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Study of Load Frequency Control in an Interconnected System Using Conventional and Fuzzy Logic Controller

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Abstract: ***The load variation on a power system results in frequency drift from its nominal value. For providing reliable and good quality electrical power, it is necessary to minimize the frequency fluctuations. This is achieved by maintaining a balance between demand and supply of the power in real time, called Automatic generation control (AGC). In this paper, the dynamic response of the load frequency control is studied using MATLAB Simulink software. The performance of the PI controller and Fuzzy Logic controller is compared on single area and two area system. The results obtained show that the Fuzzy logic controller gives better performance than the conventional PI method.***

Keywords: AGC, Tie-line power, ACE, single area, two area, fuzzy logic

1. Introduction

The load frequency control is very important for the right operation of an interconnected power system. It requires maintenance of a balance between the instantaneous active power produced and consumed. If the production of the electric power is larger than consumption, the frequency increases and vice versa. Hence, Load Frequency Control is used to maintain the system frequency at nominal value for supplying good quality power to the consumers. The load demand keeps on increasing and decreasing during the steady state operation of power system. Irrespective of the load change, the tie line flow should be maintained at an even value. This requires the manipulation of the operation of valves of the governor with a suitable control strategy so that constant speed can be maintained, and the real power output of the generators be controlled. However, the constant speed will not be the set point and there will be an offset. Hence, an integrator is added, which automatically adjusts the generation to restore the frequency to its nominal value. Thus, the control of the real power output of electric generators in this way is termed as “Automatic Generation Control (AGC)”. AGC is basically used to divide the loads among the system, such as to achieve maximum economy and accurate control of the tie-line power interchange while maintaining a reasonably uniform frequency during normal period [1].

The frequency control in an interconnected system is accomplished through two automatic controls: primary control and secondary control. The main objective of primary control is to stabilise the system frequency at a stationary value following a disturbance, and to maintain the tie-line power between control areas at the scheduled values by adjusting the output of some generators. Secondary control is basically used for automatic restoration of the frequency and the power exchanged between the different areas of the interconnected systems, at their scheduled values (i.e. $\Delta f = 0$, $\Delta P_i = 0$), taking into account the control program. Hence, AGC has gained importance with the growth of interconnected systems. A number of control strategies exist to achieve better performance. Due to non-linearity of power system, system parameters are linearised around an operating point. The most widely used is the PI controller. The disadvantage of PI controller is that it takes more time and gives large frequency deviation. Also, their performance deteriorates with the increase in the complexity of the system. Hence, Fuzzy logic controller has received increasing attention in power system stabilization problem in recent years.

2. Theory of Load Frequency Control

2.1 Frequency Response in Primary Control

The load on a power system consists of a variety of electrical devices. Some are sensitive to frequency changes and some are not. The sensitivity depends on the composite of the speed-load characteristics of all the devices. The speed-load characteristics of a composite load is given by

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{1}$$

Where,
ΔP_L = non frequency sensitive load change
$D\Delta\omega$ = frequency sensitive load change
D = percent change in load divided by percent change in frequency (Damping factor).

When the system frequency drifts from nominal value (50Hz), the frequency sensitive components in the power system react to this change and the effective load system changes. This process is called load damping. Also, when the generator electrical load is suddenly increased, the turbine speed and hence the generator frequency begins to fall. The change in speed is sensed by governor and it adjusts the turbine input valve to change the mechanical power output so as to bring the speed to a new steady state. This can be done with the help of governed speed droop R, which is actually the feedback loop gain in the governor. The speed droop is defined as

$$R = \frac{\Delta\omega}{\Delta P}\ \text{pu} \tag{2}$$

Where,
$\Delta\omega$ = speed deviation
ΔP = output power [2]

A. Percent speed regulation R

As the load is increased, the governors are designed to permit the speed to drop for stable operation. Due to mismatch in power, speed changes. The governor system senses this change and adjusts the valve opening which in turn changes power output. This action stops once the power mismatch becomes zero. But the speed error remains[3]. The steady state characteristics of governor is shown in Figure1.

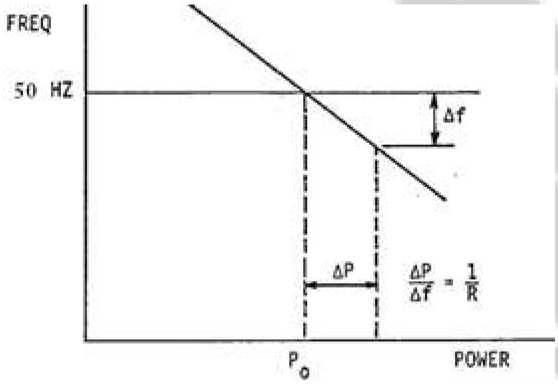


Figure 1: Ideal steady state characteristics of governor with speed droop

The slope of the curve represents the speed regulation R. It is defined as the ratio of the change in frequency from no load to full load, to change in output power (valve position).

It can be expressed in percent as:
Percent R = percent speed or frequency change/percent power output change*100

$$=\frac{\omega_{nl}-\omega_{fl}}{\omega_0} * 100 \quad (3)$$

Where
ω_{nl}= steady state speed at no load
ω_{fl}= steady state speed at full load
ω_0 = nominal or rated speed

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega \quad (4)$$

These two responses: load damping and governor response, help the system interconnection to become more stable. These responses are mathematically modelled as D and R respectively and are combined into one frequency response characteristic.

$$B = \sum\left(\frac{1}{R} + D\right) \quad (5)$$

B. AGC

The objectives of AGC are as follows:
(i) To hold system frequency at or very close to the nominal value.
(ii) To maintain correct value of interchange power between control areas
(iii) To maintain each units generation at the most economic value [4].

If the load on the system is increased suddenly, the turbine speed drops before the governor can adjust the steam input for the new load. One way to restore the speed or frequency to its nominal value is to add an integrator. The integrator unit monitors the average error over a period of time and overcomes the offset. This scheme is known as automatic generation control (AGC).

C. Area Control Error

The conventional LFC is composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error Δf and feeds this error signal into the integrator. The input to the integrator is called the Area Control Error (ACE). The ACE is defined as the change in area frequency, which forces the steady-state frequency error to zero, when used in an integral-control loop[5]. The control error for each area consists of a linear combination of frequency and tie-line error. Area Control Error is defined by

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i\Delta\omega \quad (6)$$

Where ,
i = control area for which ACE is being measured
ΔP_{ij} = power interchange in areas i and j
K_i = control area frequency bias coefficient
$\Delta\omega$ = deviation in frequency

ACE is an error signal consisting of two terms. First term represents the tie-line error in the scheduled power flows. The second term is inter-area assistance in generation from control area to prevent large deviation of interconnection frequency. ACE represents the generation versus load mismatch for the control area and indicates when total generation must be raised or lowered[6]. The ACE signal should ideally be kept from becoming too large and should not be allowed to ‘drift’.

D. Tie line bias control

Extensive power systems are composed of control areas which represents coherent groups of generators. The tie lines are used to exchange energy between these areas and also to provide inter-area support in case of any abnormal condition. Load changes in an area and abnormal conditions, lead to mismatch in required power interchanges between areas [7]. As a result of load changes in system and interconnection between generation areas, large tie-line power fluctuations and frequency oscillations take place[8]. Tie-line bias control is a control philosophy which has been developed for load frequency control in a power system. The concept allows each control area to operate its generation and to fulfil areas control obligation, independently by monitoring and control the area’s ACE.

3. AGC in a Single Area

In an isolated power system, maintenance of power interchange is not an issue. With the primary LFC loop, a change in the system load will result in a steady state frequency deviation, depending on the governor speed regulation. To make the frequency deviation zero, we must provide a reset action. This is done by introducing an integral controller which acts on the load reference setting and changes the speed set point. The integral controller increases the system type by 1 which makes the final frequency deviation to zero. The integral controller gain must be adjusted for a satisfactory transient response.

The schematic diagram of AGC is shown below. It consists of valve control mechanism, turbine, generator and governor. The change in frequency is compared with a reference speed. A valve controller is used to regulate the steam valve thereby increasing the power output from the generators which results in matching of generation and demand. As a result the frequency is restored to the original value [9]. Based on this, the network can be classified as single area or two area systems as discussed below.

The combined block diagram of single area system with, governor prime mover – rotating Mass/load model is shown in Figure2.

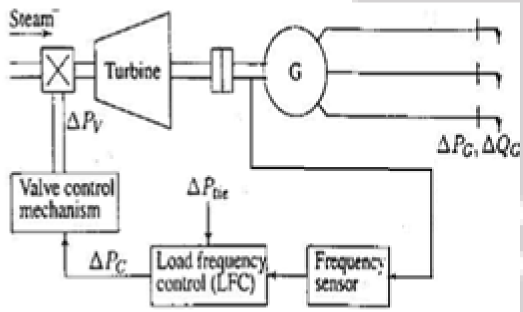


Figure 2: Schematic diagram of an LFC of a synchronous generator [10]

A. Model of AGC of a single area (with secondary loop)

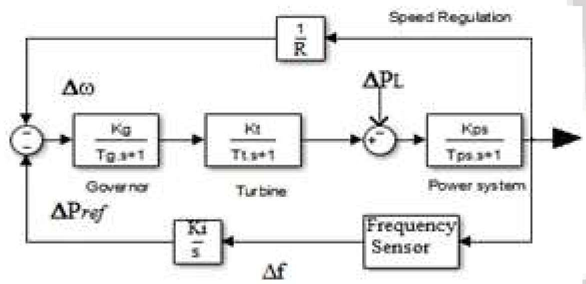


Figure 3: Block diagram of single area (with PI controller) [11]

The restoration of the frequency to the nominal value requires an additional control loop called the supplementary loop. This loop consists of an integral controller which makes the frequency deviation zero. The ALFC with the supplementary loop is generally called the AGC as shown in Figure4. In order to make Δω=0, the speed changer setting is changed in response to Δω(s) through an integrator. Thus the integral action results in automatic adjustment of ΔP_{ref} so as to make Δω=0.The transfer function with the integral group is given below

$$\frac{\Delta\omega(s)}{-\Delta PL(s)} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_T s)(1+\tau_g s)+K1+s/R} \tag{7}$$

B. Two Area system (with PI controller)

The block diagram of a simple AGC for a two-area system is shown in Figure 4.

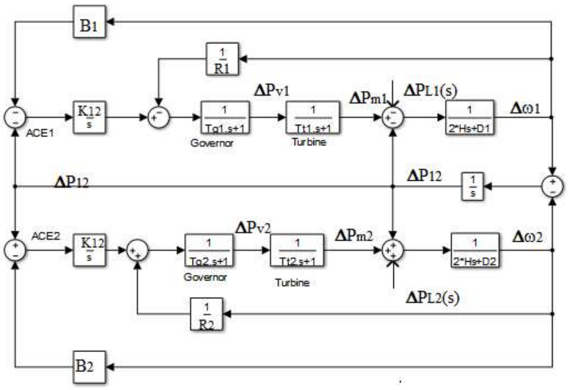


Figure 4: Two Area System (with secondary Loop)

ACEs are used as actuating signals to activate changes in the reference power set points, and when steady-state is reached, $\Delta P_{12} and\ \Delta\omega$ will be zero. Conventional LFC is based upon tie-line bias control, where each area tends to reduce the area control error (ACE) to zero. The control error for each area tends to consists of linear combination of frequency and tie-line error.

$$ACE_i = \sum n_j = \Delta P_{ij} + K_i \Delta\omega \tag{8}$$

4. Fuzzy Controller

Artificial intelligence based gain scheduling is a technique used commonly in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical formula[12]. Fuzzy Logic Controller (FLC) is more useful than conventional controller and helps in achieving fast and good dynamic response in load frequency problems. The fuzzy logic controller designed for the system analysis is shown in Figure5.

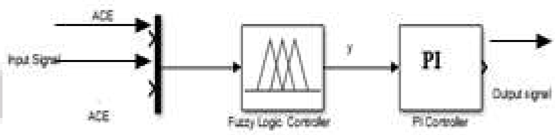


Figure 5: Fuzzy Logic Controller

A fuzzy logic controller consist of three sections namely: fuzzifier, rule base and defuzzifier[13]. In this paper input to the fuzzy controller is taken as area control error (ACE) and change in error (ΔACE). The block diagram of fuzzy logic controller is shown in Figure 6.

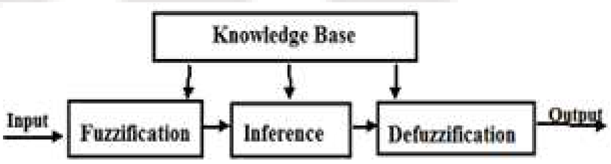


Figure 6: Block Diagram [14]

Membership Functions (MF) specifies the degree to which a given input belongs to set. Triangular membership functions are used for both the inputs and output. We have used five membership functions namely, Negative Big (M), Negative

Small (N), Zero (Z), Positive Small (P), and Positive Big (Q). There are 25 rules used in this work which are given in Table I.

Table 1: Fuzzy Rules

	ACE					
$\dot{}$		M	N	O	P	Q
A	M	N	N	N	N	O
	N	N	N	N	O	P
C	O	N	O	O	P	P
	P	O	O	P	P	P
E	Q	O	P	P	Q	Q

Finally, Defuzzification is done which is the process of converting inferred fuzzy control actions into a crisp control action. The method employed here is the centre of area method.

5. Simulation Results

The models of single area and two areas are simulated in SIMULINK.

A. Single area system (with PI controller)

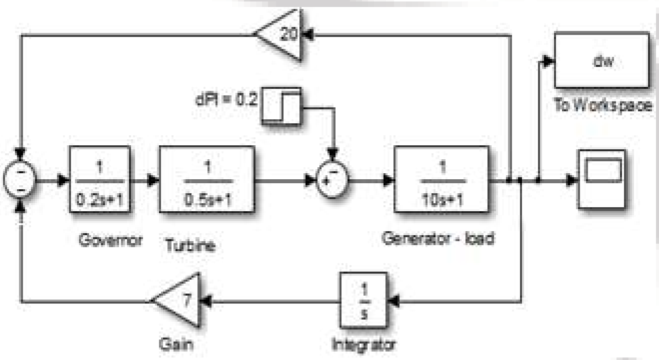


Figure 7: Single area system with PI controller

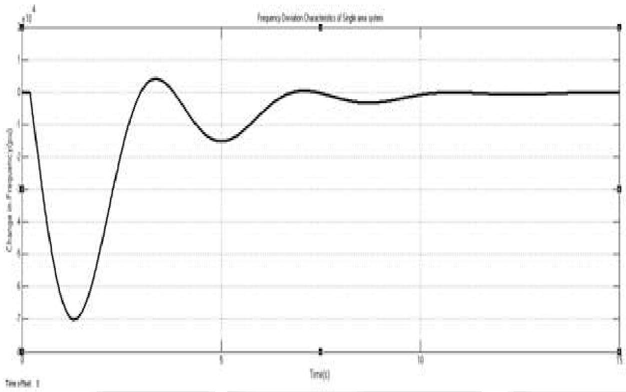


Figure 8: Simulation result of Single area system with PI controller

Figure 7 shows the single area system with a secondary loop where an integral controller with a gain is adopted to adjust the speed reference signal so that $\Delta\omega(s)$ returns to zero.

Figure 8 shows the simulation results of single area with the secondary loop and it can be seen that the frequency drift has been made zero due to the integral loop.

B. Two area system (with PI controller)

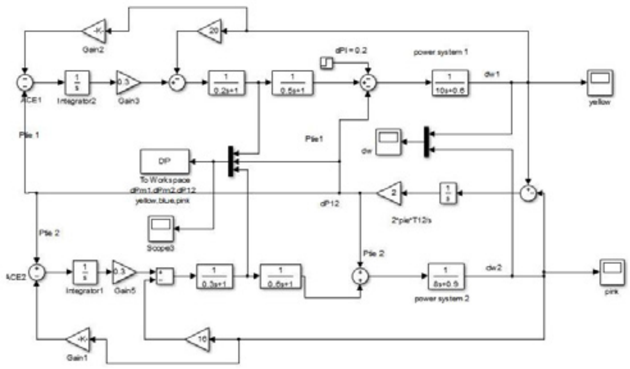
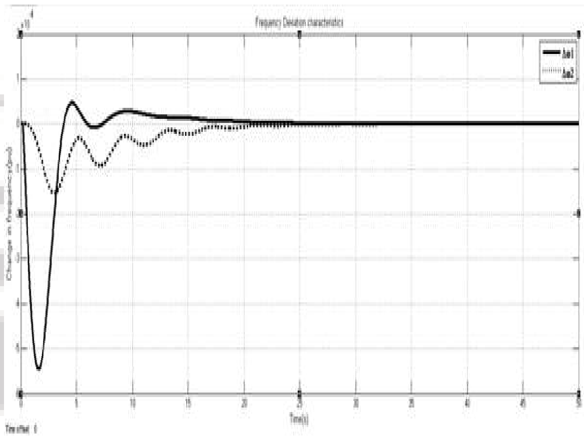
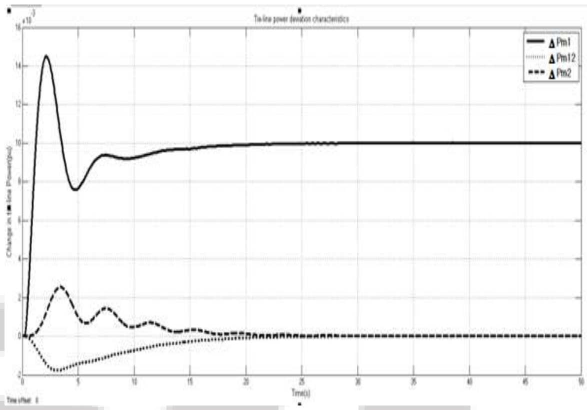


Figure 9: Two area system with PI controller



(a) Change in frequency of area 1 and area 2



(b) Change in tie-line power

Figure 10: Simulation result of two area system with secondary loop

As seen from Figure 10 the secondary loop causes the return of frequency drifts to zero.

C. Single area system with fuzzy PI

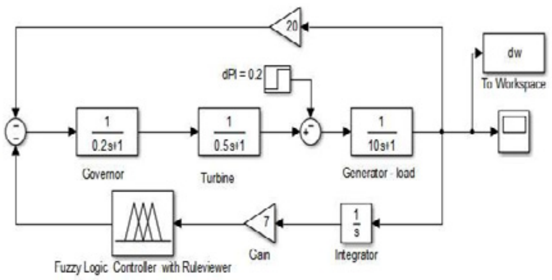


Figure 11: Single area system with fuzzy PI

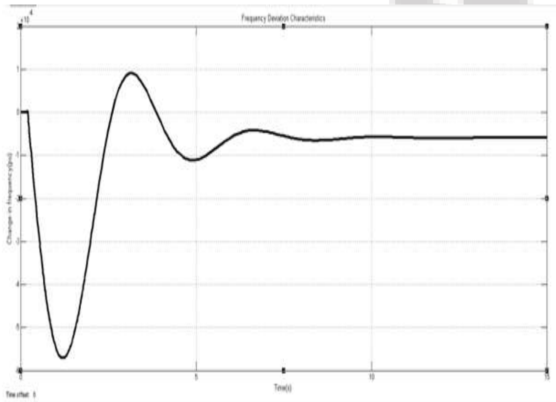


Figure 12: Simulation result of Single area system with fuzzy PI

As seen from Figure 12, the output frequency response has become more stable and does not contain high amplitude oscillations. Also, the settling time has improved considerably.

D. Single area system with fuzzy

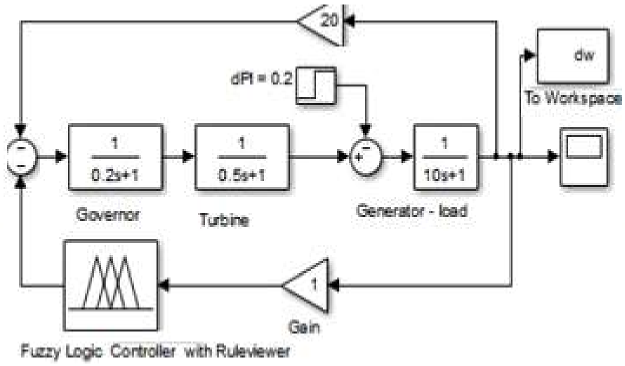


Figure 13: Single area system with fuzzy

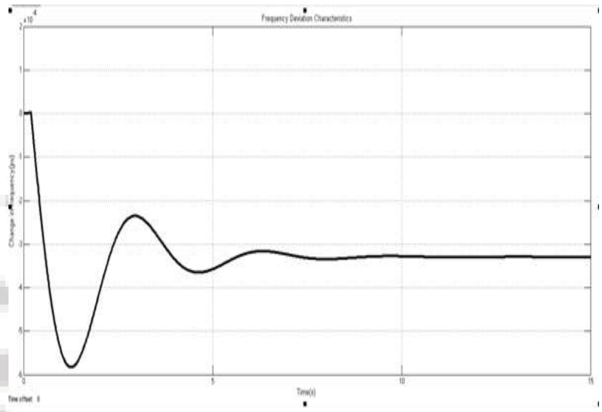


Figure 14: Simulation result of Single area system with fuzzy

E. Two area system with fuzzy PI

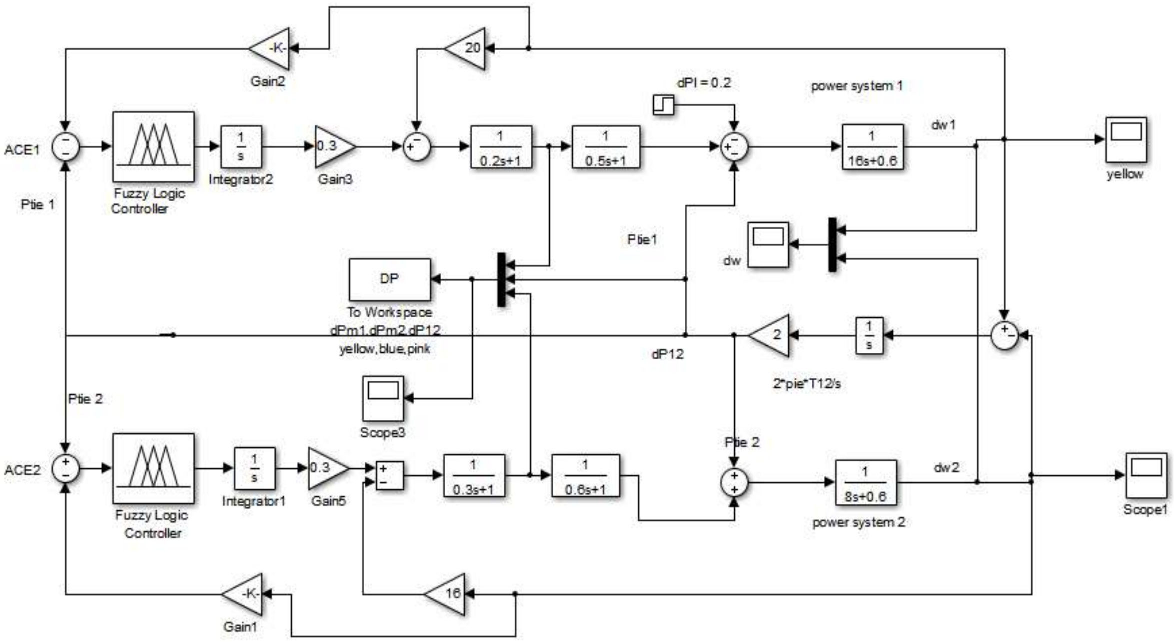
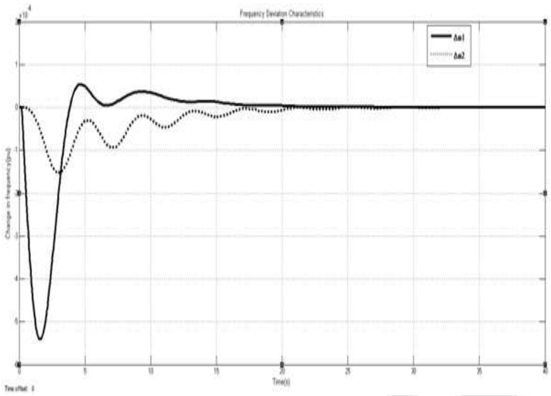
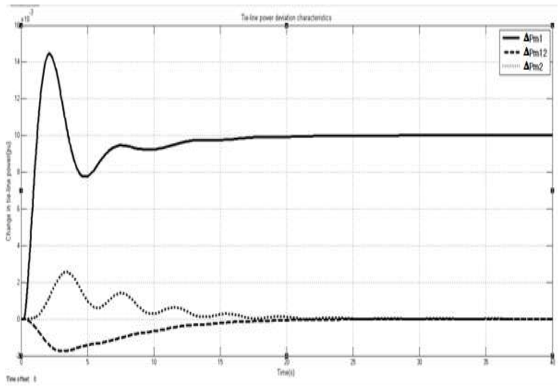


Figure 15: Two area system with fuzzy PI



(a). Change in frequency of area 1 and area 2



(b) Change in tie-line power

Figure 16: Simulation result of two area system with fuzzy PI

F. Two area system with fuzzy

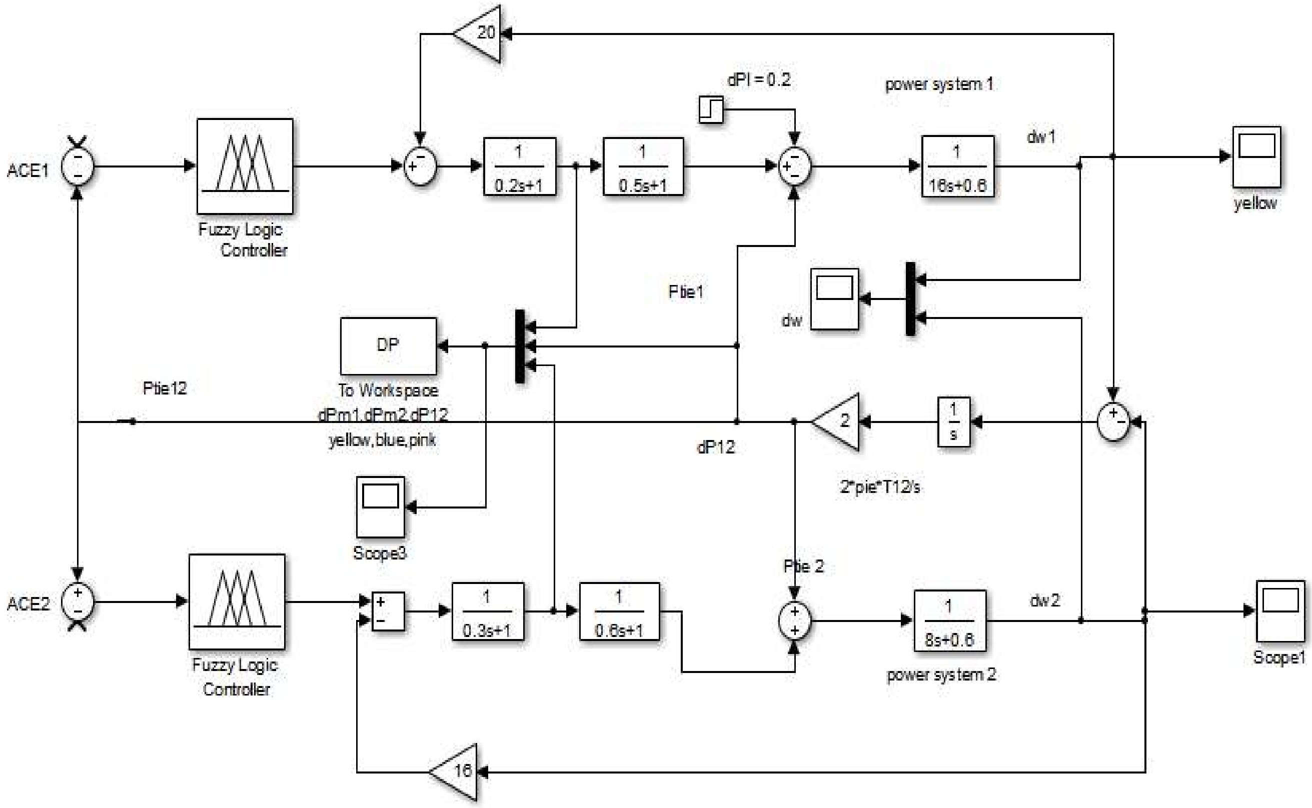
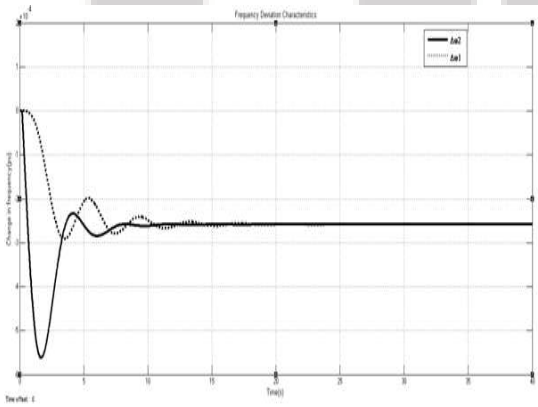
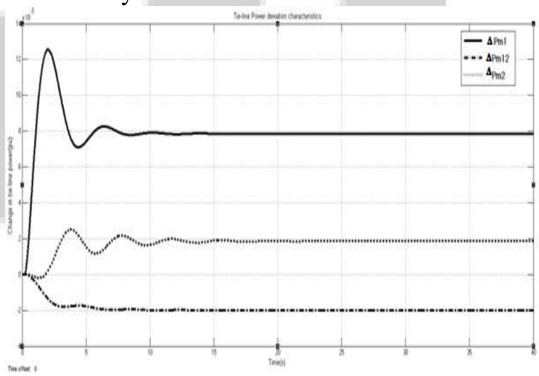


Figure 17: Two area system with fuzzy



(a) Change in frequency of area 1 and area 2



(b) Change in tie-line power

Figure 18: Simulation result of two area system with fuzzy

6. Conclusion

A simulation study of single and two area system with automatic generation and control is carried out with models developed in SIMULINK and results are analyzed. The operation of single area and two area systems with and without secondary loops are depicted through simulation models. The advantage of interconnection is can be understood by comparing the results of single and two area systems. It can be seen that the oscillations due to change in load in any area is damped down quickly because of tie line power flow. It can also be observed that the dynamic response is mainly governed by the secondary loop and hence its design criteria are extremely vital for efficient implementation. Also, the dynamic performance of conventional PI controller and Fuzzy logic controller is compared on single area and two area system. The output of FLC is compared with Conventional controller and is found superior in terms of peak overshoot, number of oscillations and settling time.

Appendix

Data for interconnected system:

$R_1 = 0.05$ $R_2 = 0.0625$

$B_1 = 20.6$ $B_2 = 16.9$

$H_1 = 5$ $H_2 = 4$

$D_1 = 0.6$ $D_2 = 0.9$

$T_{g1} = 0.2$ $T_{g2} = 0.3$

$T_{t1} = 0.5$ $T_{t2} = 0.6$

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