control in two area power system by using with and without integral controller. The main purpose of operating AGC is to keep uniform the frequency changes during the load changes. It is ensure that their steady errors to be zero. In an interconnected power system, as a power load demand varies randomly, both area frequency and tie line power interchange also vary. As a consequence of load variations, the frequency of the generator changes overtime. Frequency transients are minimized and zero steady state error is obtained. This paper will study about the two area frequency variation and tie-line power flow deviation in comparison of with and without controller. This paper also presents the detail analysis and comparisons of load changes for both areas 1 and area 2 that affected on the variation of load and frequency. Details of integral (tie-line) bias control, frequency control and area control error (ACE) are also described to perform the simulation model of two area power system. For this application MATLAB/ SIMULINK software is used.

Index Term—Frequency Deviation and Tie-line Power Flow, Area Control Error, Two Area Power System, With and Without Integral Controller.

I. INTRODUCTION

This introductory provides a general description of frequency control in electric power system. 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 frequency within limits. Changes in real power affect mainly the system frequency but reactive power is dependent on voltage. The increasing load is a vast problem for power generation plants due to increase in power demand. So, making balance between generation and load demand is the operating principle of load frequency control. The change in turbine output results due to governor and speed changer actions. Modern power systems are divided into various areas. Each of these areas is generally interconnected to its neighboring areas. The transmission lines that connect an area to its neighboring area are called tie-lines. Power sharing between two areas occurs through these tie-lines. The power system frequency rises when the load decreases while the frequency drop if the load increases. However it is desirable to maintain the constant frequency such that Δf=0. The objective of each area regulator is to maintain scheduled frequency and net tie-line interchange. If there is a large power balance disturbance in one sub-system, the regulators in each area should try to restore the frequency and net tie-line interchange. If there is a large power balance disturbance in one sub-system, the regulators in each area should try to restore the frequency and net tie-line interchange. Each area absorbs its own load change. Increase generation to supply extra load in the area or decrease generation when the load demand in the area has reduced. For large scale power systems which consists of interconnected control areas, load frequency then it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. To accomplish this, it becomes necessary to automatically manipulate the operation of main stream valves in accordance with a suitable control, which intern controls the real power output of electric output generators.

II. AUTOMATIC GENERATION CONTROL (AGC)

AGC plays a very important role in power system. The main objectives of AGC are to regulate frequency to a nominal value and to maintain the interchange power between control areas at the scheduled values by adjusting the output of the selected generators at a minimum cost. The role of AGC is to divide the loads among the system, station and generator to achieve maximum economy and to maintain a reasonability uniform frequency. A change
in system load will result in a steady state frequency deviation, depending upon governor droop characteristics and frequency sensitivity of the load. Restoration of the frequency to nominal values requires supplementary control action which adjusts the load reference set point. AGC provides an effective mechanism for adjusting the generation to minimize frequency deviation and regulate tie-line power flows. The AGC system realizes generation changes by sending signals to the under-control generating units and performs a continuous real-time operation to adjust the power system generation. Frequency control, economic dispatch, interchange transaction scheduling, reserve monitoring, and related data recording are the main functions of an AGC system. The problem of controlling the power output in this way is termed as Automatic Generation Control.

III. TIE-LINE INTERCONNECTED TWO AREA POWER SYSTEM

AGC for two area system is represented by an equivalent generating unit interconnected by a tie line with reactance $X_{\text{tie}}$. Each area is represented by a voltage source behind an equivalent reactance as shown below. During normal operation, the real power transferred over the tie line is given below and tie line resistance is negligible. The direction of tie-line power flow is dependent on the load disturbance area.

![Fig.2. Equivalent Network for Two Area Power System](image)

**A. Two area tie-line power flow**

$$P_{12} = \frac{E_1 E_2}{X_{\text{tie}}} \sin \delta_{12}$$  

$$X_{12} = X_1 + X_{\text{tie}} + X_2$$  

$$\delta_{12} = \delta_1 - \delta_2$$

For a small deviation in tie line flow

$$\Delta P_{12} = T_{12} (\Delta \delta_1, \Delta \delta_2)$$  

$T_{12}$: The slope of the power angle curve at the initial operating angle.

$$T_{12} = \frac{\left| \Delta \delta \right|}{X_{\text{tie}}} \cos \delta_{120}$$  

$$\delta_{120} = \delta_1 - \delta_2$$

If $\Delta \delta_1 > \Delta \delta_2$, the power flows from area 1 to area 2 and if $\Delta \delta_1 < \Delta \delta_2$, the power flows from area 2 to area 1. The direction of flow is dictated by the phase angle difference. We can see that tie line power error is the integral of the frequency difference between the two areas.

$$\Delta P_{\text{tie}}(s) = \frac{T_{12}}{s} [\Delta \omega_1(s) - \Delta \omega_2(s)]$$  

(7)

**B. Steady state power deviation**

- For a case of two generators connected via a transmission line, the change in mechanical power is

$$\Delta P_{m1} = \Delta P_{L1} + \Delta P_{12} + D \Delta \omega = \frac{1}{\delta_1}$$  

$$\Delta P_{m2} = \Delta P_{L2} - \Delta P_{12} + D \Delta \omega = \frac{-1}{\delta_2}$$

(8)

(9)

**C. The per unit steady state frequency deviation**

$$\Delta \omega = \frac{-\Delta P_{L1} - \Delta P_{12}}{(\frac{1}{\delta_1} + \beta_1) (\frac{1}{\delta_2} + \beta_2)}$$

(10)

**D. Area frequency response characteristics ($\beta$) for area 1 and 2**

$$\beta_1 = D_1 + \frac{1}{\delta_1} \quad \text{and} \quad \beta_2 = D_2 + \frac{1}{\delta_2}$$

(11)

Thus, frequency deviation for load change of area 1 and 2 is,

$$\Delta \omega_1 = \frac{\Delta P_{L1}}{\beta_1 + \beta_2} \quad \text{and} \quad \Delta \omega_2 = \frac{\Delta P_{L2}}{\beta_1 + \beta_2}$$

(12)

**E. The change in tie-line power**

$$\Delta P_{12} = \frac{\beta_2}{\beta_1 + \beta_2} (-\Delta P_{L1})$$

(13)

IV. AREA CONTROL ERROR (ACE)

The integral control is composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error $\Delta \omega$ and this error signal is fed into the integrator. The input to the integrator is called the area control error (ACE). ACEs are used as actuating signals to changes in the reference power set points and when steady state is reached, $\Delta P_{12}$ and $\Delta \omega$ will be zero. ACE changes the frequency in each area and forces the steady-state frequency error to zero. ACE is the combination of deviation in frequency and tie-line power. Assume load increase in one area, $\Delta \omega_1$ will slightly decrease than that of area two. Interchange from affected area decreases ($\Delta \text{net interchange} < 0$) while other increases ($\Delta \text{net interchange} > 0$). That is, affected area has negative ACE but other area ACE is small (nearly zero). If ACE<0, it must increase generation but ACE>0, decrease generation. When all areas have zero ACE, net interchange and frequency deviation will be zero steady state error but frequency bias factor will work ($\beta \neq 0$) ACE measures area load change and give us good control. Two area systems are as follows.

![Fig.3. Power Flow Deviation for Two Area System](image)
\[ \text{ACE}_1 = \Delta P_{12} + \beta_1 \Delta w_1 \]  
\[ \text{ACE}_2 = \Delta P_{21} + \beta_2 \Delta w_2 \]  
\[ \Delta F = \frac{\text{ACE}_1 + \text{ACE}_2}{(\beta_1 + \beta_2)} \]  
\[ \Delta P_{\text{tie}} = \text{Net interchange} = \text{Scheduled} - \text{Actual} \]  
\[ \Delta F = \Delta w_0 = \text{frequency deviation} \]  
\[ \beta = \text{frequency bias factor (pu MW/PU frequency)} \]

V. INTEGRAL–CONTROLLER

The popularity of integral controllers is due to their functional simplicity and reliability. They provide reliable performance for most systems and the parameters are tuned to ensure a satisfactory closed loop performance. When the integral control signal is added to each area of the uncontrolled plant in forward path the steady state error in the frequency becomes zero. The task of controller is to generate a control signal, \( U \), that maintains system frequency and tie line interchange power at predetermined values. The area bias (proportional gain) \( K_i \) determines the amount of interaction during a disturbance in the neighboring areas. An overall satisfactory performance is achieved when \( K_i \) is selected equal to the frequency bias factor. Users of control systems are frequently faced with the task of adjusting the controller parameters to obtain a desired behavior. There are many different ways to do this. One way to do this is to go through the steps of modeling and control design. A simple idea is to connect a controller, increase the gain until the system starts to oscillate, and then reduce the gains by an appropriate factor. As a result, they may also control uncertain processes. The value of integral gains (\( K_i \)) is achieved by tunning and also by below equation.

\[ U_1 = -K_i \int ACE_1 \, dt \]  
\[ K_i = \frac{1}{4\pi f_0} \left[ 1 + \frac{K_{\text{PG}}}{R} \right]^2 \]

VI. SIMULATION RESULT

The simulation is conducted in Matlab Simulink for two area power system by using integral-controller. Tie-line parameters for two area power system are described in Table (1). The following Fig (6) and Fig (7) are the simulation models of with and without controller respectively. In this paper, the simulation performance of frequency and power deviation for load changing of each area are clearly presented. The sudden load change of 200 MW in area 1 and area 2 are compared both under controller and non-controller. The mechanical power output and direction of tie-line power flow is shown in comparison between two areas. Then, the effect of controller is shown clearly below. The integral controller is used to maintain zero steady-state errors for frequency and power deviation.

TABLE I

<table>
<thead>
<tr>
<th>Description</th>
<th>Area 1</th>
<th>Area 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Power</td>
<td>1000 MVA</td>
<td>1000 MVA</td>
</tr>
<tr>
<td>System frequency, ( F )</td>
<td>50 Hz</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Governor gain constant, ( K )</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Integral gain constant, ( K_i )</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Governor time constant, ( T_g )</td>
<td>0.2 sec</td>
<td>0.3 sec</td>
</tr>
<tr>
<td>Turbine Time Constant, ( t_t )</td>
<td>0.5 sec</td>
<td>0.6 sec</td>
</tr>
<tr>
<td>Governor Inertia Constant, ( H )</td>
<td>5 sec</td>
<td>4 sec</td>
</tr>
<tr>
<td>Governor Speed Regulation, ( R )</td>
<td>0.05 pu</td>
<td>0.0625 pu</td>
</tr>
<tr>
<td>The sudden load change, ( \Delta P_{\text{load}} )</td>
<td>200 MW</td>
<td>200 MW</td>
</tr>
<tr>
<td>The Frequency Sensitive Load, ( D )</td>
<td>0.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Fig. 4. ACE Generation System

Fig. 5. Conventional Integral Controller

Fig. 6. Simulation Model of Two Area Power System for Load Change of Area 1 and Area 2 without controller
Performance Analysis of Automatic Generation Control in two Area Power System Using Integral Controller

**Fig. 7.** Simulation Model of Two Area Power System for Load Change of Area 1 and Area 2 with controller

**Fig. 8.** Comparison of Frequency Deviation for (200MW) Load Change in Area 1 with and without Controller

**Fig. 9.** Comparison of Frequency Deviation for (200MW) Load Change in Area 2 with and without Controller

**Fig. 10.** Power Deviation for Load Change of 200 MW in Area 1 without Controller

**Fig. 11.** Power Deviation for Load Change of 200 MW in Area 1 with Controller

Fig (9) shows the comparison of simulation output waveforms for the frequency deviation with and without controller. This is introduced for the two area power system with a sudden load increase of (200MW) in area 2. In this figure, the nominal frequency is 50Hz (Δω=0pu) at t=0 sec (or) no load change. Since area 1 load is increased, area 2 frequency declination is more than that of area 1. Under without controller, two frequencies of area 1 and area 2 finally approaches to the steady state frequency deviation of (Δω = -0.005pu) or (F=49.72Hz) at t=25sec. Under the integral controller, although load is increased in area 2, two frequencies of area 1 and area 2 automatically returned to the nominal frequency of (Δω= 0pu) or (F=50Hz) at t=25sec. It is clear that, there is no steady state error by using integral controller. In comparison, frequency deviation of zero steady state error (Δω = 0pu) is obtained with controller but (Δω = -0.005pu) error is obtained without controller.

Fig (10) and Fig (11) show the simulation output waveforms for power deviation with and without controller respectively. This is introduced for the two area power system with a sudden load increase of (200MW) in area 1. When the system is without controller, the mechanical power of area 1 is (0.11pu) or (110 MW) and that of area 2 is (0.09pu) or (90MW). When load is increase in area 1 only, the required load (90 MW) from area 2 is transferred to area 1. That is, 90 MW of tie line power flow from
area 2 to area 1. There is still steady state tie-line power variation error for area load changing without controller. When the system is with controller, the mechanical power of area 1 is only (0.11pu) or (110 MW) but the machine in area 2 can generates the required load (90MW) for safe its own load of (200 MW). Thus, there is no tie-line power flow from area 2 to area 1. It is clear that, there is also no tie-line power deviation error by using integral controller. In comparison, no tie-line power deviation error (\(\Delta P_2 = 0\) pu at \(t = 25s\)) is occurred with controller but tie-line power deviation error (\(\Delta P_2 = 0.09\)pu at \(t = 25s\)) is occurred without controller.

\(\text{Fig.12. Power Deviation for Load Change of 200 MW in Area 2 without Controller}\)

\(\text{Fig.13. Power Deviation for Load Change of 200 MW in Area 2 with Controller}\)

Fig (12) and Fig (13) show the simulation output waveforms for power deviation with and without controller respectively. This is introduced for the two area power system with a sudden load increase of (200MW) in area 2. When the system is without controller, the mechanical power of area 1 is (0.11pu) or (110 MW) and that of area 2 is (0.09pu) or (90MW). When load is increase in area 2 only, the required load (110 MW) from area 1 is transferred to area 2. That is, 110 MW of tie line power flow from area 1 to area 2. There is still steady state tie-line power variation error for area load changing without controller. When the system is with controller, the mechanical power of area 2 is only (0.09pu) or (90 MW) but the machine in area 2 can generates the required load (110 MW) for safe its own load of (200 MW). Thus, there is no tie-line power flow from area 1 to area 2. It is clear that, there is also no tie-line power deviation error by using integral controller. In comparison, no tie-line power deviation error (\(\Delta P_2 = 0\)pu at \(t = 25\)sec) is occurred with controller but tie-line power deviation error (\(\Delta P_2 = 0.11\)pu at \(t = 25\)sec) is occurred without controller.

CONCLUSIONS

In this study, a two area system connected by a tie line is presented with simulated MATLAB for both two areas load changing system of with and without controller. The new steady state frequency and tie-line power exchange error are shown in simulation result. When the system is without controller, the change of power in area 1 and area 2 was met by the increase in generation in both area associated with a change in the tie line power and a reduction in frequency so that the demand of areas are satisfied at the new frequency deviation error. Thus, a simple control strategy is needed for more reliable power system network in order to get safe mode of operation and minimum cost. When the system is with controller, a simple control strategy for the normal mode keeps frequency approximately at the nominal value (50Hz) and maintains tie-line power flow at about schedule. Conventional load frequency control is based upon tie-line bias control, where each area tends to reduce the area control area to zero. The area bias \(K_i\) determines the amount of interaction during a disturbance in the neighboring areas. An overall satisfactory performance is achieved when \(K_i\) is selected equal to the frequency bias factor of that area. Thus, frequency deviation returns to zero with a settling time of approximately 20 sec and also the tie-line power exchange reduces to zero and the increase in each area load is met by the increase in each generation respectively.

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