Load Frequency Control in two area multi source interconnected system using Fuzzy Logic Controller

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***Abstract* - The application of renewable energy sources has been experiencing some implications on power systems. The most significant control of this type is the load frequency control (LFC). In this work, the LFC problem is addressed by employing contemporary control methods on a two area multi source interconnected power system. As well as a photovoltaic solar power plant (PV-SPP) which was also hooked up to find out the impact of the frequency on the system. A Fuzzy Logic controller(FLC), which is used to control the frequency of the system, has been developed. Conventional proportional-integral-derivative (PID) and PID with genetic algorithm (GA-PID) controllers were additionally developed for comparison purposes. The proposed control scheme demonstrated a more accurate operation compared to the conventional and the others modern control methods in terms of the low overshoot and quicker settling time. Simulations were all done with MATLAB-Simulink software.**

Keywords—Load frequency Control, Two Area, Genetic Algorithm, Fuzzy logic controller, PV cell.

I. INTRODUCTION

RESs are preferable in new power grids to mitigate the drawbacks of conventional energy sources. The load on a power system is dynamic in nature and thus LFC plays a major role in sustaining the system stability against such variations of load. Today’s power system comprises of a large network consisting of several control areas interconnected through a tie-line power for interchange of power amongst the control areas. Variations of load in any of these control areas may cause frequency deviation in that area as well as in other areas also and further it may cause deviation in the tie-line power flow between different areas. If frequency and tie-line power fluctuations are not efficiently damped out within short time then the stability of system and power quality of the power provided to consumers are adversely affected. Thus, it’s essential to uphold system frequency and the tie-line power within the acceptable limits in order to ensure the system stability and quality of power delivered.

Therefore, the penetration of RESs in the connected power system poses many controlling problems, such as problems related to the inequality between load demand and generated power. Thus, load frequency control (LFC) is an important aspect of sustaining grid frequency under different conditions of demand disturbances.

Renewable Energy sources (RES) are utilized either in the grid on or off-grid mode. Large changes of output parameters may occur from climatic changes, this circumstance is also observed in PV-SPP systems as shade is unavoidable. Due to this effect their output voltages and frequencies are not always constant [1].

A threat of network collapse occurs when there are large frequency or voltage changes. Moreover, the quality of the produced energy reduces. Such situations can be dangerous for both the grid and the generation fleet consumers. This issue can be erased with the help of load frequency control (LFC) [2]. LFC is one of the most significant factors in the operation of a power system. The energy balance within the generation and loads process is handled by means of the numerical value using the sensors. The real-time monitoring of the grid frequency [3,4]. Hence a solution to the load frequency problem is proposed that involves the following: various control strategies have been offered by previous researchers. These studies were designed to the end of fix the frequency at a desired one.

Generally multi-area power systems have a large quantity of parameters that have to be monitored. Therefore, the monitor procedures and operating systems becomes more complex. More than anything else, this is the most challenging part in order to maintain the frequency in each area, smart control systems have to be engineered for LFC [5,6]. Numerous system instabilities can be managed by digital PID controller. Nevertheless, the classic PID controller does not meet the requirements since the grids are expanding. Utilizing the various modern optimization methodologies is critical for competitive positioning. load frequency control can be possibly achieved by adopting the methods embedded in existing PID controller by some researchers [8,9].

We implement LFC to make the system parameters at tolerable range and for keeping the generation of every plant within their nominal cost. The set position of the generator is controlled by the help of LFC to keep the ACE i.e. Area Control Error at minimum value. The variation of system parameters has to be kept as minimum as possible to make the system robust and reliable [10]. The PID controller will take a long time to stabilize the system frequency, the limitation will be to perform a large area of overshooting and undershooting in steady-state frequency deviation [11].

The study on LFC during normal and disturbance (i.e. change in load) condition is going on by the researchers. There are several control techniques taken to solve the LFC problem. Many optimization techniques are taken like, PSO technique, ZN technique, Hybrid PSO Optimization have been proposed for LFC. One of the main advantages of metaheuristic algorithms is that they are able to handle uncertainty and nonlinearity, which can be challenging for conventional LFCs. They are useful in reaching the global optimum point and avoid trapping in the local optima. Moreover metaheuristic optimization algorithms are a powerful tools for the optimal control design of power systems[12].From the recent research we came to know that the close loop performance of a controller is improved by adding the Fuzzy logic controller (FLC) in the controller part. In FLC no mathematical equations required to select proper fuzzy parameter (i.e. inputs, outputs, membership function, Scaling factors, rule base etc) [13,14].

As the world rapidly changes, the development of electric grids increases the importance of choosing the best control method. Since the frequency value continuously changes, depending on the energy consumption, it is more difficult to maintain the desired frequency value. In this paper, in order to solve the LFC problem, a new Fuzzy Logic Controller(FLC) is suggested, simulated, and verified, for a two area multi source interconnected power system.

II. MODELLING OF POWER SYSTEM

The investigated system for LFC in this study is a two area interconnected power system with non-reheat turbine type thermal unit in each area. In an interconnected power system, a sudden load perturbation in any of the interconnected areas causes the deviation of frequencies of all the areas and also of the tie-line powers. Since the time constant of the excitation control system is smaller than the time constant of the load frequency control system, thus the transients in excitation voltage control vanish much faster and do not affect the dynamics of the load frequency control. That is the reason why excitation control and load frequency control are non-interactive for small changes in load, and therefore, can be modeled and analyzed independently. This important fact simplifies the development of the two-area power system model for load frequency control. The transfer function model of a two area non-reheat thermal power system is shown in Fig. 1.

Load frequency control is achieved by two different control actions in two-area power systems: the primary control that makes the initial coarse readjustment of the frequency by making the various generators in the control area track a load variation and share that in proportion to their ratings. The supplementary or secondary control, which operates only after allowing the primary control to act, is a precise control strategy for fine adjustment of the frequency that helps bring back the frequency to nominal or very close to nominal value. The main objective of the supplementary control is to restore balance between each control area load and generation after a load disturbance, so that the system frequency and the tie-line power flows are maintained at their scheduled values. The supplementary controller of the i the area is therefore, made to act on area control error (ACE;), which is an input to the controller [11] that is shown (1)

$$ACE_i = \sum_j \Delta P_{tie,ij} + B_i \Delta f_i \qquad (1)$$

Where

ACE_i = area control error of the i^{th} area

Δf_i = frequency error of i^{th} area

$\Delta P_{tie,ij}$ = tie-line power flow error between i^{th} and j^{th} areas

B_i = frequency bias coefficient of i^{th} area

At the simulation process, it is assumed that there is a step load changing in the control area-I, area-2. From Fig. 1, it is clear that Rl and R2 are regulation constants, Tgl and Tg2 are speed governor time constants, Ttl and Tt2 are turbine time constants, Tp1 and Tp2 are power system time constants, Kp1 and KP2 are power system gains, dfl and df2 are frequency deviations of each control area.

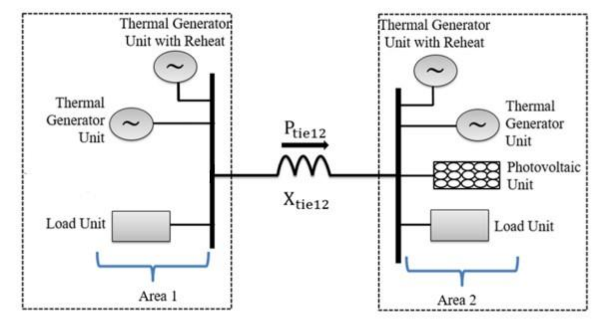


Fig-1: Two area multi source interconnected power system.

III. PID CONTROLLER

PID controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energy storage.

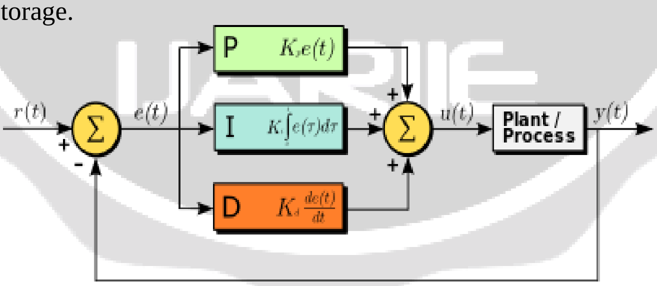


Fig-2 : PID Controller tunned by ZN method

Despite the fact that PID controller is faster and has no oscillation, it tends to be unstable in the condition of even small changes in the input set point or any disturbances to the process than P-I controllers. Ziegler-Nichols Method is one of the most effective methods that increase the usage of PID controllers.

If we compare these two methods, Ziegler-Nichols can be used for any order of the systems, especially for the higher ones, while Cohen-Coon can only be used for first order systems. Therefore, Ziegler-Nichols tuning method is more widely used. Ziegler-Nichols is applicable when the dead time is less than of the time constant. Therefore for systems having time delay this tuning method is more convenient. All in all, despite the fact that tuning a system seems easy to apply, in practice, it is really hard to analyze and pick a tuning method satisfying all system requirements.

TABLE-1 : Conventional PID Parameters by ZN method

Controller	**Kp**	**Ki**	**Kd**
PID	6	3.5	3.65

IV. GENETIC ALGORITHM (GA-PID)

The Genetic Algorithm is used to optimize gains of PID controller (Kp, K[, KD) and also scale factors of Fuzzy Logic controller. The used fitness function is shown in (2) F=L,wfi (2) Where j; = response characteristic such as Overshoot, Undershoot, Settle Time and Zero-crossing. Wi = Weighting coefficients The procedure of applied genetic algorithm for the tested system in this work is given below: a) Generate randomly a popUlation of parameter strings to form parameters vector. b) Calculate the fitness function as given in (2) for each individual in the population. c) Choose parents and applying crossover function to create next generation. d) Applying mutation function on new population. e) Compute the children and parents finesses. t) If the iteration criteria reaches to the maximum value optimization will stop, otherwise; return to step (c).

The tuned parameters of two controllers are shown in T ABLE II. The convergence characteristics of the GA for the three mentioned scenarios are depicted in Fig11. It is clear that the convergence of GA for scenario A is faster than the scenarios B and C. Genetic algorithm parameters are taken as given below: The number of population=50 The maximum iteration = 100 The probability of crossover = 0.8 The probability of mutation = 0.2

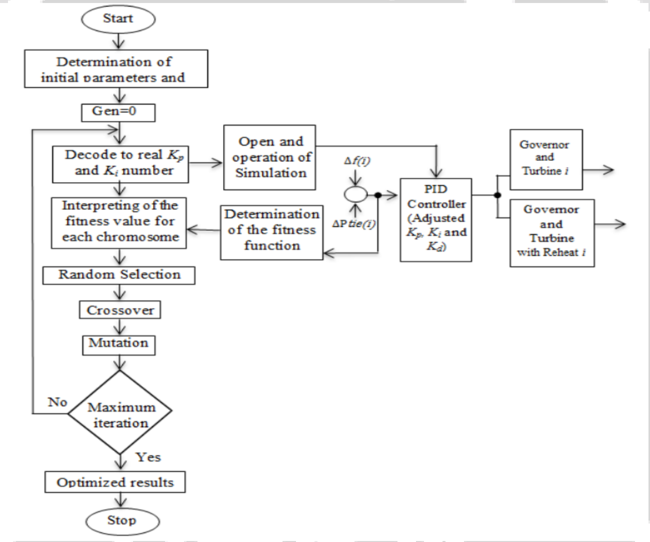


Fig -3 : Genetic Algorithm flowchart in PID controller

V. FUZZY LOGIC CONTROLLER

Recently, Fuzzy Logic is used in almost all sectors of industry and science, one of them is power system control because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solution. On the other hand, their robustness and reliability make fuzzy controllers useful for solving a wide range of control problems in power systems [8]. Fuzzy logic controller is designed to minimize fluctuation on system outputs. In the design of the fuzzy logic controller, there are five parts of the fuzzy inference process: 1. Fuzzification of the input variables.

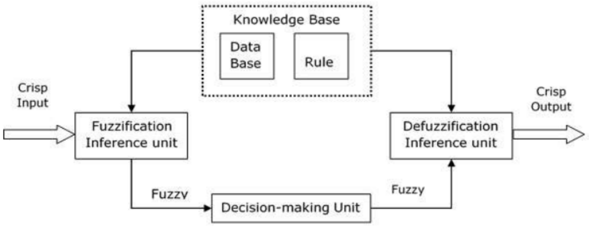


Fig-4: Block Diagram of Fuzzy Logic Controller

Application of the fuzzy operator (AND or OR) in the antecedent. 3. Implication from the antecedent to the consequent. 4. Aggregation of the consequent across the rules. 5. Defuzzification. The ACE (e) and change in ACE (e) are inputs of FLPID. Each membership function consist of two trapezoidal memberships and five triangular memberships as shown in Fig. 2. Two inputs signals are converted to fuzzy numbers first in fuzzifier using seven membership functions. Large Positive (LP), Medium Positive (MP), Small Positive (SP), Zero (Z), Small Negative (SN), Medium Negative (MN), Large Negative (LN). Finally resultant fuzzy subsets representing the controller output are converted to the crisp values using the Center of Gravity (COG) defuzzifier scheme. For the case of two-input and one-output, the control rules can be shown graphically as surface view in Fig. 3. The control rules built from the statement: IF inputl and input2 THEN outputl. For instance, consider the third row and forth column in TABLE I that mean: IF e is SN and e is Z Then U is SP.

TABLE-2 : Fuzzy Rules

$\dot{e}$ / **e**	**LN**	**MN**	**SN**	**Z**	**SP**	**MP**	**LP**
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	Z	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

NL: large negative, NM: medium negative,
NS: small negative, Z: zero, PS: small positive,
PM: medium positive, PL: large positive.

VI. SIMULATION AND RESULTS

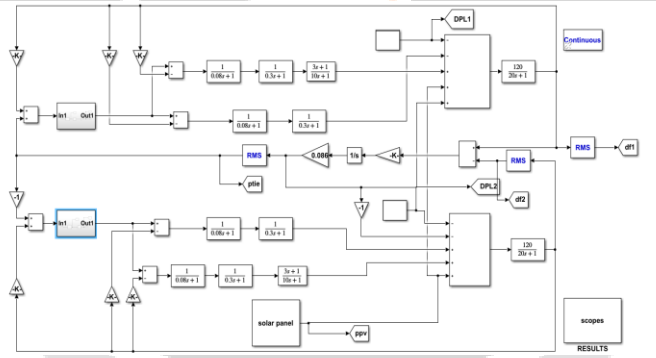
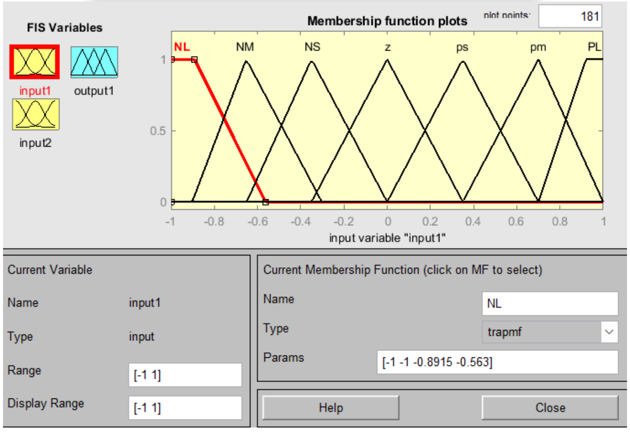


Fig-5 MATLAB Model



Current Variable

Name input1

Type input

Range [-1 1]

Display Range [-1 1]

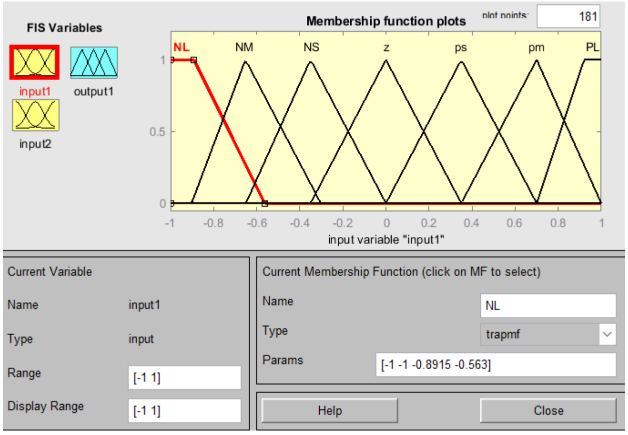
Current Membership Function (click on MF to select)

Name NL

Type trapmf

Params [-1 -1 -0.8915 -0.563]

Fig-6 Fuzzy system with input- 1&2 and output



Current Variable

Name input1

Type input

Range [-1 1]

Display Range [-1 1]

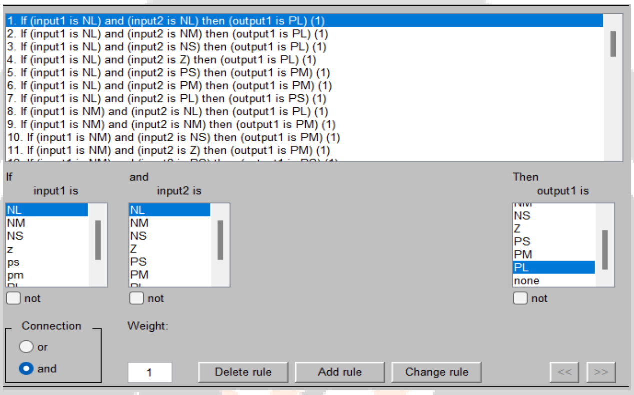
Current Membership Function (click on MF to select)

Name NL

Type trapmf

Params [-1 -1 -0.8915 -0.563]

Fig-6 (b) Fuzzy Input-1:Error, Input-2 Change in error



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1. If (input1 is NL) and (input2 is NL) then (output1 is PL) (1)
2. If (input1 is NL) and (input2 is NM) then (output1 is PL) (1)
3. If (input1 is NL) and (input2 is NS) then (output1 is PL) (1)
4. If (input1 is NL) and (input2 is Z) then (output1 is PL) (1)
5. If (input1 is NL) and (input2 is PS) then (output1 is PM) (1)
6. If (input1 is NL) and (input2 is PM) then (output1 is PM) (1)
7. If (input1 is NL) and (input2 is PL) then (output1 is PS) (1)
8. If (input1 is NM) and (input2 is NL) then (output1 is PL) (1)
9. If (input1 is NM) and (input2 is NM) then (output1 is PM) (1)
10. If (input1 is NM) and (input2 is NS) then (output1 is PM) (1)
11. If (input1 is NM) and (input2 is Z) then (output1 is PM) (1)
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Fig-6 (c) Fuzzy Rule viewer

TABLE-3 : Obtained results

Parameter		PID	GA-PID	FLC
df1	**Overshoot (Hz)**	**2.579e-04**	**2.246e-04**	**1.222e-04**
	Undershoot (Hz)	**-6.399e-03**	**-6.36e-03**	**-2.29e-03**
	Settling time (ms)	**____**	**____**	**____**
df2	**Overshoot (Hz)**	**9.76e-03**	**2.282e-01**	**4.366e-03**
	Undershoot (Hz)	**-4.867e-03**	**-1.786e-02**	**-3.27e-03**
	Settling time (ms)	**19.460**	**19.421**	**14.013**
dPtie	**Overshoot (Hz)**	**1.893e-03**	**1.902e-03**	**4.05e-04**
	Undershoot (Hz)	**-2.32e-05**	**-2.32e-05**	**1.07e-05**
	Settling time (ms)	**____**	**____**	**7.700ms**

The results from our research demonstrate that FLC is the better option if the primary focus is the prevention of sudden oscillatory variations. The FLC controller we proposed regulates the ACE1 within designated permissible limits, producing very smooth oscillations.

Above table gives an overview of the obtained results. Impressively, FLC implementation brings the most satisfactory settlement, hitting 7.70ms, with an overshoot of 1.222e-04.

From the table it is observed that there are differences between the values of ACE1 for Area 1 among the different controller scenarios and confirms the FLC effectiveness as well.

In the section of Area 2, it shows the detailed outcomes of the simulation. In the same manner of Area 1, the set of the changes of ACE2 over the duration of the simulation are shown, in which the instances of load fluctuation and long-term reduction in solar power plants are given. On the basis of Table, FLC gives a settlement time of 7.70ms and flags error reductions distinctly that sets the superiority of the comparative controllers.

GRAPHS

PID

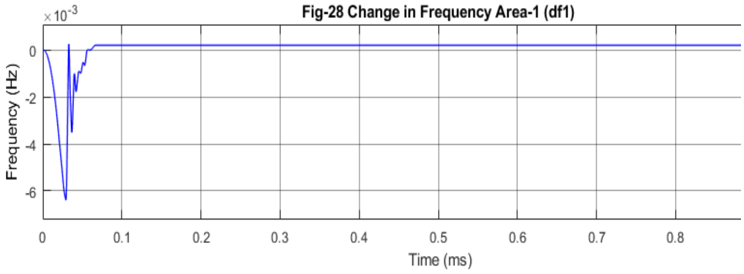

Fig-5 : Change in frequency 1

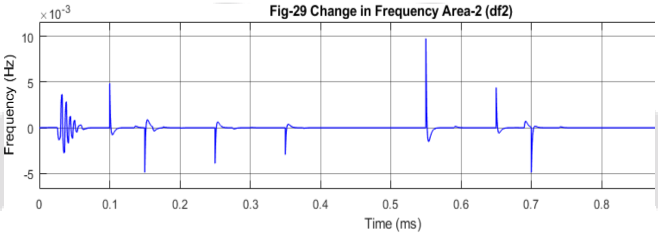

Fig-6 Change in frequency 2

PID dPtie

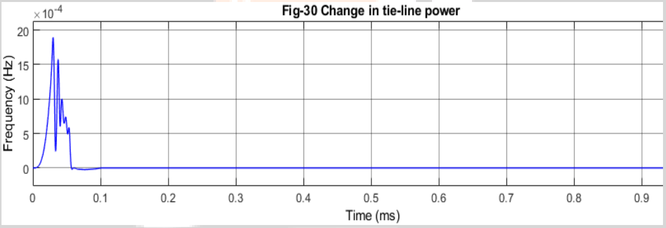

Fig-7 Change in tie-line power

GA-PID

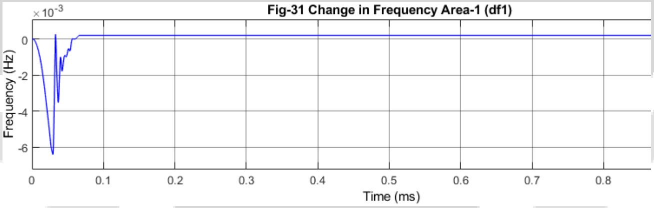

Fig-8 Change in frequency 1

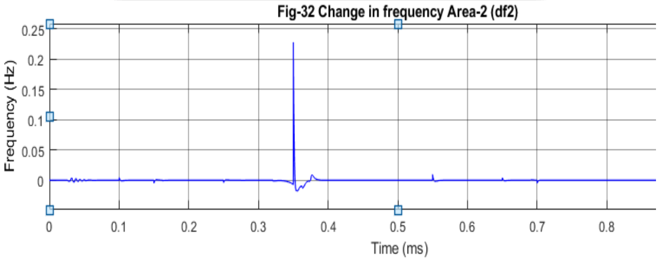

Fig-9 Change in frequency 2

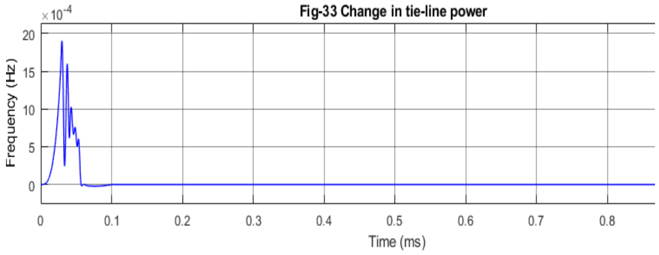

Fig-10 Change in tie-line power

FLC

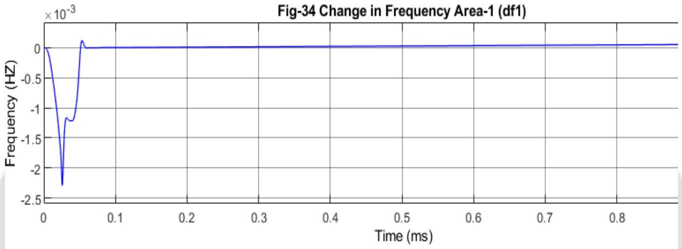

Fig-11 Change in frequency 1

FLC df2

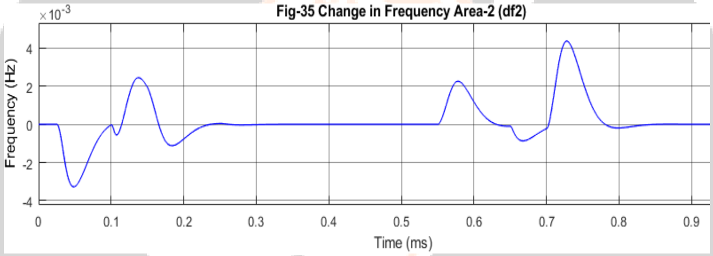

Fig-12 Change in frequency 2

FLC dPtie

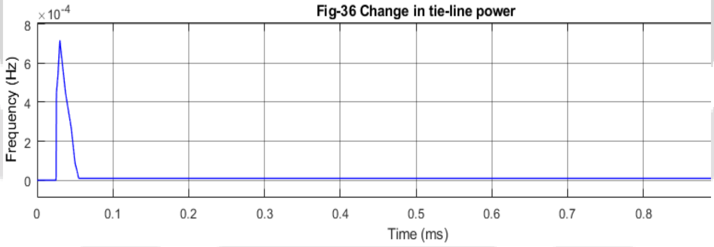

Fig-13 Change in tie line power

VII. CONCLUSION

In this paper, a new FLC controller was proposed for frequency stability problems in a two area multi source interconnected power system. The power system to be controlled was consisted of a thermal, a reheated thermal, and a PV unit. In addition to the proposed controller, conventional PID and GA-based PID controllers were designed. All systems and controllers were designed and simulated with the MATLAB-Simulink program. In the simulations, a change in the frequencies and the tie-line power were observed by implementing each controller. Since there was a two-area power system and they were connected by a tie-line, the outputs of the system were individually plotted. In the meantime, the optimum values of the parameters for the PID controller were determined by the Zigler-Nichols method. As can be seen from the above graphs, the proposed controller produces better results than the other controllers, both in terms of overshoot and settling time values. These values were taken during the load increase and the solar power decrease periods. Therefore, this demonstrates the reaction of the system at the moment of operation and a more realistic simulation was realized.

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