Design of Controller to Damp Inter area Oscillations

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***Abstract*— This paper deals with the analysis and simulation of power system operation with an integrated control viz., under single area and two-area control and it was carried out with the help of MATLAB. The simulation studies will enable an easier understanding of the effect of an actual load change and how the frequency and voltage are maintained by introducing state feedback controller. The paper deals with simulated results using MATLAB to show the response of the system like tie-line power, frequency deviation for different torques. The modeling, analysis and simulation has been carried out for a detailed performance evaluation of a real time power system. Such a study has helped in proposing methods to examine the stability of the system. The stability of the system is improved by feedback gain matrix.**

Keywords—Controller design; Inter area oscillations;Small Signal analysis

I. INTRODUCTION

The system used in a cogeneration plant consisting of two alternators each of 22.8 MW power output. The two Synchronous generators are operating in single machine connected with grid. The difficulties in operating the single machine connected are

- Whenever the grid fails the entire load on the individual machine is thrown-off and there will be torsion / jerk on the rotor of generator.
- As the load on the plant changes the backpressure is affecting the process.
- The efficiency is less as the generators are operating at under-loads.
- Redundancy is absent.

To overcome the above difficulties an Integrated Control System with Automatic Load management System to suit for 2x22.8 MW generators can be installed, which connects the two generators in parallel to supply island load and interface with grid. The modeling, Analysis and simulation of Single Area (single generator) and Two Area (Two generators) control problem help us to solve the load frequency control issues [7][10].

Our analysis deals with small deviations in frequency, angle and voltage magnitude represented by Δf, $\Delta\delta$and $\Delta|V|$ respectively which indirectly affect tie line power. The present work examines the behavior of a generator for different load

variations. The tie-line power deviations are analyzed for safety operation of two generators connected in parallel

(Integrated System)[11]. The power swings in tie-line and hence frequency deviations are analyzed for stability. The numerical solutions and also designing of a state feedback controller are presented to verify analytical results.[12]

II. MODELING OF SINGLE AREA POWER SYSTEM

The power system contains governor, steam turbine, generator and power system in cascaded form. The model is obtained by considering the time constants of system components.

1. *Speed Governor*

Electro hydraulic governors are provided with three-term controllers with proportional-integral-derivative action as shown in Figure 1. PID controllers provides both transient gain reduction and transient gain increase. The derivative action is beneficial for isolated operation.

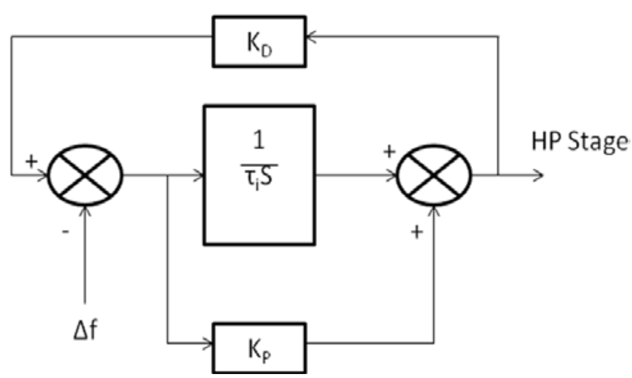

Figure 1

2. *Tandem compound non reheat type turbine*

A steam turbine converts energy stored in high pressure and temperature steam into rotating energy, which in turn converted into electrical energy. The heat source for the boiler supplying the steam may be a furnace fired by fossil

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fuel (bagasse with trash, coal and mixture of coal with bagasse). Tandem compound non reheat type turbine is shown in Figure 2.

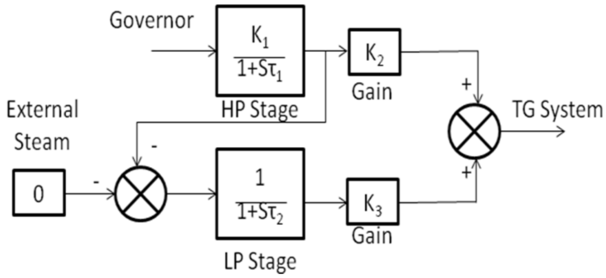

Figure 2

3. *Turbine generator rotation system:*

The time taken by the Turbine Generator system is represented as time constant τ_3. The Figure 3., represents the TG Rotation system.

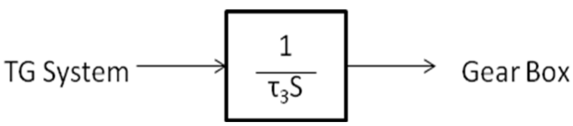

Figure 3

4. *Gear Box*

The gearbox in a steam turbine converts the fast 5615 rpm, low-torque rotation of the turbine into much slower 1500rpm rotation of the electrical generator. The Figure 4. represents the gear box system.

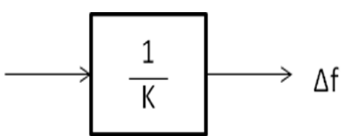

Figure 4

5. *Turbine Speed:*

The turbine runs at a speed of 5615 r.p.m. The Figure 5., represents the inverse of Rotation of the system.

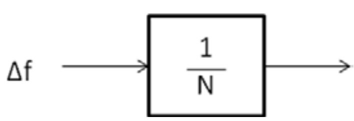

Figure 5

6. *Model of Single area Power system*

The different components of the system are connected to form block diagram of existing 22.8MW TG system as single area system shown in Figure 6. The output observed is change in frequency as the step load changes on the system.

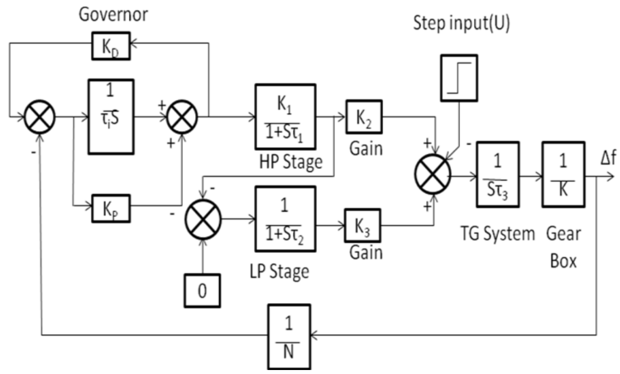

Figure 6

7. *Transfer function of single area system*

The input applied is step. Varying step loads are applied to observe frequency deviation. The transfer function of the system for change in frequency to change in step input are simulated and presented in Figure 7.

$$T(s) = \frac{\Delta f}{U(s)} = \frac{-3.10628X10^{-4}S^3 - 0.0108S^2 - 0.108S - 0.04}{3.277X10^{-3}S^4 + 0.1139S^3 + 1.1439S^2 + 0.7307S + 2.6372} \quad (1)$$

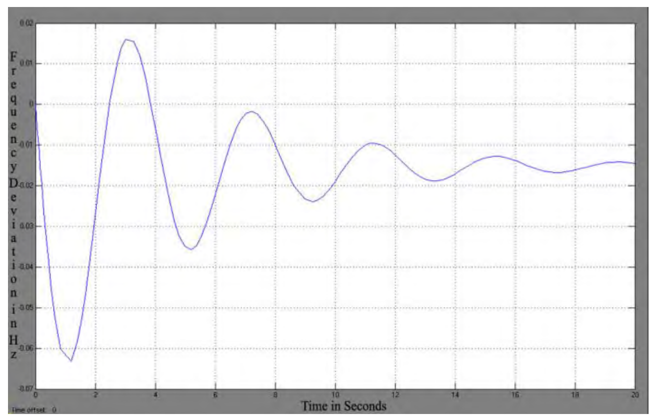

Figure 7

III. Modeling of Two Area Power System

Frequency control of interconnected areas, or power pools, is more important than those of isolated areas. Nowadays all power systems are tied together with neighboring areas, and a problem of load-frequency control becomes a joint undertaking. It is necessary to control the power flows on tie lines.

1. *General form of Two-Area System*

Consider two generating units, which are inter-connected by a weak tie-line. Frequency deviations in the two areas are represented by two variables Δf_1 and Δf_2 respectively as shown in Figure .8.

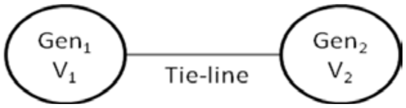

Figure 8

The tie-line can be modeled as given by equation 2.

$$\Delta P_{12} = \frac{2\pi T^{\circ}}{S}(f_1(s) - \Delta f_2(s))\ MW \quad (2)$$

The two area system static response tells us

1. Fifty percent of the added load in area 2 will be supplied by area 1 via the tie-line.
2. The frequency drop will be only half that which could be experienced if the areas were operating alone or island mode.

The power system variable like bus voltage and frequency are sensitive to generator oscillations[4]. The oscillation frequency lies in the range of 0.1 to 2 Hz. Properly damped systems are allowed to have 10% damping as accepted value. The system modes are function of operating point [12].

Two Turbo generators of similar characteristics are interconnected in parallel. The Frequency response of two area system for equal load sharing is shown in Figure 9.

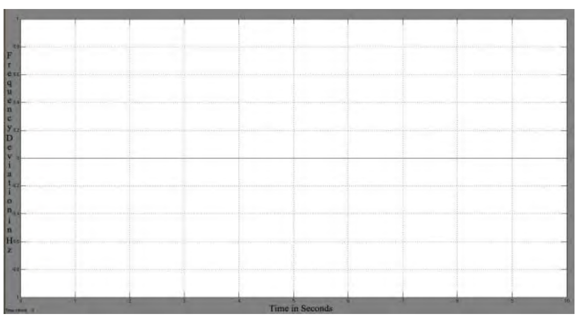
Figure 9

Frequency response of two area system for unequal load sharing without controller is shown in Figure 10.

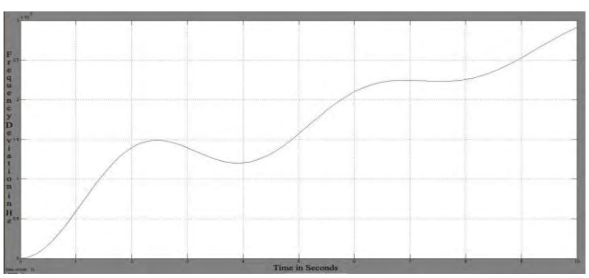
Figure 10

IV. METHODOLOGY

Step1- Obtain the system transfer function by block diagram reduction method.[13]

Step2- Obtain the State space representation of the system.

Step3- Examine the system stability by Eigen value analysis.

Table I

Sl.No.	Mode of System	Sl.No.	Mode of System
1	-133.71	8,9	0.34 ± 0.38i
2,3	-0.4 ± 0.38i	10,11	12.85 ± 89.49i
4,5	-0.33 ± 0.34i	12,13	0.26 ± 2.60i
6	-1.63	14,15	0.4 ± 0.35i
7	-0.03		

Step 4- Examine the system stability by analyzing the system response for various types of load sharing.

Root Locus of two area system for unequal load sharing without controller unstable system is shown in Figure 11.

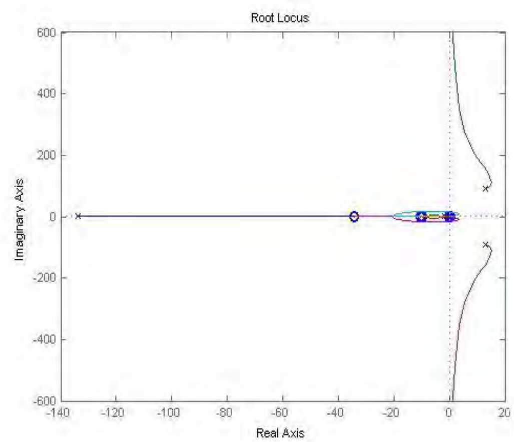

Figure 11

The Eigen value analysis, root locus plot and the step response shows that the two area system for unequal loading is unstable.

Step5- The stability analysis carried on the basis of Eigen value analysis. It is observed that the system under consideration is unstable.

Step6- Desired location of poles to make the system stable as that of System1 are given in Table II.

Table II

Sl.No.	Mode of System	Sl.No.	Mode of System
1,2	-120.85 ± 0.0000i	10	-3.45
3	-30.4	11	-3.35
4	-20.6	12	-3.3
5	-13.37	13	-3

6,7	-4 ± 2.3i	14	-2.6
8,9	-4 ± 0.00i	15	-1.63

The controller gains for the system with more than one controlled input or sensed output are listed in Table III.

Table III

K=1.0e+013*

Sl.No.	Controller Gain	Sl.No.	Controller Gain
1	0.0000	9	0.5901
2	0.0000	10	2.0137
3	0.0000	11	4.9446
4	0.0000	12	8.5057
5	0.0002	13	9.7164
6	0.0021	14	6.6082
7	0.0194	15	2.0200
8	0.1256		

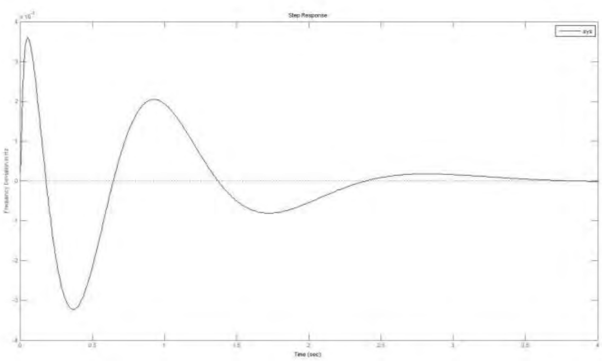

Figure 12.

The below Figure 13. Shows Root-Locus representation for Stable System

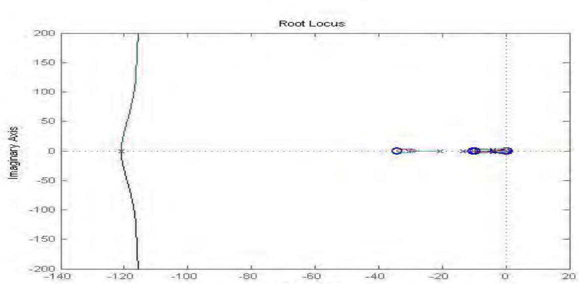

Figure 13.

V. RESULTS

1. System Eigen values before using controller:

TABLE I

Sl.No.	Mode of System	Sl.No.	Mode of System
1	-133.71	8,9	0.34 ± 0.38i
2,3	-0.4 ± 0.38i	10,11	12.85 ± 89.49i
4,5	-0.33 ± 0.34i	12,13	0.26 ± 2.60i
6	-1.63	14,15	0.4 ± 0.35i
7	-0.03		

The observation of above Eigen values reveals that the system is unstable since they lie on the right half of S-plane.

2. System feedback gain matrix as obtained from the designed controller:

The larger value of real part of a closed loop pole makes the system response fast. The input required also must be of larger magnitude. The systems with larger magnitude input are more prone to enter into nonlinear operating range.[3]

The section of desired closed loop poles requires a balance of bandwidth, overshoot, sensitivity and other design requirement.

The controller is designed for system with more than one controlled input or sensed output.

TABLE II

K=1.0e+013*

Sl.No.	Controller Gain	Sl.No.	Controller Gain
1	0.0000	9	0.5901
2	0.0000	10	2.0137
3	0.0000	11	4.9446
4	0.0000	12	8.5057
5	0.0002	13	9.7164
6	0.0021	14	6.6082
7	0.0194	15	2.0200
8	0.1256		

3. System Eigen values after using designed state feedback controller:

TABLE III

Sl.No.	Mode of System	Sl.No.	Mode of System
1,2	-120.85 ± 0.0000i	10	-3.45
3	-30.4	11	-3.35
4	-20.6	12	-3.3
5	-13.37	13	-3
6,7	-4 ± 2.3i	14	-2.6
8,9	-4 ± 0.00i	15	-1.63

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