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Application of PID Controller for Automatic Load Frequency Control of a Six Area Interconnected Power System

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Abstract—*This paper aims at improving system dynamic response for a multi area system in which six areas have been interconnected. System equations that include all the areas as well as their interconnections have been simulated in this paper. Necessary load demand changes in all the areas have been put as well as application of PID Controller have been applied in all these areas to observe automatic load frequency control. The error minimization operation was successful and quick. Software used is Matlab/Simulink.*

Keywords*: AGC. ALFC, ACE, PID, AVR.*

1. INTRODUCTION

Many complications have arrived in power systems in recent years. Many industrial establishments are affected by operating point variations [3].

Now a days, demand for Electric Energy is increasing a lot and so its our prime objective to supply this energy effectively and without any interruption. We know that electric network consists of many interconnected systems and if a fault occurs in system, disturbances and interruptions adversely affect power quality taking place in the power system. Power flows and frequency is regulated by interconnected power systems with the help of Automatic Generation Control (AGC) [1]. The power output of various generators at different power plants are adjusted by AGC which operates in closed loop , with response to changes in the load. Also AGC helps in maintaining the balance between the generation and demand of a particular power system [9].

AGC comprises an Automatic load frequency control (ALFC) loop and an Automatic Voltage Regulator (AVR) loop [4]. The ALFC loop regulates the real power output and the corresponding frequency of the generator power output [1].ALFC helps in meeting the specified power changes among the members of interconnection. Also ALFC loop is functional only during little and slow changes in load and frequency [2]. AVR plays an important role in controlling reactive power to enhance system stability. Area Control Error (ACE) plays an important role in interconnected Power Systems. ACE is change in area frequency which when used with tuned PID Controllers helped in bringing system frequency error to zero [2].

In this paper fully automatic control strategy has been used and applied to 6 area interconnected power system. The load demand change in each similar area is kept equal. The frequency change and incremental tie line power has been observed and rectified to improve the system stability and ensuring good and non-interrupted power quality. The necessary system equations have been developed and error being reduced to null point at a quick time.

2. SIX-AREA INTERCONNECTED POWER SYSTEM

Power system comprises of different controlling units which are discrete [5]. These parts are connected with each other by tie lines and power flow in them has to be controlled [6].

Large Power systems have many interconnected areas in which main aim is to supply reliable power to the consumers even if any load demand change in either of the areas occur. The continuity of power supply must be maintained at any cost.

The frequency changes are kept uniform by Load Frequency Control (LFC) .Frequency, active powers and rotor angle is being changed while power system is being operated [7]. We will discuss about how 6 areas have been interconnected in our paper.

(a) Area 1 connected to Areas (2,3,4)

(b) Area 2 connected to Areas (1,3)

(c) Area 3 connected to Areas (2,1)

(d) Area 4 connected to Areas (1,5,6)

(e) Areas (5,6) are interconnected

The following figure illustrates clearly the interconnections among the 6 areas.

The six area interconnected system block diagram is shown in Fig. 2. The system frequency deviation Δf,i, the deviation in the tie-line power flow ΔPtie,i, load disturbance ΔPDi have been depicted and analyzed.

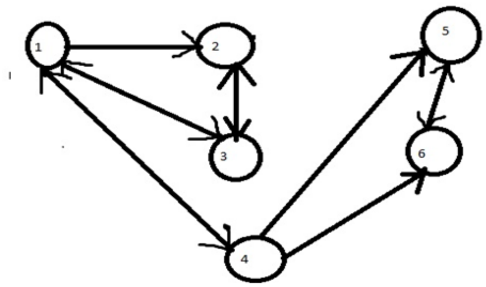


Fig. 1: Interconnected Power System

In this paper six similar areas have been interconnected. It is to be observed that while six areas are interconnected which makes a very powerful grid but also makes the system pretty complex and even minute changes can also affect the synchronism of the system, that's why appreciable load demand changes have been applied in all the six areas (2 p.u.). Application of tuned PID controllers accordingly have been applied in all the six areas as interconnection of six areas with load demand changes in all of them do give rise to dynamic disturbances which have to be reduced to zero in very quick time. If such disturbances aren't eliminated quickly and exist in the system for greater amount then that may lead to complete shutdown of the system with production of harmonics.

3. PID CONTROLLER & ALFC

PID Controller: It is a control loop feedback mechanism widely used in industrial control systems. It generally calculates an error value as the difference between a measured process variable and a desired set point. The value of parameters (K_P, K_i and K_d) of PID Controller have been tuned to improve the performance of the system i.e, rise time, overshoot, steady state error.

Controller must be sensitive against changes in frequency and load. Intelligent controllers have been used in place of conventional controllers to get fast and better system response in large interconnected power systems [10].

To analyze the control system, the mathematical model must be established [8]. Mathematically PID is represented as:

$$y(t)=K_p\,[e(t)+T_d\,\frac{d(e)}{d(t)}+\frac{1}{T_i}\int_0^t e(t)d(t)]\ldots \quad .(i)$$

$$y(t)=[K_p\,e(t)+K_d\,\frac{d(e)}{d(t)}+K_i\int_0^t e(t)d(t)]\ldots. \quad .(ii)$$

$$K_i=\frac{K_p}{T_i} \text{ and } K_{d=}K_p.T_d \quad [2]$$

Automatic Load Frequency Control (ALFC): is being applied in power system to allow an area to first meet its own load demand changes and then in returning the steady state frequency of the system Δf to zero. Load frequency control operates with a response time of few seconds to keep system frequency stable.

The frequency and power in case of turbine governor can be related as

ΔPm = (ΔPref-1/R*Δf)

Where

ΔPm = change in turbine mechanical power output.

ΔPref = change in reference power setting

Δf = change in frequency

R = Regulation constant which identifies the sensitivity of the generator to a change in frequency.

4. CIRCUIT DESCRIPTION

In this paper six similar areas have been interconnected. It is to be observed that while six areas are interconnected which makes a very powerful grid but also makes the system pretty complex and even minute changes can also affect the synchronism of the system, that's why appreciable load demand changes have been applied in all the six areas (2 p.u.). Application of tuned PID controllers accordingly have been applied in all the six areas as interconnection of six areas with load demand changes in all of them do give rise to dynamic disturbances which have to be reduced to zero in very quick time. If such disturbances aren't eliminated quickly and exist in the system for greater amount then complete shutdown of the system with production of harmonics will take place. In all these areas, gains and time constants of hydraulic amplifier, turbine and power system blocks have been modified and tuned so as to help the PID controllers to reduce rise time, overshoot and the error to zero in 2secs as evident from the graphs 1,2,3,4,5,6. The output of the PID controller in all the six areas is given as

$$C= -p*ACE-K_{in}\int ACEdt + K_p\,\frac{d}{dt}(ACE)$$

When load demand increases turbine power output also increases in the primary ALFC loop. But due to this a frequency drop (negative) is caused which in turn causes positive output of the PID controller which increases reference power setting. Rise time and overshoot get reduced by Proportional and derivative control whereas the integral control action will reduce the static frequency error to zero. This entire action is performed by secondary ALFC loop. Tie lines are required to import power from one area to another area in case of load increments as in large networks lower values of speed regulation may hamper system stability. For interconnected networks secondary ALFC loop maintains frequency and interchange of power always remain at their normal values. Network regulator is provided to each area where telemetered signals of the exported or imported signals are fed which consists of the algebraic sum of frequency input and inputs of the regulator as the regulators regulate the power interchange and frequency from the relevant network by transmitting signals to the regulating generators to adjust their generated powers. In order to ensure that each network eliminate its frequency deviations is the job of secondary ALFC loop so that finally $\Delta P_{tie} = 0$ and Δ f = 0. PID controllers here are the network regulators provided in each area having two types of inputs viz., one being the change in frequency and other type being the incremental change in tie-line power which is equal to the difference between the scheduled power and actual power. Here simulation is performed on the basis where the multi-area network consists of six similar areas interconnected to each other having equal load demand changes in each area.

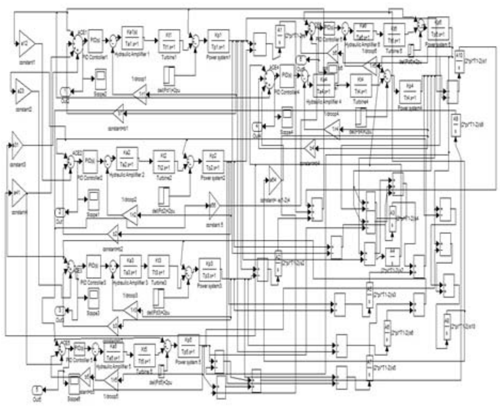


Fig. 1: Simulink Diagram for 6 Area Interconnected Power System

5. SYSTEM EQUATIONS

The system equations for all the six areas have been developed and shown below:

$$\Delta f(s) = G_P(s)[\Delta P_T(s) - \Delta P_D(s)] \quad (1)$$

$$\Delta f_1 \propto \Delta P_{T1} - \Delta P_{D1} - \Delta P_{12} \quad (2)$$

$$\Delta f_2 \propto \Delta P_{T2} - \Delta P_{D2} - \Delta P_{21} \quad (3)$$

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1 \quad (4)$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \quad (5)$$

The Area Control Errors (ACEs) for six interconnected areas is given below:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie1} - \Delta P_{tie3} - \Delta P_{tie4} \quad (6)$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie2} - \Delta P_{tie1} \quad (7)$$

$$ACE_3 = B_3 \Delta f_3 + \Delta P_{tie3} - \Delta P_{tie2} \quad (8)$$

$$ACE_4 = B_4 \Delta f_4 + \Delta P_{tie4} - \Delta P_{tie6} - \Delta P_{tie1} \quad (9)$$

$$ACE_5 = B_5 \Delta f_5 + \Delta P_{tie5} - \Delta P_{tie4} - \Delta P_{tie4} \quad (10)$$

$$ACE_6 = B_6 \Delta f_6 + \Delta P_{tie6} \quad (11)$$

The incremental change in tie-line power for six areas is given below:

$$\Delta P_{tie1} = \frac{2\Pi T_{12}}{s}[\Delta f_1(s) - \Delta f_2(s)] + [\Delta f_1(s) - \Delta f_3(s)] + \frac{2\Pi T_{14}}{s}[\Delta f_1(s) - \Delta f_4(s)] \quad (12)$$

$$\Delta P_{tie2} = \frac{2\Pi T_{21}}{s}[\Delta f_2(s) - \Delta f_1(s)] + \frac{2\Pi T_{23}}{s}[\Delta f_2(s) - \Delta f_3(s)] \quad (13)$$

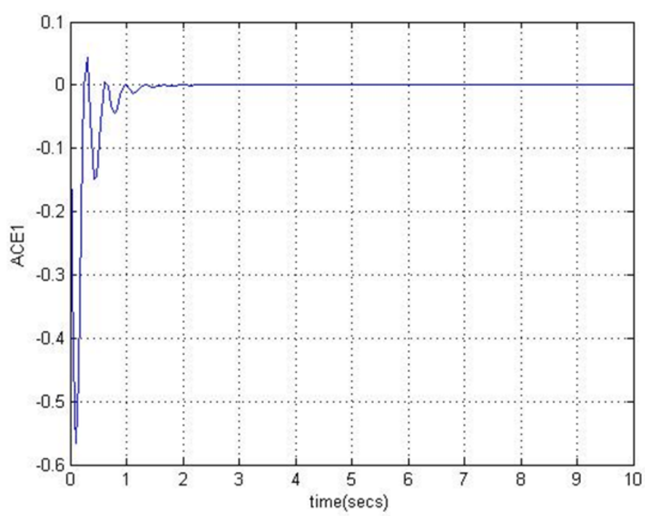
$$\Delta P_{tie3} = \frac{2\Pi T_{31}}{s}[\Delta f_3(s) - \Delta f_1(s)] + \frac{2\Pi T_{32}}{s}[\Delta f_3(s) - \Delta f_2(s)] \quad (14)$$

$$\Delta P_{tie4} = \frac{2\Pi T_{41}}{s}[\Delta f_4(s) - \Delta f_1(s)] + \frac{2\Pi T_{45}}{s}[\Delta f_4(s) - \Delta f_5(s)] + \frac{2\Pi T_{46}}{s}[\Delta f_4(s) - \Delta f_6(s)] \quad (15)$$

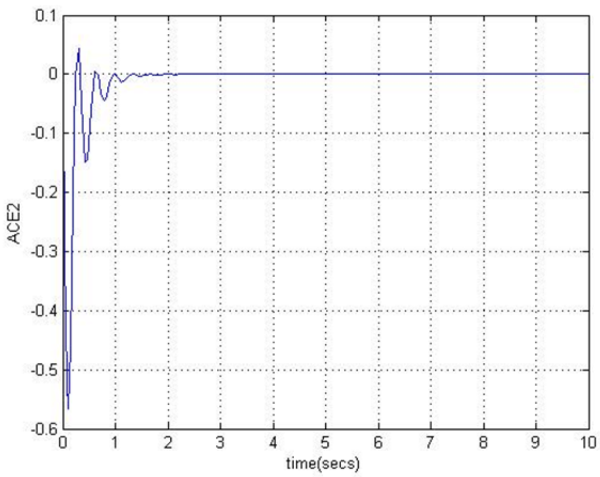
$$\Delta P_{tie5} = \frac{2\Pi T_{54}}{s}[\Delta f_5(s) - \Delta f_4(s)] + \frac{2\Pi T_{56}}{s}[\Delta f_5(s) - \Delta f_6(s)] \quad (16)$$

$$\Delta P_{tie6} = \frac{2\Pi T_{64}}{s}[\Delta f_6(s) - \Delta f_4(s)] + \frac{2\Pi T_{65}}{s}[\Delta f_6(s) - \Delta f_5(s)] \quad (17)$$

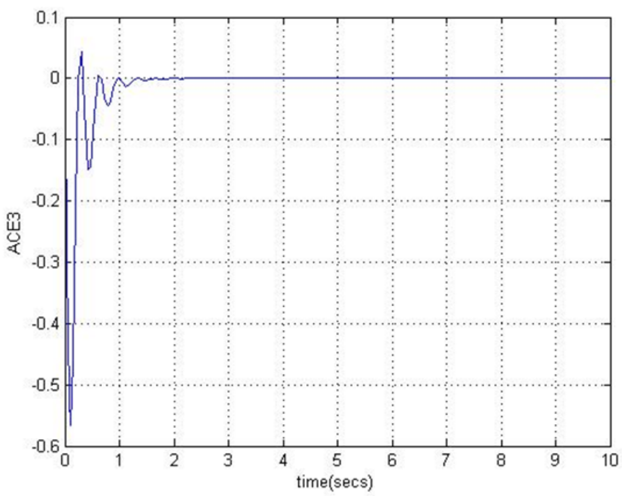
6. SIMULINK GRAPHS



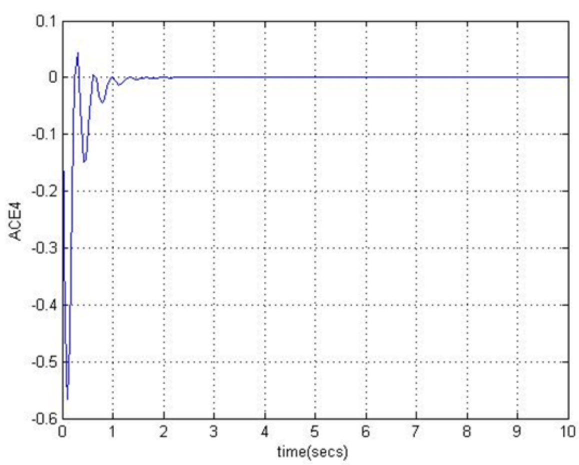
Graph 1: System Dynamic Response With Tuned PID for Area1



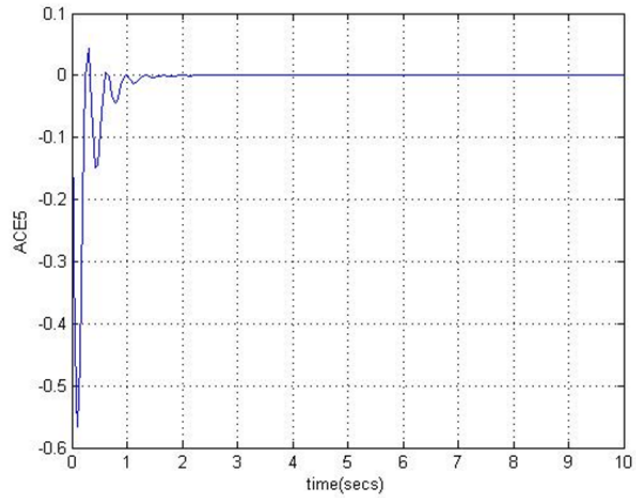
Graph 2: System Dynamic Response With Tuned PID for Area 2.



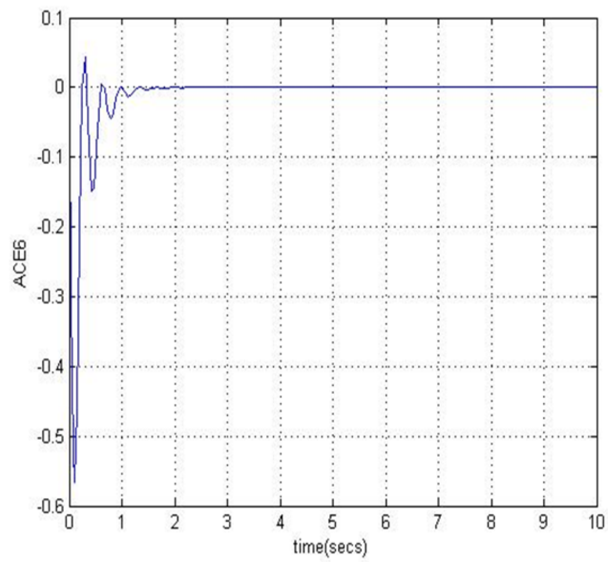
Graph 3: System Dynamic Response With Tuned PID for Area 3



Graph 4: System Dynamic Response With Tuned PID for Area 3

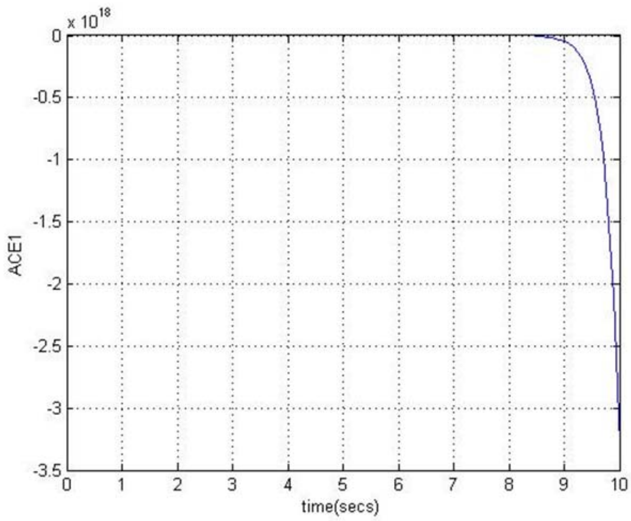


Graph 5: System Dynamic Response With Tuned PID for Area 5

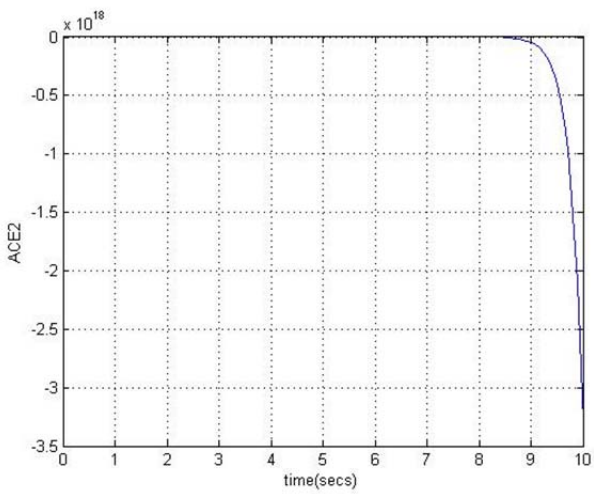


Graph 6: System Dynamic Response With Tuned PID for Area 6

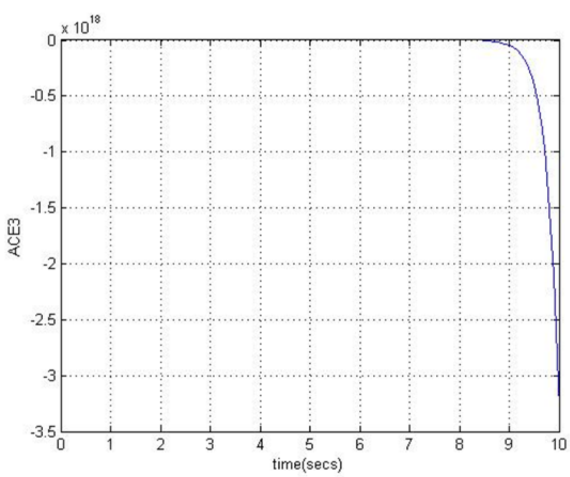
Referring to graphs (1-6), it is clear that the ACE which has occurred in six different areas have been eliminated and brought to zero within a very quick time.i.e.(2 secs) with the help of Tuned PID controllers. Thus system stability has been achieved.



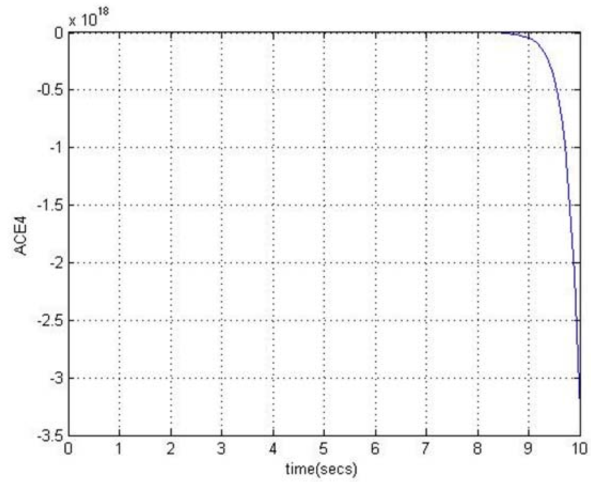
Graph 7: System Dynamic Response Without Tuned PID for Area 1



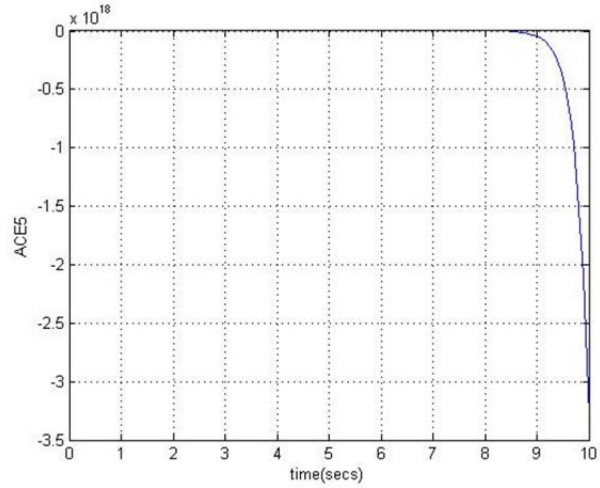
Graph 8: System Dynamic Response Without Tuned PID for Area 2



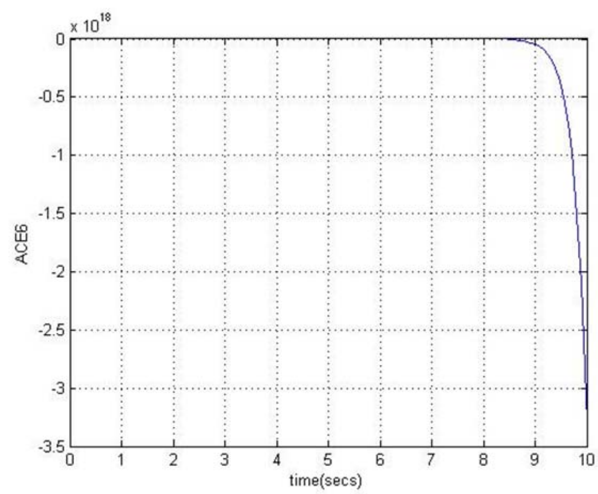
Graph 9: System Dynamic Response Without Tuned PID for Area 3



Graph 10: System Dynamic Response Without Tuned PID for Area 4

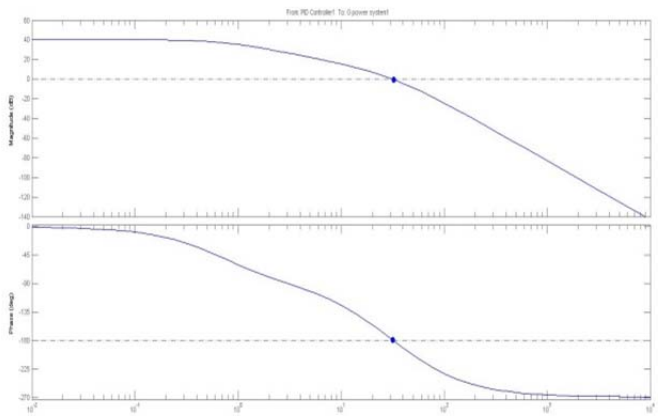


Graph 11: System Dynamic Response Without Tuned PID for Area 5



Graph1 2: System Dynamic Response Without Tuned PID for Area 6

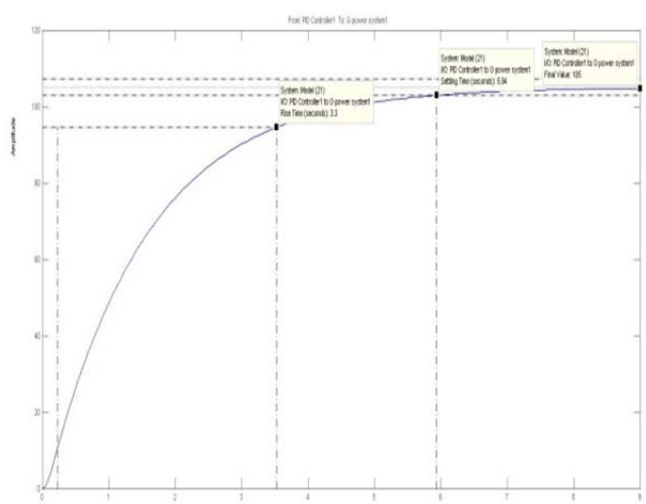
Referring to graphs (7-12),it is clear that after removing the Tuned PID Controllers from six different areas, the ACE for all the areas have risen to extremely high magnitude and also pertaining for a long interval of time and disturbing the overall system stability. Also it has been observed that even after tuning the PID controllers, the ACE could not be brought to zero within quick time. So Governor, Turbine and power system have also been tuned to bring the ACE to zero in quick time.



Graph 13: Bode response of 6 area system for area 1

The Bode Response for area 1 having PID 1 and power system 1 block is shown above. Results show that the Gain Margin is 0.401db at frequency 32.4 rad/s Phase Margin and Delay Margin are 1.21^0 and 0.00067sec respectively at frequency 31.6 rad/s and the system is closed loop stable.

Similarly the Bode response of the remaining 5 areas also showed the same remarkable closed loop stability with both Gain Margin > 0 and Phase Margin > 0.



Graph 14: Step Response of 6 area system for area 1

The step response of the area 1 with PID1 and Power System1 is shown in graph 14 which is found to have a Rise time of 3.3 seconds and Settling time of 5.94 seconds with the final value settling at an amplitude of 105 within the tolerance band of 104 to 106. The final value of the output response stays within +-2% tolerance band. For 5.94 s of settling time the damping ratio is 0.013468.

Similarly the step responses of the remaining 5 areas also showed the same steady state stability. The final value of the output response stays within +-2% and for 5.94 s of settling time the damping ratio is 0.013468.

7. CONCLUSION

The Area Control Errors (ACEs) for all the six interconnected areas have been calculated and brought to null position within a quick time i.e (2 secs). Thus maintaining system stability even when load demand changes occur in all the areas. The necessary graphs and simulink diagram have been given which shows how the error is being reduced to zero and stability is achieved.

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