Load frequency control of two-area interconnected power system using fuzzy logic control approach

Iydin Javadi Marand , Saeed Barghandan*
Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran
Email:saeed_barghandan@yahoo.com

Abstract

Power systems are composed of power units that are constantly connected to each other and the electric power flux is constantly moving between them. All systems must be implemented in such a way that not only under normal conditions but also unwanted inputs or disturbances, are applied. It also remains stable or returns to a stable name at the earliest possible time. The fundamental factors of stability control in a power system are the frequency of different areas and the power flux between different areas. Now that the main goals of controlling stability in a system of power are expressed, they must be maintained by designing and implementing controllers of these indicators in their optimal range. In this study, the frequency control function is initially expressed. Subsequently, the design of several additional controller parameters is based on this algorithm and ultimately, by applying additional controllers designed on the simulated power system, the results of the effect of each of them on the faster loss of frequency oscillations will be discussed.

Keywords: Load frequency control; fuzzy logic; two area power system

1- Introduction

All systems should be implemented in a way that not only in ordinary conditions, but also after the implementation of unwanted inputs or disturbances they should be consistent or should return to the consistent conditions in the most rapid possible time. Power systems are not exceptional and their consistency is highly important. This is due to the fact that the construction and exploitation of power systems are more costly and if an unwanted input can lead the power system to inconsistency, this range of inconsistency will increase during the pass of time and it can even finally lead to collapse the power network and this can cause a great deal of cost.

The important question posed here is that how we define the consistency in a power system and which factors could be investigated? To respond this question we should consider that the biggest part of the electric power produced in a power system is supplied through a great deal of synchronic generators. The frequency of output electric power of a synchronic generator is equal to the input mechanical speed frequency multiplied by a fixed amount of $(\frac{p}{2}=)$.

Now if a synchronic generator is forced to produce electric power with a certain frequency (network frequency), when the frequency of power system which is equal with output electric power frequency is deviated while the input mechanical speed to the rotor shaft is being fixed, there would be differences of speed between cycling magnetic fields resulted from the stator and rotor within the current aerial distance. If such a difference is low or it is obviated rapidly, the synchronic generator above will be in a consistent working mode. But if such a difference becomes higher than a certain amount, the cycling magnetic field resulted from the rotor would not be bearable and it will stay in a couple state with the cycling magnetic field caused by the stator. Here, the synchronic generator would not be able to supply and inject electric power into the power system and it could not deliver any power in its output. Following this incident, when the output electric power- the same as the resistance power- will be removed by the generator and since the input power is fixed, the rotor shaft cycling speed will suddenly increase and this cab create fractures on rotor shaft and even the whole synchronic generator may be destroyed.

Regarding what was pointed above we can consider the basic factors for controlling the consistency in a power system as the frequency in different areas and the amount of fluctuations of the power between the different areas. Now that we talked about the major goals in controlling consistency in a power system, we should keep these indexes with optimal amounts through designing and implementing the controllers. One of the mechanisms proposed regarding this issue was automatic generation control (AGC). AGC follows three major goals:

1- Preserving the system frequency within the boundary of nominal amount or an amount close to it

2- Holding transferring power between the areas in an optimal amount

3- Putting the production of each unit within the economical appropriate boundary

The most principal goal followed by AGC is to regulate the frequency within the nominal boundary and to preserve the transferring power between the areas through the implementation of changes in output power of the manufacturing units. This process is the same as Load Frequency Control (LFC). When the load increases, the turbine speed will be lowered and up to the time the governor can harmonize the input steam with the new load, such a reduction of speed can lead the power system into inconsistency. A way to retrieve the nominal amounts of the speed or frequency is to add PI or PID controllers in the form of a complementary controlling process into the system. PI/PID controller above reveals the average amount of the error and will eliminate the fluctuations. On the other hand, since the load changes in power systems are permanent, the production control will be put into automatic mode to retrieve the nominal amounts of the frequencies readily.

The dependent frequency will have the real power of (P) and any changes in the real power will affect the frequency of power system. An optimal power system should be able to bear the abrupt load changes and to preserve the voltage and frequency within the acceptable boundary. Since the flow of real power and the reactive power in a power system are independent of each other, in most cases these two are discussed and investigated in isolation. As it can be observed below, in the studies carried out before on the real power in power systems, the flow of reactive power was not considered in the calculations. Since the real power (P) with the frequency (f) and reactive power (Q) do have a close relationship with voltage profile, and regarding the high importance of keeping the frequency and voltage profile in the power system within the optimal boundary, the control of real power and reactive power is certainly deemed important.

Considering the close relationship between the frequency and real power in a power system, if the equilibrium is violated in a small part of a power system, such inequality in power will result in lack of equilibrium in fixed frequency of the system and due to the sameness of the frequency within the whole system, this will be represented as a lack of equilibrium in frequency within the whole power system. The most principal and basic speed control in any production unit is done through the governor. In other words, governor is responsible for controlling the primary frequency and the complementary controlling process of the speed will be carried out by the other controllers added to the system. If the power system is formed by the connection of two or several independent areas, the power system is known as congregational power system. In congregational power systems, in addition to controlling the frequency in any area independently, the production power in each area should be programmed in a way that the power flow in connection lines between the areas should be controlled either and at least we should have electric power charge in these lines. The process above is known as load frequency control.

LFC has been a topical issue for more than three decades. On the other hand, power systems mainly are in big sizes and have nonlinear dynamics. Meanwhile, the things considered to resolve LFC problems are considered to be a power system of two or more areas in a linear format. These nonlinear behaviors of the power system and the problems arisen from the easy state and the linear feature have been explained in details in a reference like [1]. Also the effects resulted from GRCs on outputs both in permanent and contemporary time states were investigated in several studied such as [2]. If we notice many of studies carried out in the field such as [3], we can observe that controlling approaches utilized in resolving the LFC problems had been a centralized controlling approach. If we look deeply in the issue, we can observe that control systems method of 'centralized state' require the exchange of data from the control areas to all power system fields which are placed in very far distances regarding geographical discussions.

Also such a controlling state has lots of complicacy in calculations and storing all results of it would be very difficult. In this way, a concept of a controlling method based on decentralized control strategy emerged to respond LFC issue in the form of an efficient strategy. Therefore, many studies suggested utilizing decentralized control strategy to resolve load frequency control problem in permanent and isolated forms and some of them are mentioned in reference [3]. Also in reference [2] a sketch of controllable and observable power system with a decentralized control strategy has been proposed in which the controlling feedback loops are completely independent of each other. On the whole, we can divide power system control into 5 categories below:

1- Classic control method
2- Control method with a changing and adaptive structure
3- Resistant controller method
4- Smart control method
5- Digital state control method

Due to the complexity and multiple variable nature of the conditions in a power system, the classic state and inflexible designs of control systems can not be good representatives for responding load frequency control problem. This reason has led to the emerge of flexible control methods in a way that through the things carried out above on these controlling methods and the emerge of smart controlling methods such as controllers based on ANN, Fuzzy Logic, and GA, the novel control systems could be able to respond the LFC problem in big power systems.

Recently fuzzy logic has been applied in most parts of industry and engineering sciences. One of its functions is in control systems in power systems. 'great resistance' and 'reliability' of controllers based on fuzzy logic have led them to play an important role in resolving LFC problems. Unlike the traditional methods of control theory which were necessarily based on the mathematical model of fields under control, in fuzzy control method we try to apply controller directly based on orders of the operators and technicians who apply the control of the fields manually.

2- Experimental part

Modeling load frequency system

In this part first we considered the presuppositions and appropriate estimates of the individual generators that feed a area of local power distribution and then our investigation was over-generalized for several generators which were all residing in a single area and then the connection between different areas were examined.

Generator model

The equation for fluctuation of a synchronic machine regarding a small disturbance was as follows:

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \qquad (1)$$

Where, H is the fixed machine inertia in a power based on the system and ΔP_m and ΔP_e are the equipments of input mechanical power and output electric power of the generator, respectively. The power angle is represented based on electric radiant and ω_s is known as the angle speed based on electric radiant on second. Equation (1) is written as follows for the small deviations in speed:

$$\frac{d\Delta\omega}{dt} = \frac{\omega_s}{2H}(\Delta P_m - \Delta P_e) \qquad (2)$$

And be replacing the frequency instead of angle speed we have:

$$\frac{d\Delta f}{dt} = \frac{f_s}{2H}(\Delta P_m - \Delta P_e) \qquad (3)$$

Where, f_s is the nominal frequency of the system based on Hz. As we calculate Lap lass exchange in two directions of the equation above and arranging them, the block representation for the generator would be as follows:

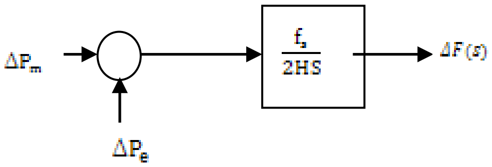


Fig.1. The block model of the generator

Load model

Load is a power system entailing a vast spectrum of electric tools used for resistance loads such as light and heat loads of independent from frequency electric power. The motor loads are sensitive to changes in frequency and the amount of their sensitivity depends on the composition of load characteristics and their speed. Considering the combined load speed feature of $D\Delta\omega$, the load changes are sensitive to the frequency and parameter D can be calculated regarding the following equation:

$$D = \frac{\partial P_e}{\partial f} \tag{4}$$

If we presuppose that P_e is changing linearly compared to the frequency, D is equal to the percentage of change in frequency. For example, if frequency is changed one percent, the load is changed 1.6 percent and in this case D will be equal to 1.6. If we add the load model to the block representation of the generator and delete the feed over branch, we can reach the following block representation:

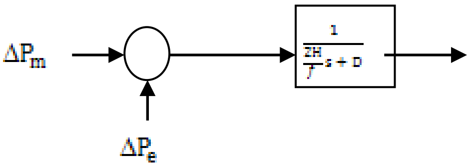


Fig.2.The block model of generator and load

Turbine model

The simplest model of the primary stimulant is the steam turbine model of pre heat which is a first order system with a fixed time of T_0 and it is shown as the following transfer equation:

$$\frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+T_0 s} \tag{5}$$

The fixed time T_0 is within the range of 0.3 to 2 s. The change equations of other turbines are very complicated. The block representation of a simple turbine is shown in the figure below:

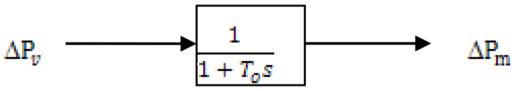


Fig.3. Turbine's block model

Speed governor model

The reduction of movement energy leads to reduce turbine speed and following that the generator frequency will be reduced. The speed change will be senses by the turbine's governor and it adjusts the input entry of the turbine in a way that the output mechanical power of the turbine will increase enough to reach a new permanent speed. To have a consistent performance, governors are designed in a way that as the load to the generator increases, it is let to lower the speed. The speed governor mechanism works as a comparison tool. Its input is ΔP_g time of the difference between the adjusted reference power of ΔR_{ref} and the power of $1/R\Delta f$.

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta f(s) \quad (6)$$

The order ΔP_g is changed into position change of the steam tap through the hydraulic reinforce. Considering a linear relationship and a fixed time amount of T_g for hydraulic reinforce, the following equation would be resulted:

$$\Delta P_v = \frac{1}{1+ST_g}\Delta P_g \quad (7)$$

The overall model of load frequency

Through the adjustment of the block representation of the figures 1 to 3 and the introduction of the parameters T_p and K_g we can reach the complete block representation of the load frequency control of a unit of isolate power system represented in the following figure.

$$K_p = \frac{1}{D} \quad (8)$$

$$T_p = \frac{2H}{f.D} \quad (9)$$

Two area power system model and system simulation

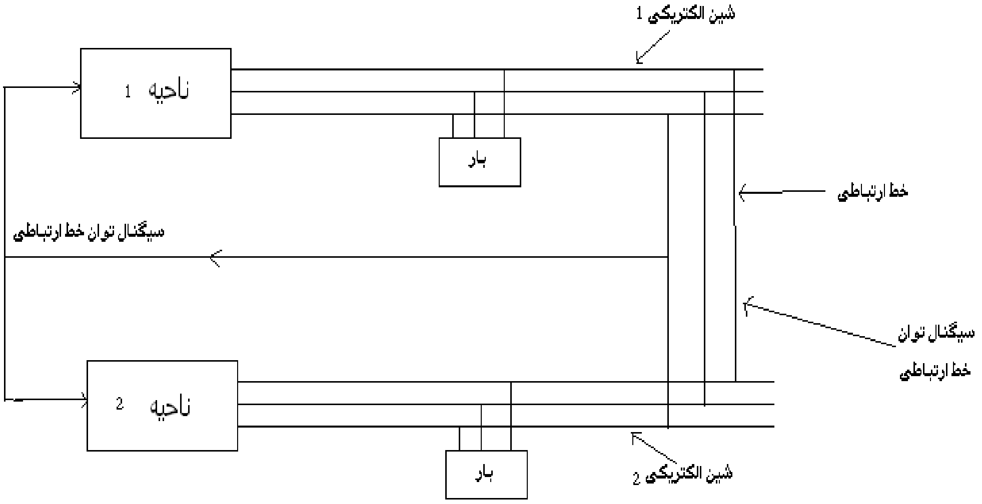


Fig.4. two area power system representation

We can start load control of a multiple area system with studying a two areas system. Consider two control areas 1 and 2 in figure 4 connected through a connection line without losses and with a reactance load of X_{tie}. Each area is explained as a voltage source and a counterpart reactance. During the natural performance, the real power exchanged through the connection line is as follows:

$$P_{12} = \frac{|E_1|.|E_2|}{X_{12}} \sin \delta_{12} \tag{10}$$

Where, $\delta_{12} = \delta_1 - \delta_2 X_{12} = X_1 + X_{tie} + X_2$

Thus for any small deviations, the transfer power would be somewhat close to the nominal amount as:

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}} \Delta\delta_{12} = T_{12} \Delta\delta_{120} \tag{11}$$

The quantity T_{12} is known as the curve slope of power angle in nominal working point of $\delta_{120} = \delta_{10} - \Delta\delta_{20}$ and it is called the congruence coefficient. Thus, we have:

$$T_{12} = \frac{dP_{12}}{d\delta_{12}} = \frac{|E_1|.|E_2|}{X_{12}} \cos \Delta\delta_{120} \tag{12}$$

Therefore, the line power of the connection will be calculated in the following form:

$$\Delta P_{12} = T_{12}(\Delta\delta_1 - \Delta\delta_2) \tag{13}$$

Through substitution of the changes of the angle with frequency changes and calculating the transformation from the two sides above, one can get:

$$\Delta P_{12} = \frac{2\pi T_{12}}{S} [\Delta F_1 - \Delta F_2] \tag{14}$$

Regarding that we have ignored the losses in connection line, $\Delta P_{12} = \Delta P_{21}$, or based on pu we have:

$$\Delta P_{12} S_1 = -\Delta P_{21} S_2 \tag{15}$$

Where, S_1 and S_2 are the nominal powers of areas 1 and 2 based on MVA. If the coefficient a_{12} is defined as the equations below, we would have:

$$\Delta P_{21} = a_{12} \Delta P_{12} \tag{16}$$

$$a_{12} = \frac{S_1}{S_2} \tag{17}$$

By entering the transfer power of (s) ΔP_{12} in block representation of area 1 we would have:

$$\Delta F_1 = \frac{K_{p1}}{1+ST_{p1}} [\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}] \tag{18}$$

And similarly for frequency change in area 2 we would have:

$$\Delta F_2 = \frac{K_{p2}}{1+ST_{p2}} [\Delta P_{m2} - \Delta P_{L2} - a_{12} \Delta P_{12}] \tag{19}$$

The current power appears as a result of the connection line in the form of load increase in a area and load decrease in another area. The power direction is defined through the difference between the angles, that is if $\Delta\delta_1 > \Delta\delta_2$, the direction of the power would be from area 1 to area 2. We should get feedback from resulted from changes in connection line power in addition to frequency changes and consider the combination of the two lines as the input of the controller. This linear combination is known as area control error or ACE and it is defined according to the equation below in each area.

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1 \tag{20}$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \tag{21}$$

Therefore, if we use the integral controller, we would have:

$$\Delta P_{ref1} = -K_{i1} \int ACE_1 dt \tag{22}$$

$$\Delta P_{ref2} = -K_{i2} \int ACE_2 dt \tag{23}$$

B is called the area frequency bias coefficient and usually its amounts are equal to β or the frequency response characteristic of each area.

3- Results and discussion

By using the amounts below for the parameters of the two areas in the power system and considering the two inputs for load changes in these two areas, this system could be simulated in a simulated environment of MATLAB software.

Table 1- The amounts of parameters in two areas of the system

Parameters	Area 1	Area 2
Fixed integral interest	$K_{i1} = 0.5$	$K_{i2} = 0.5$
Governor speed fixed time	$T_{g1} = 0.08$	$T_{g2} = 0.08$
Turbine fixed time	$T_{t1} = 0.3$	$T_{t2} = 0.3$
Proportional fixed interest	$K_{p1} = 120$	$K_{p2} = 120$
Power system fixed time	$T_{p1} = 20$	$T_{p2} = 20$
Arrangement fixed	$R_1 = 2.4$	$R_2 = 2.4$
Frequency bias factor	$B_1 = 0.425$	$B_2 = 0.425$
Synchronizer power coefficient	$T_{12} = 0.086$	
Nominal power rate	$a_{12} = -1$	

First without considering the load frequency control loop and for the load increase in area 1 of the system was simulated and frequency changes in areas 1 and 2 and the change amounts in transmission power between the two areas were recorded.

As it can be observed in figures 8, 9, and 10, through the implementation of load frequency control all three parameters of ΔF_1, ΔF_2, and ΔF_{12} will become zero after the fluctuations. Therefore, no power change occurs in the connection line between the two areas and the frequency will return to its original amoun

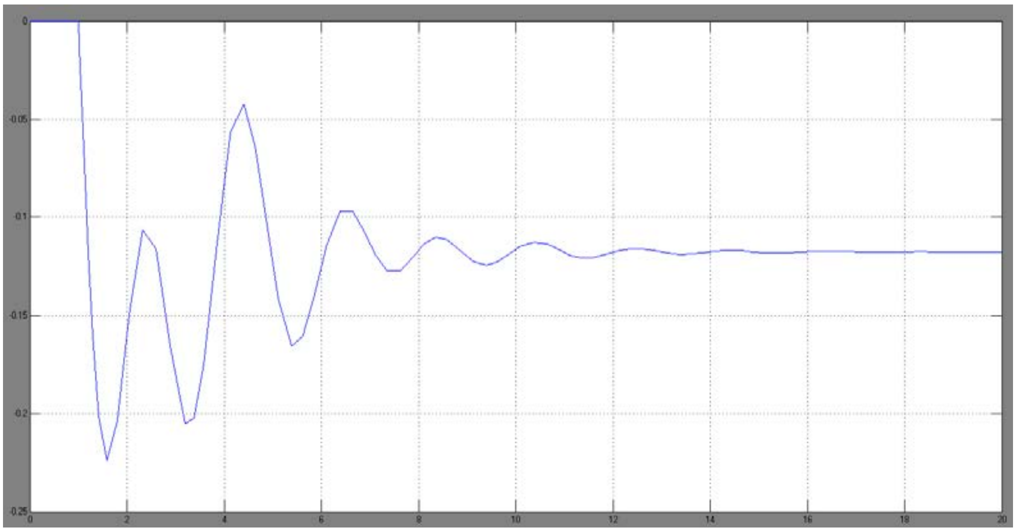


Fig.5.Frequency changes of area 1 regarding load increase in area 1 without LFC

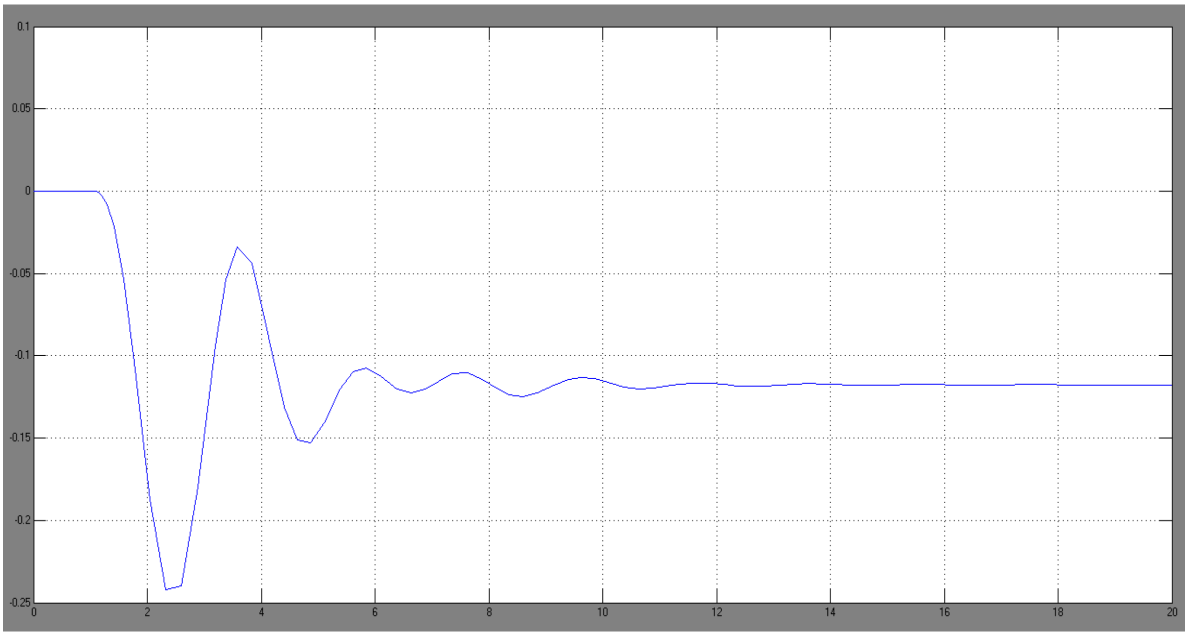


Fig.6. Frequency changes of area 2 regarding load increase in area 1 without LFC

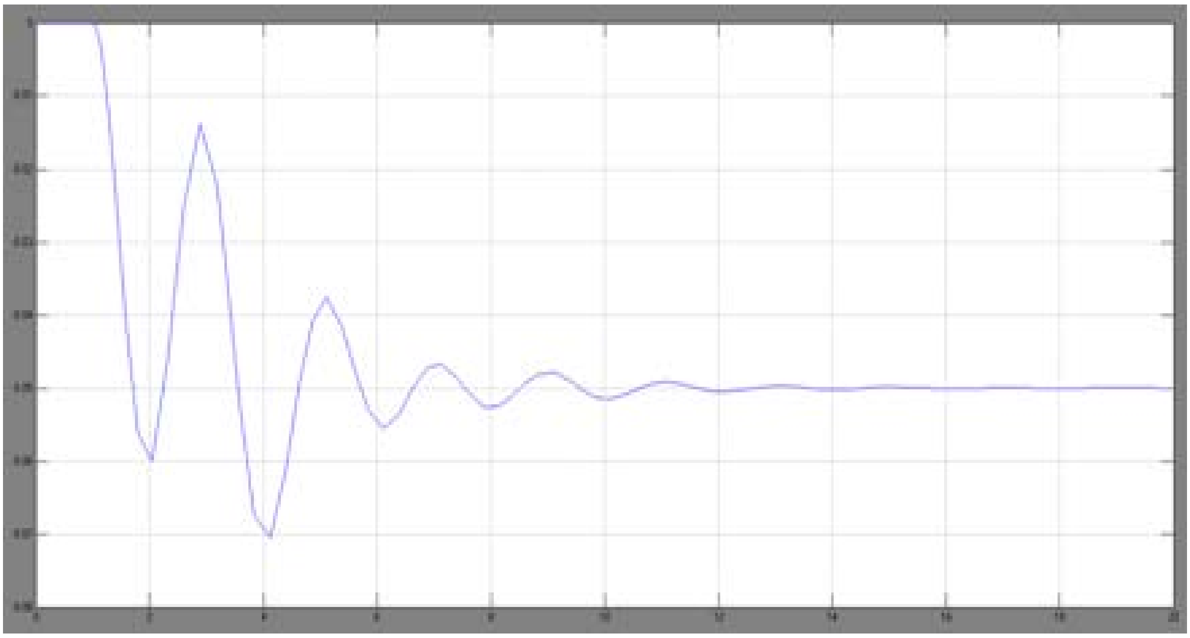


Fig.7. Transferred power changes from area 1 to area 2 regarding load increase in area 1 without LFC

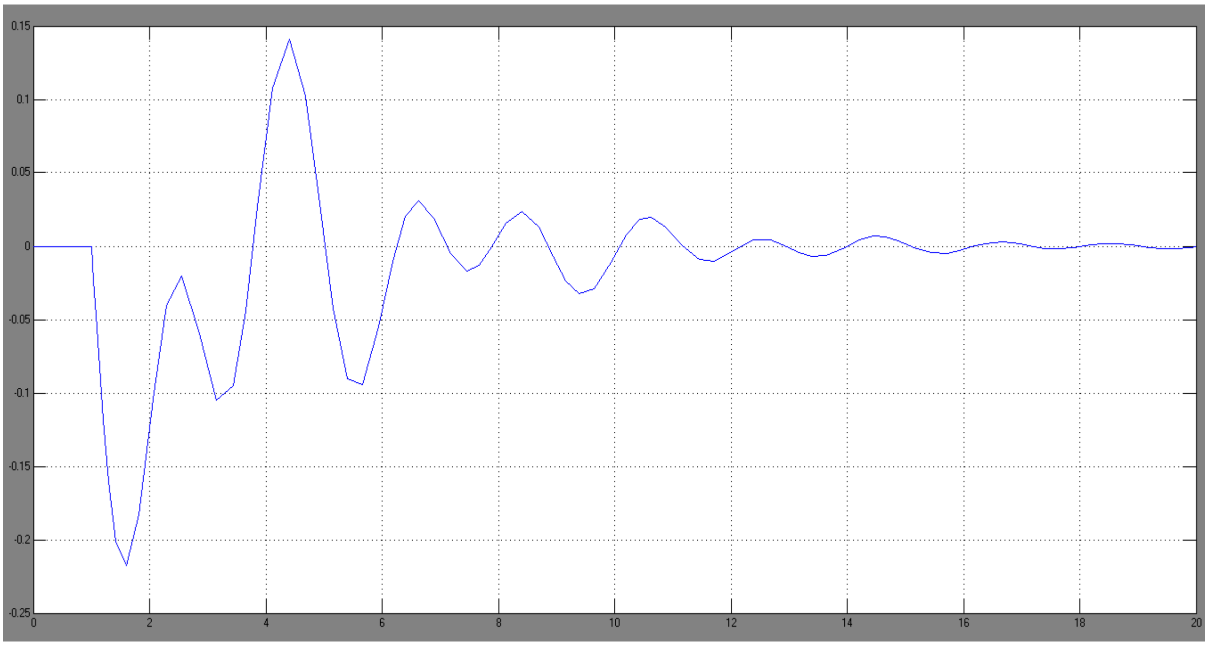


Fig.8.Frequency changes of area 1 regarding load increase in area 1 with LFC

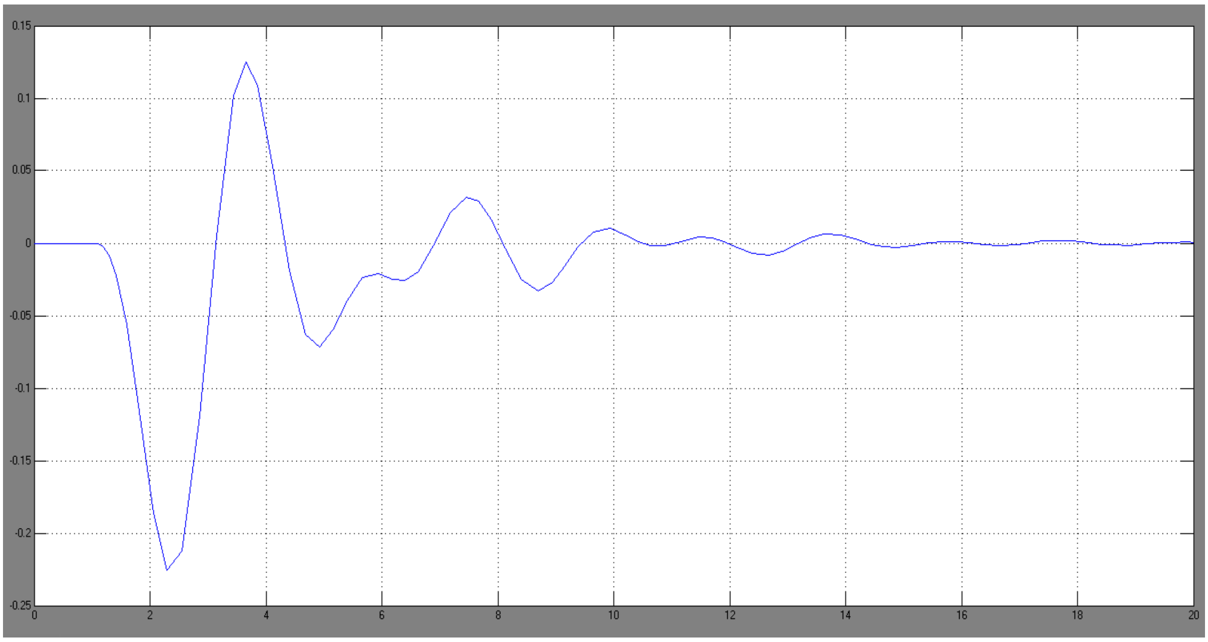


Fig.9. Frequency changes of area 2 regarding load increase in area 1 with LFC

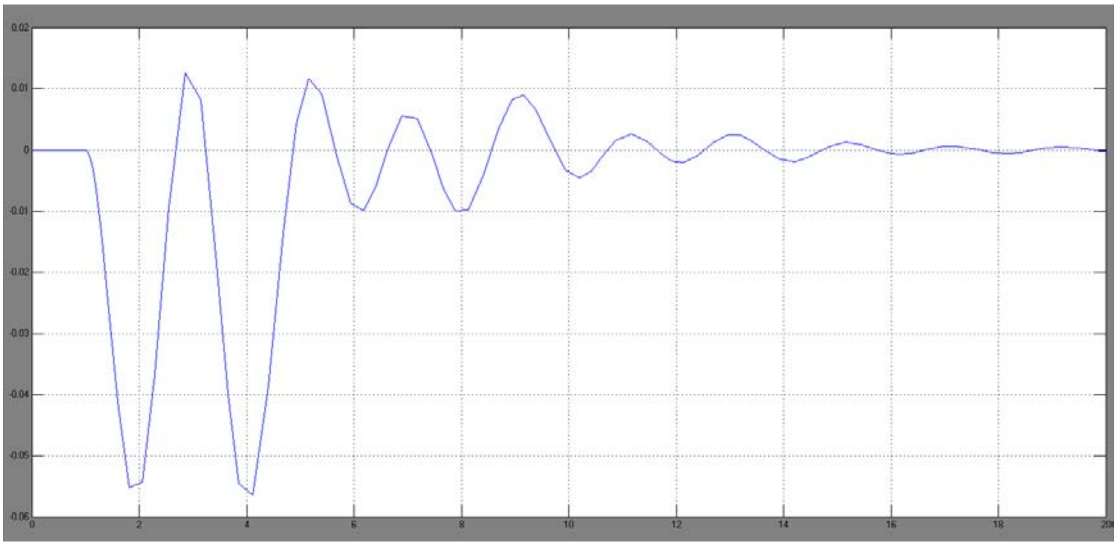


Fig.10. Transferred power changes from area 1 to area 2 regarding load increase in area 1 with LFC

As it can be observed in figures 8, 9, and 10, through the implementation of load frequency control all three parameters of ΔF_1, ΔF_2, and ΔF_{12} will become zero after the fluctuations. Therefore, no power change occurs in the connection line between the two areas and the frequency will return to its original amount.

Designing and simulating fuzzy load frequency controller

Today fuzzy logic is used in many fields of science and industries and load frequency control in power systems is among them. The final goal of load frequency control is to create equilibrium between production and consumption and the traditional control methods could not be appropriate resolutions due to the complexity and multiple variable conditions in the process. For this reason fuzzy controllers are known as reliable and resistant controllers in a vast range of uses.

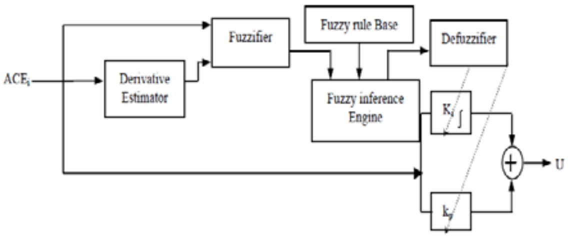


Fig.11 A sample fuzzy controller containing one input and one output

Regarding ACE as the system input, the output control vector for PI controller is defined as follows:

$$u_i = -k_p ACE_i - \int k_i (ACE_i) dt$$
$$= -k_p(\Delta P_{tie,i} + b_i \Delta f_i) - \int k_i(\Delta P_{tie,i} + b_i \Delta f_i) dt \qquad (24)$$

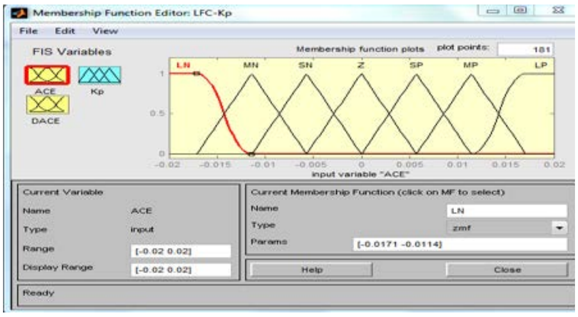
Fuzzy system input and output

We consider two inputs of ACE and ΔACE for the fuzzy system. Regarding formula (10), we define an area control error for each area and consider the changes of this quantity as the inputs of fuzzy system. We consider 7 membership functions for both inputs called:

LP (Large Positive) , MP (Medium Positive) , SP (Small Positive) , Z (Zero)

SN (Small Negative) , MN (Medium Negative) , LN (Large Negative)

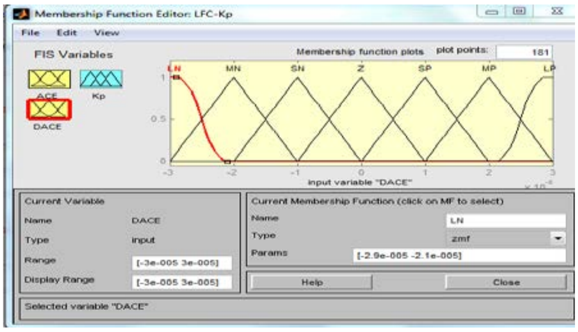
Where we have MP, SP, Z, SN, and MN functions in triangular forms and LP function is in S-shape and LN function in represented as Z-shape. Also, the range of changes in ACE input changes would reside within [-0.02 0.02] and ΔACE input would reside in the range of [-3$_e$-005 3$_e$005]. The following figures represent membership functions of inputs in MATLAB software fuzzy system.



Current Variable
Name ACE
Type input
Range [-0.02 0.02]
Display Range [-0.02 0.02]

Current Membership Function (click on MF to select)
Name LN
Type zmf
Params [-0.0171 -0.0114]

Ready



Current Variable
Name DACE
Type input
Range [-3e-005 3e-005]
Display Range [-3e-005 3e-005]

Current Membership Function (click on MF to select)
Name LN
Type zmf
Params [-2.9e-005 -2.1e-005]

Selected variable "DACE"

Fig.12.Membership functions of K$_p$ and K$_i$ outputs

The two outputs of K$_p$ and K$_i$ are implemented on PI fuzzy controllers. For both outputs we consider 7 membership functions with same names as the inputs with the same format within the ranges of [0.01 0.15] and [0.1 0.55]. The following figures represent membership functions of outputs in MATLAB software of fuzzy system.

Current Variable
Name Kp
Type output
Range [0.01 0.15]
Display Range [0.01 0.15]

Current Membership Function (click on MF to select)
Name LN
Type zmf
Params [0.01233 0.031]

Selected variable "Kp"

Current Variable
Name Ki
Type output
Range [0.1 0.55]
Display Range [0.1 0.55]

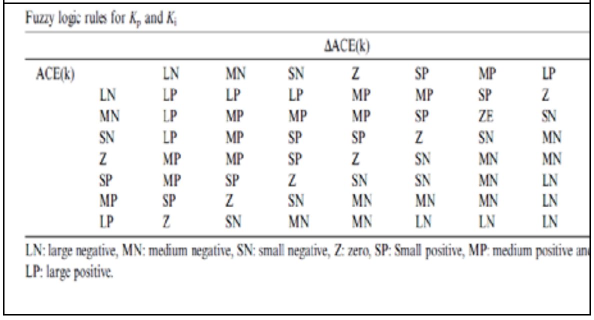
Current Membership Function (click on MF to select)
Name LN
Type zmf
Params [0.1075 0.1675]

Selected variable "Ki"

Fig.13. Membership functions of K$_p$ and K$_i$ inputs

The fuzzy principles are as follows:

Table 2- Fuzzy principles for two input systems



Fuzzy logic rules for K_p and K_i

ACE(k)	ΔACE(k)						
	LN	MN	SN	Z	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	ZE	SN
SN	LP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	MN	MN
SP	MP	SP	Z	SN	SN	MN	LN
MP	SP	Z	SN	MN	MN	MN	LN
LP	Z	SN	MN	MN	LN	LN	LN

LN: large negative, MN: medium negative, SN: small negative, Z: zero, SP: Small positive, MP: medium positive an
LP: large positive.

The application of such a fuzzy system with this type of principles requires a controller whose most important factor is control time and it produces problems such as long calculation time. To alleviate such a problem we can use only ACE input to control the system. Thus, fuzzy principles will be confined into following 7 principles.

Table 3 Fuzzy principles for single input systems -

ACE	K_p& K_i
LN	LP
MN	MP
SN	SP
Z	Z
SP	SN
MP	MN
LP	LN

Through applying a single input system it can be observed that the control time has been reduced tremendously and the results will be produced with a good approximation as in double input state. The comparison and results of both systems will be presented later.

4- System simulation

We simulated two area power system loads using fuzzy PI controller in two states of the previous section namely considering two inputs for fuzzy system and single input in a simulation environment of MATLAB.

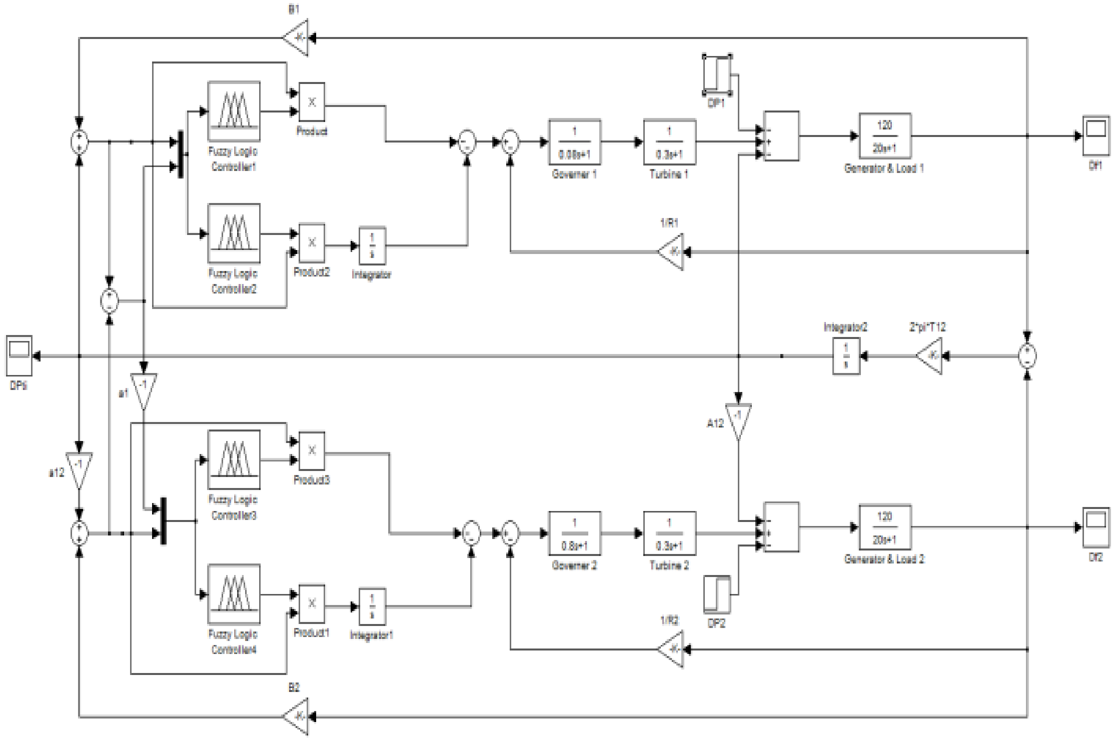


Fig.14.Simulation of two area power system load frequency control considering two inputs for the fuzzy system

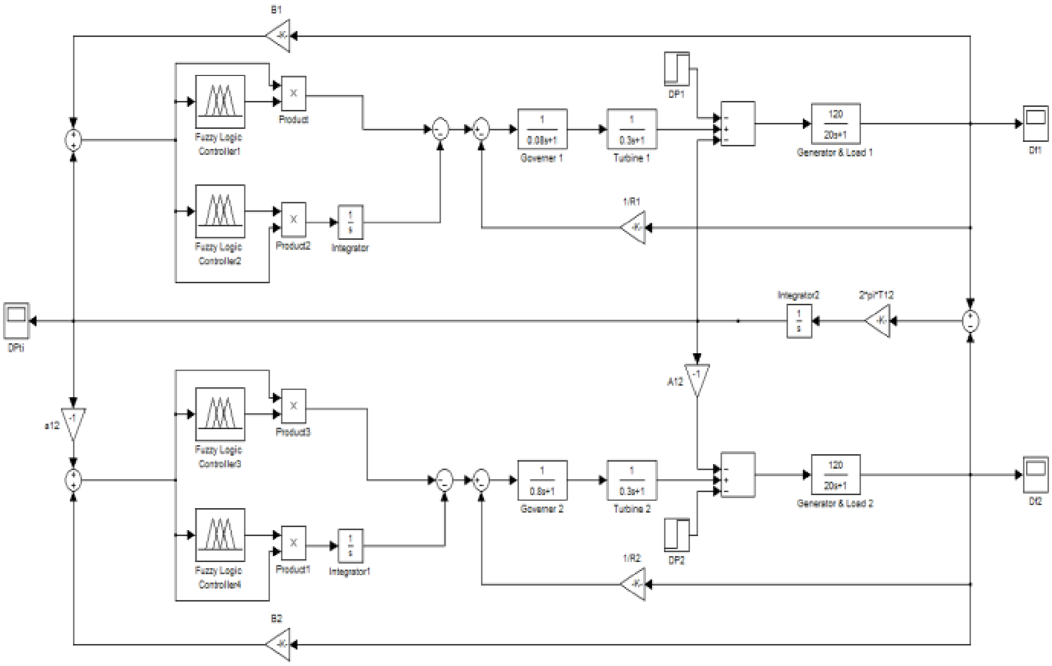


Fig.15. Simulation of two area power system load frequency control considering a single input for the fuzzy system

Since in the present study we have compared two classic and fuzzy systems with each other, the same amounts in table (1) are considered for the parameters of the two areas in a power system and the load change is enforced through an input step function with the same amount as in area 1.

First we consider the fuzzy system with two inputs and record the frequency changes in areas 1 and 2 and also we record the amounts of changes in transfer power between the two areas.

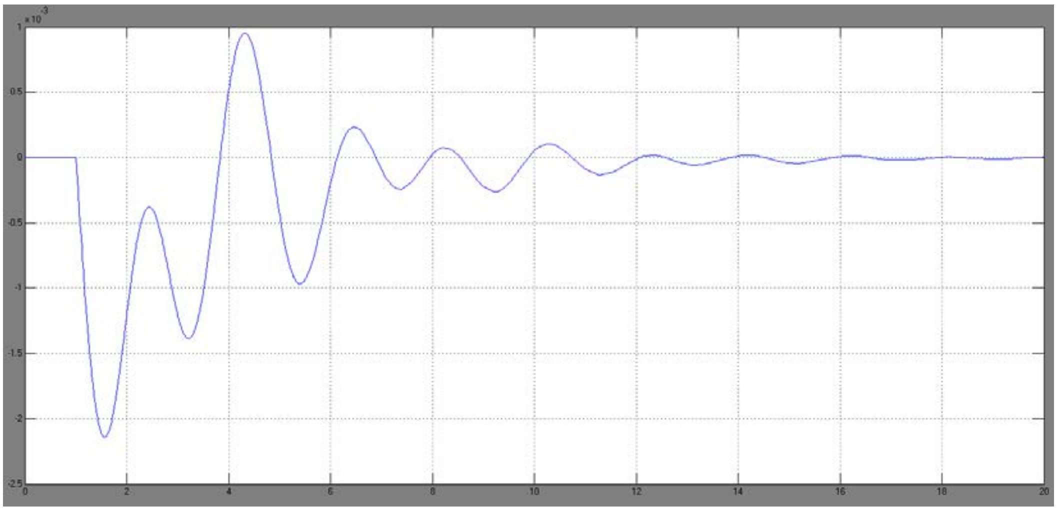


Fig.16. Frequency changes of area 1 regarding load increase in area 1 considering a two inputs fuzzy control

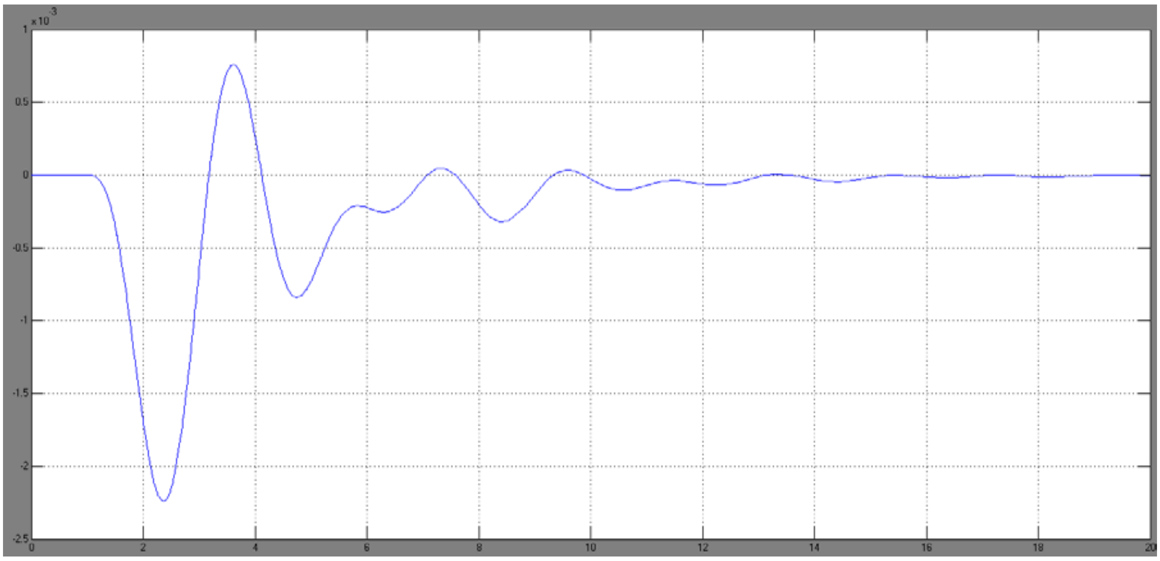


Fig.17. Frequency changes of area 2 regarding load increase in area 1 considering a two inputs fuzzy control

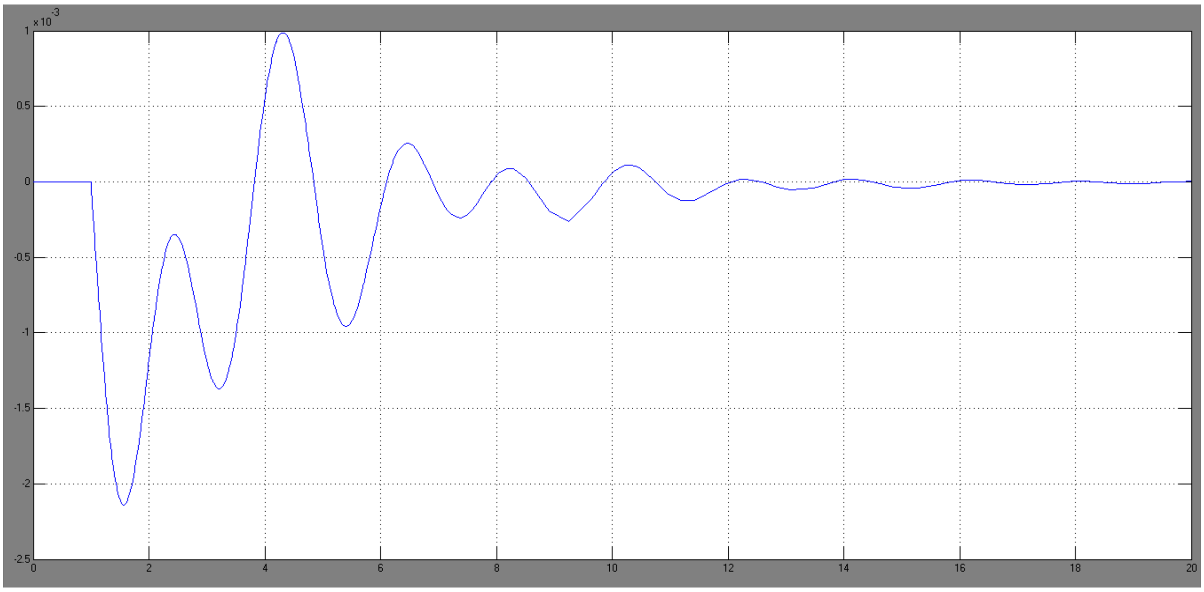


Fig.18. Power changes transferred from area 1 to area 2 regarding load increases in area 1 considering a two inputs fuzzy control

As it can be observed in figures above, both frequency and changes in transferred power will be zero after some time. But the time required for simulation lasts between 20 seconds and longer than an hour. Now we consider a single input system and record the results again.

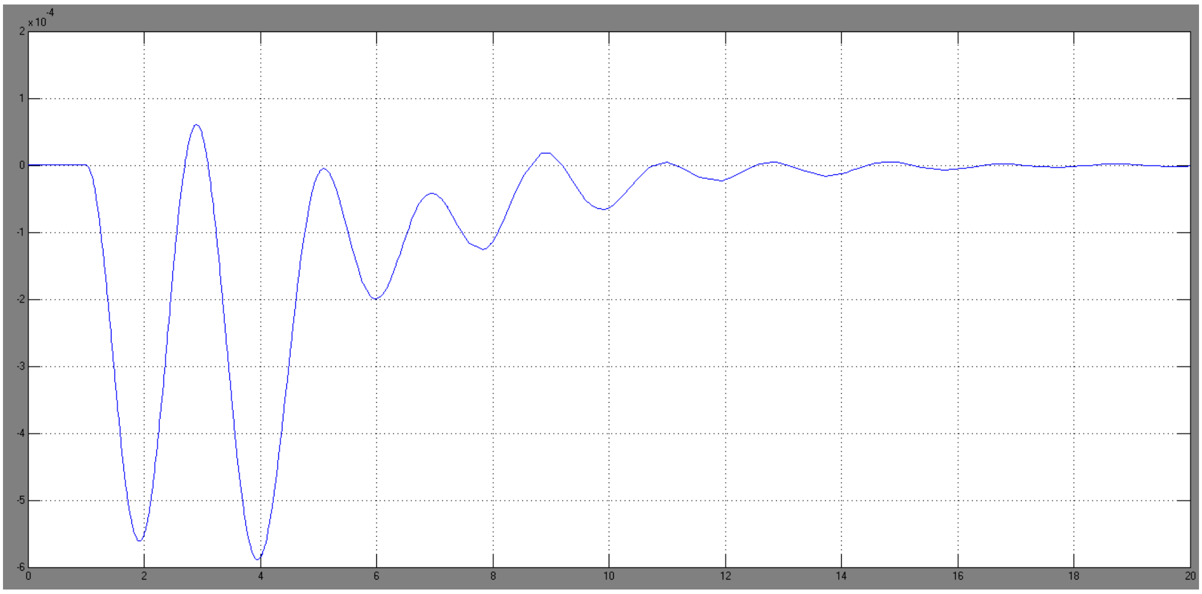


Fig.19. Frequency changes of area 1 regarding load increase in area 1 considering a single input fuzzy control

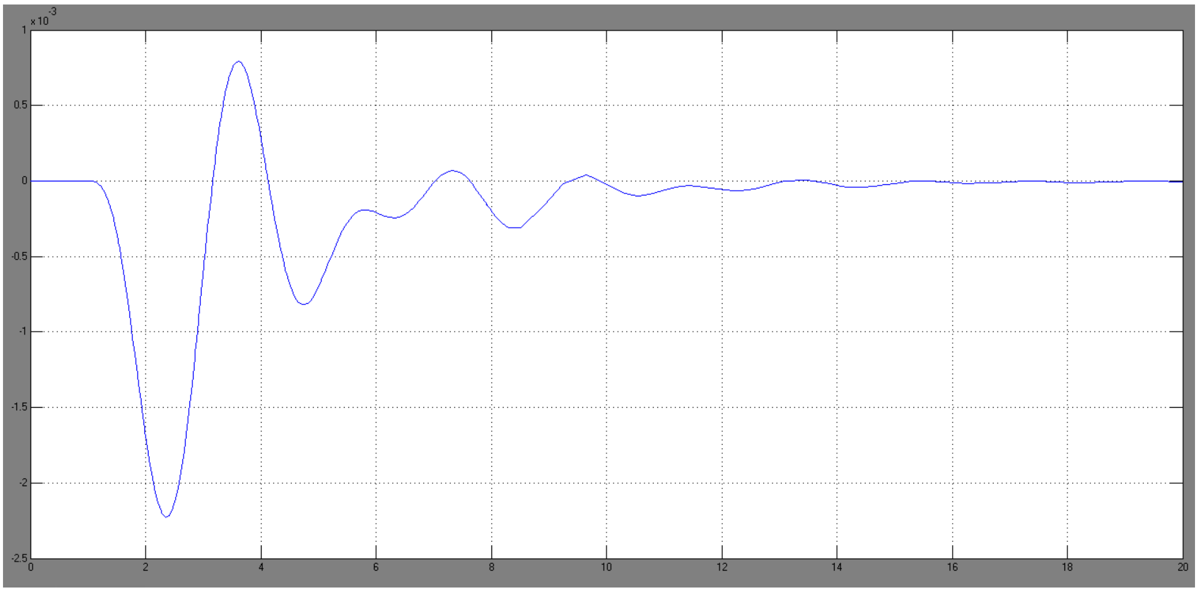


Fig.20.Frequency changes of area 2 regarding load increase in area 1 considering a single input fuzzy control

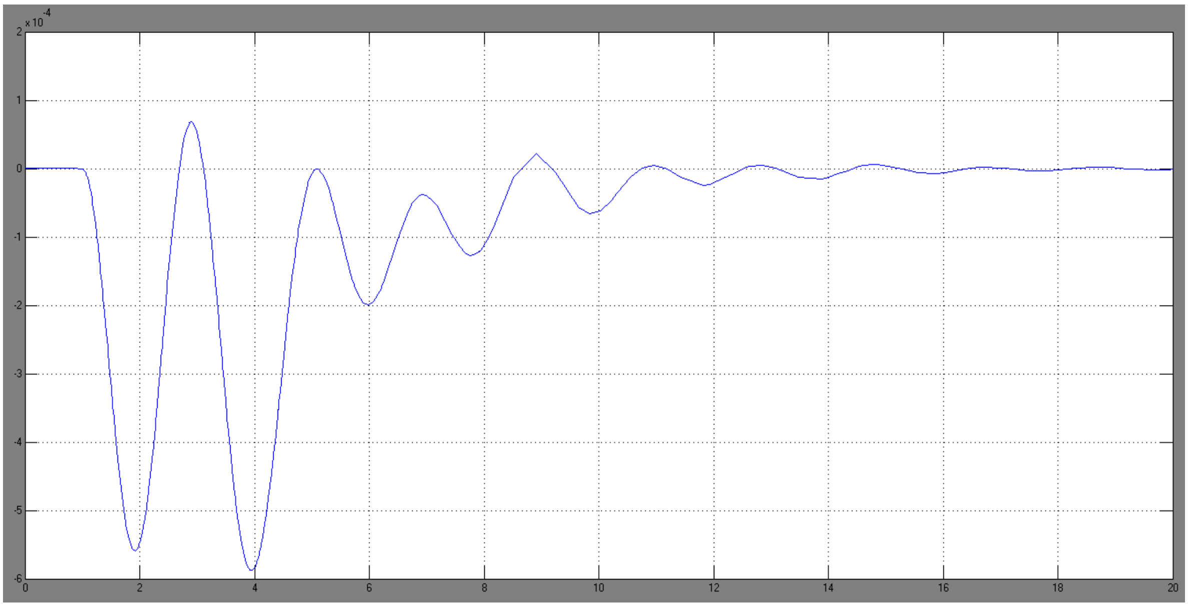


Fig.21.Power changes transferred from area 1 to area 2 regarding load increases in area 1 considering a single input fuzzy control

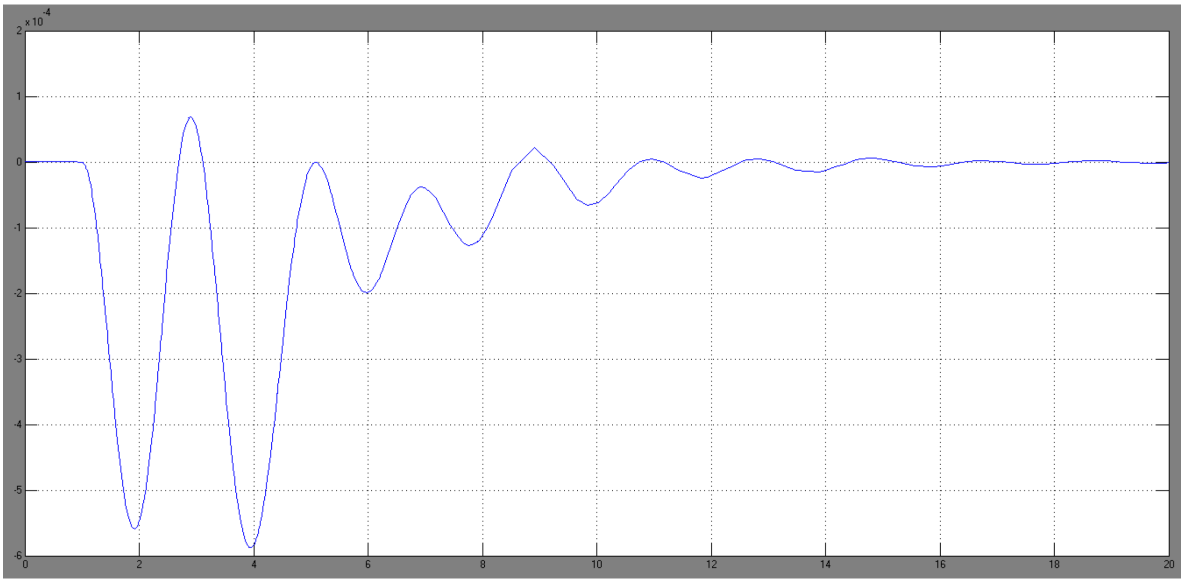


Fig.22.Power changes transferred from area 1 to area 2 regarding load increases in area 2 considering a single input fuzzy control

If we compare the results of two input fuzzy system with a single input system we can observe that the changes of the parameters are very similar to each other. Meanwhile, the simulation of the system in a single input system lasts for only 20 to 30 seconds and thus it acts much more rapidly than the system with two inputs.

The comparison of fuzzy and classic controllers

To compare the frequency changes of area 1 regarding load change in area 1 with a single input fuzzy controller (figure 20), we compare the results with its classic state (figure 8). As it can be observed in both figures, the consistent error for both controllers becomes zero after some time and this shows the proper performance of both controllers. But the major difference between these two controllers is in temporary state of this parameter and when surplus load occurs. As it can be seen in figure (5), in classic controller and regarding the worst possible state the frequency of area 1 will decrease 0.21 and the peak to peak frequency changes amounts to 0.35. Meanwhile, regarding figure (20), the frequency has reduced 0.021 using a fuzzy controller and the peak to peak frequency changes amount to only 0.022. This is trivial regarding the classic state and since it accompanies with frequency losses, the overall load in the system is reduced and this can have a great role in system consistency and lack of load reduction in the system.

Similarly we can compare the changes of frequencies in area 2 (figure 9 and figure 21) and the changes in transferred power from area 1 to area 2 (figure 10 and figure 22) in fuzzy and classic controllers. In this way we can observe the improvement of the dynamic behavior of the system in utilizing fuzzy controllers. Considering figures (9) and (21), the changes in frequency of area 2 in classic controllers amount to 0.36. Meanwhile, it amounts to 0.02275 in fuzzy controllers. Also, the change in transfer power from area 1 to area 2 in classic state is 0.0222 and it amounts to a trivial amount of 0.0006 in fuzzy systems. This shows the great improvement in temporary state of this parameter in using fuzzy controllers.

Conclusion

Results showed that the behavior of fuzzy controllers considering load changes has been better than classic controllers and they have shown a more resistant performance. Also the dynamic behavior of the system with fuzzy controllers under different circumstances has become more optimal compared to classic controllers. Therefore, it seems that fuzzy controllers have been more practical for implementation.

Fuzzy controllers are more flexible and represent a resistant performance against the change of system parameters and nonlinear factors such as growth rate constrains (GRC) under different load change conditions and they can be investigated in details in future research projects.

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