International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 8, October - 2012

Automatic Generation Control of Multi-Area Hybrid System Using Conventional Integral Controller

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Abstract

Automatic Generation Control (AGC) or Mega Watt frequency control problems are that of sudden small load perturbations which continuously disturb the normal operation of an electric energy system. This paper deals with AGC of interconnected multi-area hydrothermal systems. Thermal area is considered with reheat turbine and hydro area is considered either with an electric governor or a mechanical governor. Optimization of conventional integral controllers in all the areas has been carried out using integral square error (ISE) criterion. Effect of changing step load perturbations in different areas on dynamic responses has been explored. The effect of changing sampling time period on dynamic responses has also been investigated with conventional integral controller considering small step perturbations in different areas.

Keywords

Automatic generation control; frequency deviation; tie line power deviation; area control error (ACE).

1. Nomenclature

f = Nominal system frequency.
i = Subscript referring to area (i=1, 2, 3).
Pri = Rated power of i^{th} area.
del f = Incremental change in frequency.
del Ptie = Incremental change in tie line power.
Tii = Synchronizing coefficient.
Ri = Governor speed regulation parameter for i^{th} area.
Tri = Steam turbine reheat time constant for i^{th} area.
Tti = Steam turbine time constant for i^{th} area.
Tgi = Speed governor time constant for i^{th} area.
Tpi = Power system time constant for i^{th} area.
Kpi = Power system gain for i^{th} area.
Kri = Steam turbine reheat coefficient for i^{th} area.
Kii = Gain of integral controller for i^{th} area.
ACEi = Area control error for i^{th} area.

Bi = Frequency bias for i^{th} area.
Kd, Kp, Ki = Electric governor derivative, proportional, integral gains, respectively.
TR, T1, T2 = Mechanical governor constants.
J = Cost function.

2. Introduction

In order to ensure constancy in frequency and tie-line power of an interconnected multi-area power system, it is necessary to design a suitable AGC system which maintains the balance in generation and load. The operating point of the power system changes in a daily cycle due to inherent characteristics of changing load i.e. system may experience deviations from nominal system frequency and scheduled power exchanges to other areas. AGC tries to achieve this balance by maintaining the system frequency and tie line flows at their scheduled values [1, 2].

The AGC control is guided by Area Control Error (ACE), which is a function of system deviations and tie line flow deviations. The ACE represents a mismatch between area generation and load taking into account any interchange agreements with neighboring areas.

Generation in large interconnected power system comprises of thermal, hydro, nuclear and gas power generation [3, 4]. Nuclear owing to their high efficiency are usually kept at base load close to their maximum output with no participation in system AGC. 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. So, the natural choice for AGC falls on either thermal or hydro units.

The characteristics of hydro turbine differ from steam turbine in many aspects [5]. In a hydro turbine, relatively large inertia of water causes a greater time lag in the response of the change in prime mover torque to a change in gate position. Also, there is an initial tendency for the torque to change in a direction opposite to that finally produced. Now a days, hydro units are normally equipped with electric governors in which the electronic apparatus is used to perform low power functions associated with speed sensing and droop compensation.

Most of the work in the area of automatic generation control pertains to interconnected thermal system and relatively lesser attention has been devoted to automatic generation control of an interconnected hydro-thermal system involving multi area thermal and hydro subsystems of widely different characteristics [6,7,8,9]. These investigations mostly pertain to two equal area thermal systems or two equal area hydrothermal systems considering the system model either in continuous or continuous discrete mode with step loads perturbation occurring in an individual area.

The main objectives of the present paper are following:

1) To optimize the conventional integral controllers in all the three areas (thermal-thermal-hydro) using ISE criterion, considering 1% step load perturbation in each area.

2) To study the effect of changing step load perturbations in different areas on dynamic responses of the multi-area interconnected systems.

3) To study the effect of varying sampling time period on dynamic responses of the multi -area interconnected systems.

4) To compare the performances of mechanical and electric governors in hydro area.

The rest of the paper is structured as follows: Section 2 presents the multi-area power system transfer function model. Section 3 simulations, controller parameters optimization with ISE criterion, results and discussions are presented; finally, conclusions are given in Section 4.

3. System investigated

A three area hybrid power system as shown in Fig. 1 is considered as a test system to study the AGC problem and illustrate the effectiveness of optimized gain parameters in load frequency control in conventional PI controller. An interconnected hybrid system comprising of thermal-thermal –hydro has been used for simulation studies. Area1 and area2 are reheat thermal systems and area3 is a hydro system. Simulation model has been developed in MATLAB to obtain dynamic responses for various parameters for 1% step load perturbation in each area. The power system parameters used in the model are given in Appendix-A. The optimum values of integral controller gains have been found using ISE technique, considering step perturbation in any one area, keeping all other areas uncontrolled. The objective function (cost function) J for ISE technique is

$$J = \int [delf^2 + delPtie^2]\, dT$$

where,

dT = small time interval during sample

delf = incremental change in frequency of area

delPtie = incremental change in tie line power of area.

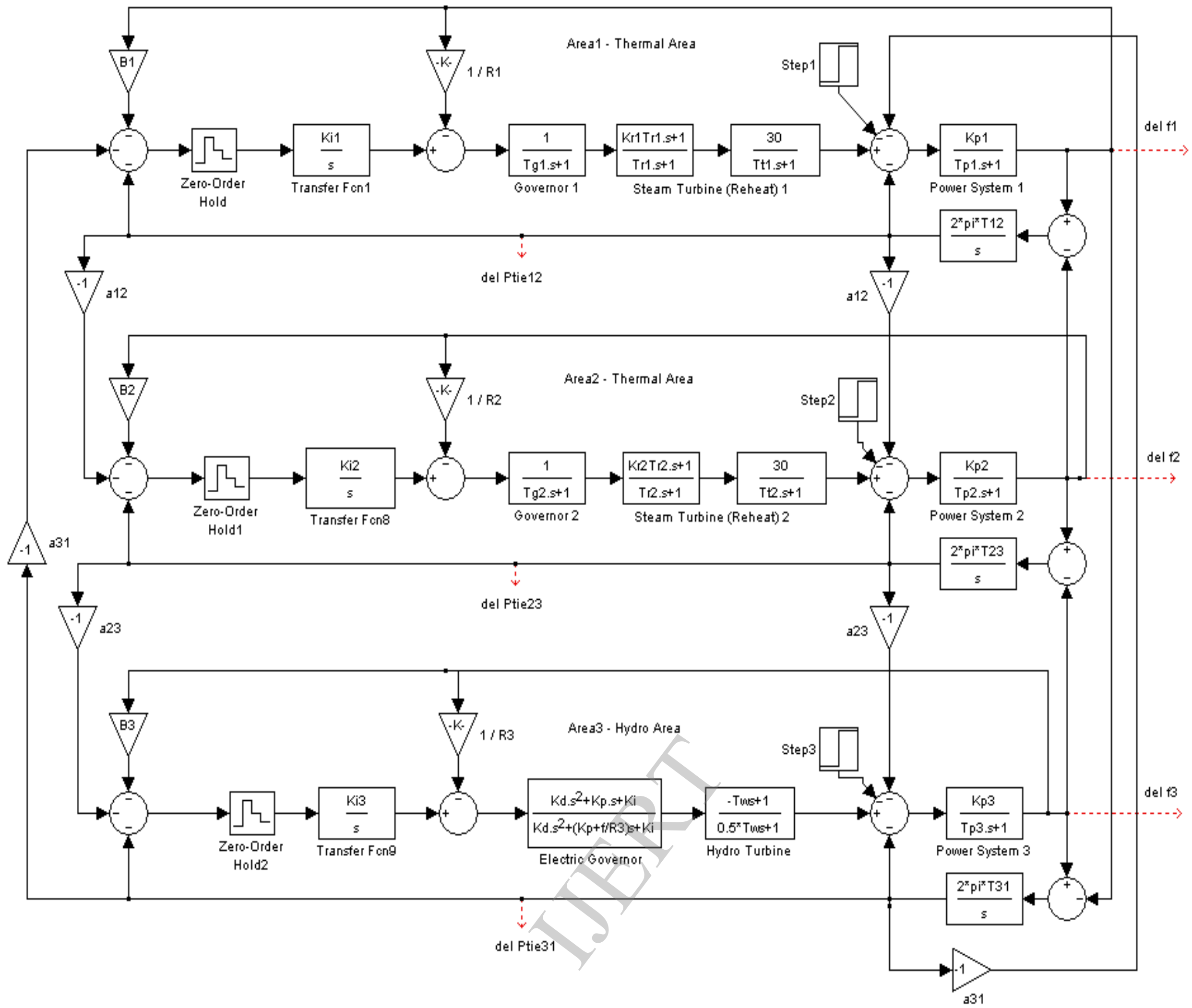

Figure 1. Transfer function model of three area thermal-thermal-hydro system

In the control application, we use integral method to decrease the rise time and reduce the steady state error. The speed changer setting can be adjusted automatically by monitoring the frequency changes. For this purpose, a signal delf is fed through an integrator to the speed changer. The system now modifies to a proportional plus integral controller. This, as is well known from control theory, gives zero steady state error, i.e.

$delf|_{steady\ state}=0.$

The signal fed to the integral controller is called ACE (area control error). The integrator output, thus the speed-changer position, attains a constant value only when the frequency error has been reduced to zero. Now proportional integral method is applied to three area system for analysis. Individual controller is applied to each area for designing conventional controller for three area systems.

4. Results and analysis

Before The dynamic response of the three area hybrid system has been obtained for a small load perturbation of 1 percent with conventional PI controllers. The system model has been simulated under following situations.

4.1. Tuning of parameters

To obtain the optimum response, system parameters have to be tuned. The optimal values of integral controllers are obtained using cost function J vs time graphs as shown in Figs. 2 to 4. Optimum value is obtained on individual basis. The parameters are varied over a wide range and response is plotted. To obtain optimum value of Ki1, the other two gain values Ki2 and Ki3 are taken as zero. From all these three graphs, optimum settings of the three controllers have been obtained as: Ki1 = 0.06; Ki2 = 0.1; Ki3 = 0.1.

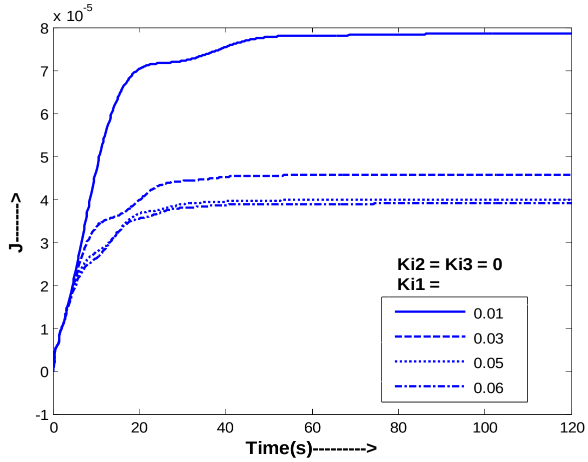

Figure 2. J Vs time for different Ki1

4.2. Effect of load perturbation

In this case a load perturbation of 1% is applied in each area. The tuned values of gains are used for all perturbations in each area. Fig. 5 and Fig.6 show the frequency response of area-1 and area-2 respectively for load perturbation in their respective areas. Graph for area-3 can be obtained in similar way. The deviation in tie-line power i.e. delPtie23 has been plotted in Fig. 7 for a step load perturbation of 1% in each individual area. Graphs for delPtie12 and delPtie31 can be obtained in similar way. Responses are similar in terms of settling time for 1% step load perturbation in individual area, however peak overshoots and undershoots of the response are affected by the place of load perturbation

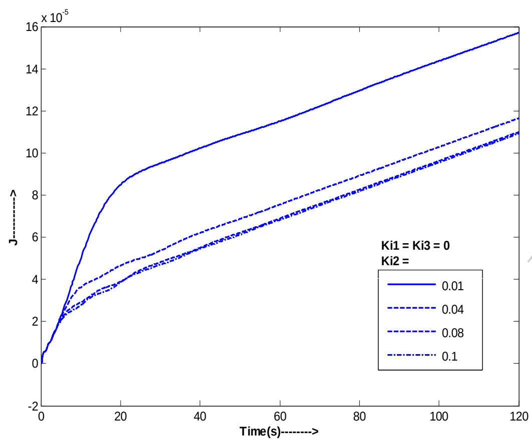

Figure 3. J Vs time for different Ki2.

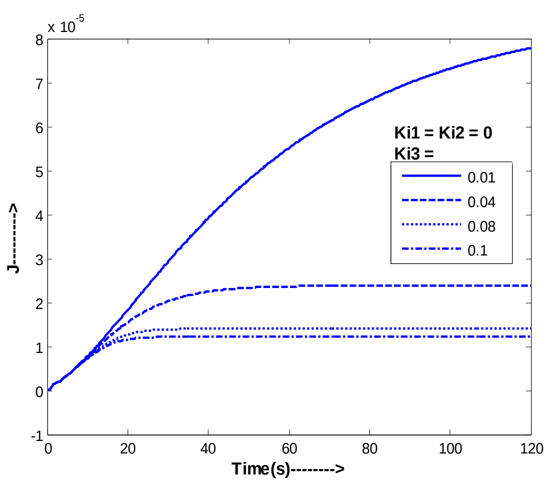

Figure 4. J Vs time for different Ki3.

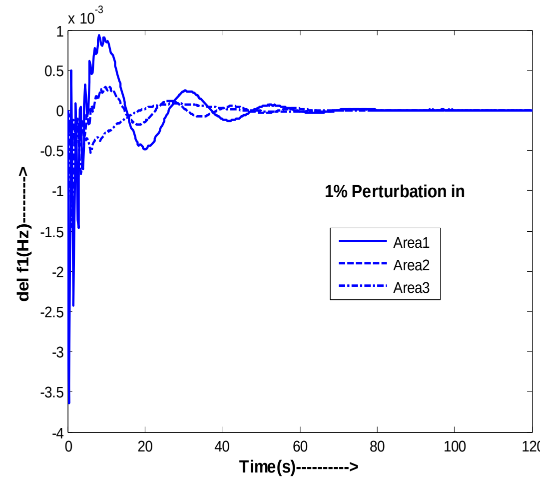

Figure 5. del f1 Vs time.

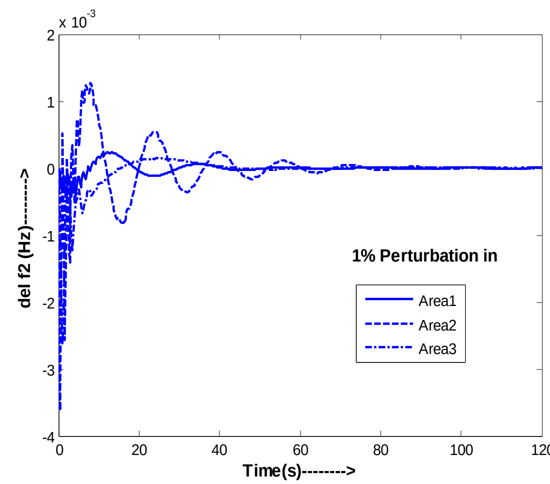

Figure 6. del f2 Vs time.

ISSN: 2278-0181
Vol. 1 Issue 8, October - 2012

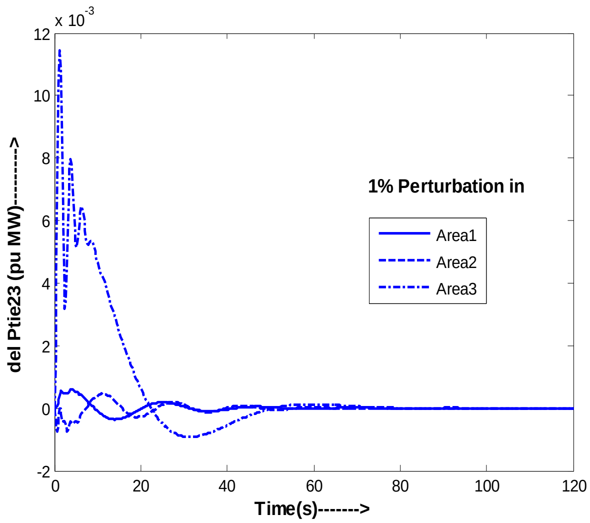

Figure 7. del Ptie23 Vs time

4.3. Effect of sampling time variation

Figs. 8 to 10 show the behavior of del f1, del f2, and del f3 for different sampling times. Load perturbation is applied on each individual area and responses are obtained at optimized values of the parameters of integral controller. To obtain graph of delf1, Ki1 is set at its optimum value and rest of the gains are taken as zero. Sampling time of 2 seconds is taken as permissible value for all the three samplers in different areas. This will reduce the wear and tear of sampler. Moreover, sampling time higher than this, may distort the frequency response and tie line power deviations curves.

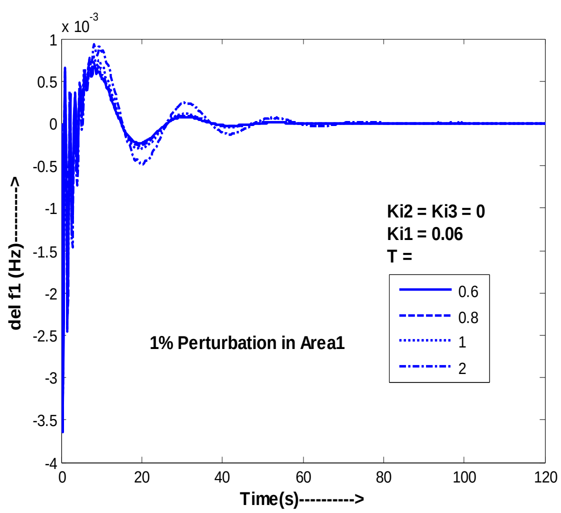

Figure 8. del f1 Vs time for different sampling times.

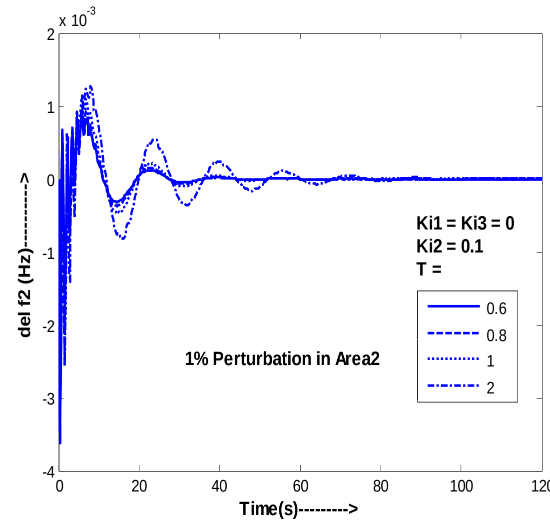

Figure 9. del f2 Vs time for different sampling times.

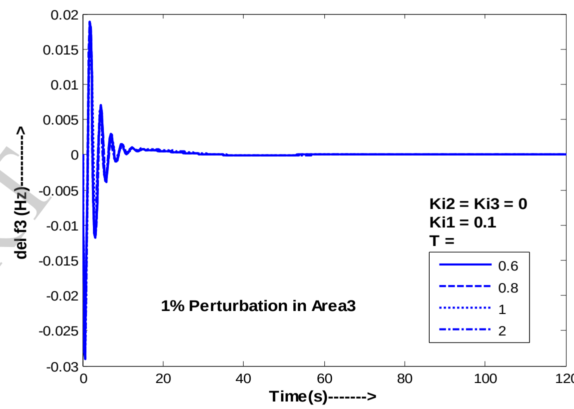

Figure 10. del f3 Vs time for different sampling times.

4.4. Comparison of mechanical and electric governors

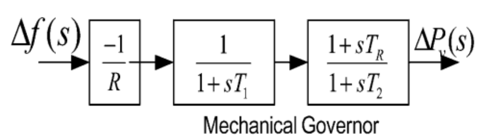

Figure 11. Transfer function model of mechanical governor.

Fig. 11 shows the transfer function model of mechanical governor [3]. The temporary droop (δ) in mechanical governor plays a very important role in the stability of the system. An improper selection of δ will make the system unstable. The approach for finding out the suitable value of δ from stability considerations is as follows:

a) Consider both the areas uncontrolled, it is seen that any value of δ less than 0.7 and greater than 1.1 makes the system unstable. When δ is increased beyond 0.7, the system become stable and more or less the best response is obtained at δ = 0.95.

b) In the presence of optimum integral controller in both areas, δ is varied around 0.95. Responses reveal that δ = 0.95 again provides more or less the best response.

Fig. 12 shows the comparison of mechanical governor with δ = 0.95 and electric governor in terms of dynamic responses. It is clearly seen that electric governor provides much better response compared to mechanical governor in terms of peak deviations and settling time.

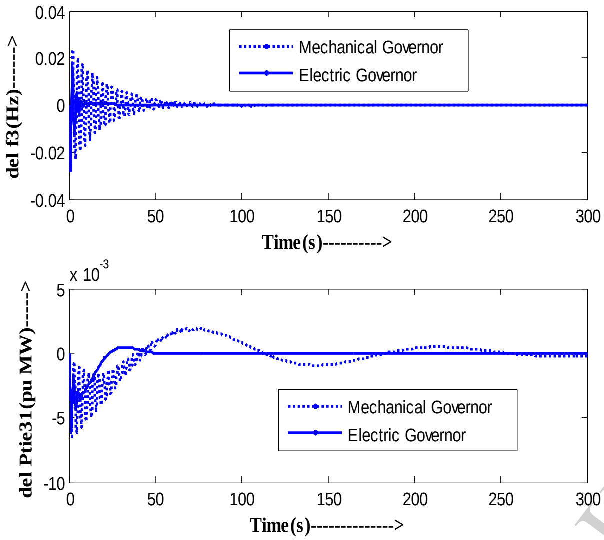

Figure 12. del f3 and del Ptie31 Vs time for different governors.

5. Conclusions

Frequency is one of the most important parameter to determine the stability of a system. To improve the overall dynamic performance in the presence of the plant parameters changes and system non linearities the conventional PI controller based AGC problem has been formulated as an optimization problem based on system performance index ISE for multiple operating conditions. In a multi-area hydrothermal system, dynamic responses obtained, for step load perturbations in different areas, are almost similar in terms of settling time. Thus, it hardly matters, in which area, the step load perturbation has taken place. The AGC system balances it well in terms of frequency deviations and tie line power deviations. With conventional integral controllers, sampling time period of 2 seconds is permissible in each area. Electric governor gives better dynamic reponses as compared to mechanical governor in terms of peak deviations and settling time.

6. Appendix

f= 60Hz

Pr1 = Pr2 = Pr3 = 2000 MW

Ptie-max = 200MW

Tg1 = Tg2 = 0.08 s

Kr1 = Kr2 = 0.5

Tr1 = Tr2 = 10s

Tt1 = Tt2 = 0.3s

Kp1 = Kp2 = 30Hz/puMW

Kp3 = 80 Hz/puMW

Tp1 = Tp2 = 20s

Tp3 = 13s

T12 =T23 = 0.086 puMW/radian

T31 = 0.043 puMW/radian

R1 = R2 = 2.4 Hz/puMW

R3 = 4.8 Hz/puMW

B1 = B2 = 0.425

B3 = 0.221

Kd = 4; Kp = 1; Ki = 5

Tw = 1s

TR = 2s

T1 = 48.75s

T2 = 0.513s

a12 = a23 = a31= -1

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