Volume 3, Issue 11, November 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Sensitivity Analysis of Multi-Area Hybrid Power System Integrated with Integral Controllers

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Abstract- This paper deals with the various aspects of 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. Sensitivity analysis is done on the system which means the study of effect of various parameter variations on system's dynamic performance. 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).

I. 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.

II. 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 do sensitivity analysis i.e. to study the effect of varying various parameters on the dynamic responses of the multi -area interconnected systems.
3) To study the effect of varying sampling time period on the dynamic responses of the system.

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

III. 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.

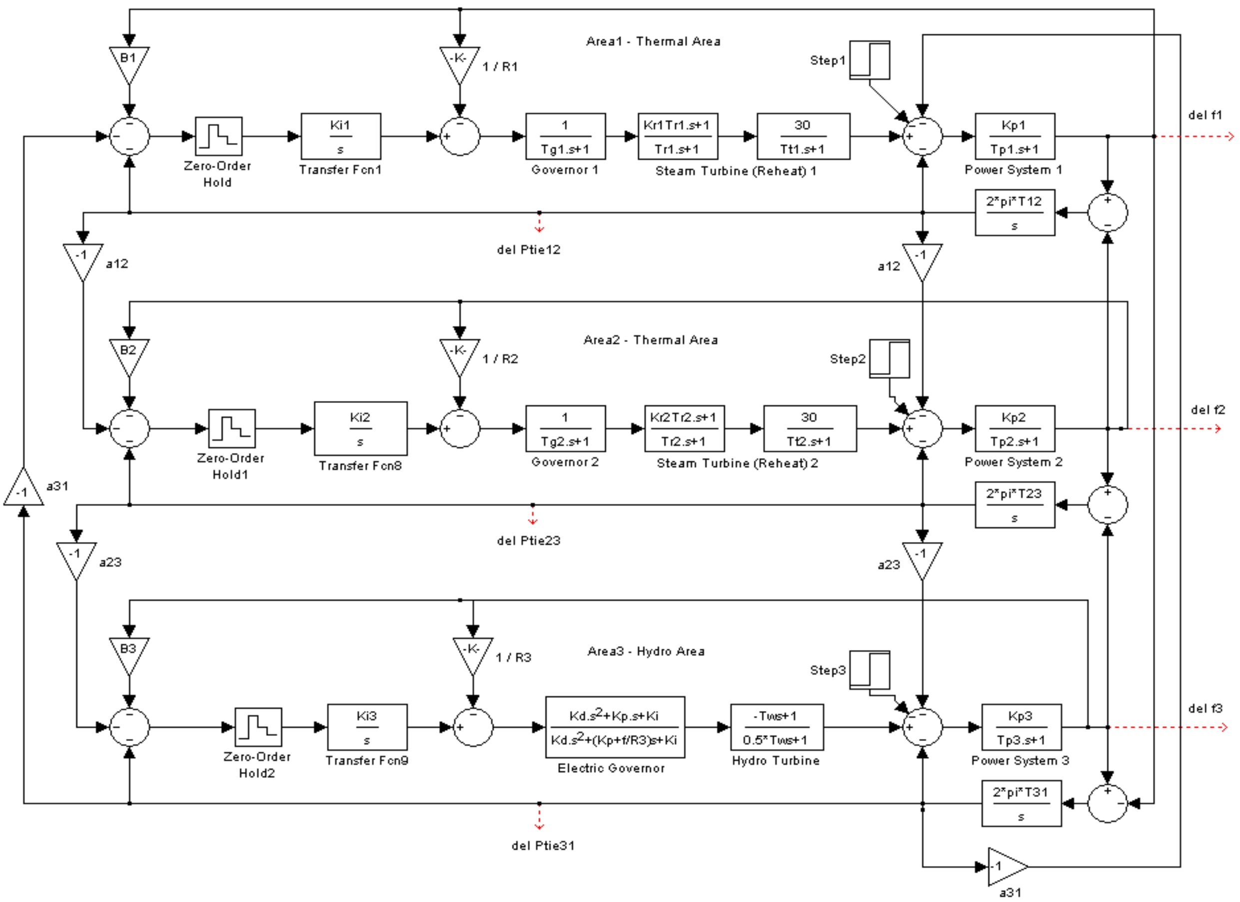

Fig 1. Transfer function model of three area thermal-thermal-hydro system

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.

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

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.

IV. Results and Analysis

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.

A.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.

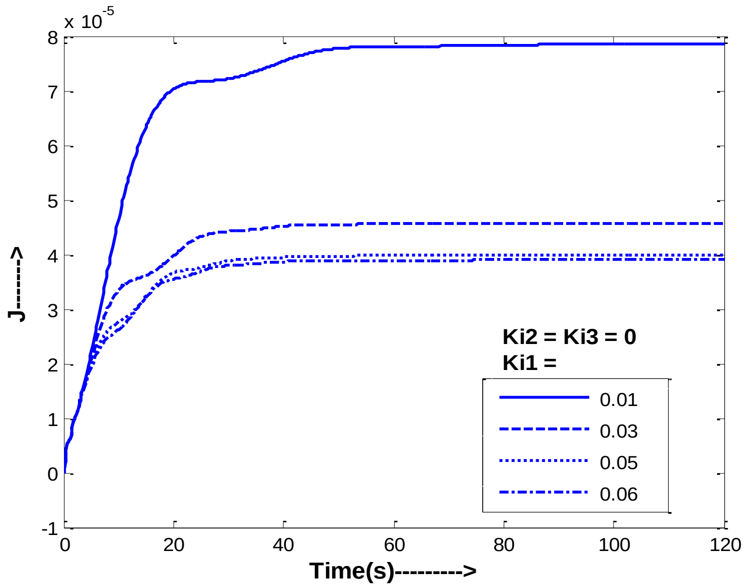

Fig 2. J Vs time for different Ki1

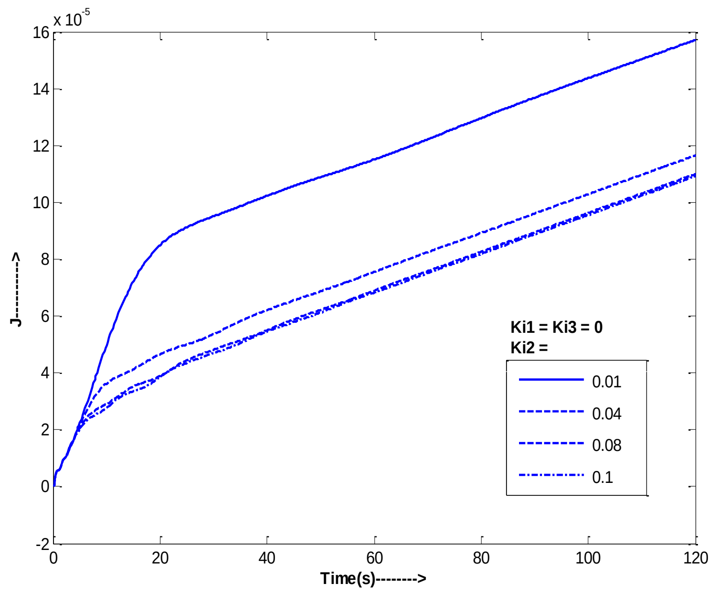

Fig 3. J Vs time for different Ki2.

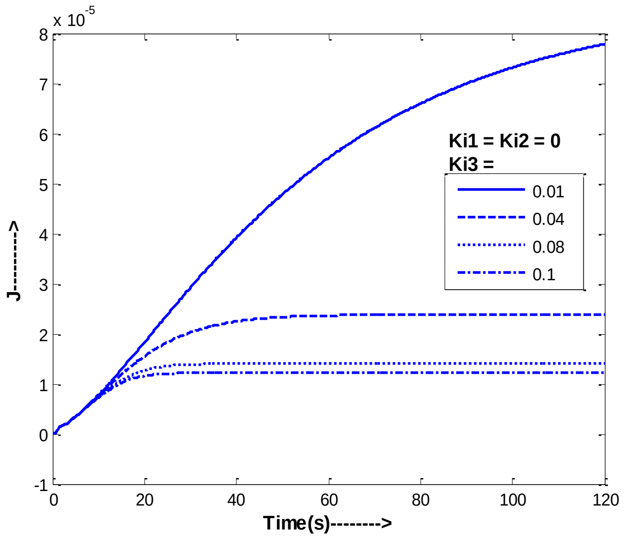

Fig 4. J Vs time for different Ki3.

B. Sensitivity Analysis

It includes the study of effect of varying system parameters like Tg, Tt, Kr and Tr on the dynamic performance of hybrid power system. These parameters are varied by ±25% from their nominal values and these variations are done one at a time. Fig. 5 to Fig. 8 shows the frequency responses of different areas under different parameter variations. Graphs reveal that the dynamic responses hardly change when these parameters are changed by ±25% from their nominal values.

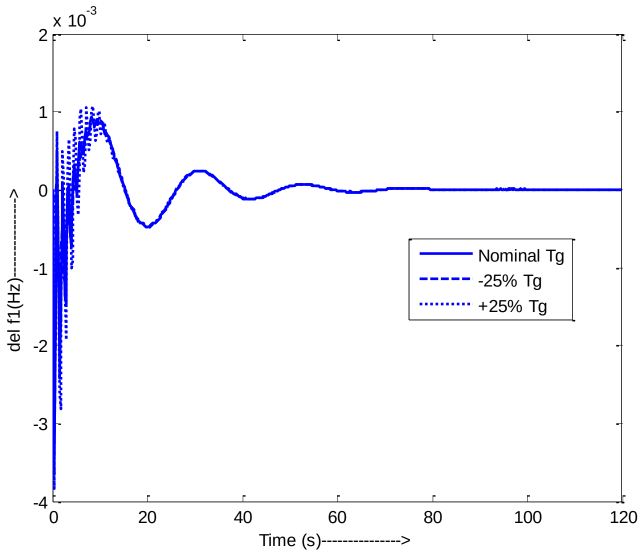

Fig 5. del f1 Vs time for different values of Tg.

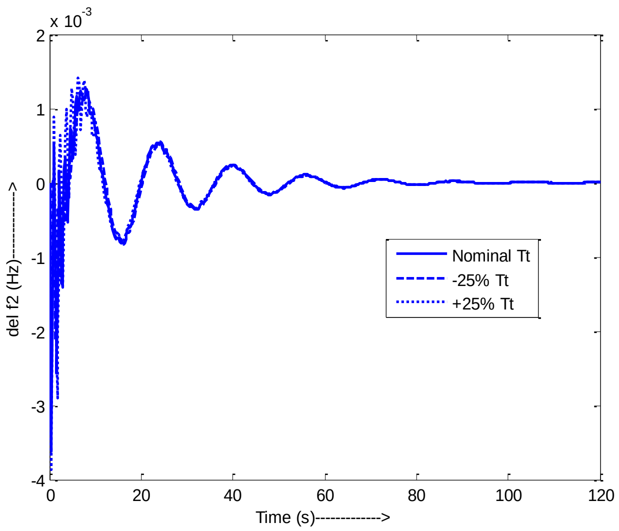

Fig 6. del f2 Vs time for different values of Tt.

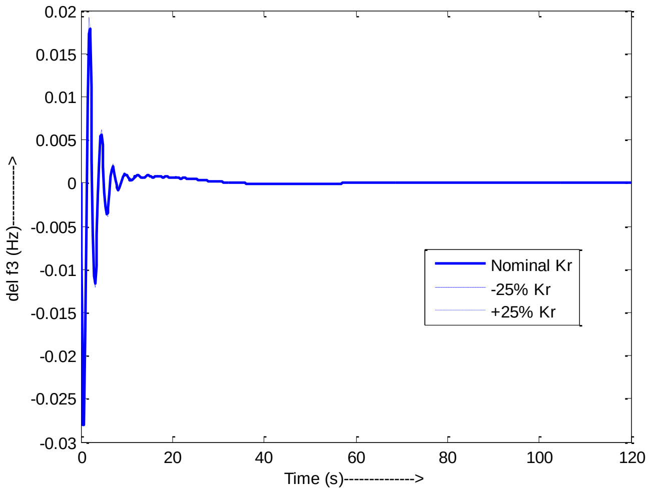

Fig 7. del f3 Vs time for different values of Kr.

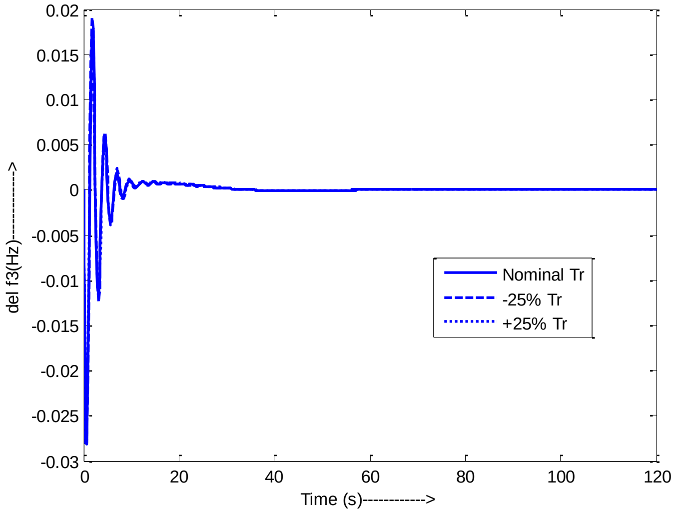

Fig 8. del f3 Vs time for different values of Tr.

C. Effect of Sampling Time Variation

Figs. 9 to 11 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.

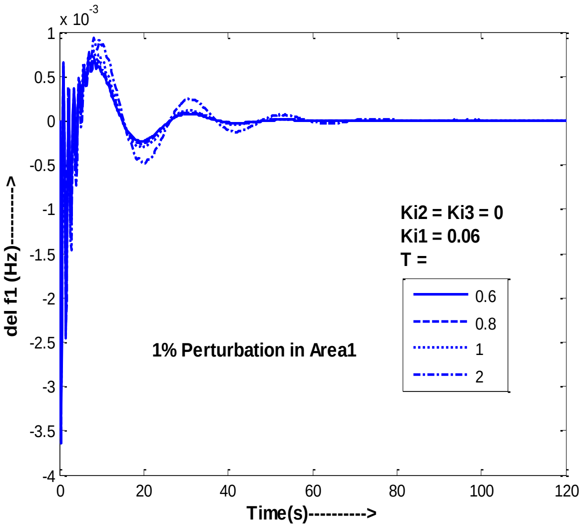

Fig 9. del f1 Vs time for different sampling times.

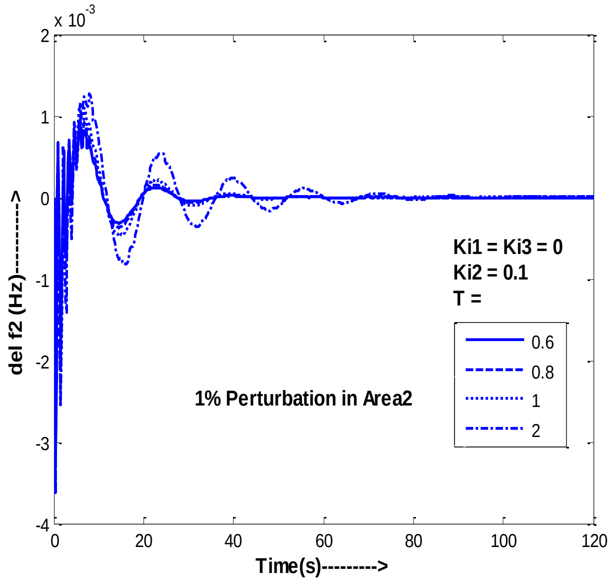

Fig 10. del f2 Vs time for different sampling times.

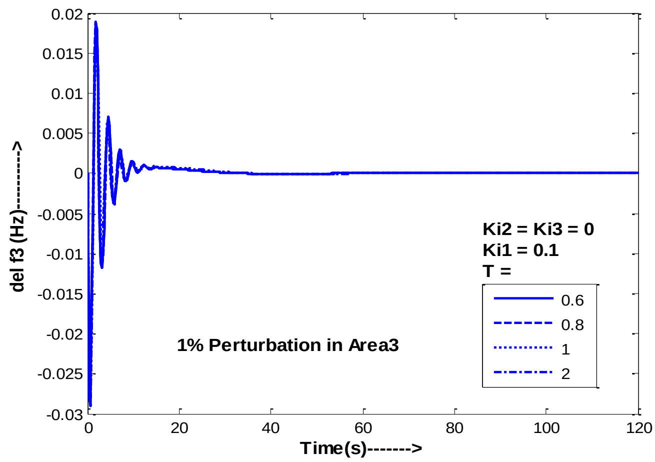

Fig 11. del f3 Vs time for different sampling times.

V. 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 different parameter variations in different areas, are almost similar in terms of peak deviations and settling time. So, the AGC system is quite insensitive towards parameter variations. With conventional integral controllers, sampling time period of 2 seconds is permissible in each area. Above this value, the wear and tear of sampler increases.

VI. 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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