

# Analyses of the Effect of DG Integration on Load Frequency Control in a 3-Area System with a PI Controller

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## Abstract

In this paper, we analyse the feasibility of employing photovoltaics to regulate load frequency across three geographically dispersed regions. The frequency of each adjustment was calculated, and the PV system was attached to each area requiring control. Unacceptable frequency fluctuations or oscillations in discrete areas of interconnected systems might have knock-on effects elsewhere in the system. A simple PI controller is used to maintain the desired system frequency. The PI controller requires little in the way of training before it can manage the frequency of the load. In this research, we compare the system without a PI controller to one with a controller and then assess the load frequency variations under each scenario. The results of this research may be used to compare the efficiency of a PV system with and without a load frequency controller in a linked system.

**Keywords:** Interconnection, Area, Frequency, Controller, PI, PV System.

## 1. Introduction

The AGC is responsible for balancing the system's total generation with its total load and losses in order to maintain the appropriate frequency and power exchange with surrounding systems. If there is a discrepancy between supply and demand, the system's frequency will diverge from its average value. This means that high-frequency variations in the system might cause failure. A quick and precise controller is needed to keep the nominal frequency stable. Traditional controls are slow and inefficient when dealing with non-linearities in the system. This fact justifies the development of an automatic gain controller. By matching the power output of the electrical generator with the demand for energy, automated generation control (AGC) aims to maintain the frequency within acceptable limits in response to changes in the system and tie-line loads. This capability is often referred to as load frequency

control (LFC). International connections between power networks are quite widespread for reasons of redundancy. In addition to increasing system reliability, interconnection also raises system efficiency. Given the scale and complexity of the system, careful analysis is more important than ever before for maintaining its steady operation. The addition of additional utilities has made the existing system more complex, which may exacerbate the supply-and-demand mismatch [2]. Inadequate damping and subsequent inter-area oscillations may result from heavy load circumstances in tie-lines brought on by electric power exchange. Unpredictable loading conditions further complicate the process. This has been a major concern ever since the establishment of interconnected power grids. That's why AGC is so important to the power grid: it automatically adjusts the amount of energy being produced. few initiatives have been performed out for the AGC of connected power systems throughout recent few decades [3]-[7].

Automatic Generation Control (AGC) allows dispatchers to adjust the relative phase angle between two system voltages, perhaps allowing for more precise regulation of real power transfers between two connected power systems. Power flow oscillations after a load disturbance in either zone are dampened as a result. Series correction in phase shifters may also aid in increasing reliability [8-9]. Attractive about phase shifters is the potential to increase steadiness by taking use of their lightning-fast reactions. The purpose of the automatic generator controller (AGC) is to regulate the flow of electricity in a power grid efficiently. Dampening electromechanical oscillations in the power system [2] is a common application for the kinetic energy of the generator rotor to meet unexpected surges in power demand.

Solar power is quickly becoming one of the most viable alternatives to conventional energy sources like pollution and dwindling fossil fuel supplies in order to keep up with the ever-increasing demand for electricity. Solar power has a number of benefits over the current system, including being lightweight and easy to transport, lasting a long time with little care,

and providing a lot of energy for its size. The photovoltaic (PV) cell is the part of a solar power system that converts light into energy. This might provide a DC voltage with an output that fluctuates with the quantity of stellar radiation and ambient temperature.

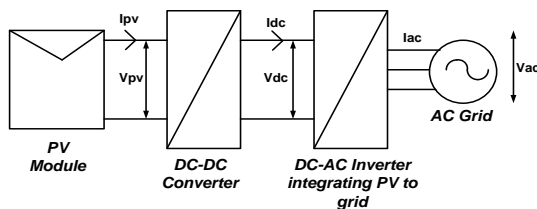


Fig.1: System with PV integration to utility Grid

To provide maximum output power in non-standard working settings, it serves a special operational purpose. The most efficient power point tracking (MPPT) enables us to simply get maximum power and might form part of a power acquisition system. In order to maximise electricity production from photovoltaic (PV) modules despite shifting climatic circumstances, a power acquisition system (PCS) is used. A boost DC-DC converter is used to transform a variable low DC input voltage into a steady high DC output voltage. When compared to other renewable energy sources, solar is the most powerful with zero carbon emissions. A device called a cell is necessary for transforming solar energy into electricity. A panel consists of a network of cells working together. An array is a group of panels that have been electrically connected asynchronously, while a generator is a collection of arrays that have been connected in parallel to generate the necessary quantity of electricity.

Electrical phenomena systems are becoming more and more widespread, making distribution systems a logical match. Power distribution networks have become increasingly decentralised as a result of the increased usage of renewable energy made possible by government incentives. Recent studies reveal an exponential increase in the worldwide electrical phenomena's power capacity. The focus of current studies is on discovering methods to both reduce expenses and boost productivity. Photovoltaics (PV)

is a technology that can transform solar energy back into direct current (DC) electricity. Star cells still can't provide enough energy for the world's population because of their hefty upfront cost. PV cells provide DC energy, which may be used immediately. Most household and commercial electrical equipment runs on alternating current (AC), thus this DC power must be regenerated. An electrical converter is used to change the power that the PV cells generate from direct current (DC) to alternating current (AC). The power, which would be alternating current, might be sold to a utility. Small loads, such as lights and DC motors, could be driven directly from the terminal voltage and current of a PV device. Electronic converters are needed to allow for more flexible usage of PV system electricity. These converters may also be used to control the voltage and current of loads in grid-connected systems. Power is sent from the cell to the DC-DC boost converter, which increases the input voltage to the required DC level before supplying it to the DC-AC inverter.

Both the depletion of fossil fuel supplies and the release of greenhouse gases, which contribute to global warming, are problems associated with conventional power plants. Long-distance transmission of power also increases losses. As a consequence, distributed generation (DG) emerged, wherein power is generated close to the demand using RES to reduce transmission losses and air pollution. Due to DG's extensive acceptance, several researchers have lately zeroed in on medium and low voltage transmission of energy. Using a PV system to produce power has little or minimal negative effects on the environment. However, frequency fluctuations may be brought about by PV system integration into the area. Here, we examine the challenge of load frequency regulation throughout a three-area system in which each zone is equipped with its own PV connection. We compared the frequency change in a three-area networked system with and without the PI controller. A boost converter is used to enhance the low voltage output of a PV system to the required voltage level for connecting the PV system to the grid. The output of the boost produces a DC voltage that is quite high. Once converted to AC, this DC output is added to the electrical grid. In this research,

we showed how a PV system, a boost converter, and an inverter can all be modelled mathematically.

## 2. ALFC for Frequency Control

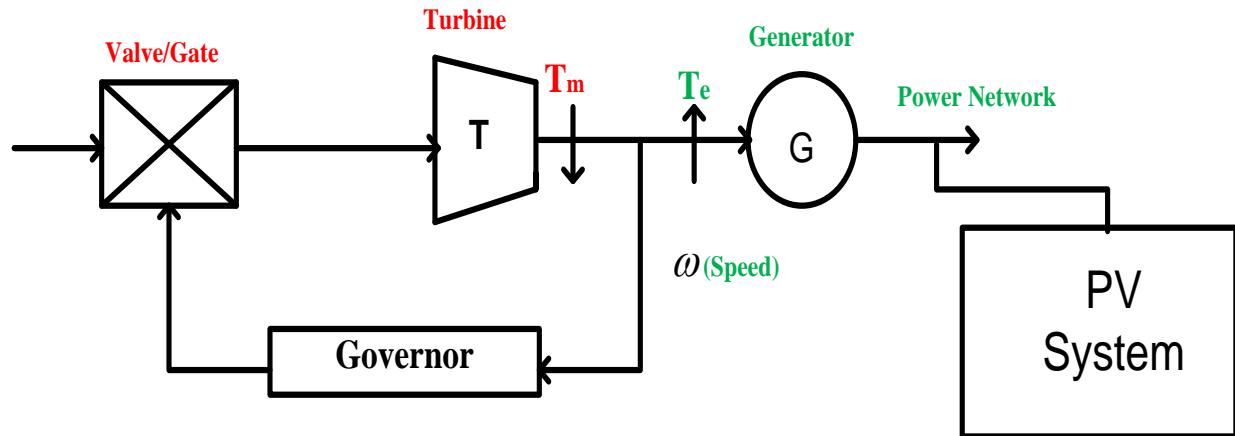


Fig.1. Schematic representation of ALFC system

Figure 1 shows a simplified diagram of a PV-integrated automatic load frequency control (ALFC) system. In this configuration, steam or water is used to generate electricity for the turbine. The turbine's input may be changed via a valve. The kinetic energy of a fluid flow is converted into rotational motion by a mechanical device known as a turbine. To identify a turbine, which is a kind of turbo machine, just look for a shaft or drum that has blades connected to it. As a consequence of the fluid's action, the blades rotate

and provide rotational energy to the rotor. This situation might be powered by a water turbine, steam turbine, gas turbine, or wind turbine. The turbine shaft is coupled mechanically to the generator. The alternator is a device that converts mechanical energy into electrical power. This energy may be distributed into the grid via a transformer interface. In addition to the PV system, the ALFC system was also connected.

### 2.1 Single Area Control

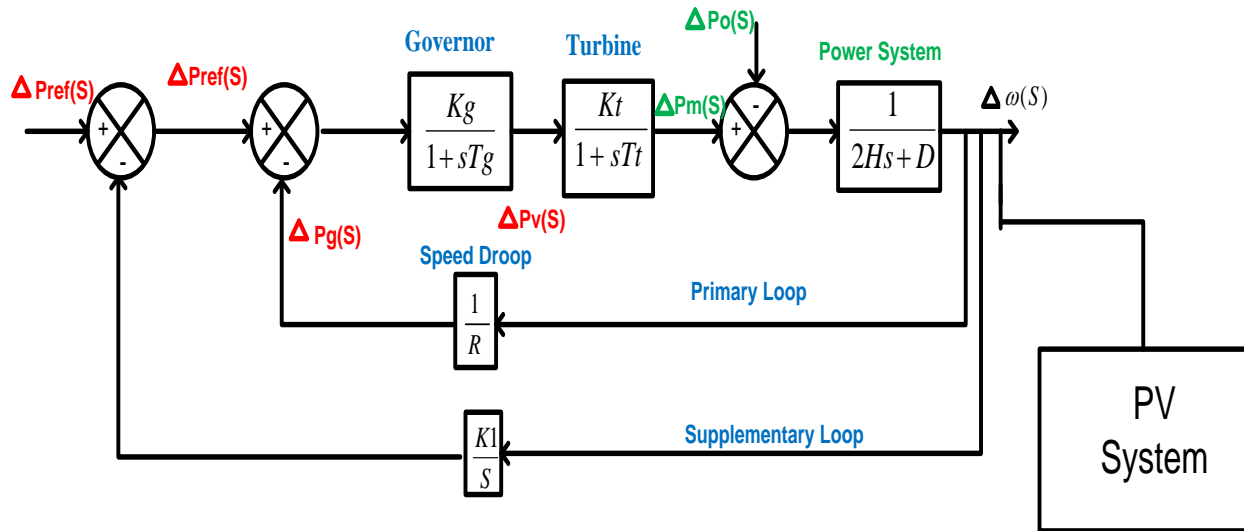


Fig.2.The block diagram representation of single area AGC with PV system

In Fig. 2, we have a block schematic of an automatic generation control system for a PV system with a single installation area. In this block diagram, there are two loops: the primary loop and the secondary loop. The primary loop regulates turbine output to meet variable load conditions and maintain constant power delivery. Regardless of variations, the load is maintained by the other power plants. However, this results in supply schedule variations. These frequency differences may be regulated by a supplementary loop, an additional control loop. Using an integral controller, we can ensure that the frequency variation in this loop is exactly 0. When PV systems are connected to the grid, frequency changes may occur, requiring control. Connectivity between the PV system and the localised FCU is shown in the diagram.

### 3 Interconnected Power System

International connections between power networks are quite widespread for reasons of redundancy. In addition to increasing system reliability, interconnection also raises system efficiency. Given the scale and complexity of the system, careful analysis is more important than ever before for maintaining its steady operation.

#### 3.1 Three-Area System without ALFC

The addition of additional utilities has made the existing system more complex, which may

exacerbate the supply-and-demand mismatch [2]. Extreme load circumstances on tie-lines due to electric power exchange might result in inter-area oscillations. Unpredictable loading conditions further complicate the process. This has been a major concern ever since the establishment of interconnected power grids. The whole connected generating system is shown in block form in fig. 3. There is a network of tie lines that links the three power plants together.

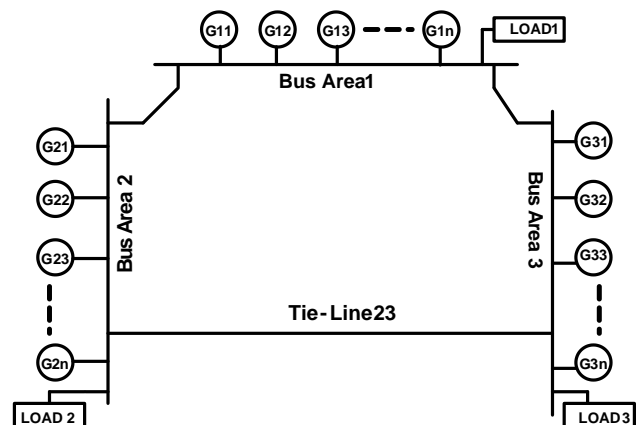


Fig. 3. Three-area power generation system

### 3.2 Three-Area ALFC with PV system

The method to control is based on frequency-domain techniques such as Fourier analysis, wavelet analysis, and infinite impulse response. Harmonic components are recovered from harmonically polluted data using Fourier transformation or wavelet transformation to provide compensating instructions. When used online, Fourier transform or wavelet transform (the

solution to a set of nonlinear equations) causes a very long reaction time. As a result, this creates difficulties for real-time applications with dynamic requirements. Figure 4 depicts the PV system's connection to the ALFC using the example of a three area system.

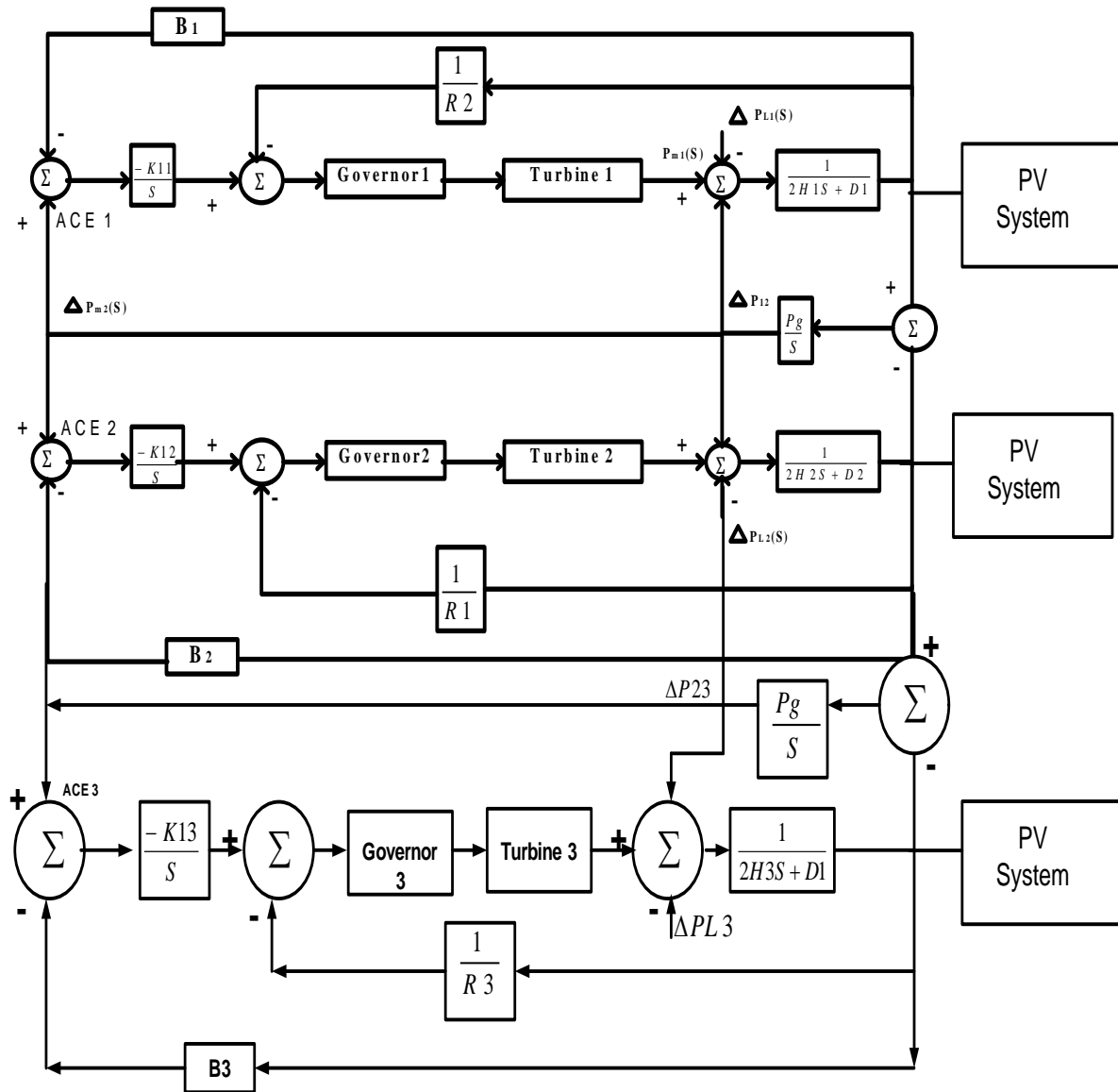


Fig.4. AGC for three-area operation with interconnected PV system.

(a) Current in a PV array is transformed into instantaneous power using a transfer function defined as

$$\frac{p(s)}{I_{pv}(s)} = \frac{p(s)}{i_{ac}(s)} \frac{i_{ac}(s)}{I_{pv}(s)} = \frac{p(s)}{i_{ac}(s)} \frac{i_{ac}(s)}{I_{dc}(s)} \frac{I_{dc}(s)}{I_{pv}(s)} \tag{1}$$

The eqn depicts the transfer function from the input current of the solar panel to the output current of the averaging module, P. (2)

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

The transfer function for a PV cell may be expressed in its simplest form as

$$\frac{I_{pv}}{\text{solar irradiation}} = k \quad (3)$$

(b) However, as demonstrated in the following equation [4]-[6], the transfer function of a boost converter in real time implementation may be stated with more precision.

$$G'_1(s) = \frac{H_1}{1 + s\frac{L}{R} + s^2LC} = \frac{\frac{H_1}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} \quad (3)$$

(c) The inverter's transfer function at input and output is

$$V_C(S) = \frac{1}{L_f C_f S^2 + j R_f C_f} V_A(S) - \frac{L_f S + R_f}{L_f C_f S^2 + j R_f C_f + 1} I_o(S) \quad (4)$$

$$\frac{V_C(S)}{V_A(S)} = \frac{Z_L}{s^2 L_f C_f + s L_f + R_f C_f s Z_L + R_f + Z_L} \quad (5)$$

By summing the transfer functions of the photovoltaic array, the boost converter, and the inverter, we can get the system's total transfer function.

$$\frac{P}{V_a(s)} = \frac{s^2}{(s^2 + \omega^2)} \frac{V(s^2 + \omega^2)(s^2 + 2\omega^2)(1 - e^{-sT_s})}{KS^2(s^2 + 4\omega^2)} \frac{1}{sT_s} * \frac{H_1}{1 + s\frac{L}{R} + s^2LC} = \frac{\frac{H_1}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} * \frac{Z_L}{s^2 L_f C_f + s L_f + R_f C_f s Z_L + R_f + Z_L} \quad (6)$$

#### 4. Matlab/Simulation Results And Discussions

Case-1: system and PV system linked to area-1 without a controller

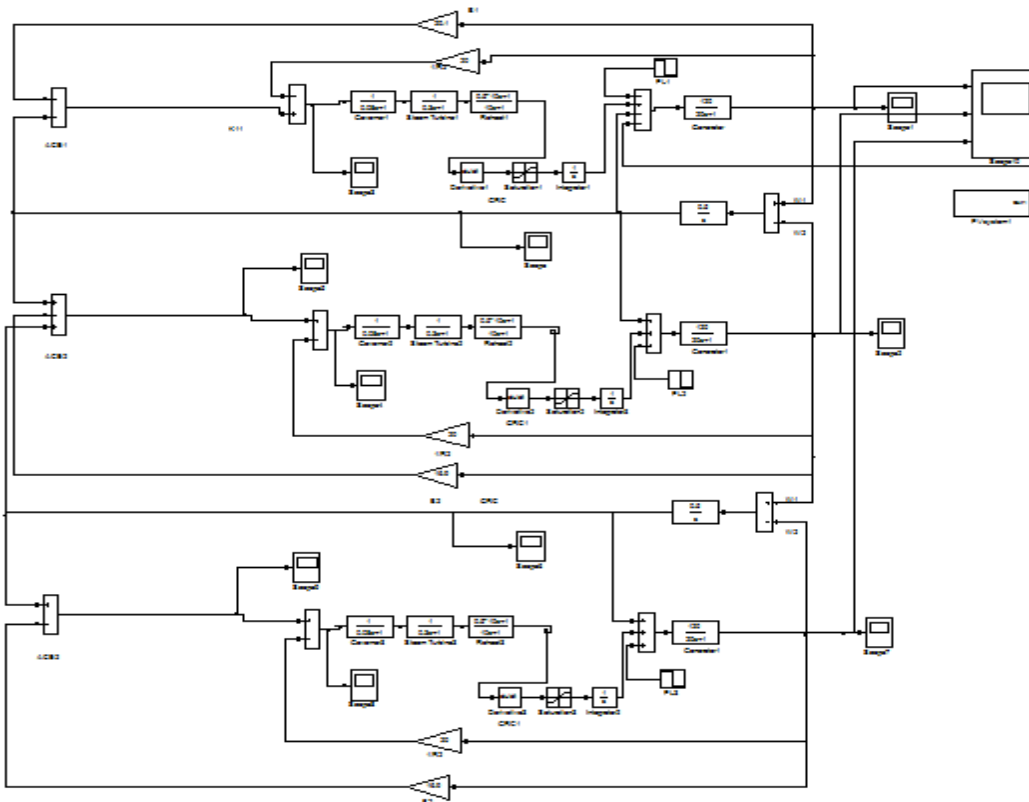


Fig.5: The ALFC and PV system linked to area-1 in Simulink without a controller.

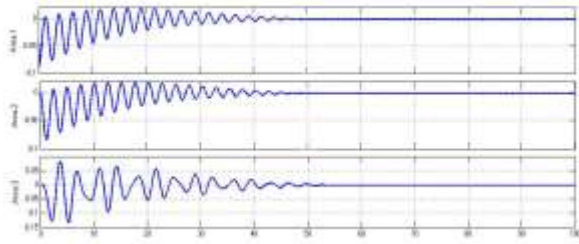


Fig.6: frequency shift in three locations without controller or PV system in area-1

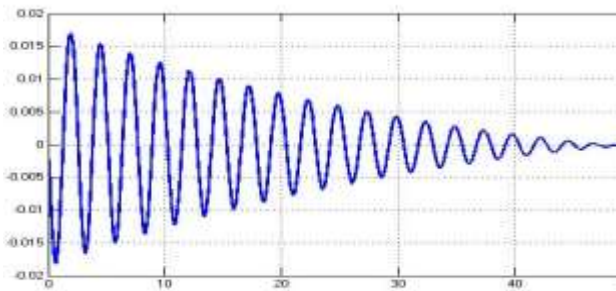


Fig.7: Frequency shift on tieline-1, which has no controller and is connected to an area-1 PV system

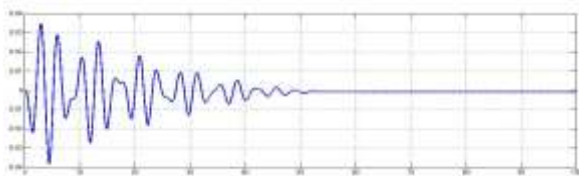


Fig.8: Frequency shift on tieline-2 due to PV system in area-1 but no controller

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). When just PV system linked for area-1 of interconnected system, frequency change as shown in Figure 6. 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, and the PV system attached to Area-2, none of which have a controller

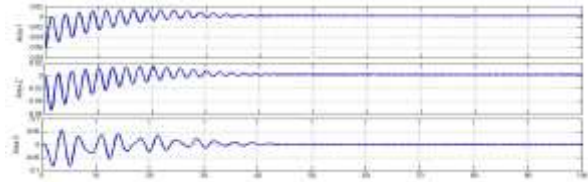


Fig.9: frequency shift in three locations devoid of a controller and the area-2 PV system

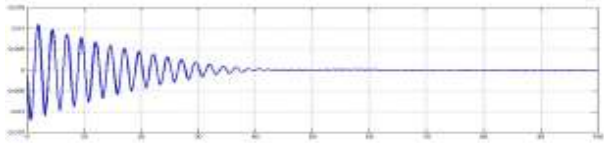


Fig.10: Frequency shift on tieline-1, no controller present, and PV system in area-2

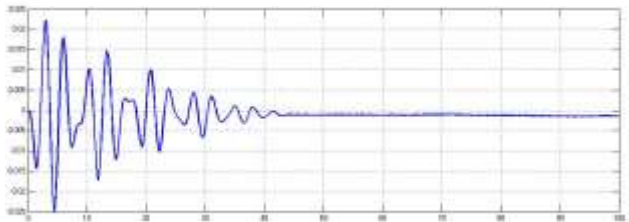


Fig.11: Frequency shift on tieline-2 due to an unregulated photovoltaic (PV) installation feeding area-2

When the PV system was simply linked to area-2 without a controller, as shown in Figure 9, the frequency in all three regions of the interconnected system changed. When the PV system is linked just for area-2 without a controller, the frequency of tie-line 1 changes as shown in Figure 10, and the frequency of tie-line 2 changes as shown in Figure 11.

Case-3: system and PV system linked to location 3 without a controller

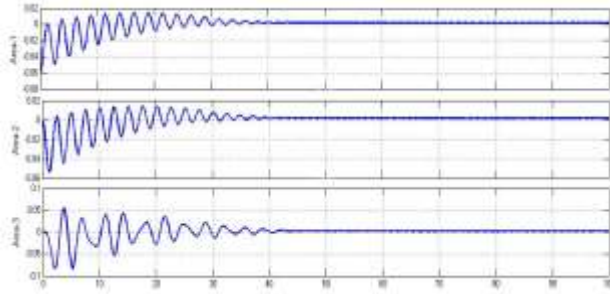
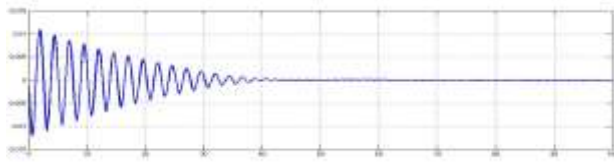


Fig.12: frequency shift in three locations without a controller and a photovoltaic system attached to location three



Case-4: system without a controller and a photovoltaic array connected to all three locations

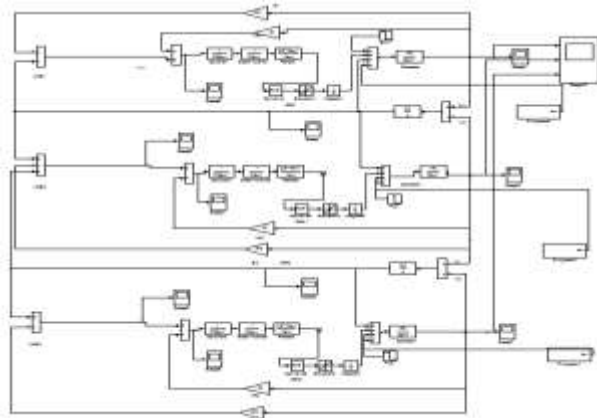


Fig.15: Connecting the PV system to all three zones, and modelling an ALFC in Simulink without a controller.

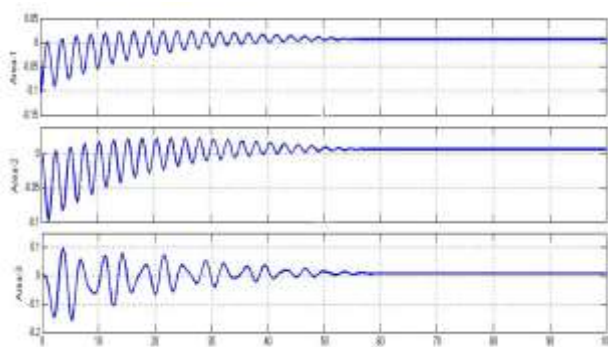


Fig.13: Frequency shift on tieline-1, no controller present, and PV system in area-3

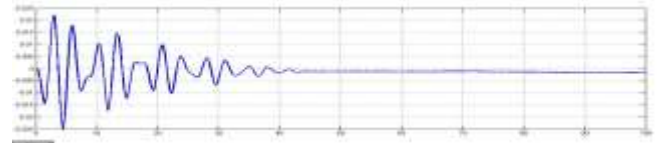


Fig.14: Frequency shift on tieline 3 due to PV system in area 3 but no controller

Figure 12 depicts the frequency shift over a three-area network without a controller, where only the PV system is linked to area-3. When the PV system is linked simply for Area-3 without a controller, Figure 13 displays the frequency shift on Tie-Line 1, whereas Figure 14 displays the frequency shift on Tie-Line 2.

Fig.16: frequency shift in three locations when no controller or PV system is attached

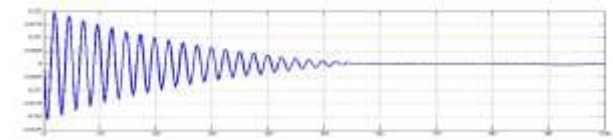


Fig.17: Frequency shift on tieline-1, no controller present, all regions wired to PV.

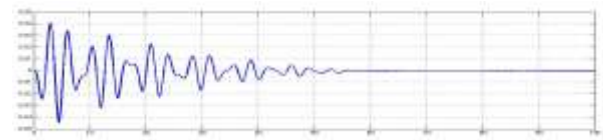


Fig.18: Frequency shift on tieline-1, no controller present, all regions wired to PV.

There is no controller shown in the Simulink model of the 3-area LFC shown in Figure 15. Figure 16 depicts the variation in frequency across three locations of an interconnected system 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: area-1 linked system consisting of a PI controller and a PV array

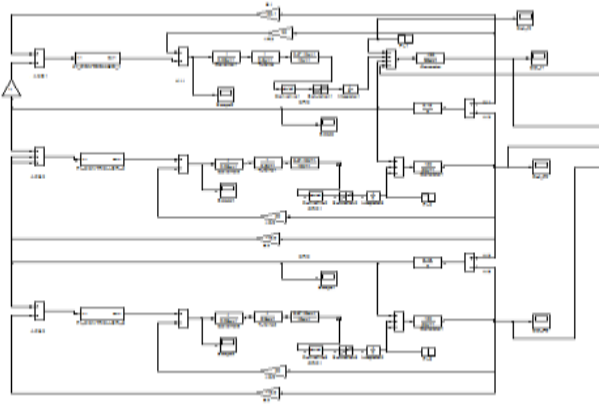


Fig.19: Area-1 PV system coupled to an ALFC modelled in Simulink.

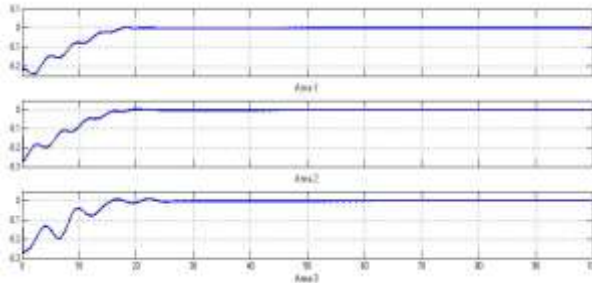


Fig.20: Three-area frequency shift controlled by a PI controller and a photovoltaic array linked to area-1.

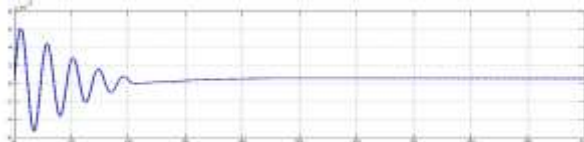


Fig.21: Frequency shift in tieline-1 using a proportional-integral (PI) controller and a photovoltaic (PV) system serving Area

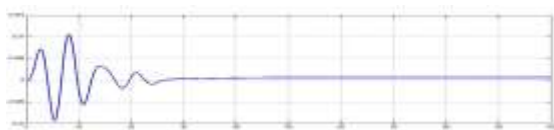


Fig.22: Tieline-2 frequency shift with controller and photovoltaic system linked to zone-1

The Simulink model of a 3-area LFC with a PV system linked to Area-1 using a PI controller is shown in Figure 19. In Figure 20, we can see how the three regions of the linked system differ in their frequency when just the area-1 PV system is

connected. Figure 21 depicts the frequency shift on tie-line 1 when the PV system is linked exclusively to area-1 with the PI controller, and Figure 22 depicts the frequency shift on tie-line 2 under the same conditions.

Case-6: area-2 system that uses a PI controller and a photovoltaic array

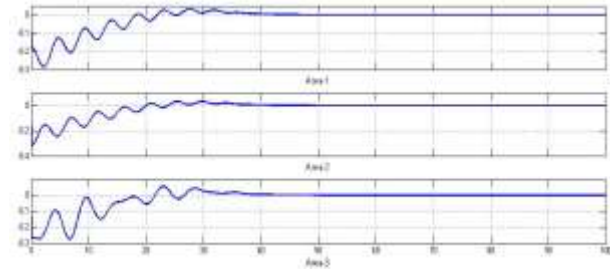


Fig.23: three-area frequency shift controlled by a PI controller and powered by a PV array in the 12th area.

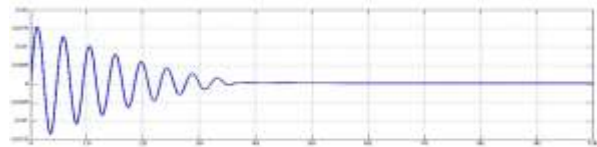


Fig.24: Modulation of Tieline-1 Frequency using PI-Controlled Photovoltaic System Serving Area-2

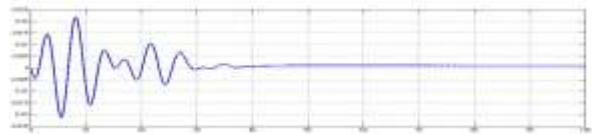


Fig.25: Tieline-2 frequency shift with proportional integral (PI) controller and PV system in area-2

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. When the PV system was simply linked to Area-2 with the PI controller, the results are shown in Figure 24 for the frequency shift on Tie-Line 1, and in Figure 25 for the frequency shift on Tie-Line 2.

Case-7: area-3 linked system consisting of a PI controller and a PV array

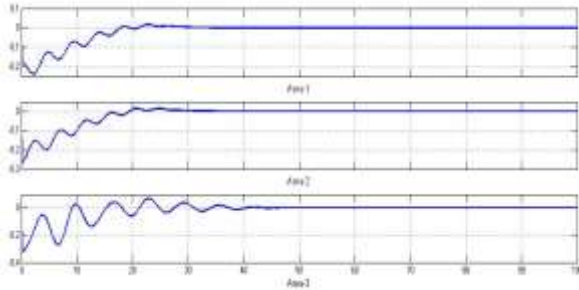


Fig.26: frequency shift in three zones using a PI controller and a PV system linked to zone 3.

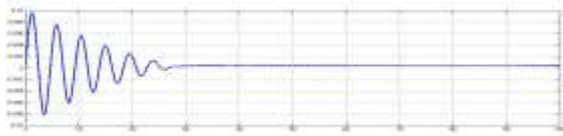


Fig.27: Frequency shift in tieline-1 using a proportional-integral (PI) controller and a photovoltaic (PV) system

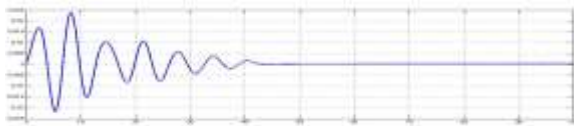


Fig.28: Frequency shift on tieline-2 without a controller, with a photovoltaic system hooked up to zone-3

Figure 26 displays the frequency shift across three independent subsystems when a PV system is linked to just area-3 using a PI controller. When the PV system is linked exclusively for area-3 with the PI controller, the frequency of tie-line 1 (Figure 27) and tie-line 2 (Figure 28) shift.

Case-8: system equipped with a PI controller and a PV system linked to all three sections

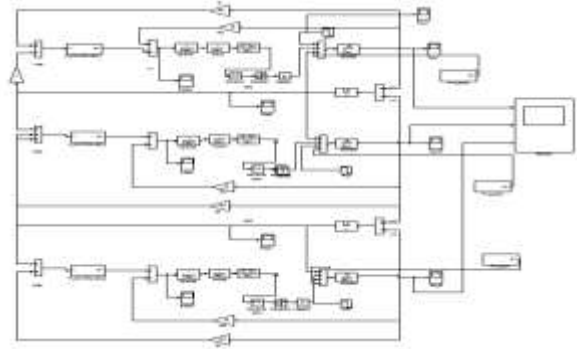


Fig.29: Model of an ALFC in Simulink, complete with PI controller and PV system

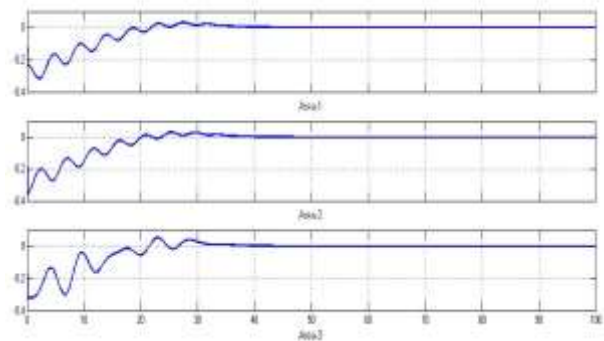


Fig.30: frequency shift in three locations using a proportional integral (PI) controller and a photovoltaic (PV) system that is wire

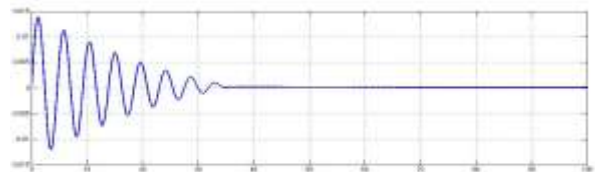


Fig.31: Frequency shift in tieline-1 using a proportional integral (PI) controller and a PV system that serves all regions

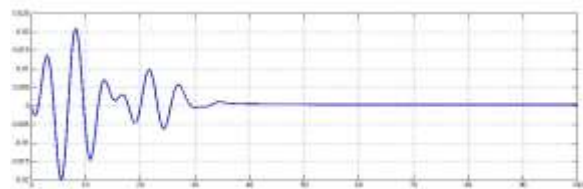


Fig.32: Tieline-2 frequency shift with programmable integral (PI) controller and distributed photovoltaic (PV) system

Figure 29 displays the Simulink model of a three-area LFC using a PI controller with the PV system linked to all three areas. When just the PV system is linked to all regions, as shown in Figure 30, the frequency in all three areas changes. When the PV system is the

sole source of power in all locations, the frequency of tie-line 1 changes as shown in Figure 31, and the frequency of tie-line 2 changes as shown in Figure 32.

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

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

## 5. Conclusion

Managing the load's frequency is important because fluctuations in frequency may degrade system performance if not handled properly. An ALFC and PV system were used to conduct research on load frequency management, the findings of which are presented in this study. The PV system's effect on all three ALFC zones was examined with and without it installed, and the results were compared. The ALFC system was investigated in both its uncontrolled and regulated forms. It is obvious from the comparison table that the time it takes for the frequency to stabilise when the system is controlled by the controller is much shorter than when the same system is operated without a controller. The controller shortens the time it takes for the system to reach steady state, allowing it to work reliably, compared to a system without a controller.

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