Comparative Analysis of Load Frequency Control with DG in 3-Area System Controlled with PI and Fuzzy Controllers

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Abstract - Load frequency control (LFC) is the focus of this research; it's one of the primary roles of automatic generation control (AGC). One of the critical control issues in developing and operating electrical power systems is load frequency control (LFC), which involves keeping the output power of the generator in step with the changeable load demand on the system. So focuses on the comparison analysis for 3-area load frequency control whenever the realm is linked with a PV system. All of the regulated regions are linked to the photovoltaic system, therefore we analyzed the system to see how the frequency of changes in each area might be adjusted. As the scale and complexity of the world's interconnected electrical systems continue to grow, maintaining a stable frequency is more important than ever. Frequency-related disturbances in isolated parts of linked systems are unacceptable because any frequency-related change or oscillation will result in undesirable disturbances and significant harm to the interconnected system as a whole. The PI controller is a simple but effective tool for managing the system frequency. Because of its user-friendliness and potential to regulate load frequency, the PI controller has gained widespread use. Additionally, frequency oscillations may be suppressed with the help of a fuzzy controller. In this study, we examine the differences between the load frequency fluctuations with and without a controller, as well as those with a PI controller and a Fuzzy controller. Once a PV system has been integrated into a given area's electrical grid, this study may assist evaluate how well the systems are working together with and without a load frequency controller.

Keywords - AGC, fuzzy controller, interconnected system, Load frequency control, PI controller, PV System, three area.

1. Introduction

Load-frequency control (LFC) is an essential part of any functioning electrical power grid. The primary goal of load frequency control (LFC) is to keep the frequency of an area's power grid within specified parameters. When properly planned and managed, a power grid can keep voltage and frequency stable and within acceptable ranges despite fluctuations in demand and other disruptions. Keeping the power system's load demand in sync with the network's generation. The LFC difficulties in system have been handled with by the various researchers in different time via AGC regulator, excitation controller design and control performance and diverse load characteristics for appropriate functioning of linked network. Since today's electricity grid is too complicated for simple study, many control methods may be considered. For this reason, cutting-edge approaches to control were used to solve the LFC issue, including adaptive control, self-tuning control, robust control, and intelligent control. Artificial neural networks (ANN), fuzzy logic, and hybrid approaches like neuro-fuzzy, neuro-genetic, and PI-based controllers, etc. have all been used to further this field of study. There is a strong correlation between the controller's performance and the accuracy with which its parameters are set using appropriate optimization methods. To keep the required frequency and power exchange with neighboring systems constant, the AGC's primary function is to balance the whole system's generation against the system's load and losses. The system frequency deviates from the normal rate if there is a combination of generation and demand. As a result, the system may fail if there is a substantial frequency variation. This needs associate accurate and quick responding controller to require care of constant nominal frequency. The limits of the typical controls area unit sluggish and lack of potency in managing system non-linearity. Because of this, a bearing method for AGC has been developed. The ultimate goal of automated generation management (AGC) is to maintain a stable frequency by adjusting the output of the electrical generator in response to changes in the system and tie-line loads. Load frequency control (LFC) is a common moniker for this function [1].Since the system is wide and sophisticated, for the devoted operation, the analysis of the system is of larger importance. Presently system became too complicated with addition of additional utilities, which can results in a condition wherever provide and demand has a good gap [2]. Thanks to serious load condition in tie-lines by wattage exchange leads to poor damping which can results in inter-area oscillation? Since the loading conditions area unit unpredictable, this makes the operation additional complicated. It's been a subject of concern, right from the start of interconnected power grid operation. During this context, Automatic Generation management plays a significant role within the power grid operation. Many works are applied for the AGC of interconnected power systems for previous couple of decades [3]-[7]. By adjusting the phase difference between two systems' voltages, Automatic Generation Control (AGC) helps operators control the flow of actual electricity between two linked grids. It also reduces the amplitude of power flow oscillations after a load disturbance in either region. Part shifters conjointly offer series compensation to enhance stability [8-9]. The high-speed responses of part shifters create them enticing to be used in up stability. The AGC anticipated being an efficient management for the tie-line power flow management of an interconnected facility. Sometimes fulminate changes in power demand are met by K.E. of generator rotor, that effectively damp mechanical device oscillations in facility [2]. Conventional power generation results in two main issues those are reduction of fuel availableness and emission of inexperienced house gases resulting in heating. Additionally transmission of power for long distances will increase losses. This light-emitting diode to Distributed Generation (DG), wherever the facility is been generated at load aspect with the help of RES reducing losses and emissions. Recent interest of the many researchers was to review concerning medium and low voltage transmission of power because of the penetration of decigram. PV system provides clean energy and therefore the impact of pollution will be reduced in generating voltage. However integration PV system to space the world the realm will turn out oscillations in area frequency. This paper deals with the management of load frequency once PV system was connected to individual areas of 3-area system. Comparative analysis of the modification in frequency while not controller and with PI controller and fuzzy control was shown for 3-area interconnected system.

2. ALFC for frequency control with DG

Automatic load frequency control (ALFC) system diagram with PV system attached is shown in Fig.1. In this arrangement turbine is fueled by steam or water input. The turbine's input may be adjusted via a valve. A turbine is a mechanical device that uses rotation to transform the kinetic energy of flowing fluid into useful mechanical work. A rotor, which might be a shaft or a drum with blades attached, is what makes a turbo machine become a turbine. The blades are propelled and transmit rotational energy to the rotor by fluid pressure. This turbine might be fueled by water, steam, gas, or wind. There is a mechanical connection between the turbine shaft and the generator. To produce electricity from mechanical energy, an alternator is used. Through a transformer interface, this electricity may be sent out to the grid. The ALFC system was linked to the PV system as well.

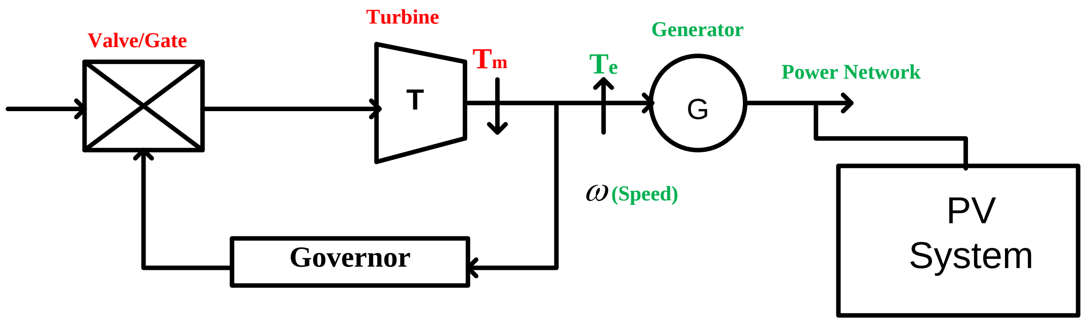


Fig.1. Schematic representation of ALFC system

2.1. Single Area Control

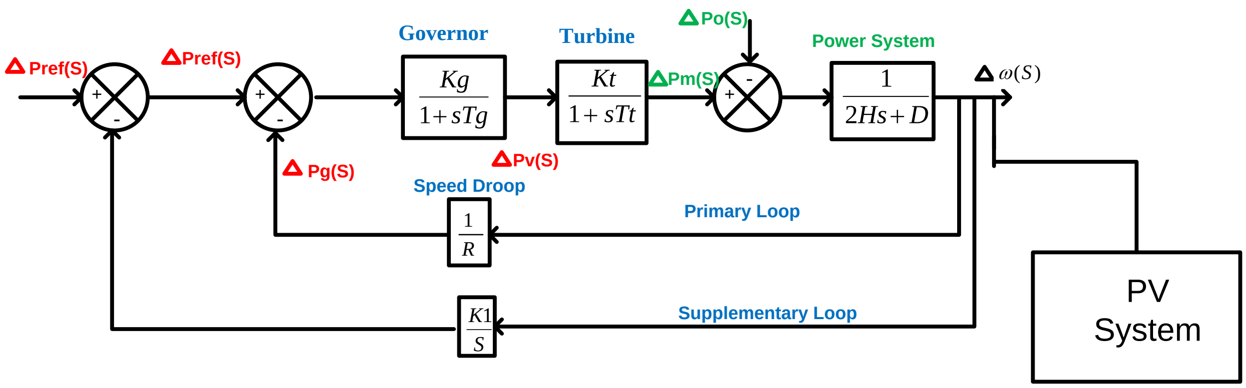


Fig.2.The block diagram representation of single area AGC with PV system

Fig.2 is a block schematic of an automated generation control system for a single-area PV installation. There are two loops in this block diagram: the main loop and the secondary loop. The primary loop controls the turbine's output to provide a stable power supply in response to fluctuating load requirements. All of the other generators keep the load from fluctuating too much. But this generates a supply frequency changes. Another control loop, known as a supplemental loop, may be used to regulate these frequency discrepancies. To ensure that there is no frequency drift, an integrated controller is utilised in this loop. Frequency shifts may occur when PV systems are linked to the grid, necessitating regulation. The graphic depicts the PV system's connection to the single-area LFC.

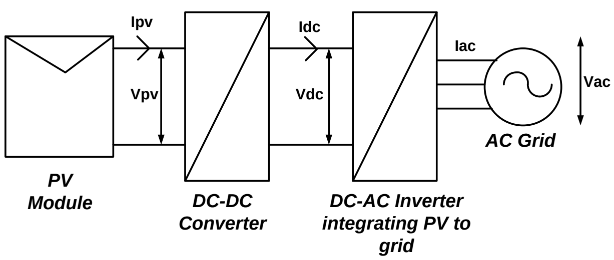


Fig.1: System with PV integration to utility Grid

(a) The relation between the instantaneous power and the current via the PV array is described by the transfer function.

$$\frac{p(s)}{I_{pv}(s)} = \frac{p(s)}{i_{ac}(s)}\frac{i_{ac}(s)}{I_{pv}(s)} = \frac{p(s)}{i_{ac}(s)}\frac{i_{ac}(s)}{I_{dc}(s)}\frac{I_{dc}(s)}{I_{pv}(s)} \quad (2)$$

$$= \frac{2S^2}{M_1M_2(S^2+4\omega^2)}\frac{V_m(S^2+\omega^2)S^2+\omega^2}{S^2(S^2+4\omega^2)} \quad (3)$$

The eqn depicts the transfer function from the input current of the solar panel to the output current of the averaging module, P. (4)

$$\frac{p}{I_{pv}} = \frac{S^2}{(S^2+\omega^2)}\frac{V(S^2+\omega^2)(S^2+2\omega^2)}{KS^2(S^2+4\omega^2)}\frac{(1-e^{-sT_s})}{sT_s} \quad (4)$$

Simplified transfer function for PV cell can be written as

$$\frac{I_{PV}}{solar\ irradiation} = k \quad (5)$$

(b) Transfer function of a boost converter:

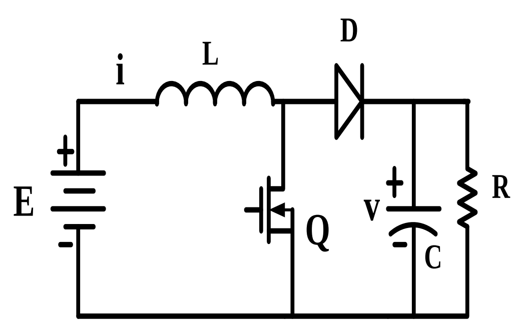


Fig.3: Boost converter

When the switch position function is set to *u* = 1, we obtain, using Kirchoff's voltage and Kirchoff's current laws, the dynamics described by the following set of equations,

$$L\frac{di}{dt} = E \quad (6)$$

$$C\frac{dv}{dt} = -\frac{V}{R} \quad (7)$$

When u = 0 is entered into the switch position function, the dynamics indicated by the equations holds.

$$L\frac{di}{dt} = -V + E \quad (8)$$

$$C\frac{dv}{dt} = i - \frac{V}{R} \quad (9)$$

For a boost converters transfer function in a real-time implementation, however, the following equation may be used [4]-[6].

$$G'_1(s) = \frac{H_1}{1+S\frac{L}{R}+s^2LC} = \frac{\frac{H_1}{LC}}{s^2+\frac{S}{RC}+\frac{1}{LC}} \quad (10)$$

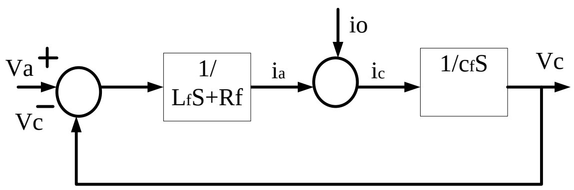


Fig.6: Block diagram of single phase inverter

(C) The inverter's input and output transfer functions are as shown in the block diagram for a single-phase system in Figure 6.

$$V_C(S) = \frac{1}{L_fC_fS^2+jR_fC_f}V_A(s) - \frac{L_fs+R_f}{L_fC_fS^2+jR_fC_f+1}I_o(S) \quad (11)$$

The transfer function in terms of frequency may be written as

$$V_C(j\omega) = \frac{1}{1-L_fC_f\omega^2+jR_fC_f\omega}v(j\omega) - \frac{jL_f\omega+R_f}{1-L_fC_f\omega^2+jR_fC_f\omega}I_o(j\omega) \quad (12)$$

To determine the transfer function:

$$V_a(S) - sL_fI_a(S) - R_fI_a(S) - V_C(S) = 0 \quad (13)$$

$$V_a(S) - V_C(S) = I_a(S)(sL_f + R_f) \quad (14)$$

$$\frac{V_a(S)}{V_C(S)} = 1 + \frac{I_a(S)(sL_f+R_f)}{V_C(S)} \quad (15)$$

$$\frac{V_C(S)}{V_a(S)} = \frac{Z_L}{s^2L_fC_f+sL_f+R_fC_fsZ_L+R_f+Z_L} \quad (16)$$

The total transfer function of the PV system plus the boost converter plus the inverter may be calculated by adding together the transfer functions of each component separately.

$$\frac{P}{Va(s)} = \frac{s^2}{(S^2+\omega^2)}\frac{V(S^2+\omega^2)(S^2+2\omega^2)}{KS^2(S^2+4\omega^2)}\frac{(1-e^{-sT_s})}{sT_s} * \frac{H_1}{1+S\frac{L}{R}+s^2LC} = \frac{\frac{H_1}{LC}}{s^2+\frac{S}{RC}+\frac{1}{LC}} * \frac{Z_L}{s^2L_fC_f+sL_f+R_fC_fsZ_L+R_f+Z_L} \quad \textbf{(17)}$$

3. Interconnected Power System

All across the world, electrical grids are linked together to provide maximum redundancy. Having systems that are interconnected makes them more reliable and efficient. The system analysis is of more relevance for the reliable operation because of the system's scope and complexity.

3.1. Three-Area System without ALFC s

Adding new utilities has made the current system excessively complicated, which might worsen the supply-and-demand imbalance [2]. Inter-area oscillations may occur as a consequence of severe load conditions in tie-lines caused by electric power exchange. The unpredictability of the loading circumstances increases the difficulty of the task. Since the inception of the functioning of linked electricity systems, this has been a source of worry. Figure 3 shows a block schematic of an integrated power generation system. These three generating areas are linked by tie lines.

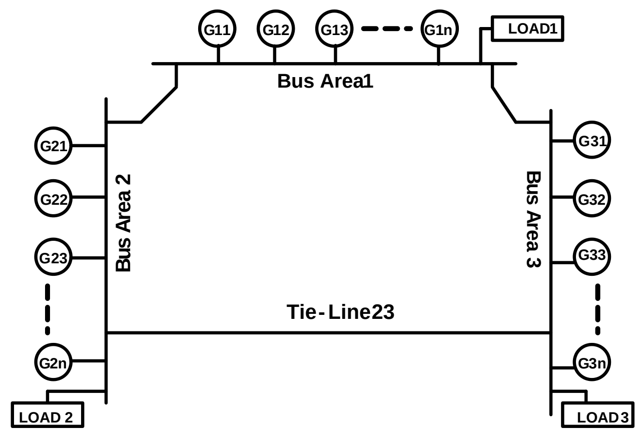


Fig. 3. Three-area power generation system

3.2. Three-Area ALFC with PV system

Control technique in the frequency domain is based on Fourier analysis wavelet analysis and infinite impulse response. The compensatory harmonic components of the harmonically contaminated signals are extracted using Fourier transformation or wavelet processing, and then combined to create compensating instructions. An extensive response time is the outcome of the online application of Fourier transform or wavelet transform (the solution of a set of nonlinear equations). Therefore, this complicates real-time applications with fluctuating demands. The PV system's link to the ALFC in the three-area system is shown in Figure 4.

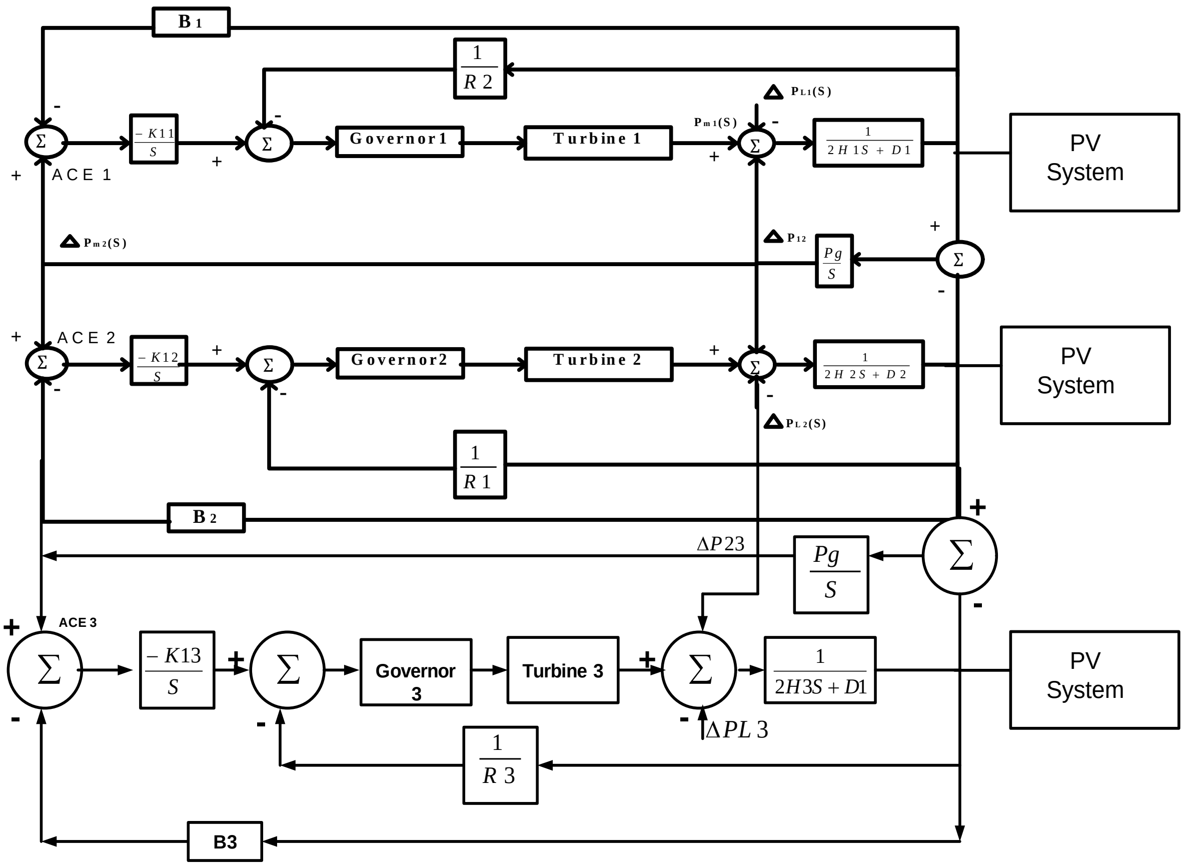
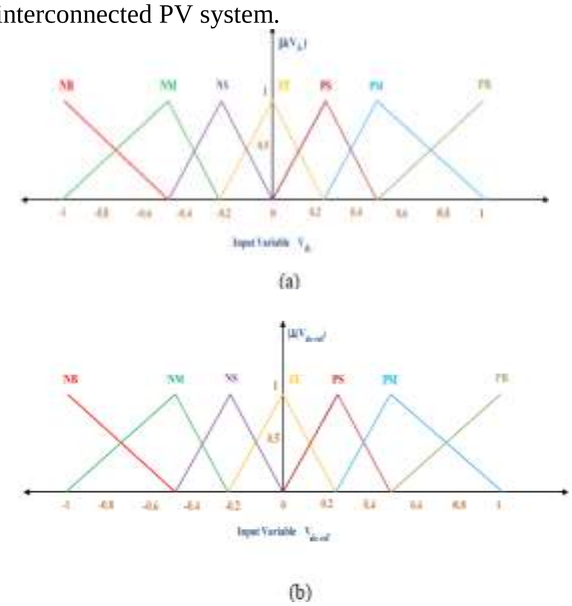
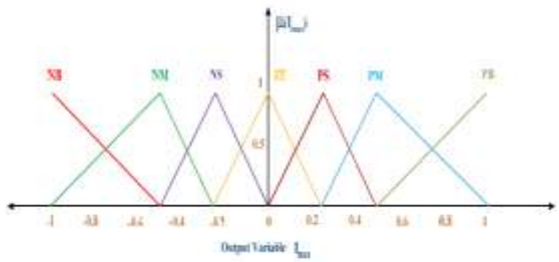


Fig.4. AGC for three-area operation with interconnected PV system.

4. FLC Controller

Problems with load frequency control and connectivity may be mitigated using AGC regulation. The field of control engineering makes extensive use of fuzzy logic. The term "fuzzy" refers to the fact that the logic at play will eventually break down notions that cannot be represented as "true" or "false," but only as "partially true." Formal logic has the advantage that the solution is forged in terms that human operators will perceive, so their expertise is employed in the look of the controller of prognosticative current control, even though other approaches, such as genetic algorithms and ANN, will perform just as well as formal logic in some cases. The linguistic variables are shown as (NB, NM, NS, Z, PS, PM, PB), where NB = large, NM = medium, NS = tiny, Z = 0, PS = medium, PM = large, and PB = large. In Fig. below, we see the membership functions.





(c)

(a) Input ANF normalized membership function; (b) Input Vdc-ref Normalized Membership Function; (c) Output Imax Normalized Membership Function.

Table I. The Membership functions for FLC

E **CE**	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NM	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z

5. Matlab/Simulation results and discussions

Simulink simulations of the PV system shown in Fig. 1 reveal that the PV array can provide 400 W of maximum power point (MPP) power at an operating voltage of 38 V. As shown in Fig. 5, we use the Simulink model and the parameters M1=10, M2=0.4466, V=120V, and ω =314 rad/sec to run the simulation.

Case-1: system without controller and PV system connected to area-1

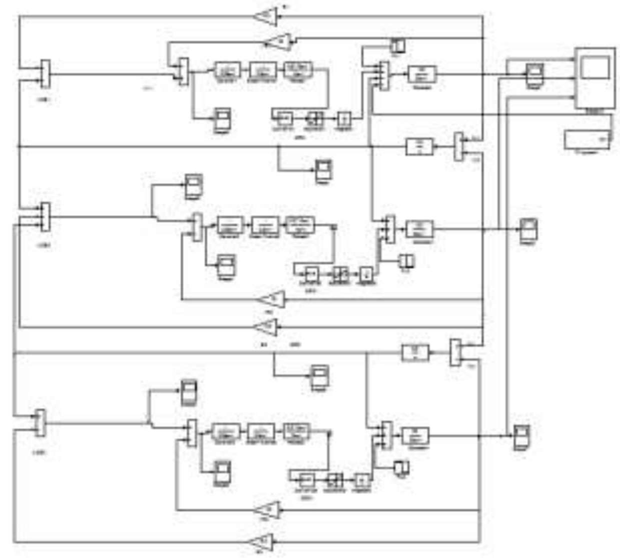


Fig.5: Simulink model of ALFC without controller and PV system connected to area-1

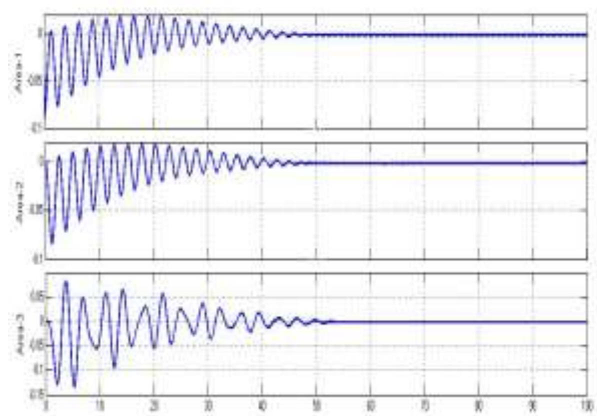


Fig.6: a shift in three different areas' frequencies without a controller or the area-1 PV system's influence

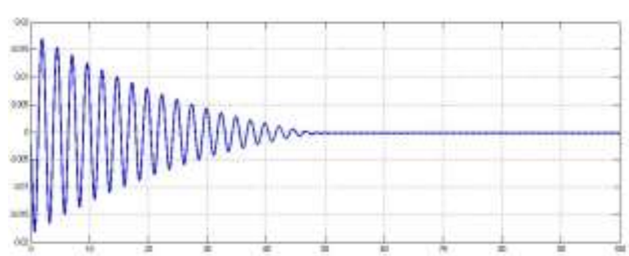


Fig.7: Frequency shift on tieline-1, which has no controller and is connected to an area-1 PV system

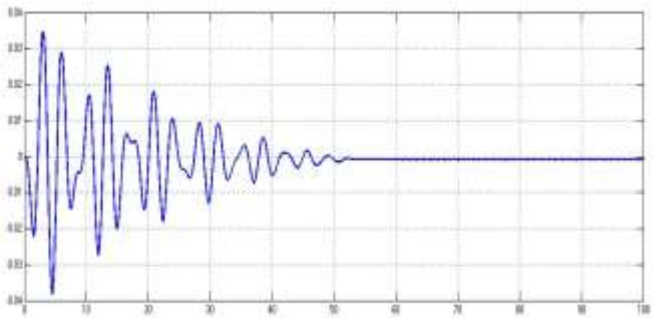


Fig.8: Tieline-2 frequency shifts without a controller or disconnect from the PV system serving Area-1

The Simulink model of a 3-area LFC is shown in Figure 5; however, the PV system is only linked for Area-1 (no controller is shown). Figure 6 depicts the change in frequency of three regions of linked system when PV system connected just for area-1.When the PV system is linked to just Area-1 without a controller, the frequency of Tie-Line 1 changes as shown in Figure 7, and the frequency of Tie-Line 2 changes as shown in Figure 8.

Case-2: system without a controller and a photovoltaic array wired to location 2

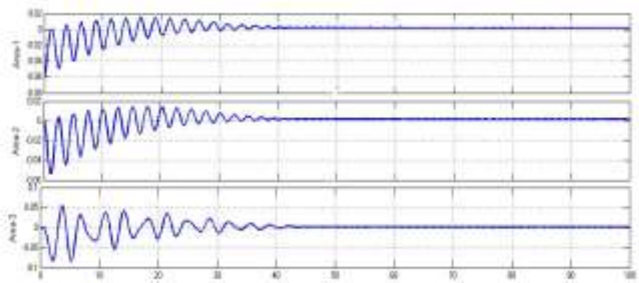


Fig.9: frequency shift in three locations without a controller and the PV system attached to location 2

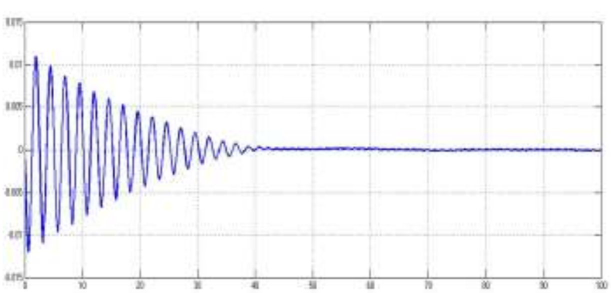


Fig.10: Frequency shift on tieline-1, no controller present, and linked photovoltaic system in area-2.

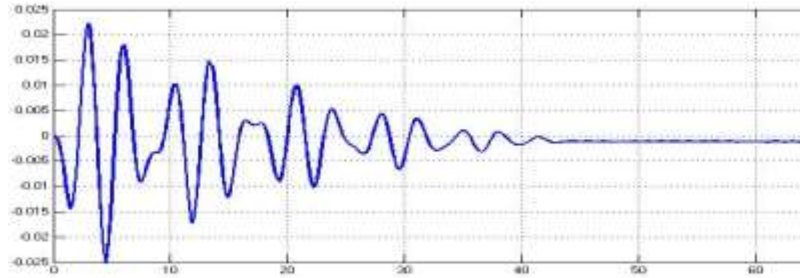


Fig.11: Frequency shift on tieline-2 due to an uncontrolled PV system's connection to area-2

Figure 9 shows the change in frequency of three areas of interconnected system when PV system connected only for area-2 without controller. Figure 10 shows the change in frequency of tie-line 1 and figure 11 shows the change in frequency of tie-line 2 when PV system connected only for area-2 without controller.

Case-3: system without controller and PV system connected to area-3

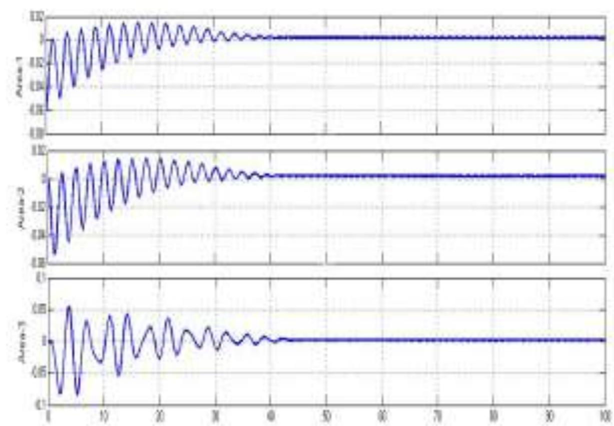


Fig.12: change in frequency of three areas without controller and PV system connected to area-3

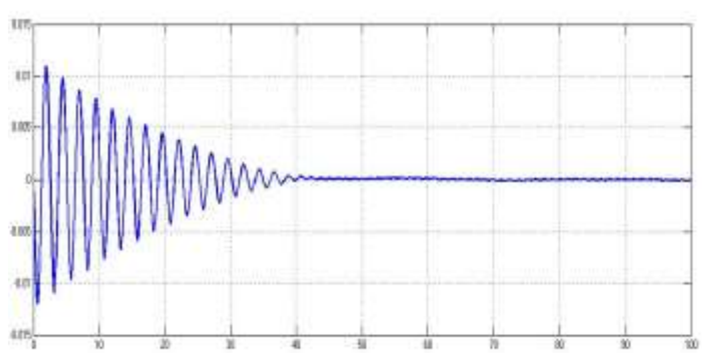


Fig.13: Change of frequency in tieline-1 without controller and PV system connected to area-3

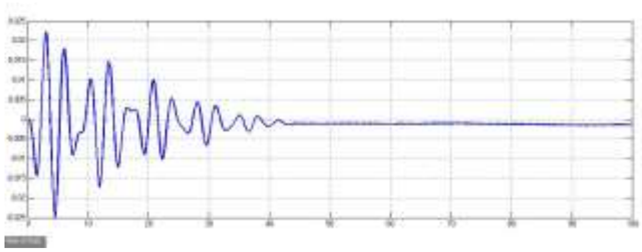


Fig.14: Change of frequency in tieline-3 without controller and PV system connected to area-3

Figure 12 shows the change in frequency of three areas of interconnected system when PV system connected only for area-3 without controller .figure 13 shows the change in frequency of tie-line 1 and figure 14 shows the change in frequency of tie-line 2 when PV system connected only for area-3 without controller.

Case-4: system without controller and PV system connected to all 3-areas

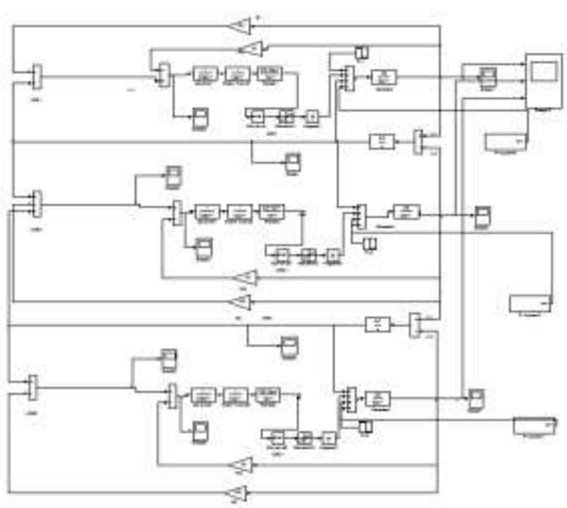


Fig.15: Model of an ALFC in Simulink without a controller and a PV system with all 3 zones interconnected.

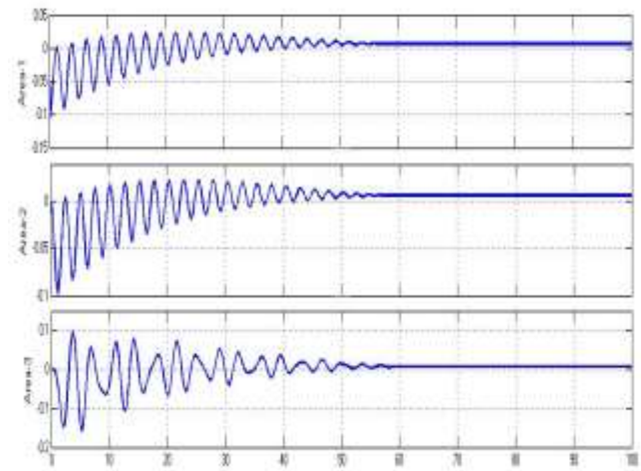


Fig.16: change in frequency of three areas without controller and PV system connected to all areas

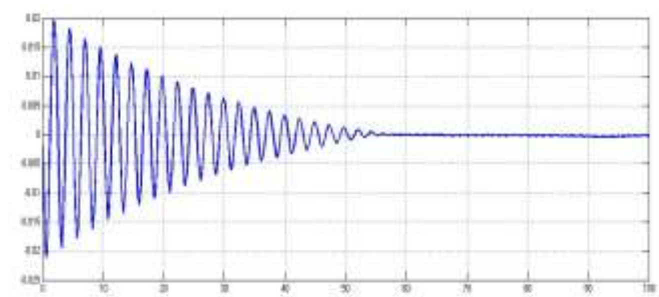


Fig.17: Change of frequency in tieline-1 without controller and PV system connected to all areas

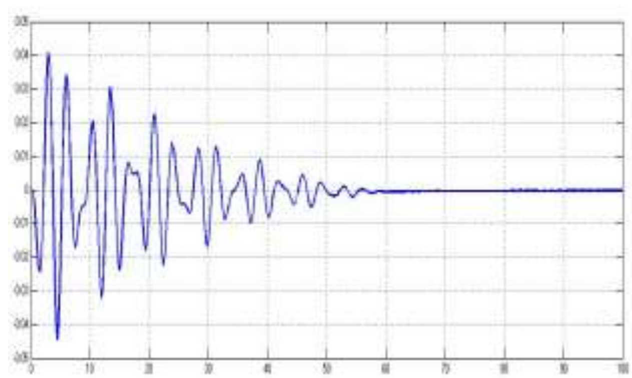


Fig.18: Change of frequency in tieline-1 without controller and PV system connected to all areas

There is no controller shown in the Simulink model of the 3-area LFC shown in Figure 15. The frequency shift between three sections of an interconnected system is seen in Figure 16 when just the PV system is linked. When the PV system was linked for all three regions without a controller, the frequency of tie-line 1 changed as shown in Figure 17, and the frequency of tie-line 2 changed as shown in Figure 18.

Case-5: system with PI controller and PV system connected to area-1

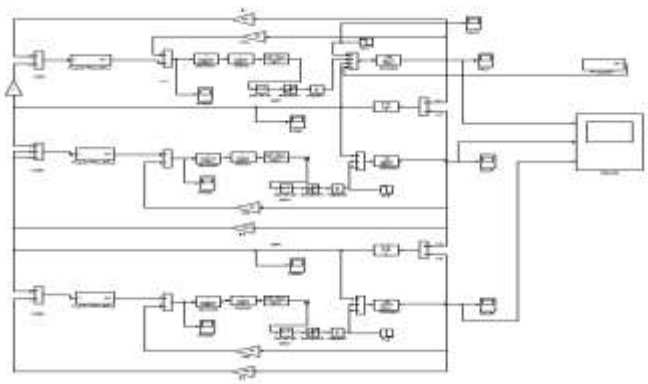


Fig.19: Simulink model of ALFC with PI controller and PV system connected to area-1

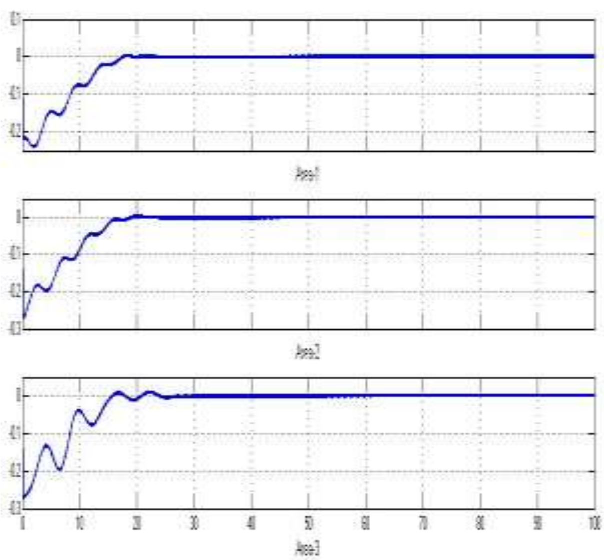


Fig.20: change in frequency of three areas with PI controller and PV system connected to area-1

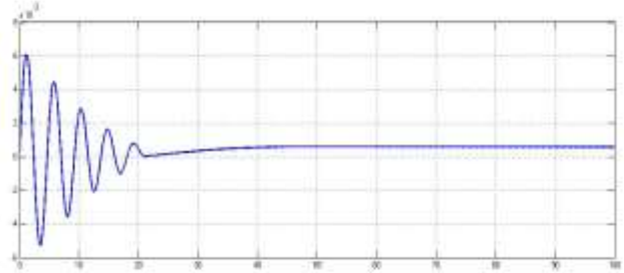


Fig.21: Change of frequency in tieline-1 with PI controller and PV system connected to area-1

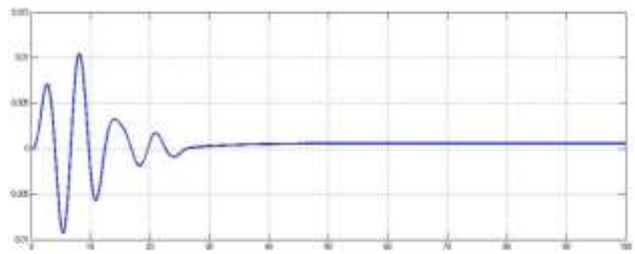


Fig.22: Change of frequency in tieline-2 with controller and PV system connected to area-1

The Simulink model of the three-area LFC with the PV system linked to area-1 with a PI controller is shown in Figure 19. Figure 20 depicts the variation in frequency across three sections of the linked system with just the area-1 PV system connected. When the PV system was simply linked to Area-1 with the PI controller, the results are shown in Figure 21 for the frequency shift on Tie-Line 1, and in Figure 22 for the frequency shift on Tie-Line 2.

Case-6: system with PI controller and PV system connected to area-2

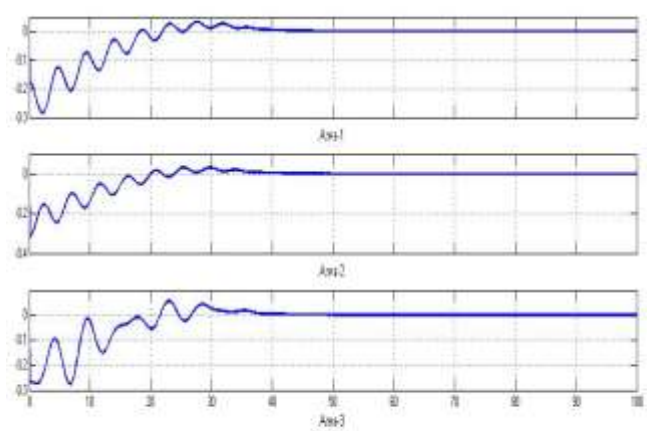


Fig.23: change in frequency of three areas with PI controller and PV system connected to area-12

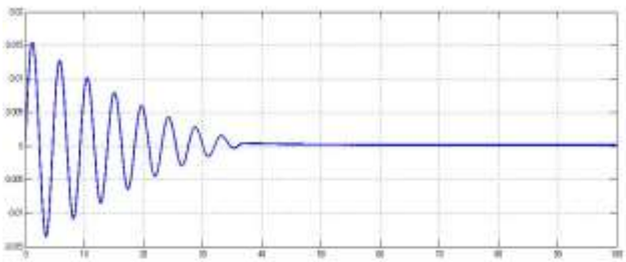


Fig.24: Change of frequency in tieline-1 with PI controller and PV system connected to area-2

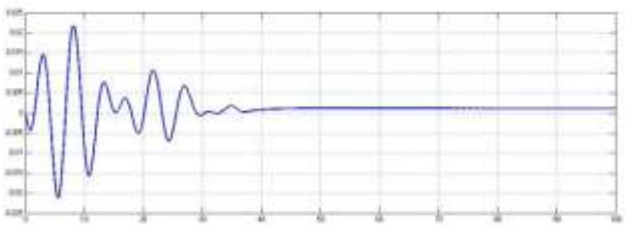


Fig.25: Change of frequency in tieline-2 with PI controller and PV system connected to area-2

The frequency shift across the three areas of the linked system is seen in Figure 23 when the PV system is connected to area-2 with a controller. Figure 24 depicts the frequency shift on tie-line 1 when just the area-2 PV system is coupled with the PI controller, and Figure 25 depicts the frequency shift on tie-line 2 under the same conditions.

Case-7: system with PI controller and PV system connected to area-3

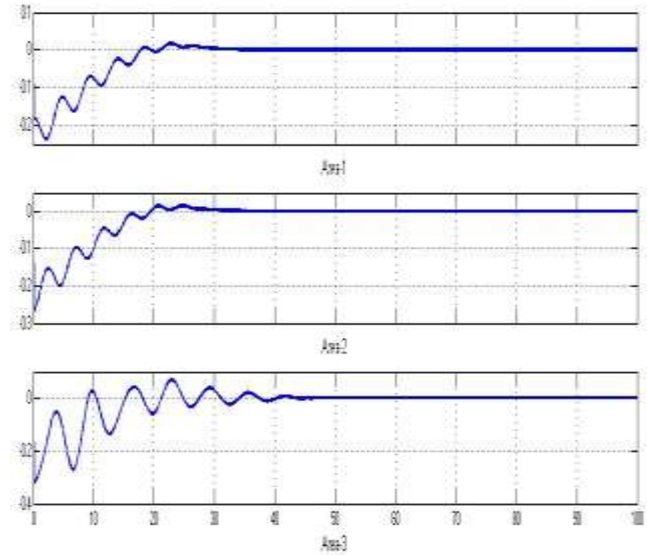


Fig.26: change in frequency of three areas with PI controller and PV system connected to area-3

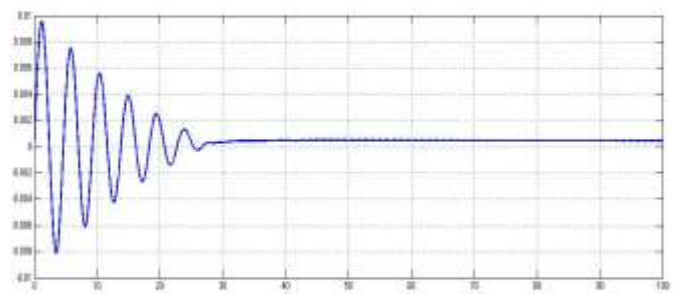


Fig.27: Change of frequency in tieline-1 with PI controller and PV system connected to area-3

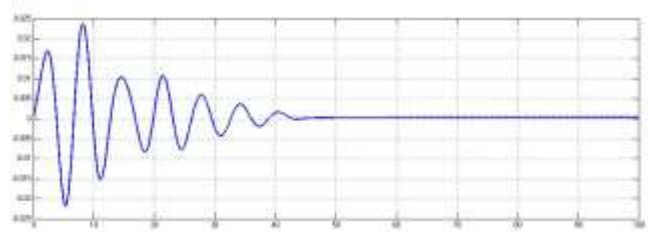


Fig.28: Change of frequency in tieline-2 without controller and PV system connected to area-3

The frequency shift across three parts of an interconnected system is seen in Figure 26 when the PV system is linked exclusively to the third part using the PI controller. When

PV system is linked solely for area-3 with PI controller, Figure 27 displays the frequency shift on tie-line 1, and Figure 28 displays the frequency shift on tie-line 2.

Case-8: system with PI controller and PV system connected to all three areas

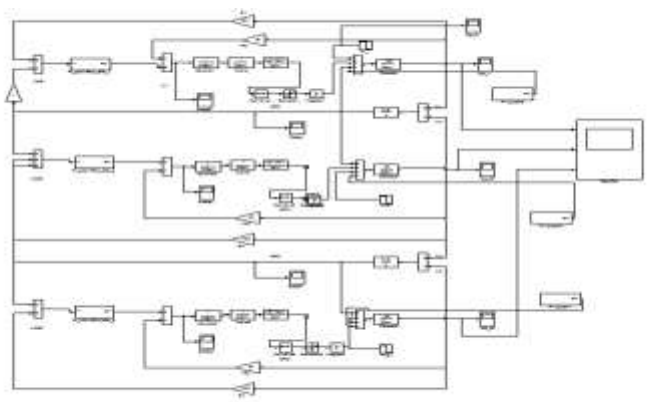


Fig.29: Simulink model of ALFC with PI controller and PV system connected to all areas

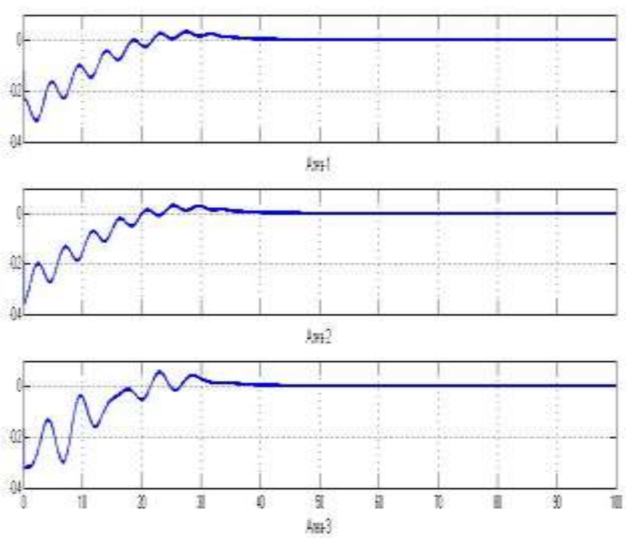


Fig.30: change in frequency of three areas with PI controller and PV system connected to all areas

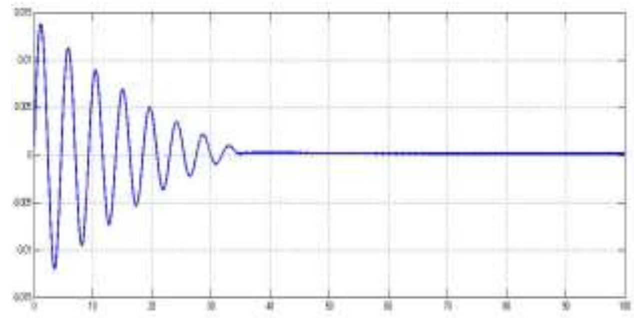


Fig.31: Change of frequency in tieline-1 with PI controller and PV system connected to all areas

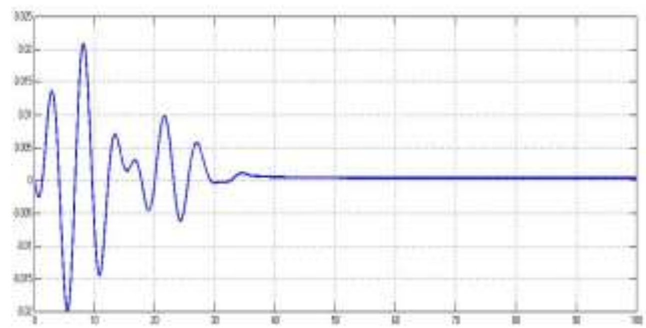


Fig.32: Change of frequency in tieline-2 with PI controller and PV system connected to all areas

Figure 29 displays the Simulink model of a 3-area LFC using a PI controller with the PV system linked to all three areas. Figure 30 depicts the variation in frequency across three linked locations when just the PV system is in use. Figure 31 depicts the frequency shift of tie-line 1 when just the PV system is connected in all regions controlled by the PI controller, and Figure 32 depicts the frequency shift of tie-line 2 under the same conditions.

Case-9: system with Fuzzy controller and PV system connected to area-1

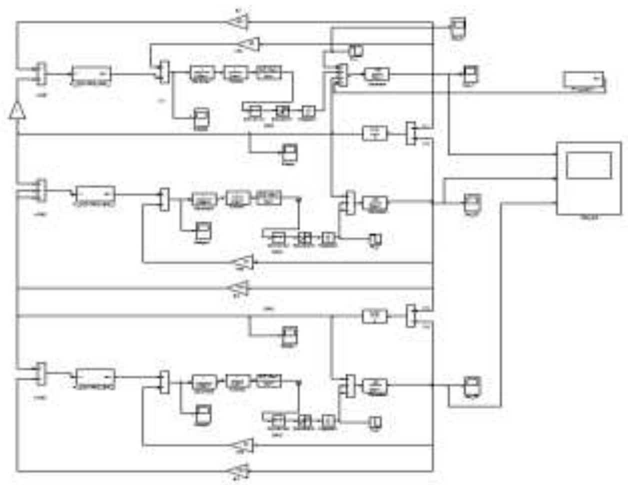


Fig.33: Simulink model of ALFC with FUZZY controller and PV system connected to area-1

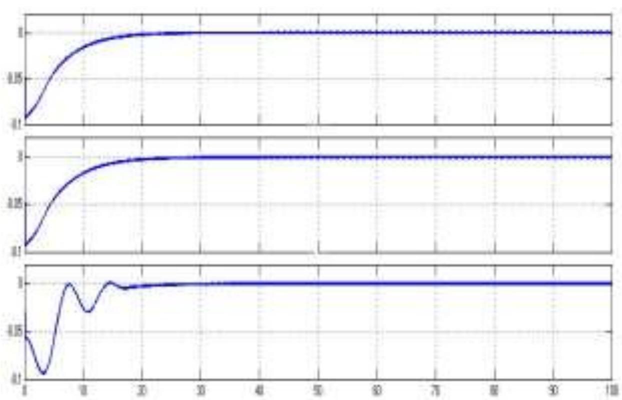


Fig.34: change in frequency of three areas with FUZZY controller and PV system connected to area-1

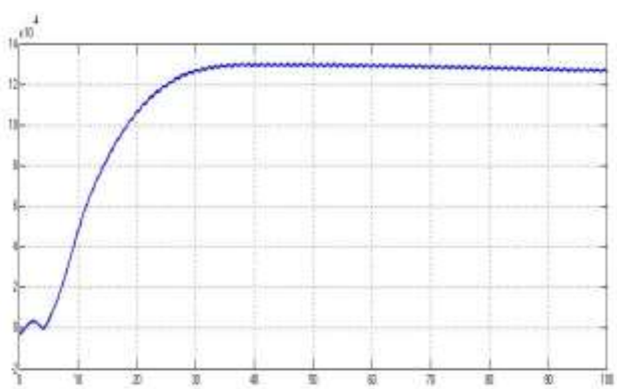


Fig.35: Change of frequency in tieline-1 with FUZZY controller and PV system connected to area-1

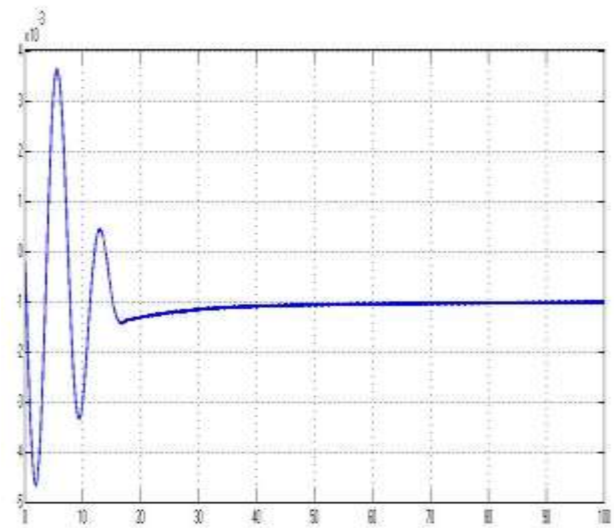


Fig.36: Change of frequency in tieline-2 with controller and PV system connected to area-1

The FUZZY controller is only linked to the PV system for area-1 in the Simulink model of the 3-area LFC shown in Figure 33. Figure 34 depicts the change in frequency of three regions of linked system when PV system connected just for area-1.When the PV system is solely linked to area-1 with the FUZZY controller, figures 35 and 36 illustrate the resulting frequency shifts on tie-lines 1 and 2, respectively.

Case-10: system with FUZZY controller and PV system connected to area-2

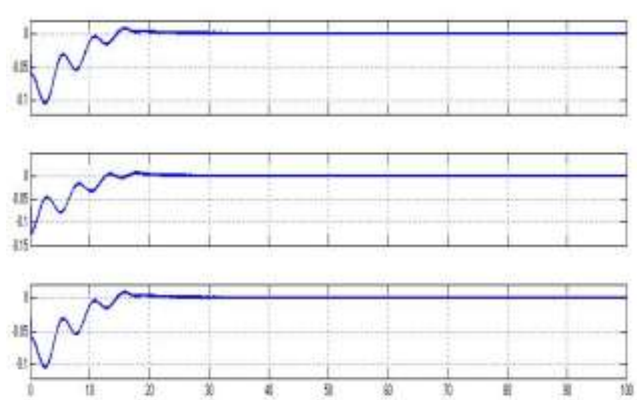


Fig.37: change in frequency of three areas with FUZZY controller and PV system connected to area-2

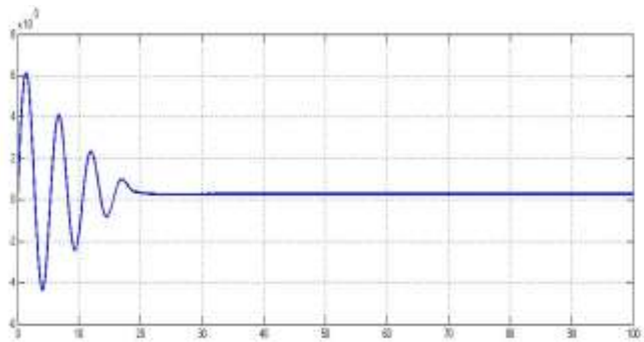


Fig.38: Change of frequency in tieline-1 with FUZZY controller and PV system connected to area-2

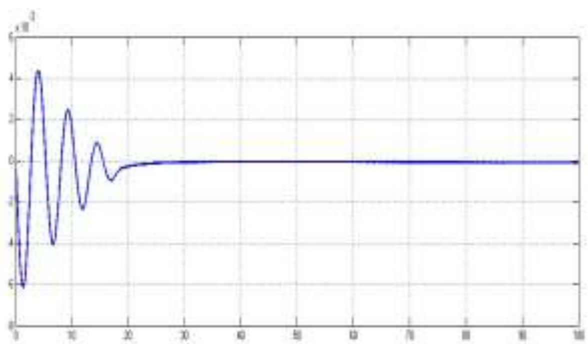


Fig.39: Change of frequency in tieline-2 with FUZZY controller and PV system connected to area-2

When just the second area of the linked system (area-2) is connected to the PV system with the controller, the frequency changes as shown in Figure 37. When the PV system is linked just for area-2 with the FUZZY controller, figures 38 and 39 depict the frequency shifts of tie-lines 1 and 2, respectively.

Case-11: system with FUZZY controller and PV system connected to area-3

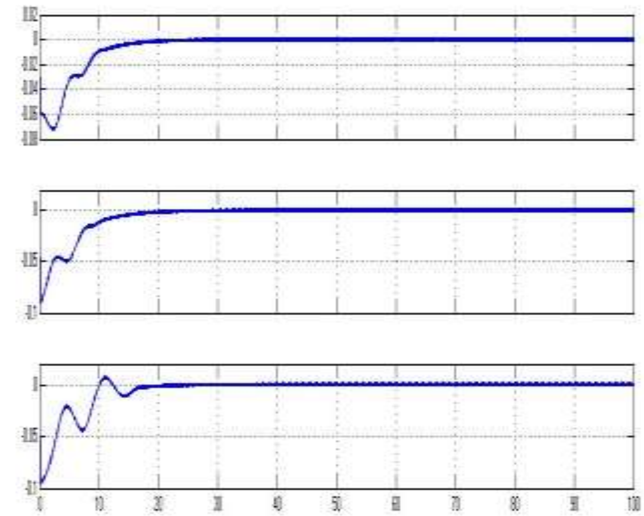


Fig.40: change in frequency of three areas with FUZZY controller and PV system connected to area-3

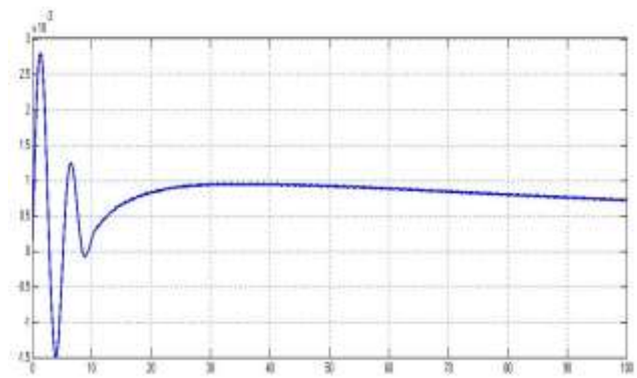


Fig.41: Change of frequency in tieline-1 with FUZZY controller and PV system connected to area-3

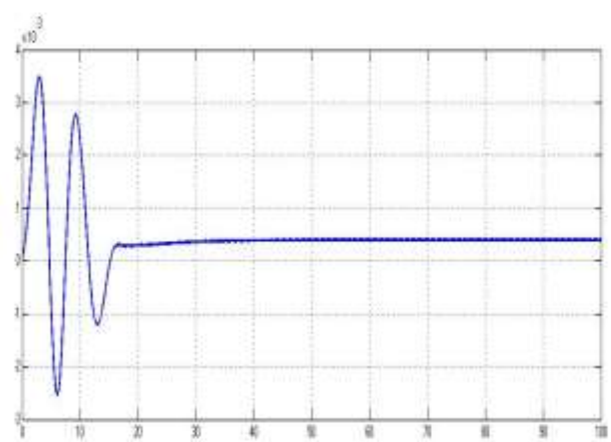


Fig.42: Change of frequency in tieline-2 without controller and PV system connected to area-3

The frequency shift between the three areas of the linked system is shown in Figure 40 when the PV system is connected exclusively for area-3 with the FUZZY controller. When PV system is linked solely for area-3 with FUZZY controller, Figure 41 displays the frequency shift on tie-line 1, and Figure 42 displays the frequency shift on tie-line 2.

Case-12: system with FUZZY controller and PV system connected to all three areas

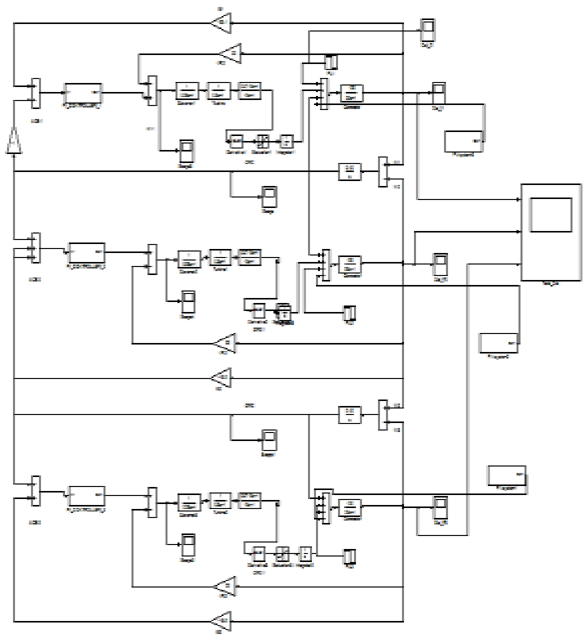


Fig.43: Simulink model of ALFC with FUZZY controller and PV system connected to all areas

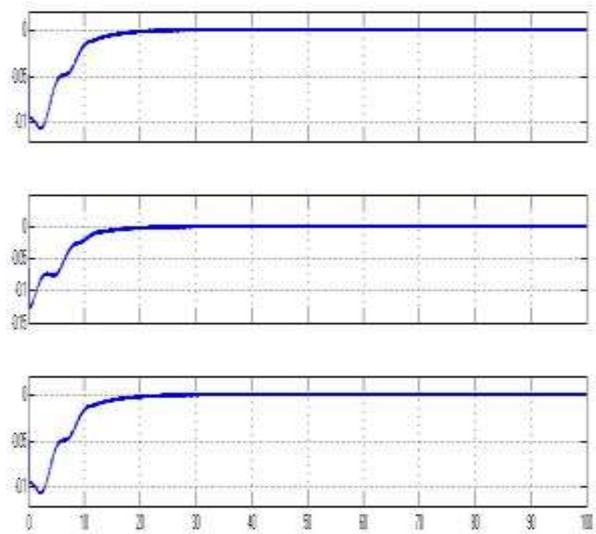


Fig.44: change in frequency of three areas with FUZZY controller and PV system connected to all areas

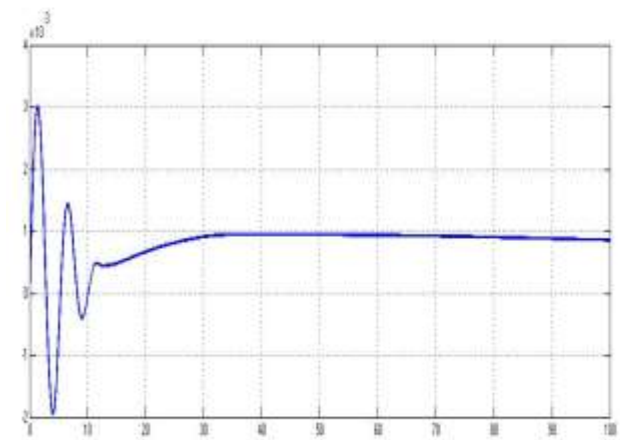


Fig.45: Change of frequency in tieline-1 with FUZZY controller and PV system connected to all areas

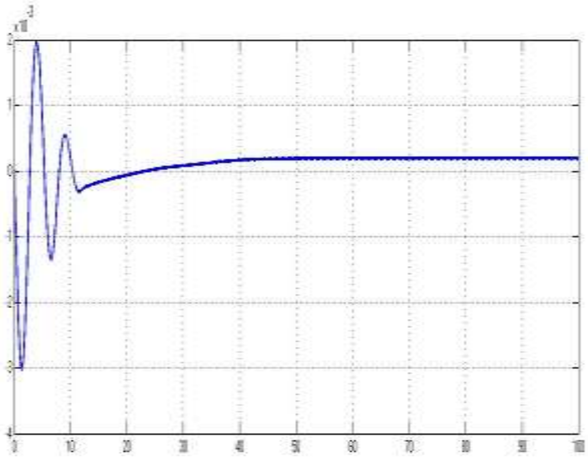


Fig.46: Change of frequency in tieline-2 with FUZZY controller and PV system connected to all areas

Figure 43 displays the Simulink model of a 3-area LFC using a FUZZY controller and a PV system that is linked to all three areas. The frequency shift between three linked locations is seen in Figure 44, where just the PV system is connected. When just the PV system is linked in all locations, the FUZZY controller causes a shift in frequency as shown in Figure 45 for Tie-Line 1, and as shown in Figure 46 for Tie-Line 2.

Table 1: Comparison of change in frequency in different areas of LFC with and without controller

Change in Frequency		PV in Area-1	PV in Area-2	PV in Area-3	PV in all three areas
Without Controller	Area-1	48	40	40	53
	Area-2	48	40	40	55
	Area-3	52	42	42	55
	Tie-line 1	48	40	40	56
	Tie-line 2	51	42	42	58
With PI Controller	Area-1	20	35	25	30
	Area-2	20	35	30	30
	Area-3	25	33	35	30
	Tie-line 1	22	35	27	33
	Tie-line 2	26	35	37	33
With Fuzzy Controller	Area-1	18	18	18	17
	Area-2	18	18	18	17
	Area-3	18	18	18	17
	Tie-line 1	20	18	23	30
	Tie-line 2	18	18	18	30

6. Conclusion

Managing the frequency of the loads is crucial, and any changes to the frequency must be managed or they may harm the functioning of the system. After connecting the PV system to the ALFC, this research examines the load frequency control. The investigation was done once PV system was linked purely to the realm one, space a pair of and exclusively to space three and thus the outcomes were compared once the PV was connected to all or any the 3 regions of ALFC. The ALFC controller and system were not included in the study. The comparison table shows that when the controller is in charge, the frequency change is limited to a shorter amount of time, however in a continuous system without a controller, the frequency takes a long period to settle down. Therefore, as comparison to a system without a controller, a system with a controller may reach its steady state for stable functioning in shorter time periods. Without a controller, the system needs a lot of time to find its stable frequency. When compared to an uncontrolled system, PI controllers may reduce frequency disturbance times significantly. When compared to the PI controller, the time saved by using a fuzzy controller is much greater.

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