Effect of PV Based Power Generation in Automatic Generation Control of the Interconnected Power System

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

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IN
ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

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CERTIFICATE

This is to certify that the Major Project Report entilted **"Effect of PV Based Power Generation in Automatic Generation Control of the Interconnected Power System"** submitted by **Ms. Harnisha Barot (19MEEE17)** towards the fulfillment of the requirement for semester IV of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems in Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institute.

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ABSTRACT

The most important part of the power system is to stabilize the frequency and load. In this paper, automatic generation control (AGC) with additional photovoltaic (PV) system is interconnected with system. To regulate the power system and balance the frequency, Proportional-integral (PI), integral (I) and Proportional-integral-derivative (PID) controllers are connected to each area. This makes it easier to keep the frequency near to its nominal value. Here, the dynamics of the system are evaluated using step load perturbation and random load perturbation in area. The frequency control study is performed using MATLAB Simulink software. The performance of the controller's effectiveness is investigated using performance such as settling time, over shoot and variation in frequency. Based on the simulation study, it is observed that PID controller has better response than the PI controller. As PID controller has fast settling time and steady state error is less compared to PID controller.

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Chapter 1

Introduction

1.1 Overview

Nowadays, the key issue of the power sector is the availability of cost-effective and continuous power. Moreover, it is becoming difficult to sustain the balance between the generation and energy required due to increased demand electric demand. By active and reactive power management, the equilibrium in the power system can be achieved. In Great Britain, the National Grid is the system operator that is responsible for maintaining the frequency response of the power system within acceptable limits. Two main levels define these limits: the operational limit, which is equal to ±0.2 Hz (i.e. 49.8 Hz to 50.2 Hz), and the statutory limit, which is equal to ±0.5 Hz (i.e. 49.5 Hz and 50.5 Hz) [20].

By controlling the load reference points of the selected generating units, the fundamentalmeans of controlling prime mover power to balance variations in device load. Since thereis zero cross coupling between the LFC block and the AVR block [21], frequency and voltagemodulation may be done concurrently and separately. The fact that the time constant of theexcitation mechanism is much smaller than the time constant of the prime mover accounts forthe marginal cross coupling between the blocks. By using the controllers can get the nominal values of frequency and tie-line power within specified limit.

A small load perturbation in system may cause mismatch in frequency and tie-line power flow from its original value. To overcome this issue, Automatic Generation Control adjusts generation automatically to return the frequency to the nominal value as the processor load varies continuously. And to overcome the issue of voltage deviation, Automatic Voltage Regulator (AVR) is used. The generator excitation regulation using an automatic voltage regulator (AVR) is the primary means of regulating generator reactive power. The voltage profile is controlled by the reactive power control, and the active power generation manages the frequency level of the device as per the necessary demand and hence, ensure the power users get quality energy.

In an integrated power system with two or more separately operated zones, in response to frequency control, the generation of each region must be controlled such that tie - line power exchange is maintained. Load frequency control (LFC) refers to the control of generation and frequency.

The impact of distributed generation technologies such as wind turbines, solar photovoltaics, and fuel cells on modern power systems is extensively investigated by numerous authors in their LFC research papers. Solar adoption is expected to grow significantly in the future smart grid. As a consequence, power grid tie-line power and frequency can fluctuate. However, plug-in hybrid electric vehicles (PHEV) are widely planned to be deployed on the customer side. Power and frequency fluctuations can be stabilised using PHEV's bidirectional power modulation. The control configuration of a bidirectional power controller of a PHEV for robust smart grid frequency stabilisation with a photovoltaic device is presented here. Plug-in hybrid electric cars (PHEV) are widely planned to be deployed on the customer side. With enough energy stored in the PHEV's battery, the bidirectional charging and discharging power management of PHEVs or the vehicle to grid (V2G) principle can be used to reduce power fluctuations. The power charging control of PHEV has been applied to control frequency in an integrated power grid with PV system.

In this case, a bidirectional power charging controller of a PHEV for frequency fluctuation stability in a smart grid with a PV configuration is used. To achieve high efficiency and robustness, the PI control parameters of the PHEV controller are calibrated.

1.2 Reasons for maintaining constant frequency

In steady state, the frequency across a synchronous power grid is the same. The ability to maintain a near-constant frequency is recognized as a significant necessity of power system operation.

1) Normal operating of frequency is 50Hz. Variation of frequency beyond this limit can damage the turbine blade. A 50 Hz steam turbine cannot withstand the frequency deviation of +2.5 or -2.5 Hz.

2) Electrical equipment is usually designed to operate at a particular frequency. Variation in frequency causes reduction in power output.

1.3 Necessity to control of Reactive Power

1) Both customer and power system appliances are equipped to work within a voltage range, generally within ±5 percent of the nominal voltage.At low voltages, the equipments acts poorly and .

2) Reactive power necessitates the use of transmission and generation services. Reactive power flows must be minimised to optimise the amount of actual power that can be transmitted through a congested transmitting interface.

3) The transmission system incurs actual power losses as reactive power is moved. To compensate for these losses, both power and energy must be supplied.

1.4 Interconnected power system

The power system network is a network that is linked together. This implies that all generators are connected to the grid. As a result, if one generator is overwhelmed, the load may be shifted to other generators. By interconnected power system the increase the reliability of power supple and the system in interconnected area frequency should be same.

The below are some fundamental operational principles of an interconnected power system:
1)The loads should strive to be carried by their own control areas under normal operating conditions, except the scheduled portion of the loads of other members, as mutually agreed upon.
2)Each region must cooperate on implementing, governing, and controlling techniques and equipment that are useful under both regular and irregular conditions.

1.4.1 Advantage of Interconnection

1. The integrated grid greatly improves the efficiency of the power supply. In the event of a generating station outage, the network (grid) would share the load of the generating unit. The most notable benefit of a grid system is increased stability [16].
2. Continuous power supply.
3. Depending on the consistency of the load, the installed capacity of the generating station is configured in such a way that the plant will operate at nearly maximum capacity for a large portion of each day. As a result, power production will be cost-effective [16].

1.5 Organization of Thesis

The thesis represents a single and two-area power system of automatic generation control of integrated with Photovoltaic system and Plug-in hybrid vehicle respectively. By changing or rise in load demand, the system frequency and tie-line power deviate to their actual value. And system will not remain in steady-state condition.

Chapter 1 presents the introduction, a basic overview of the title. Chapter 2 presents the basics of Load frequency control (LFC), and explain the single area and two-area system interconnected with other systems, and derive the mathematical modelling of the LFC's different components to derive the block diagram of LFC. Chapter 3 presents the Automatic Generatin Control (AGC). The objective, and need of AGC in power system, and also explain the single area and two-area system. Chapter 4 presents the Automatic Voltage Regulatir (AVR), and derive the equation of AVR. Chapter 5 presents the Photovoltaic system and its modelling, chapter 6 presents the problem identification and how its implement in the system. Chapter 7 is all about simulink modeling done on the MATLAB software. Here first, single area of AGC with interconnected power system and analyse the change in frequency, by step load change in load, and also perform the deviation in frequency in two-area power system with plug-in hybrid electric vehicle.

Chapter 2

Load Frequency Control (LFC)

The term ”power systems” refers to the interconnection of multiple control areas via tie lines. In both static and dynamic environments, the generators in a control area often change their speeds together to maintain frequency and relative power angles to predefined values . The two primary goals of Load Frequency Control are:

- Tie-line Power control
- In the interconnected power system is used to Maintain the actual frequency and the desired power output

If a sudden load shift happens in a control area of an integrated power system ,then there will be frequency deviation as well as tie line power deviation. Frequency and tie line power deviations will occur , whenever there is a sudden load shift happens in a control area of an integrated power grid.

LFC's operating goals are to maintain a relatively consistent frequency, divide the load among generators, and monitor the tie-line interchange schedules[8]. A slight difference in load capacity in a single area power system, causes a power mismatch for both generation and demand. This imbalance problem is eventually overcome by extracting kinetic energy from the system , which results in a decrease in system frequency. If the frequency steadily decreases ,so does the power expended by the old load. When the newly introduced load is disrupted by reducing the power absorbed by the old load and power linked to kinetic energy extracted from the system, massive power systems can achieve stabilization at a single stage.

2.1 LFC of Single Area Power System

A single-area power system with a governor, a turbine, and a generator with constant feedback control is examined. A step load change input to the generator is also included in the method. This is primarily concerned with the controller unit of a single area power grid. The LFC loop controls the actual power output as well as the frequency of the generator power output . The primary LFC loop detects turbine speed and monitors the action of the turbine power input control valves through the speed governor. This loop is quicker than the secondary LFC loop, which detects the electrical frequency of the generator output and ensures proper power exchange with the interconnections .This loop responds slowly and is unaffected by sudden load and frequency shifts. The main LFC loop usually operates in seconds, while the secondary LFC loop operates in minutes.

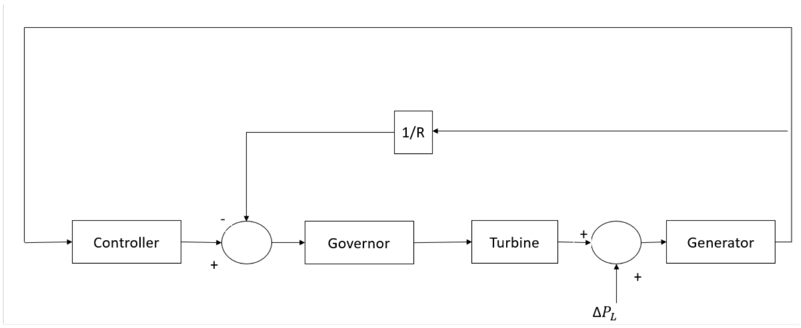

Figure 2.1: A block diagram of a single area power system with the controller

2.2 LFC of Two Area Power System

In a two-area integrated power grid, in which the two areas are linked by tie lines the control area is provided for every area and power movement between the areas is permitted by the tie lines. While the output frequencies in both areas are influenced by a minor shift in load in each of the areas, so is the tie line power flow. As a result, the control scheme of each region requires the transient condition knowledge from all other areas in order to recover the predefined values of tie line powers and area frequency.

A two area interconnected power system operates where there is interconnection between two control areas via tie line. The below diagram depicts a two-area power grid in which each area provides its own area and the tie line allows power to pass through the areas. In this case of a two-area power grid, it is assumed that the individual areas are strong and the tie line between the two areas is weak.

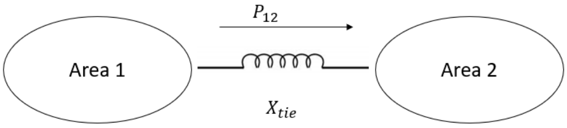

Figure 2.2: A block diagram of a single area power system with the controller [17]

2.3 Mathematical modelling of LFC

The mathematical modelling of the system is the first step in the study and development of a control system. It is critical to obtain appropriate power system models for LFC analysis. In this study, a two-area power system model was used. The transfer function strategy and the state variable solution are the two most general approaches. The state variable method can be used to depict both linear and nonlinear processes. The method must be linearized in order to use the transfer function and linear state equations. Proper assumptions and approximations are used to linearize the mathematical equations representing the system, and a transfer function model for the following components is obtained [8].

2.3.1 Mathematical modelling for generator

$$\frac{2H}{w_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \tag{2.1}$$

or in terms of small deviation in speed

$$\frac{d\Delta \frac{w}{w_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \tag{2.2}$$

With speed in per unit , without explicit per unit notation

$$\frac{d\Delta w}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \tag{2.3}$$

Taking Laplace transform of equation 2.3,

$$\Delta\Omega(s) = \frac{1}{2H_s}[\Delta P_m(s) - \Delta P_e(s)] \tag{2.4}$$

Block diagram of above is shown in below figure;

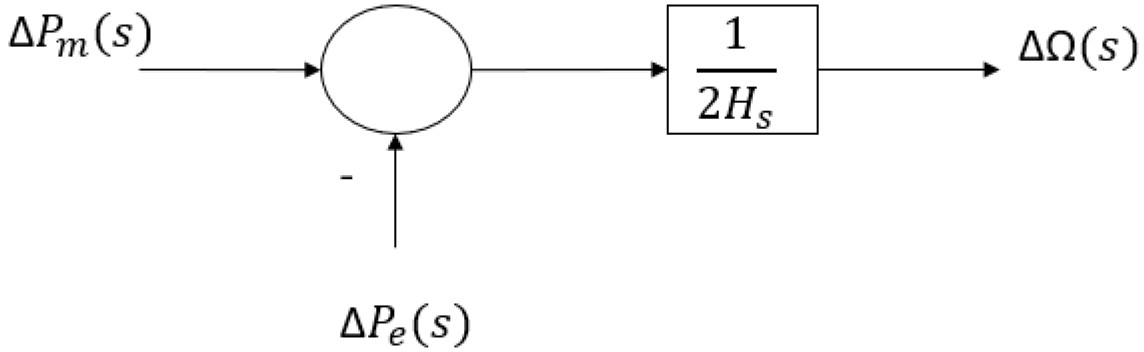

Figure 2.3: Transfer function block diagram generator [8]

2.3.2 Mathematical modelling for load

A power system's load is made up of various kinds of electrical equipment. Such as, resistive loads and motor loads. A composite load's overall frequency-dependent characteristic can be expressed as:

$$\Delta P_e = \Delta P_L + D\Delta\omega_r \tag{2.5}$$

Where,

ΔP_L = Non-frequency-sensitive load change

$D\Delta\omega_r$ = Frequency sensitive load change

D = Load damping constant

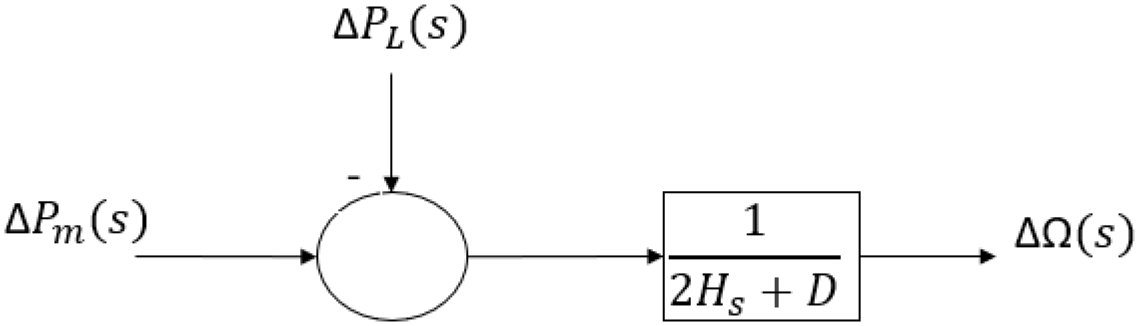

Figure 2.4: Block diagram of Generator and Load [17]

2.3.3 Mathematical modelling for Prime mover (Turbine)

The source of mechanical energy , often referred to as the prime mover. The turbine model relates changes in mechanical power output ΔP_m to changes in steam valve position ΔP_v. The non-reheat steam turbine prime mover model can be expressed as T_T. The transfer function of turbine model is:

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1 + T_T(s)} \tag{2.6}$$

The block diagram of simple turbine is as given in [8]

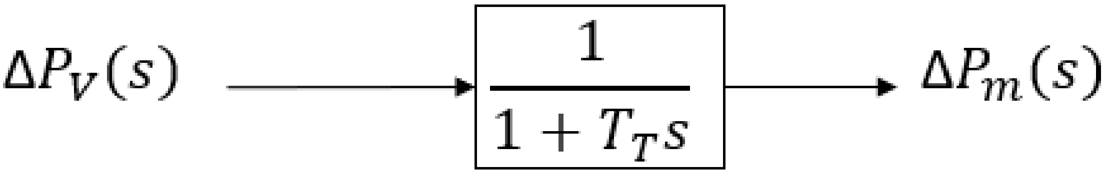

Figure 2.5: A block diagram of a non-reheat steam turbine

2.3.4 Mathematical modelling of Governor

When the electric load on the generator is abruptly raised, the electrical output exceeds the mechanical power supply. The kinetic energy retained in the spinning mechanism compensates for this power deficit. The reduction in kinetic energy reduces the rotor speed and, as a result, the generator frequency falls . The turbine governor detects the shift in speed and adjusts the turbine input valve to change the mechanical power output, bringing the speed to a new steady-state. Figure 2.6 shows the basic elements of a typical watt governor, which consists of the following main parts:

1. Speed Gorvernor
2. Linkage Mechanism
3. Hydraulic Amplifier
4. Speed Changer

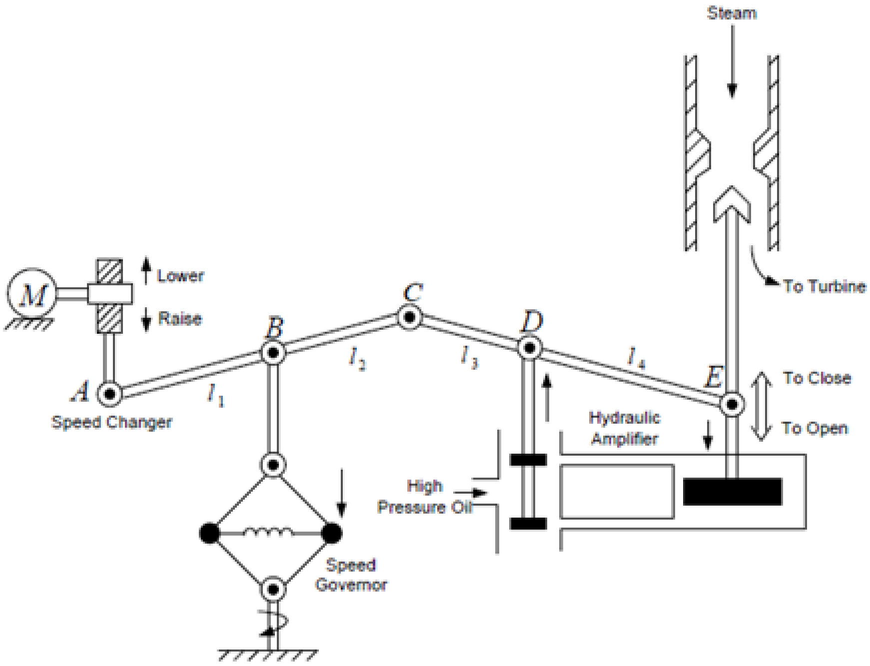

Figure 2.6: Schematic diagram of speed governing system - [8]

$$\Delta P_v(s) = \frac{1}{1+\tau_g}(\Delta P_r ef(s) - \frac{1}{R}\Delta\Omega(s) \tag{2.7}$$

2.4 LFC Block Diagram of an Isolated Power System

The complete block diagram of the load frequency control of an isolated power system is shown in figure 2.7 [8]. The LFC block diagram above is consist of primary loop control.

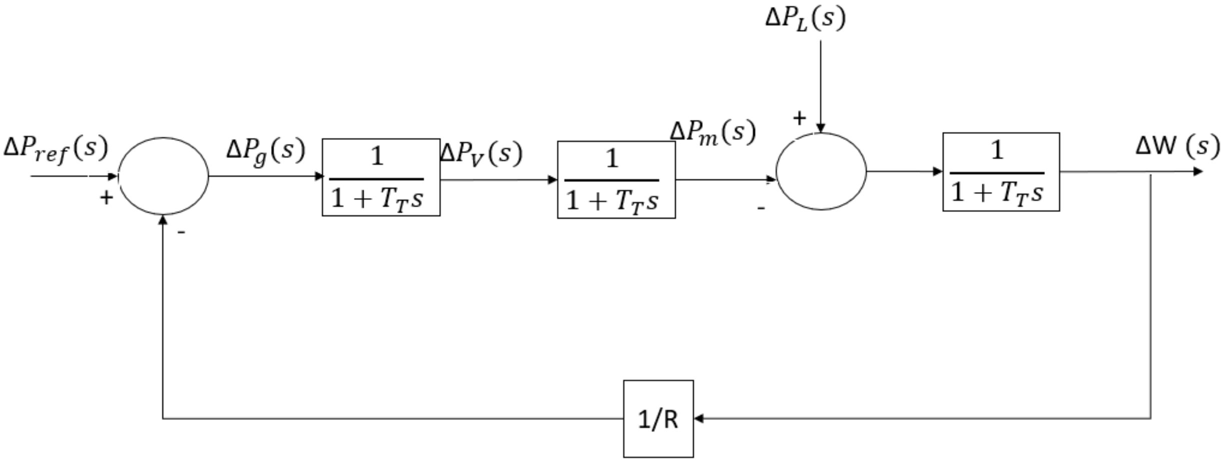

Figure 2.7: Block diagram of LFC of single area power system [8]

But the LFC primary control loop is not enough in interconnected power system to regain its original system frequency. Therefore, an additional control loop is also required which is called as secondary control loop is connect with integral controller. The integral controller is used to reduce the steady state error in system frequency. If any load disturbance occurs, the secondary control loop automatically adjusted the generated power which get the frequency to its nominal value. This system is known as automatic generation control (AGC).

Chapter 3

Automatic Generation Control

Automatic generation control (AGC) is required for the generation, transmission, and distribution of electrical power economically and reliably to maintain the power quality within its specified limits. Automatic generation control is to maintain the frequency of the system and to maintain an energy balance within each control area, to maintain the assumed net interchange between control areas during its abnormal conditions. By random changes in load, which create a mismatch between generation and load side. And the effect on power quality, which is very important in power system operation and control. The aim of AGC is to maintain a nominal frequency in an integrated power system and to maintain a net power exchange between control areas at specified values [9].

In a single generating unit in each control area in an integrated power system network, it has the direct ability to stabilize the system frequency with change in load. Whereas, in numerous control areas, there must be a need for an AGC because in large systems there are frequent changes in load, which do not give the exact amount of output power of each area. Many tuning techniques such as Genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), bacterial foraging optimization algorithm (BFOA) etc., have been used for the design of tuning the parameters of these controllers for AGC in power systems.

3.1 Need of AGC

1. The majority of grid-connected loads are inductive. As a result, the whole structure is non-linear by nature. As a result, the market for actual and reactive power is not continuous and fluctuates continuously over time.
2. The prime mover and exciter must be managed in order to maintain true and reactive force. In reality, neither mechanism can be operated manually, necessitating the use of AGC.

Usually AGC is organized in different levels:

1. The primary control is provided by the speed regulators of the generating units, which respond immediately (automatically) to a sudden shift in load (or change of frequency). A change in system frequency greater than the dead band of the speed governor would result in a change in unit power generation by using primary control. Transients under primary power occur on a timescale of seconds.
2. Secondary regulation adjusts the output of selected generators to return frequency to its nominal value and sustain power exchange between areas. Secondary power transients are measured in minutes.

3.2 AGC in a Single Area System

Depending on the governor speed control, a shift in system load will result in a steady-state frequency variance with the primary LFC loop. Provide a reset action to reduce the frequency deviation to zero. The reset operation is accomplished by incorporating an integral controller that acts on the load preference setting to adjust the speed setpoint. Secondary regulation adjusts the output of selected generators to return the frequency to its nominal value and sustain power exchange between areas. Secondary power transients are measured in minutes [8].

The integral controller multiplies the circuit form by one, causing the final frequency variance to be zero. The figure depicts the LFC system with the insertion of the secondary ring. For a sufficient transient response, the integral controller gain must be balanced. The equivalent block diagram is seen in the figure after integrating the parallel divisions [8].

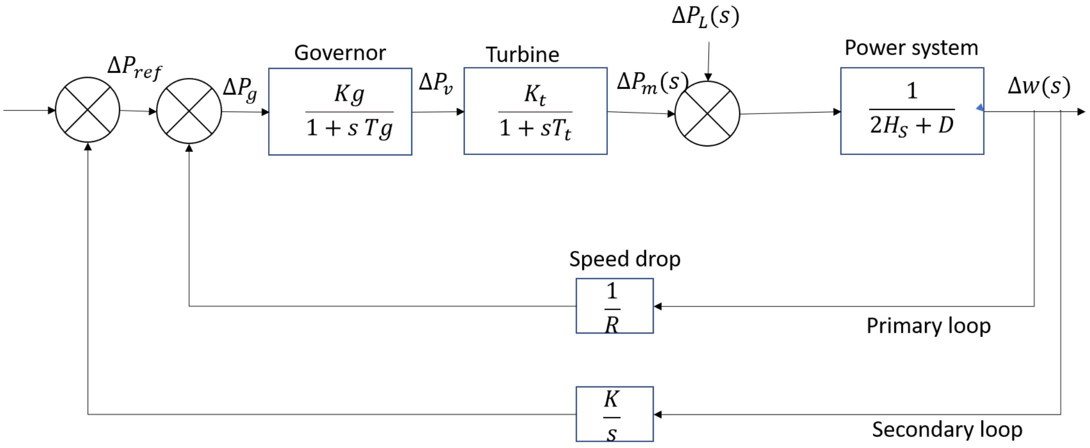

Figure 3.1: Block diagram of AGC for a single area system

3.3 AGC for Two Area System

In certain instance, a set of generators is internally coupled and swings in unison. Furthermore, the reaction characteristics of generator turbines are similar. A set of such generators is said to be coherent. The LFC loop can then be used to describe the whole device, which is referred to as a control field.

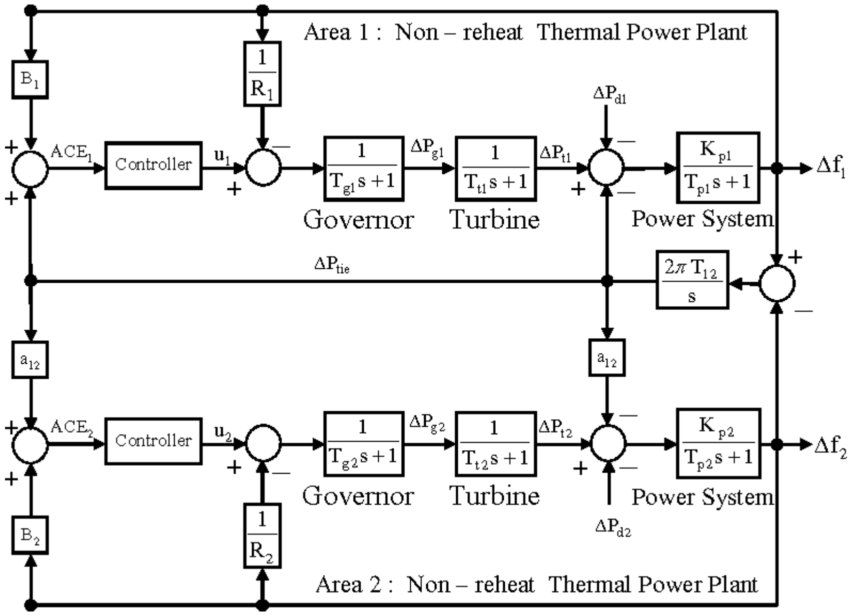

Figure 3.2: Block diagram of AGC for a two-area system-

Chapter 4

Automatic Voltage Regulator

The generator excitation device regulates generator voltage and manages reactive power flow. Older systems can provide generator excitation via slip rings and brushes via DC generators mounted on the same shaft as the synchronous machine's rotor. The generator excitation device regulates generator voltage and manages reactive power flow. Older systems can provide generator excitation via slip rings and brushes via DC generators mounted on the same shaft as the synchronous machine's rotor. The generator's reactive powers are controlled by field excitation. Other methods for improving the voltage in transmission lines are static Var capacitors, transformer load tap changers. The generator excitation regulation using an automatic voltage regulator is the primary means of regulating generator reactive power (AVR). The reactive power control controls the voltage profile, and the active power generation manages the frequency level of the device based on the required demand, ensuring that power users receive quality energy.

The role of AVR is to hold the terminal voltage magnitude of a synchronous generator at specified value. Below figure shows the block diagram of AVR.

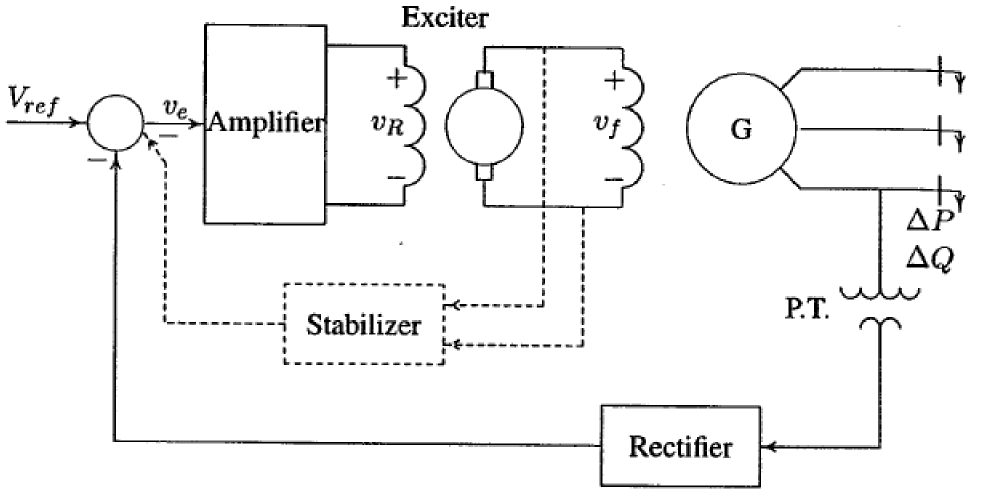

Figure 4.1: Arrangement of AVR [8]

4.1 Amplifier model

Excitation system may be a magnetic amplifier, rotating or modern electronic amplifier. The amplifier is represented by K_A and a time constant T_A. The transfer function of Amplifier is:

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1 + \tau_A(s)} \tag{4.1}$$

The values of K_A and T_A is 10 to 400 and 0.02 to 0.1 sec.

4.2 Exciter model

There are different types of excitation system are available. A modern excitation device makes use of an alternating current power source through a solid-state rectifier. Because of the saturation effect in magnetic circuit, the output function of the exciter is non-linear function of the field voltage. In a linearized model, it ignores the saturation and the other non-linearity and takes into account the major time constant. The transfer function of exciter model is:

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1 + \tau_E} \tag{4.2}$$

4.3 Generator model

The synchronous machine generated emf is determined by the machine magnetization curve, and its terminal voltage is determined by the generator load. In the liearized model, the transfer function relating the generator terminal voltage to Its field voltage can be represented by gain K_G and τ_G[8]. The transfer function of generator model is:

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1 + t_G(s)} \tag{4.3}$$

4.4 Sensor model

The voltage is sensed by a potential transformer and rectified by a bridge rectifier in one form or another. A basic first order transfer feature is used to model the sensor. The transfer function of sensor model is:

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1 + \tau_R(s)} \tag{4.4}$$

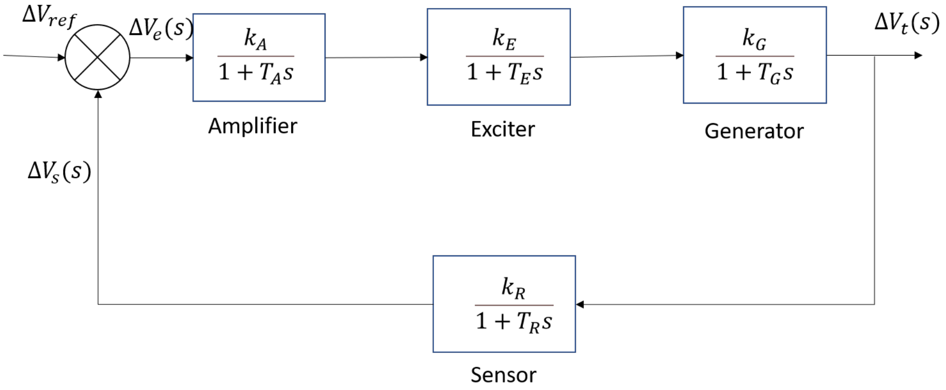

Figure 4.2: Complete block diagram of AVR

The combine block of AVR and LFC is shown below:

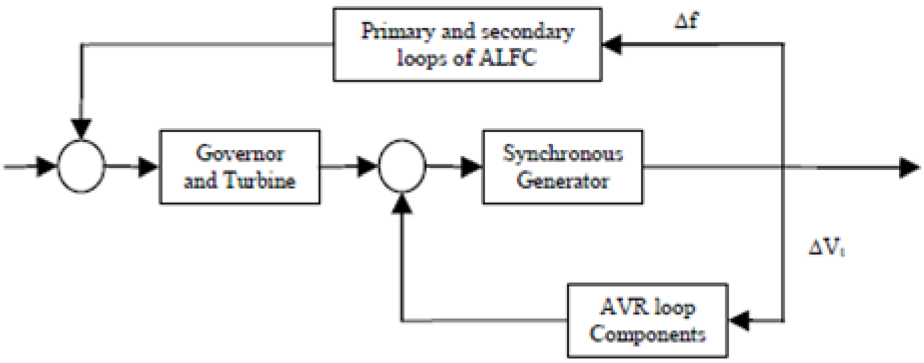

Figure 4.3: Combine block diagram of AVR and LFC [8]

Chapter 5

Mathematical modelling of Photovoltaic System

The output power of a grid-connected solar PV device is affected by a variety of factors such as insolation, level temperature, and so on. The power provided by the solar PV system varies with the amount of insolation. The difference in output powers has an effect on the load frequency, which is regulated by a synchronous generator-based grid, by changing its active power output.

As seen in figure 5.1, the PV cell model consists of a current supply that is directly proportional to solar radiation parallel to a diode and a small series contact resistance. The performance of a photovoltaic cell is affected by many factors, including solar irradiation and surface temperature. To increase the effectiveness of the PV system, the maximum power point tracking (MPPT) algorithm was introduced to ensure maximum power extraction from the PV system and thus improve PV system accuracy. The below equation of a PV setup, which includes a PV panel, an inverter, an MPPT, and a filter [18].

$$G_{pv} = \frac{-18s + 900}{s^2 + 100s + 50} \tag{5.1}$$

For the purposes of this method, it is presumed that the PV system generates power in area-1 and that the control area-2 has thermal generation from a steam governor and a steam turbine that is successfully coupled to the synchronous generators. The two control areas are connected by an alternating current tie-line.

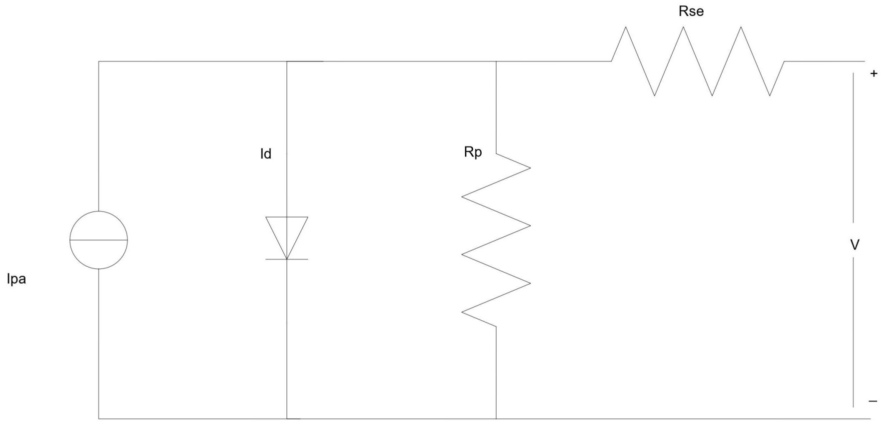

Figure 5.1: Equivalent circuit of PV cell

Chapter 6

Problem Statement

A variety of controllers are used in practice in order to maintain the power system in the regular operating state. The system changes as the demand is varying its normal operating values. Based on a past survey of AGC shows that the selection of secondary control design and its parameters clearly confirm that the interconnected AGC operation highly influenced. Still, because of the simplest and efficient control, the control design based on a conventional controller such as integral (I), proportional-integral (PI), and proportional integral derivative (PID) are also the first-choice option in the various industries. In this paper, the conventional controllers are used to regulate the electric generator power output within a specified region response to changes in system frequency, tie-line loading, in order to maintain the frequency in specified limit.

The investigation has been carried out on a single area system. Proportional- integral (PI), and proportional integral derivative (PID) controllers are considered for this. The nominal system parameters are shown in an appendix. The transfer model of a single area of AGC integrated with a PV system is shown in below figure. MATLAB has been used to obtained dynamic response for step load perturbation.

Also Automatic Generation control with two-area system is integrated with PV and PHEV [19].

6.1 System Investigated

The AGC is used in a single-area integrated power grid with PV system, with area consisting of a non-reheat thermal generation unit. In two areas integrated power grid, the one area is linked with thermal power plant and the other area is linked with the PV system and are linked together by a tie-line. The simulation models of LFC and AVR are developed using Hadi Sadaat's proposed block diagram method. The simulink model of the combined LFC and AVR system is shown in Fig.4.3.

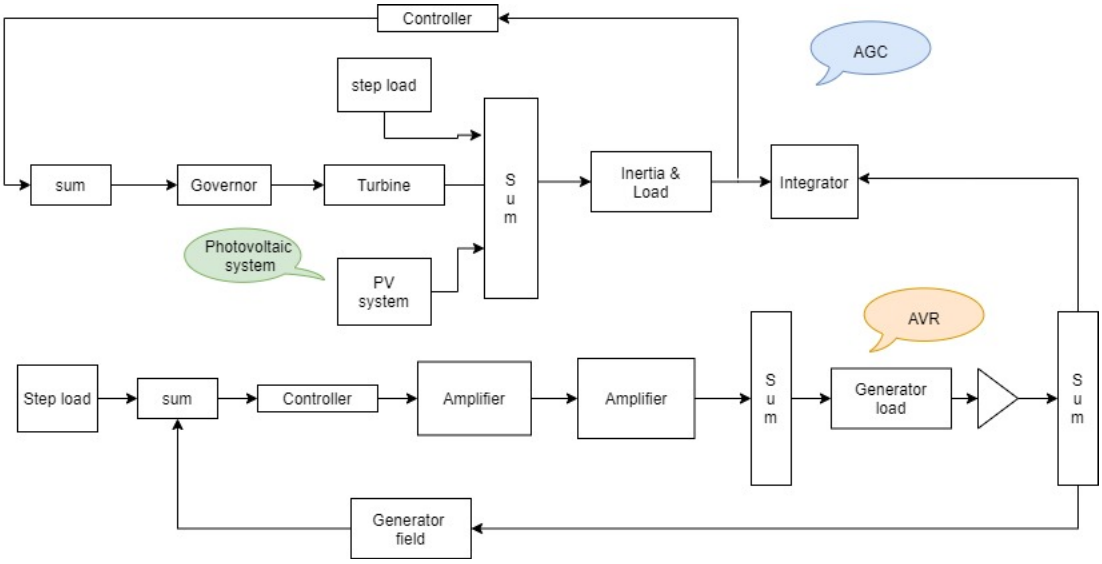

Figure 6.1: Block diagram of interconnected power system in AGC with PV system

Chapter 7

Simulation Analysis

7.1 Simulation Analysis of AGC interconnected without PV system

In this case, Solar Photovoltaic system is include in the system. Here, we see the change in frequency and terminal voltage after changing in step load value. System is investigating by using of conventional controller such as PI and PID controller.

The waveforms of frequency deviations and terminal voltage with different controllers are shown below. Controllers are used to the change in frequency and bring back the frequency to its nominal state. To optimize the controller gain, we tuned the controllers and get the values of frequency and terminal voltage with zero value error in waveforms.

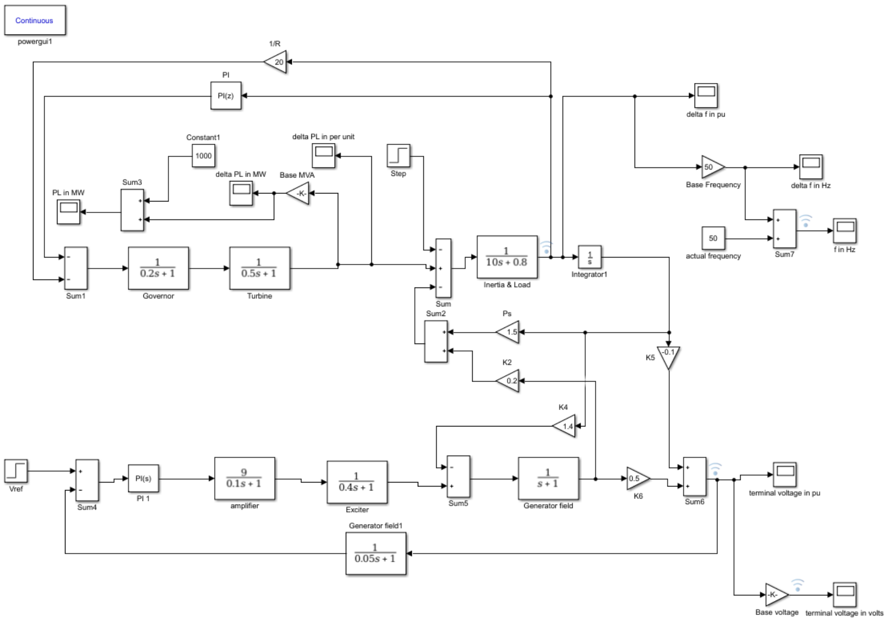

Figure 7.1: AGC and AVR integrated without PV for single area with PI controller

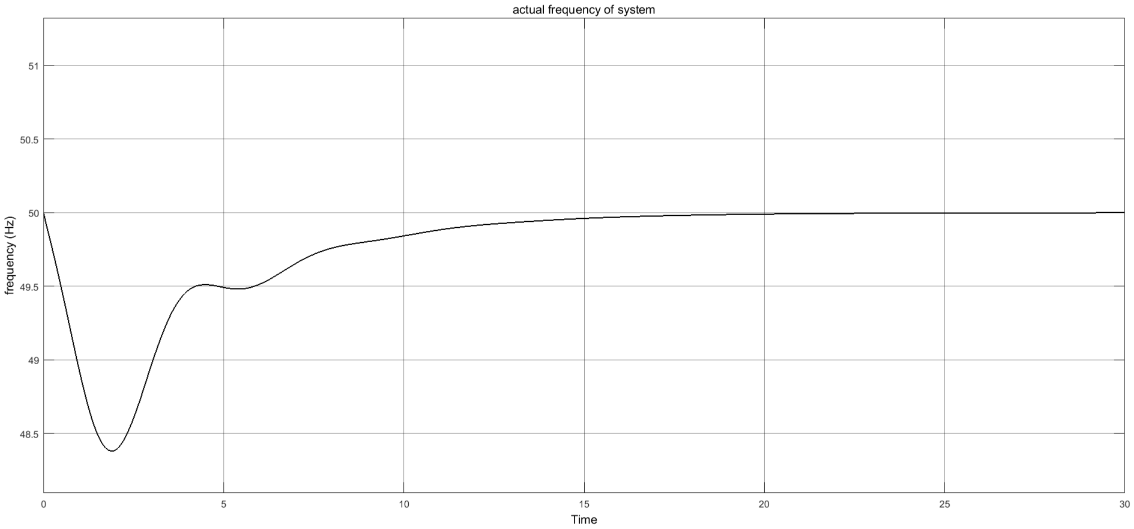

Figure 7.2: Frequency deviation of AGC and AVR integrated without PV for single area with PI controller

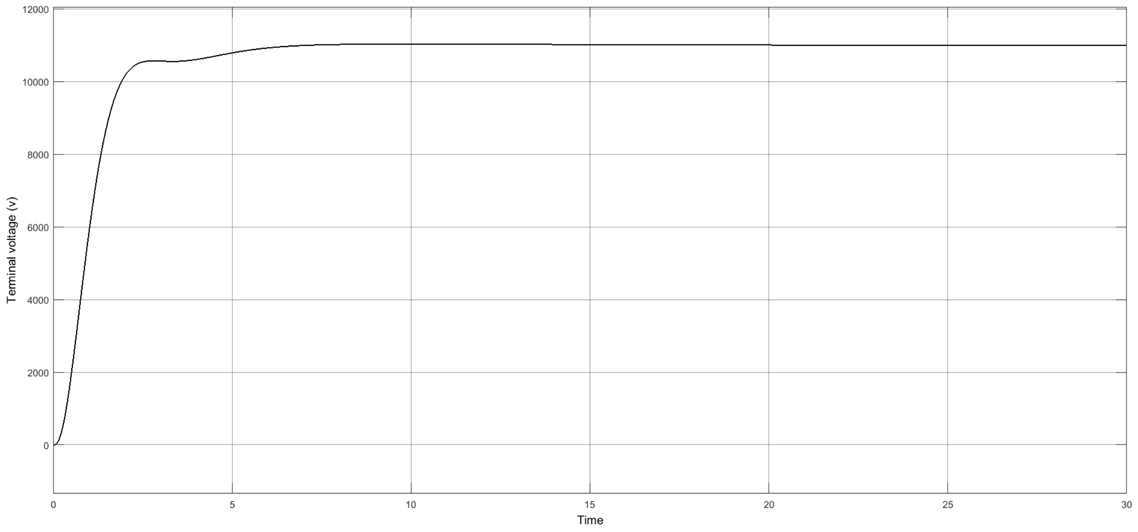

Figure 7.3: Terminal voltage of AGC and AVR integrated without PV for single area with PI controller

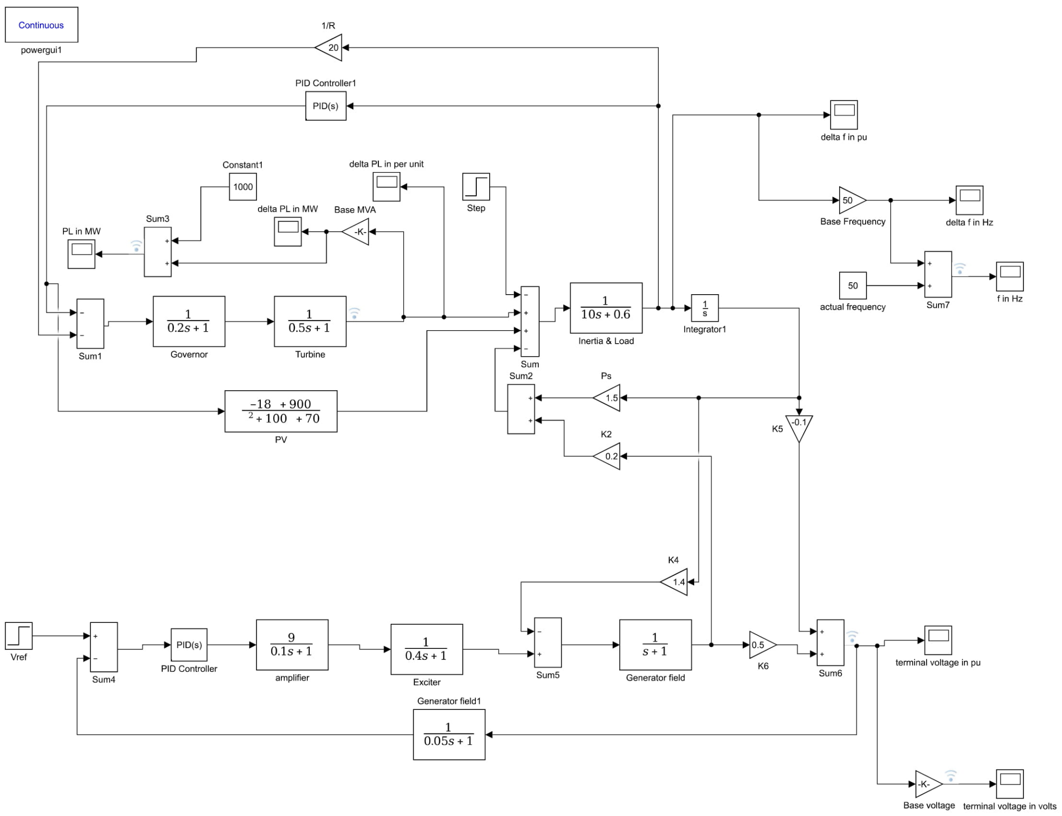

Figure 7.4: Simulink diagram of AGC and AVR integrated with PV for single area with PID

7.2 Simulation Analysis of AGC interconnected with PV system

The below simulink diagram 7.1 shows the single area automatic generation control integrated with PV system. In area-1, the Photovoltaic system is integrated with the thermal power plant. Here, a single area system consists of supplymentry controller, which contain governor, turbine and generator with constant feedback. The initial coarse frequency change is made by the primary AGC loop. It operates between the first 2 to 20 seconds of a disruption and adjusts the turbine power output in proportion to the frequency shift, depending on the turbine type. The primary loop, as shown in fig.6.1, includes governor dynamics, hydraulic valve actuator transfer function, turbine generator transfer function, and power system dynamics in the control sector. According to the steady state analysis of the main AGC loop, there will often be a steady state frequency error due to the operation of the primary control loop. The secondary AGC loop takes over fine frequency correction by resetting the speed changer via integral control action and taking the frequency error to zero. This loop is much longer, with a response time of around one minute. The secondary loop's control operation is controlled by the following relationships:

$$\Delta P_e = -K_I \int \Delta f dt \tag{7.1}$$

where K_I is gain of integral controller
Taking laplace transform,

$$\Delta P_e(s) = -\frac{K_I}{s}\Delta f(s) \tag{7.2}$$

7.2.1 Simulation Results

The load-frequency monitoring of a two-area interconnected power grid, which included solar panels affected by climatic changes, was achieved in this report. The controllers were simulated separately in the planned system during the controlling phase. First, the standard PI and PID controllers were modelled. Figure 7.2, 7.3 shows the waveform of frequency

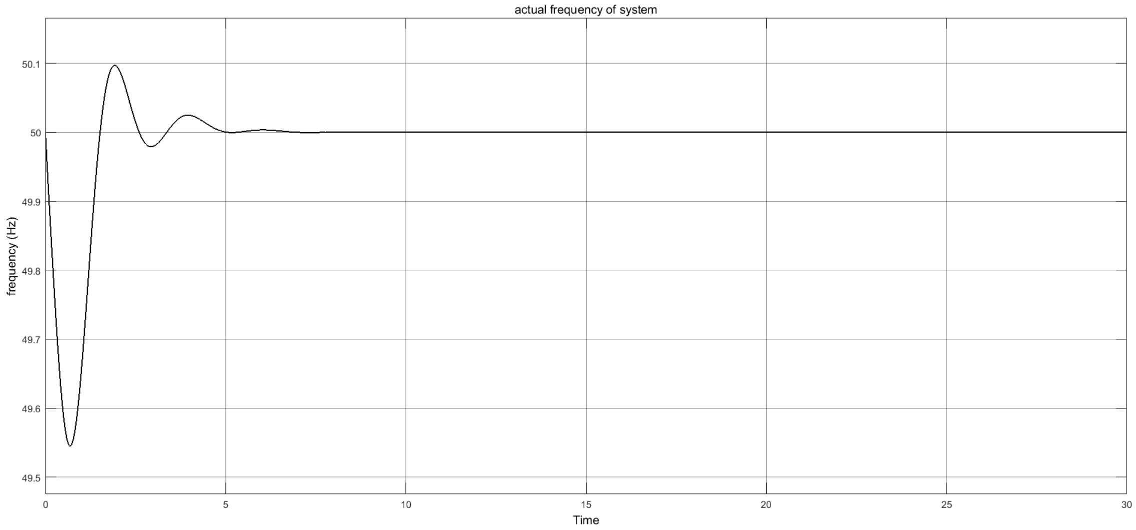

Figure 7.5: Frequency deviation of AGC and AVR integrated with PV for single area with PID

deviation of AGC and AVR integrated with PV for single area by PID controller. Here,

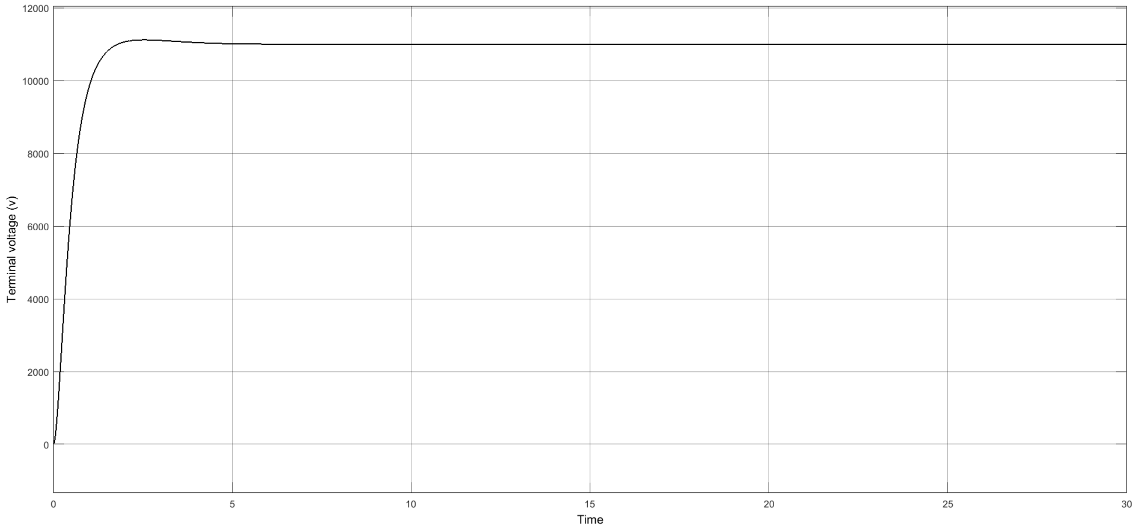

Figure 7.6: Terminal voltage of AGC and AVR integrated with PV for single area with PID

MATLAB SIMULINK is used to replicate the models described in fig.7.1. As seen in figure, a difference in load induces a change in speed, which causes a change in frequency. It observed that by using a controller in secondary loop, the frequency value drift to zero. The initial coarse frequency change is made by the primary AGC loop. It operates between the first 2 to 20 seconds of a disruption and adjusts the turbine power output in proportion to the frequency shift, depending on the turbine type.

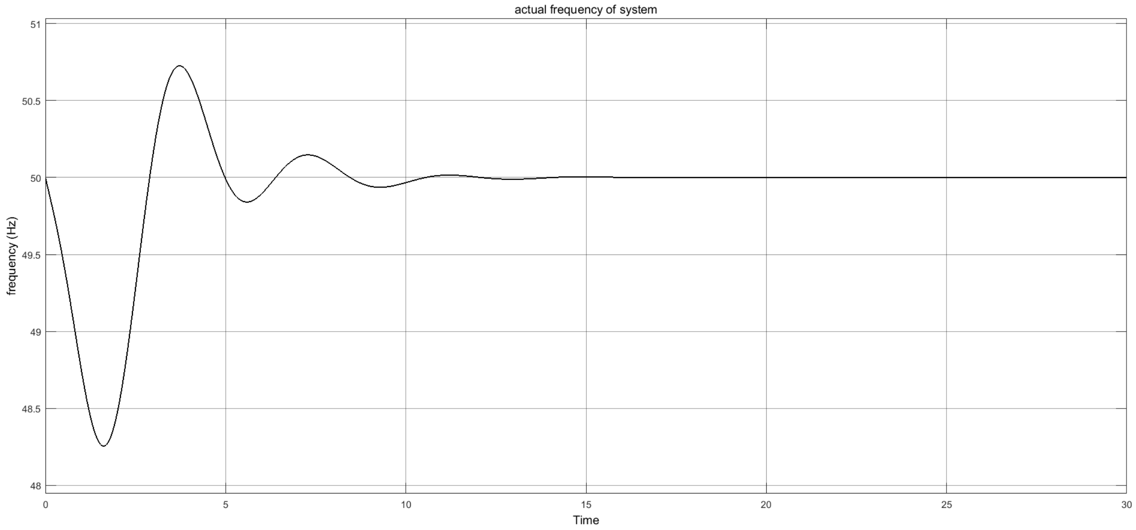

Figure 7.7: Frequency deviation of AGC and AVR integrated with PV for single area with PI controller

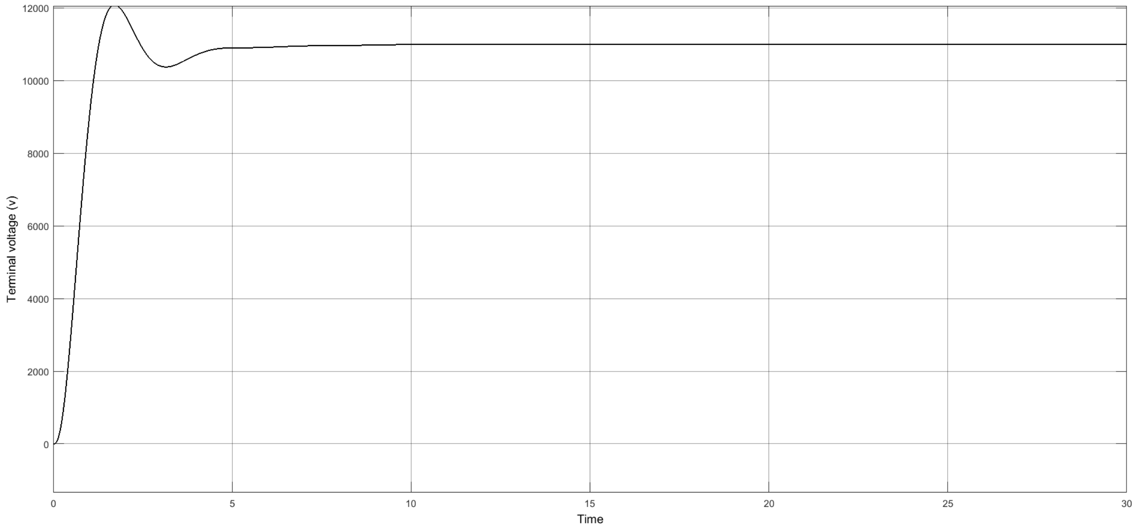

Figure 7.8: Terminal Voltage of AGC and AVR integrated with PV for single area with PI controller

Above figure 7.4 and 7.5 shows the waveform of frequency deviation and terminal voltage of AGC with AVR integrated with PV with PI controller respectively. The above simulation plots show that the system experiences frequency drift after a load interruption, which is mostly caused by a mismatch between the electrical load and the mechanical input to the turbine. By 0.1 p.u. change in load causing the frequency deviation. Frequency error can be reduces to zero by adding secondary loop as controller in system.

7.3 Simulation analysis of Two-area system

Here, a two-area interconnected power system is explain. In each area its consists of photovoltaic system, thermal power plant, load frequency control (LFC), plug-in hybrid electric vehicle (PHEV) and load. The control signal is sent to the PHEV by the local control centre in each region through the smart metre. The extreme frequency fluctuation in both areas is caused by erratic wind power and random load shifts. Furthermore, the power of the thermal hydro plant turbine (TB) and governor (GOV) is insufficient to keep the frequency fluctuation within a reasonable range. To address this problem, PHEVs deployed in both areas are used to collaborate with TB and GOV of thermal hydro plant for compensation of the sudden imbalances of power generation and load, since the complex response of PHEV is faster than that of TB and GOV of thermal hydro plant.

The figure shows a linearized model of a two-area interconnected power grid. The generator and frequency sensitive load are expressed by the 1st-order transfer function in each field, with the inertia constant M and damping coefficient D. The tie-line bias control is used to control the LFC in each region. In each field, the frequency controller is a first-order transmission mechanism with a time constant T_{ACEi} and the area control error (ACEi) as an input signal. Block diagram shows $K_{system1}$ and $K_{system2}$ are the area 1 and 2 system constants, respectively, f_0 is the standard system frequency, a_{21} is the area capability ratio, P_{21} is the tie-line power difference from area 2 to area 1, and T is the synchronising power coefficient.

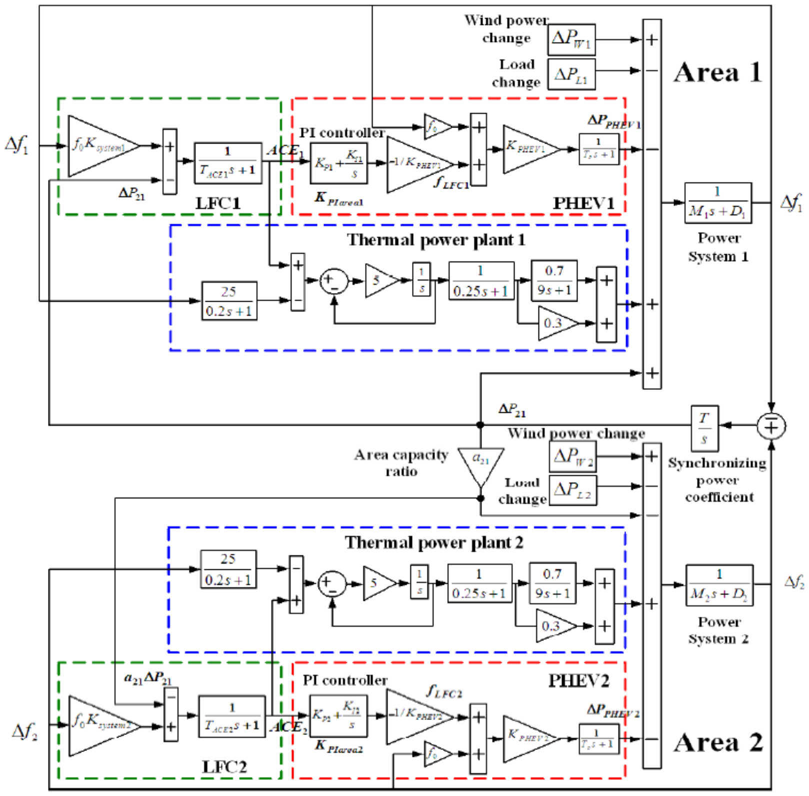

Figure 7.9: Terminal voltage of AGC and AVR integrated without PV for single area with PI controller [13]

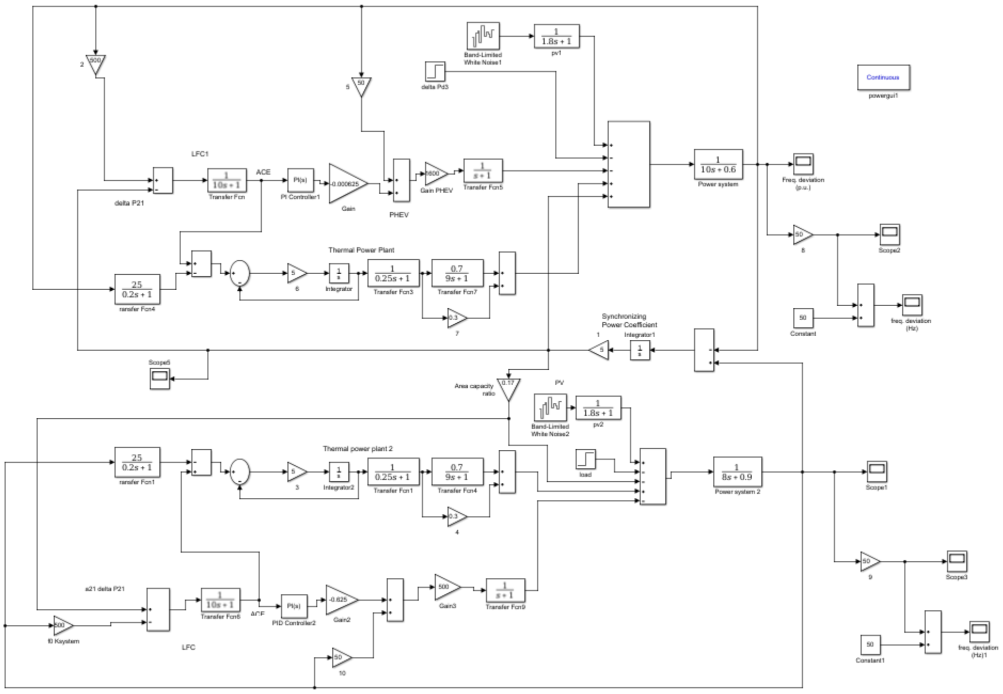

Figure 7.10: Simulink block diagram of two-area power system

7.3.1 Simulation results

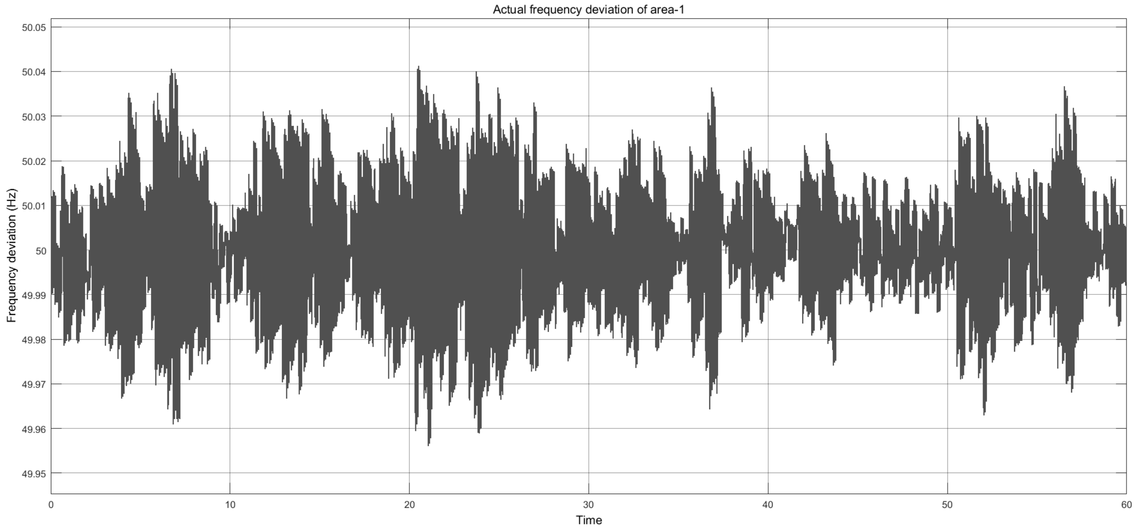

Figure 7.11: Frequency deviation in area-1

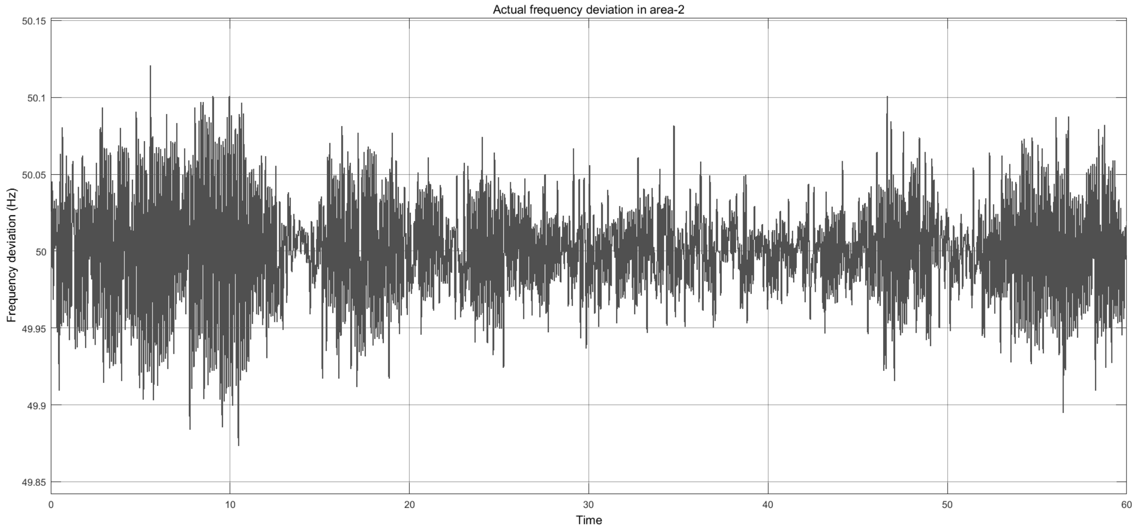

Figure 7.12: Frequency deviation in area-2

Since this analysis takes into account minor disturbances such as load shift and PV output change, the device model can be linearized around a stable operating stage. In the linearized method, the simulation analysis can be carried out. It is assumed that the 0.1 puMW step load is applied to area 1. Figure shows the frequency deviation of area 1 in case of the linearized system.

The paramters of the PI, and PID controllers of single-area and two-area system so obtained by given in below tables:

Table 7.1: Frequency deviation of single area power system without PV system

Types of controller	settling time	Steady-state error
PI	21	0.08
PID	15	0

Table 7.2: Terminal voltage of single area without PV system

Types of controller	settling time	Steady-state error
PI	10	0
PID	9	0

Table 7.3: Frequency deviation of single area power system with PV system

Types of controller	settling time	Steady-state error
PI	17	0.0056
PID	8	0

Table 7.4: Terminal voltage of single area with PV system

Types of controller	settling time	Steady-state error
PI	7	0
PID	5	0

7.4 Appendix

Table 7.5: Parameters of thermal power system in AGC [5]

Parameter	Symbol	Value
Nominal frequency	f	50 Hz
Load disturbance	ΔP	50 MW
Inertia constant of area	H	5
Speed regulation	R	20
Governor time constant	T_g	0.2
Turbine time constant	T_t	0.5
Base power	P	1000 MVA

Table 7.6: Parameters of AVR [5]

Parameter	Symbol	Value
Amplifier	$K_A = 9$	$T_A = 0.1$
Exciter	$K_E = 1$	$T_E = 0.4$
Generator	$T_G = 1$	$T_G = 1$

7.5 Conclusion

In this paper a single area AGC model for a hybrid system that is interconnected to PV system and thermal power generation of single area is presented with conventional controller such as, PI and PID. And show the changes in system frequency when PV system is interconnected with AGC. For step changes in load demand, the performance of these controllers is simulated in MATLAB Simulink. The analysis of AGC, AVR with and without PV system is done, by using the controller with reduced settling time, peak overshoot of frequency response and steady-state error and also frequency deviation, terminal voltage and power deviation are observed. It is concluded that PID offers the most robust control, less settling time compared to that of PI controllers, based on outcome of different performance.

In a two area power system integrated with PHEV and PV, to create a bidirectional power charging controller for PHEVs in order to stabilise frequency fluctuations in the smart grid with a PV system. In contrast to the controls, simulation findings in a two-area integrated power grid with a PV system show that the PHEV has superior robustness and stabilising effect against system parameter heterogeneity, different wind power generation, and load changes.

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