PERFORMANCE OF LOAD FREQUENCY CONTROL IN A TWO AREA INTERCONNECTED SYSTEM USING MATLAB SIMULATION

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Abstract—*The main objective of this paper is to study the load frequency control problem associated in single and Two area electrical power systems. At first uncontrolled system is studied and then improvement of its response is learnt on the application of integral controller. Automatic generation control (AGC) is usually used to regulate with these deviations in frequency, voltage and which reduce to an acceptable level. AGC is consists of two parts which are load frequency control (LFC) and automatic voltage regulator(AVR). In systems that are operating with their maximum rating, any increase in the load will cause generators to fall, or in best cases suppliers will have to load shed some unimportant loads to recover back sufficient power supply to the grid.*
Any load change within the area has to be met by generators in both the area. Thus it can maintain the constant frequency operation irrespective of load change. In this paper, ALFC is evaluated using MATLAB and SIMULINK library for single area and multi area interconnected system. SIMULINK is used to analyze for different case studies in two area interconnected system and also analyzed with PID controllers and their performance responses are analyzed for different load change conditions.

Index Terms—*Single and Two-area electrical power systems, load frequency control and automatic voltage regulator, PID controller, MATLAB SIMULINK.*

I. INTRODUCTION

Electricity plays an inevitable role in the development of the nation. Optimization techniques are becoming essential in the field of power systems. One of the major functions of the power system is to transport electrical energy from generation side to load side. During the transportation of electric power, both the active power balance and the reactive power balance must be maintained between both ends. The changes in the active power can be determined by observing the frequency deviation. If this frequency deviates in a large scale from its nominal value (50±0.50) Hz, then the system loses its stability. So it becomes imperative to control the system frequency in order to maintain the stability. Thus the control related to frequency and active power is known as Automatic generation control (AGC) [10].

AGC is divided into Automatic Load Frequency Control (ALFC) and Automatic Voltage Regulator(AVR). Load Frequency Control is primary component of a power system to ensure continuous power supply to the consumer. Technically, power system frequency management is achieved through Automatic Generation Control (AGC). Frequency control divides the load between generators and controls the tie-line power to predetermined values to maintain sensibly load and generation balance [8].

The role of AVR is to hold the terminal voltage magnitude of synchronous generator at a specified level[5].

The increase in the demand of the load in any area that is operating at its maximum capacity causes some problems in the generation stations, a drop of the nominal operating frequency in addition to the fact that the supplier will have to overcome this problem by applying some techniques like load shading, which causes the supply of the power to the consumer to be unreliable and not constant. This problem was solved by the idea of interconnected area power systems, which is to connect two or more neighbouring areas by tie lines to exchange power. This paper aims to study the design of the control of two area power system to maintain the scheduled tie line power and the frequency of the whole system within their nominal values after subjected to disturbances.

II. Mathematical model of power system

The power system can be modelled by using all the power system components like using governor, turbine, generator and load. Equivalent transfer functions of each power system components are used to build the model and for further evaluation of regulation through automatic generation control.

A change in the load means a change in the electrical torque output of the generator Te, as per the swing equation says that in order to be at equilibrium point, the electrical torque and the mechanical torque should be equal.

$$\frac{2H}{\omega s}\frac{d^2\Delta\delta}{dt^2}=(\Delta P_m-\Delta P_e) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

When a deviation in speed occurs,the equation 1 becomes

$$\frac{d\Delta\frac{\omega}{\omega s}}{dt}=\frac{1}{2H}(\Delta P_m-\Delta P_e) \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Converting equation 3.2 into per unit values as

$$\frac{d\Delta\omega}{dt}=\frac{1}{2H}(\Delta P_m-\Delta P_e) \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Taking the laplace transform to the equation 3,

$$\Delta\omega(s)=\frac{1}{2H}(\Delta P_m(s)-\Delta P_e(s)) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The equation can be written in term of torque 'T', the change in the electrical torque 'Te', causes a mismatch between the mechanical torque and the electrical torque of the generator which means variations in the speed "equation of motion".

The rotor speed can be expressed as a transfer function in the electrical and mechanical torque, the model can be written as shown in the figure 1.

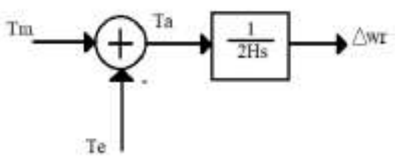


Figure 1: Speed and Mechanical power block diagram

Where:

Tm = Mechanical torque in pu

Ta = Electrical torque in pu

Te = Accelerating torque in pu

H = Inertia constant in MW-sec/MVA

Δω = Rotor speed deviation in pu

But it is more desirable to write the torque in terms of power using the following equation is

$$P = \omega_r T \quad \text{…………………. (5)}$$

When the initial values of the torque, power and frequency which can be derived from a small value,

$$P = P_0 + \Delta P$$

$$T = T_0 + \Delta T$$

$$\omega = \omega o + \Delta \omega r \quad \text{…………….. (6)}$$

The relationships become:

$$P_0 + \Delta P = (T_0 + \Delta T)\,(\omega o + \Delta \omega r) \quad \text{……..…… (7)}$$

$$\Delta P = \omega o \Delta T + T_0 \Delta \omega r \quad \text{……...…………(8)}$$

After neglecting the higher terms, at equilibrium τTe=Tm, and we consider ω =1 in p.u, the transfer function becomes:

$$\Delta P_m - \Delta P_e = \Delta T_m - \Delta T_e \quad \text{……………………..(9)}$$

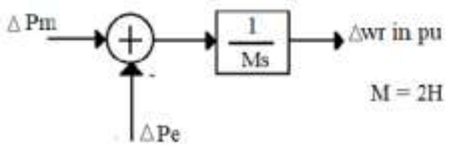


Figure 2: Generator block diagram

The turbine mechanical power is a function of gate position or valve, the resistive loads change is independent of the frequency and only dependent on the voltage magnitude, but in the case of motor loads, the electrical power changes with the frequency that changes the motor speed.

Load model: The characteristics of a load that is composite can be expressed as electrical power change:

$$\Delta P_e = \Delta P_L + D\Delta\omega_r \quad \text{…………………..(10)}$$

Where,

ΔPL =Non-frequency-sensitive load

DΔωr= Frequency sensitive load change

D = load damping constant. It is the ratio of percentage of change in load with respect to 1 percentage of change in frequency.

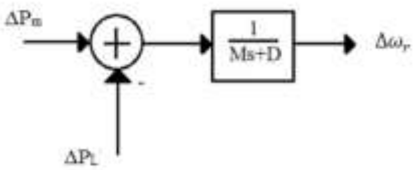


Figure 3: Generator and load block diagram

The total load in a system that covers an entire country is usually shared by more than one unit of generation that works in parallel and synchronized to a constant frequency.

Prime mover model: The prime mover is the source/turbine that controls the mechanical power, it can be hydraulici.e.moved by waterfalls or steam turbines whose energy comes from burning coal, gas, nuclear fuel.

For example in a gas turbine, any change in the valve position ΔPm is transferred into a change in the mechanical power output ΔPv by the turbine.

The characteristics of the turbine depend on its type, but it can be approximated with a time constant:

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau_T s} \quad \text{…………………..(11)}$$

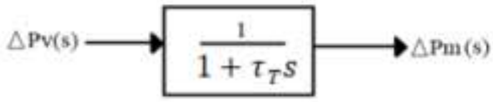


Figure 4: Prime mover block diagram

Governor model: The speed governor $\Delta P g$ is the difference between the reference set point Δ□□□f and the power(Δω/R)

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega \quad \text{……………..(12)}$$

R= the speed regulation constant

The speed of the governor Δ□□ is transformed into valve position Δ□v by the following equation,

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \quad \text{……………..(13)}$$

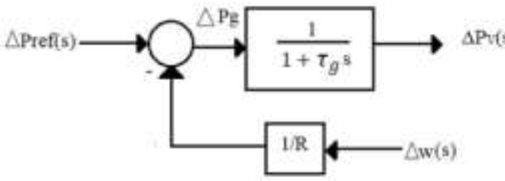


Figure 3.5 Block diagram of speed governing system

The total load frequency control block diagram is given by

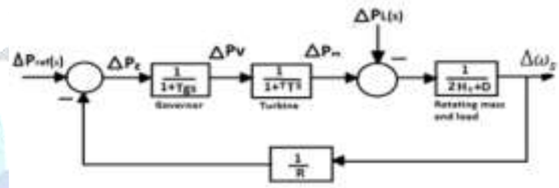
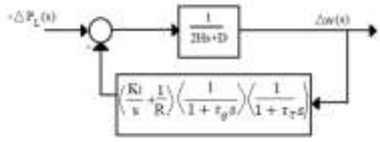


Figure 6: Block diagram of an isolated power system



Where

$-\Delta P_L =$ Input disturbance

$\Delta\omega =$ System Frequency deviation

ΔP_{ref} = Input Reference power

The block above relates the change in the frequency to the change of the load power, taking a constant set point.

The open loop transfer function is:

$$KG(s)H(s) = \frac{1}{R}\frac{1}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)} \quad \text{……….(14)}$$

The closed-loop transfer functions with respect to "$-\Delta P_L$":

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_{g1}s)(1+\tau_T s)}{(2H_2 s+D_2)(1+\tau_g s)(1+\tau_T s)+{}^1/_R} \quad \text{……….(15)}$$

From the control theory, it is known that the closed loop is more valuable. It reduces the sensitivity and effect of disturbances to maintain stability.

The system total time response is composed of two responses is

1. Transient response

2. Steady state response

The transient response: It isthe response of a system as a function of time, i.e. the time in which the system goes from initial state to the final stateandit is an important characteristic of the system.

The steady state response: Themanner by which the system behaves at infinite time while the performance characteristics of the system are to be specified from the transient response

The steady state value of a variable is given by the final value theorem, the value of that variable at t is infinity in the time domain or at s=0 at the s-domain, as shown below,

$$\lim_{t\to\infty}(t)=\lim_{s\to 0}T(s)$$

In order to calculate the value of the frequency change at the steady state condition of a system, we need to assume that the load change is a step function

And using the final value theorem we get:

$$\Delta\omega(s) = \lim_{s\to 0} s\Delta\omega(s) = (-\Delta P_L)\frac{1}{D+1/R}$$

In a system that uses multiple generators with different governor speeds

$R_1, R_2, R_3, \ldots\ldots$

The steady state frequency deviation becomes,

$$\Delta\omega_{ss} = (-\Delta P_L)\frac{1}{D+\frac{1}{R_1}+\frac{1}{R_2}+\cdots+\frac{1}{R_n}} \quad \ldots\ldots\ldots\ldots(16)$$

Automatic generation control: The primary functions of automatic generation control (AGC) are as follows, to regulate frequency for a specified nominal value due to change in load will result in frequency deviation and this is can done by adjusting the load reference set point through the primemover.

- To distribute the required change in generation among units areas to minimize operating costs.Maintain the interchange power between control areas at the scheduled values by adjusting the output of selected generators. This function is commonly known as Load Frequency Control [4].

There are two control actions performed by AGC:

- The first one called primary control or primary loop which adjusts the frequency deviation due to load change, it has some drawbacks such as the offset in the steady state error and it causes frequency drop of about 3 Hz from zero to full load.
- The second one is called the secondary loop which removes the offset in the steady state error frequency error and restores the system set point.

After adding the integral term in the secondary loop the block diagram is shown in figure 3.8

AGC in single area system:

The function of AGC is to restore frequency to specified nominal value. The reset action can be achieved by introducing the integral controller to act on the load reference setting to change the speed set-point, as shown in figure 3.7.

Multiarea power system:

Neighbouring power stations or companies are interconnected by one or more transmission lines called tie lines.

The objective is to buy or sell power with neighbouring systems whose operating costs make such transactions profitable. Also, even if no power is being transmitted over ties, if one system has sudden loss of a generating unit, the units through all the interconnection will experience a frequency change and can help in restoring frequency.

Power networks are distributed by tie lines into regular areas. Generators are required to maintain synchronism with the tie lines and connected areas [8].

Advantages of multi area power system are reliability, optimization of generation continuity of supply, cost/kW for larger generators is less.

Consider two areas are represented by an equivalent generating unit interconnected by a lossless tie line with reactance Xtie. Each area is represented by a voltage source behind an equivalent reactance as shown in figure 3.8

During normal operation, the real power transferred over the tie line is given by:

$$P_{12}=\frac{|E_1||E_2|}{X_{12}}\sin\delta_{12} \quad \ldots\ldots\ (18)$$

Where,

P_{12} = Power exchanged from area 1 towards area 2 via the tie line.

X_{12} = Reactance of the tie line.

δ1 and δ2 are the power angles of end voltages E1 and E2

δ12 = δ1 - δ2

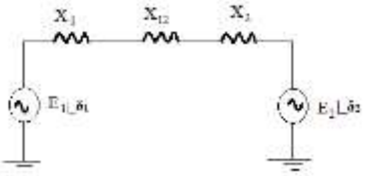


Figure 3.8: Equivalent network for a two area power system

For a small deviation in the tie-line power flow compared with the nominal value,

$$P_s=\frac{dP_{12}}{d\delta_{12}}|\delta_{120} = \frac{|E_1||E_2|}{X_{12}}\cos\Delta\delta_{12} \quad \ldots\ldots\ldots\ldots(20)$$

The tie line power flow equation can be written as,

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\Delta\delta_2)\Delta\delta_{12}$$

Assume that we have a two area system, consider a load change in area 1. Both areas will have a steady state frequency deviation. The block diagram representation of the two-area system with LFC containing only the primary loop in figure 9.

In case of normal operating state

$$\Delta\omega=\Delta\omega_1-\Delta\omega_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

$$\Delta P_{m1}-\Delta P_{12}-\Delta P_{L1}=\Delta\omega D_1$$

$$\Delta P_{m2}+\Delta P_{12}=\Delta\omega D_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(22)$$

The change in mechanical power is determined by,

$$\Delta P_{m1}= -\Delta\omega/R_1$$

$$\Delta P_{m2}= -\Delta\omega/R_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(23)$$

Substituting equation 6 in the equation 5, Change this equation with proper subscript

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1}+D_1\right)+\left(\frac{1}{R_2}+D_2\right)}$$

$$\Delta\omega = \frac{-\Delta P_{L1}}{B_1+B_2} \quad \ldots\ \ldots\ldots\ldots\ldots\ldots\ (24)$$

Where

$$B_2 = \frac{1}{R_2} + D_2$$

$$\Delta P_{12} = \frac{\left(\frac{1}{R_1} + D_1\right)\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right)\left(\frac{1}{R_2} + D_2\right)}$$

$$\Delta P_{12} = \frac{\Delta P_{L1}}{B_1 + B_2} B_2 \quad \text{………… (25)}$$

B1 and B2 are known as frequency bias factor

The change in tie-line power is given by,

$$\Delta P_{12} = \frac{\left(\frac{1}{R_1} + D_1\right)\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right)\left(\frac{1}{R_2} + D_2\right)}$$

$$\Delta P_{12} = \frac{\Delta P_{L1}}{B_1 + B_2} B_2 \text{………… ……………… (26)}$$

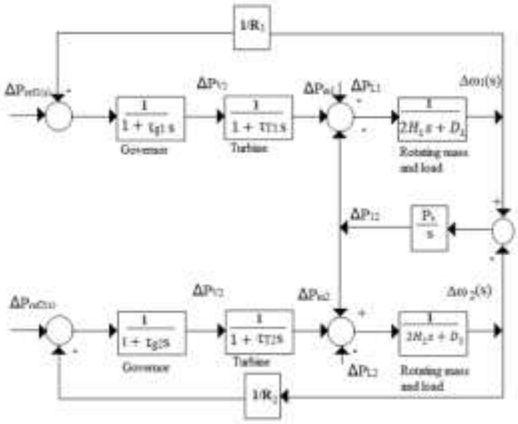


Figure 3.9: Two area system with only primary LFC loop

Area control error: A change of power in area 1 should be met by the increase in generation in both areas and a reduction in frequency. A simple control strategy in the normal state is:

- Keep the frequency approximately at the nominal value.
- Maintain the tie-line flow at about schedule.
- Each area should absorb it is own load change.

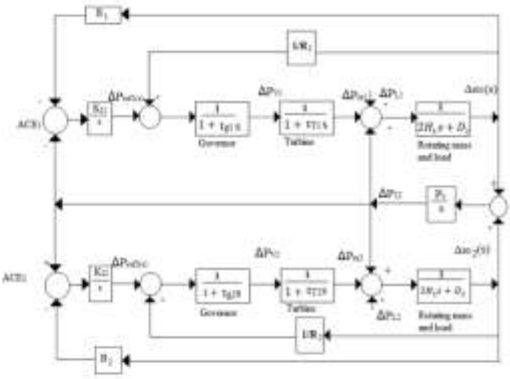


Figure 10: AGC block diagram for a two-area system

In a two-area system each area tends to reduce it is area control error (ACE) to zero, the ACE is given by this equation,

$$\text{ACE}_{\text{i}} = \sum_{j=1}^{n} \Delta \text{P}_{\text{ij}} + k_i \Delta\omega \text{ ……………………………… (3.27)}$$

Where **Ki** is the area bias helps to find out any interchange values when any kind of a disturbance occures in between the neighboring areas. The suitable performance can be achieved when 'Ki' is selected is equal to the frequency bias factor of that area.

The gain constant considered in integrator for the integrator considered to be small since to must be chosen small enough so as not to cause the area goes into chase mode. The block diagram of a simple AGC for a two area system as shown in figure 10.

III. Simulation procedure

Simulation procedure to build a model for single area using only primary loop:

The single area usually consists of the governor, turbine and generator and load. The step function usually denotes change in load. The primary control makes possible to increase or decrease in power generation to match the load. The primary and secondary control is a load frequency control which manages the load side management.

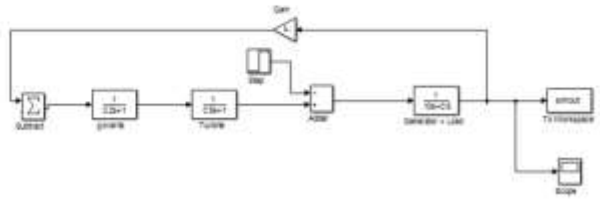


Figure 11: Single area with primary loop

Model for single area using primary and secondary loop: There is no tie line is connected to a single area system and only the function of AGC will manage to bring the frequency to the nominal value. This can be achieved by connecting an integral controller to change the load reference setting and changes in the speed set point. The integral controller forces the steady state speed deviation is zero. The ALFC with the integral controller is shown in the figure 12.

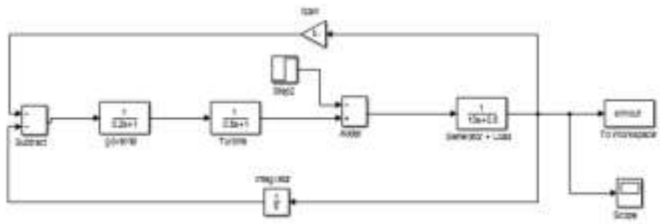


Figure 12: Single area with primary and secondary loop with unity gain

The gain Ki of the integral controller needs to be adjusted for satisfactory response in terms of overshoot, settling time, etc.

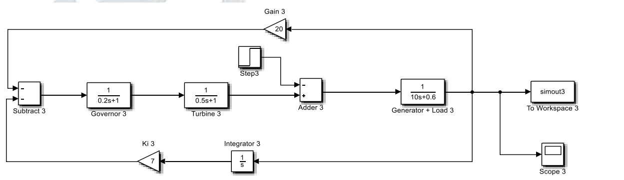


Figure 13: Single area with primary and secondary loop with gain 'Ki'

Models with different controllers: The models are build with different controllers to achieve the performance of steady state operation are Integral Controller, Proportional Integral Controller, Proportional Integral Derivative Controller.

The model with integral controller:

An integral controller can eliminate the steady state error that occurs with a proportional controller. Ki is integral constant, assume to be constant since incessant change in the control action. This controller helps in reducing the error to zero and eliminate the oscillatory performance problems which produced by the use of proportional controller. As the error move toward zero and causes in reduction in the magnitude of the integral constant. This result make sure smaller fluctuations in the power in the system.

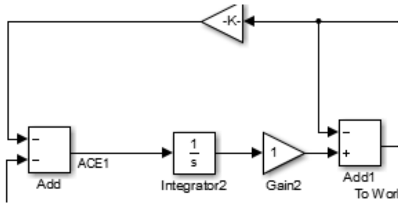


Figure 14: Integral controller interfaced with single area with primary and secondary loop with gain 'Ki'

It produces very slow response, and the system is still marginally stable.

The model proportional integral controller(pi) with primary and secondary loop system: The proportional integral(PI) controller are generally used in secondary loop control in the automatic generation controller(AGC) which results decrease in steady state error and improves the transient response of the power system frequency.

$$G(s)=K_p e(t)+K_i \int_0^t e(t)$$

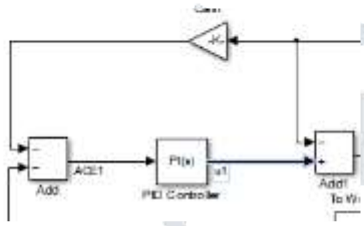


Figure 15: Proportional integral controller interfaced with single area with primary and secondary loop with gain 'Ki'

The first system steady state error tends to zero but after a long time that is a slow response with a very high overshoot and non-minimum phase behavior.

Model proportional integral derivative controller with two area system:

The PID controller interfaced with all other components used for automatic frequency control.

- With use of proportional controller helps to maintain the balanced power between generation and consumer load which results in reduced rise time and oscillatory performance.
- With use of integral controller helps in restoration of system frequency to nominal value with reduced the steady state error almost to zero.
- With use of derivative controller helps in limiting system overshoot as and when load fluctuates. It affords suitable damping which results in better transient performance with stability.

  The equation obtained by interfacing PID controller to the system is

The PID controller progress the transient response with decreases the amplitude but eventually arrive at necessary value with stedy state. The block diagram of proportional integrative derivative (PID) controller is shown in the figure 16.

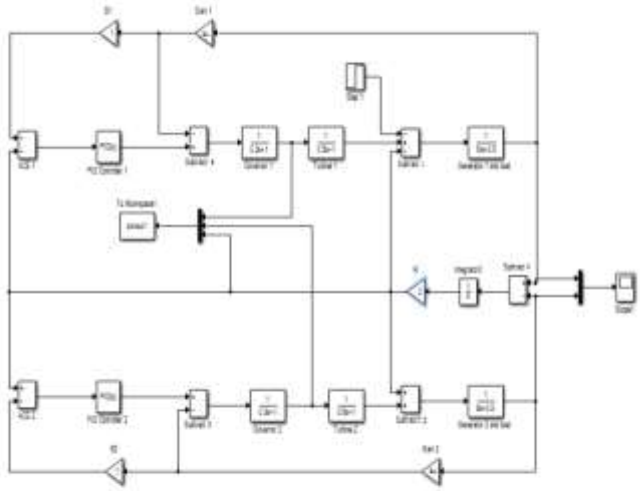


Figure 16: Proportional integral controller interfaced with two area system

By simulating through PID controller interfacing with two area system represents less ripple in the performace characteristic. The system reaches equilibrium faster than in isolated area AGC system with steady state error is to be minimized.

PRIMARY LOOP CONTROLLER WITH SINGLE AREA SYSTEM Change in load in a single area system with only primary loop controller, the response of frequency deviation with respect to time is as shown in the figure 17

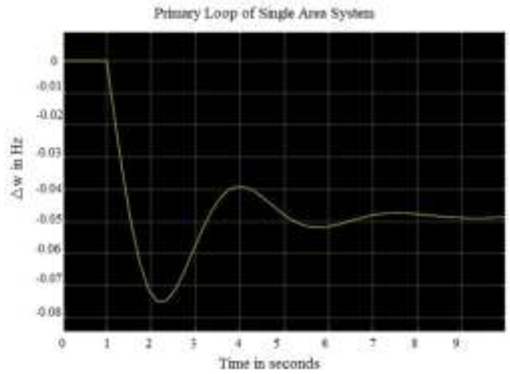


Figure 17: Frequency deviation Δw of a single area model with only primary loop control

From the output curve shows that for the variation of load with the decrease in frequency. The frequency deviation reaches steady state value at almost 0.048 Hz in the negative side that means with the decrease frequency.

Primary and secondary loop controller with single area model:

An integral loop controller is introduced with primary loop controller to remove the offset in the steady state error to zero.

A change in load in a single area system with primary loop controller and an integral loop controller the response of frequency deviation with respect to time, the resulted response is as shown in the figure 18.

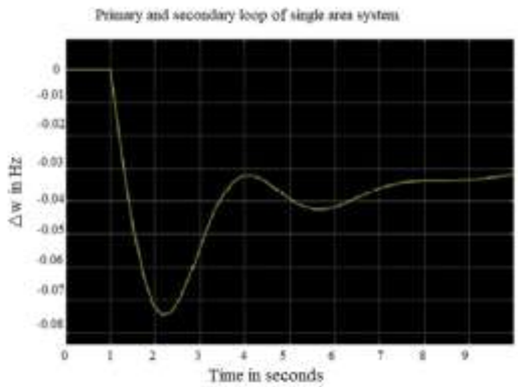


Figure 18: Frequency deviation Δw of single area with primary and secondary loop

After adding the integral controller with primary controller the response was even better than with only primary loop controller and closer to zero steady state and is almost 0.03 Hz.

Primary and secondary loop controller with single area model with gain

A gain was added to the integral controller that improves the response with steady state reaching to a value of 0.002 Hz of frequency deviation.

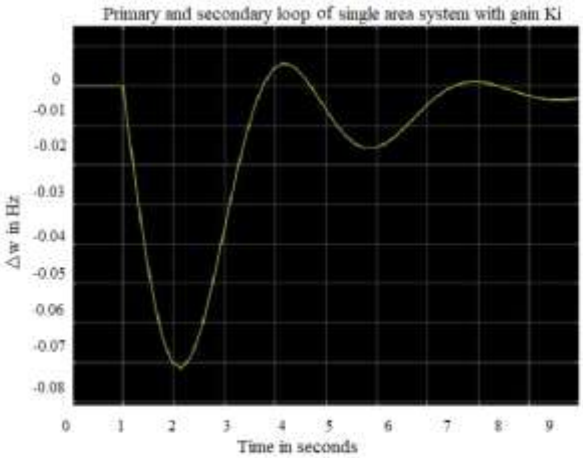


Figure 19 Frequency deviation $\Delta \boldsymbol{w}$ of single area with primary and secondary loop with gain

Integral controller interconnected with two area system:

The output response is observed in case of two area system interconnected with integral control. For a step response change in the load 1 of the two area system with automatic generation control (AGC) which is represented by the following response of the frequency deviation of Δw1 and Δw2 is as shown in the figure 20.

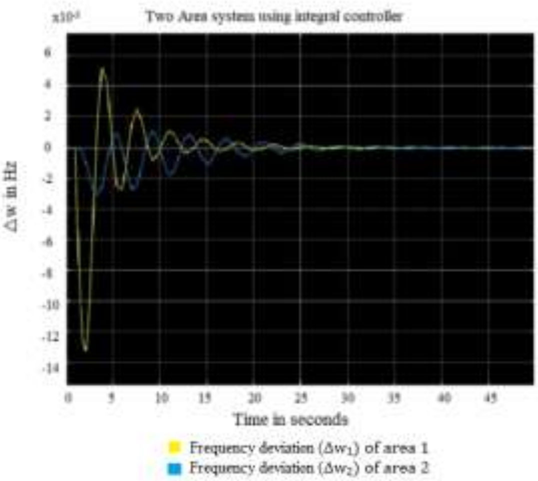


Figure 20: Frequency deviation of Δw_1 and Δw_2 of a two area system with AGC for a step change in load

For a step change in load in the area 1, the frequency deviations of Δw1 have more fluctuation than in the area 2. In the area 2 have more fast settling with AGC.

IV. Conclusions

The AGC is built to maintain the frequency of the power system constant (within a specified range of deviation at least). The first single area's AGC is proved to be working well and giving a good response. An acceptable steady state error is given by the primary loop only in response to a disturbance, with an acceptable offset. When the secondary loop is added, the response has been improved and the steady state error offset was reduced. An even better response was obtained with adding an integral $Ki = 7$, the error offset has almost been removed within 10 seconds. i.e the deviation is zero. In a two area interconnected power system's AGC, the ACE is used as the control signal that actuates the system to respond to a change in the tie line power When a conventional integral is used, the deviation recovers to exactly zero error within a range of 32 seconds. When a conventional PID is used, the deviation recovers to exactly zero error within a range of 18 seconds.

ACKNOWLEDGMENT

This research paper is made possible through the help and support of everyone from Central Power Research Institute, Bangalore and ACIT, Bangalore. Especially, dedicate my acknowledgment of gratitude toward supervisors and contributors.

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