



Performance Comparison of PI, PD and PID Controllers Frequency and Voltage Stability Enhancement in Hybrid Power Systems

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ABSTRACT—

The use of renewable energy sources like solar, wind, hydropower, geothermal, natural gas, as well as diesel in hybrid power systems leads to problems of stability of frequency and voltage arising from volatile generation and rapid loads changing. The study focuses on issues connected with frequency and voltage stability in two-area hybrid power system simulated in the MATLAB/Simulink environment. Three standard controllers such as PI, PD, and PID are applied for Load Frequency Control (LFC) and Automatic Voltage Regulation (AVR) in order to enhance the system performance. In the study, the behavior of the applied controllers is evaluated with respect to major dynamic parameter of interest, including frequency deviation, voltage deviation, settling time, rise time, overshoot, and undershoot. The simulation results show if one or another controller is able to lessen oscillations occurring in the system and return it back to the nominal condition. The comparative analysis reveals that the PID controller outperforms the PI and PD controllers in terms of overall stability as a consequence of increased controllability and stabilization speed.

Keywords: Hybrid Power System, Frequency Stability, Voltage Stability, Automatic Voltage Regulation (AVR), Load Frequency Control (LFC), PI Controller, PD Controller, PID Controller.

INTRODUCTION

Hybrid power schemes integrating renewable resources with traditional power generation systems deal with numerous issues about power supply reliability, frequency control, and voltage regulation. While renewable resources such as wind and solar energy are intermittent, various load demands can result in variations in electricity generation and lead to system frequency and voltage anomalies. This might lead to increased oscillations, longer settling time, and low reliability of the whole system. Thus, it is necessary to implement adequate control methods to keep the system at its expected operating conditions and ensure its performance. The objective of the research project is to design a hybrid energy system by integrating renewable energy sources with traditional energy sources through the use of MATLAB/Simulink. The model developed could help in investigation of the operation of the system under different operation conditions and disruptions. In addition, the effectiveness of PI, PD, and PID controllers used for Load Frequency Control and Automatic Voltage Regulation will be analysed. While the purpose of Load Frequency Control is to minimize deviations in frequency due to the changes in load and ensure the balance between the amount of electricity produced and consumed, Automatic Voltage Regulation is implemented in regard to the process of flight voltage control in the electricity system.

The controllers are evaluated using various key performance indicators including frequency deviation, voltage deviation, rise time, settling time, overshoot, and undershoot. These indicators are an effective means of determining the effectiveness of the controller in stabilizing operation of the system. The results achieved in the comparison help to determine which controller supplies shorter response times, lower deviations, and better stability. The main goal of the studies is to improve the power system's stability, reliability, and operation.

LITERATURE REVIEW

Amin et al. [1] examined the effectiveness of PID controllers in Load Frequency Control (LFC) and Automatic Voltage Regulation (AVR) within the scope of a study focused on a single-area and a two-area power system. Optimization of the parameters was performed by utilizing Exponential Distributed Optimization (EDO). This study has shown better results than the existing techniques in terms of voltage and frequency response. Yameen et al. [2] proposed a combination of Genetic Algorithm Optimization (GOA) and Particle Swarm Optimization (PSO) for tuning PID controller used in the renewable multi-source dual-area power system. The proposed method produced a better performance of the frequency regulating system as the controller parameters performance takes into account the generation of renewable energy and the changing load. Abhishek et al. [3] proposed an MGO-AO PID and FOPID control system and designed it to control voltage and frequency. Implementation of this technique resulted in enhancement of the transients and settling time for the multi-area hybrid system. Veerasamy et al. [4] made use of the Hankel matrix to construct a hybrid power generation system which was optimized using the PSO and GSA techniques. The study has proven that optimization techniques help to reduce models. The study done by

Kumar et al. gave an insight into using PSO and GA controllers to determine frequency and voltage control strategies for SPV/wind energy systems. The results provided evidence for the benefits of parameter optimization of controllers to implement improved processes in the renewable sector.

SYSTEM MODELLING

The hybrid power system with two regions contains different types of conventional and renewable energy sources connected by power transmission lines. The previously mentioned model has been created using transfer function-based models of various generators, turbine machines, governor systems, voltage control devices [5], [6].

A) Thermal System:

The thermal power plant is represented by a governor, turbine, and generator-load model [4].

$$\frac{\Delta P_{GT}(s)}{\Delta P_{mT}(s)} = \frac{(1+ST_{re}K_{re})}{(1+t_{gr}s)(1+T_{re}s)(1+t_{tr}s)} \quad (1)$$

B) Hydro system:

The hydro generating unit represents the dynamic behaviour of water flow and turbine response [4], [16].

$$\frac{\Delta P_{GH}(s)}{\Delta P_{mH}(s)} = \frac{(1+ST_{rs})(1-S_{tW})}{(1+t_hs)(1+t_{rh}s)(1+0.5t_ws)} \quad (2)$$

C) Gas system:

The gas turbine unit provides flexible generation and contributes to maintaining system frequency. Its governor and turbine dynamics are represented using suitable transfer functions [6].

$$\frac{\Delta P_{GG}(s)}{\Delta P_{mG}(s)} = \frac{(1+XS)(1-t_{CR}S)^{\alpha}}{(1+YS)(c+bs)(1+t_{FS})(1+t_{CD}S)} \quad (3)$$

D) Diesel System:

The diesel generating unit provides additional power support during load variations [6].

$$\frac{\Delta P_{GD}(s)}{\Delta P_{mD}(s)} = KD \frac{(1+S_{td1})}{(1+t_{d4}s)(1+t_{d2}s)(1+t_{d3}s)} \quad (4)$$

E) Wind system:

The wind energy production system is classified as a renewable energy source that produces inconsistent amount of energy. Its connection results in necessary adjustments, which can be done in an effective manner [5], [6].

$$\Delta \frac{P_{GW}(s)}{P_{mW}(s)} = Kw1Kw2 \frac{(1+S_{tw1})}{(1+t_{w2}s)(1+2s+s^2)} \quad (5)$$

F) Solar photovoltaic system:

Solar photovoltaic can be defined as a kind of renewable energy being produced from the heat coming from the Sun itself. While reviewing the different options of generating solar energy, it is necessary to consider about the possibility of getting electricity with a stable voltage and frequency when choosing the scheme of hybrid solar photovoltaic system.

$$\Delta \frac{P_{GPV}(s)}{f} = K_{PV} \frac{1}{1+t_{pvs}} \quad (6)$$

Under typical operating conditions, the electricity produced by producing units in the corresponding locations is provided below

$$P_{G1} = P_{GT} + P_{GH} + P_{GG} \quad (7)$$

$$P_{G2} = P_{GD} + P_{GW} + P_{GPV} \quad (8)$$

Power generation by both locations:

The generation must be adjusted according to the load variations in order to keep the power balance in each system. If the generation and load do not match, it will lead to the frequency change and affect the power being transferred through the tie line [4], [11].

$$\Delta P_{G1} = \Delta P_{GT} + \Delta P_{GH} + \Delta P_{GG} \quad (9)$$

$$\Delta P_{G2} = \Delta P_{GD} + \Delta P_{GW} + \Delta P_{GPV} \quad (10)$$

The power transfer between regions using just the AC line is shown as

$$P_{tieAC} = P_{12\sin}(\delta_1 - \delta_2) \quad (11)$$

Using only the AC line, the power transmission between regions is displayed as

$$\Delta P_{tieAC} = T_{12}(\Delta\delta_1 - \delta_2) = T_{12}(\Delta f_1 - \Delta f_2) \quad (12)$$

The synchronizing coefficient T12 is modelled as

$$T_{12} = P_{12\cos}(\delta_1 - \delta_2) \quad (13)$$

HVDC:

An HVDC link is incorporated to provide controlled power exchange between the two areas. The HVDC controller helps damp frequency oscillations and improves the dynamic response of the interconnected system [11].

$$\frac{\Delta P_{HVDC}(s)}{\Delta P_{mHVDC}(s)} = \frac{K_{HVDC}}{1+T_{HVDC}s} \quad (14)$$

Where:

- $\Delta P_{HVDC}(s)$ is the change in transmitted power via the HVDC link.
- $\Delta P_{mHVDC}(s)$ is the reference input or modulation signal.
- K_{HVDC} is the gain of the HVDC link.
- T_{HVDC} is the time constant of the HVDC link.

METHODOLOGY

The implementation of MATLAB and Simulink has assisted in the development of a hybrid power system comprising two zones. Greenhouse for development equipped with AVR and LFC control and other types of controllers was developed along with MATLAB simulation, whereby the performance of various types of controllers to assess their capabilities such as stability, errors, overshoot and settling time [1], [3], [8].

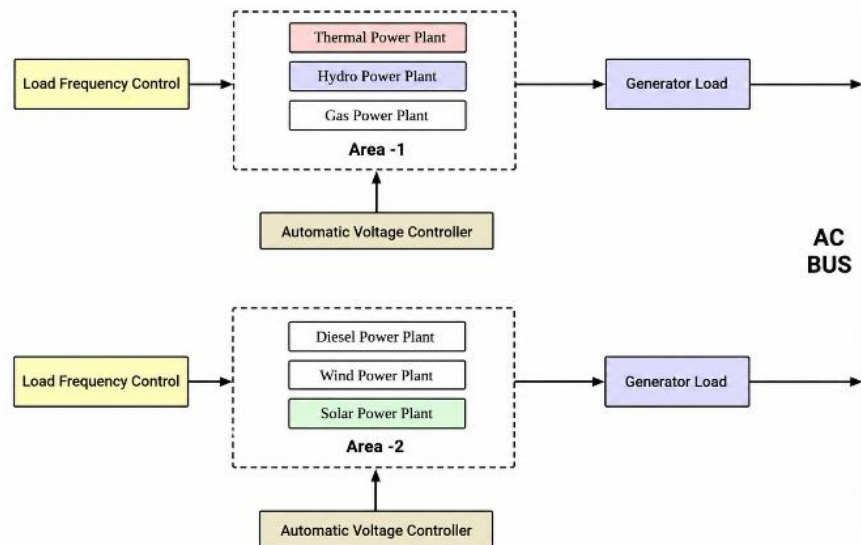


Fig 1. Two area control of LFC and AVR of Hybrid Power System

From Fig.1, In Area-1, the thermal, hydro, and gas power plants work together as a conventional generation unit. The LFC gets the frequency deviation and generates a control signal that will help adjust the generation. The AVC helps to maintain the proper voltage of the power-generating system. In Area-2, the diesel, wind, and the solar power plants are combined. The wind and the solar generation depend on natural factors, thus their generation power is variable. The LFC counteracts such variations and changes in power demand, while the AVC keeps the voltage on the appropriate level. The power produced by each area is transferred to a corresponding generator load. Both areas are finally connected to the common AC bus which enables the hybrid generation system to work as a linked power system.

AVR LOOP HANDLING

The purpose of the AVR loop is to keep the output voltage nearly equal to the reference voltage. The error is measured and transmitted to the controller which generates appropriate excitation control signal.

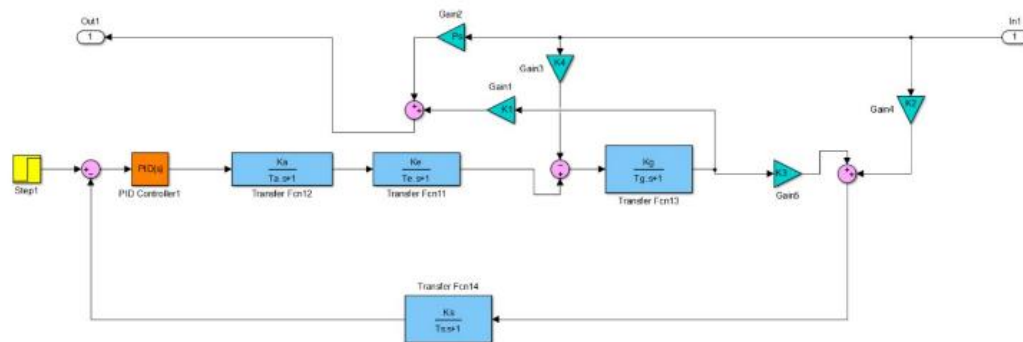


Fig 2. PID Controlled AVR System

In the diagram shown in Fig.2, it is shown how the AVR loop employs PID control to execute the generator terminal voltage. The reference voltage is fed into the voltage error mechanism, which compares it against the generator's terminal voltage. The error is then sent to the PID controller, which produces the excitation control signal for the generator. The AVR thereby effectively minimizes the voltage error and maintains the terminal voltage close to the reference value. The Transfer Function for the above AVR system is listed below,

$$G_A(s) = \frac{K_A}{1+sT_A} \quad (15)$$

$$G_E(s) = \frac{K_E}{1+sT_E} \quad (16)$$

$$G_F(s) = \frac{K_S}{1+sT_S} \quad (17)$$

$$G_S(s) = \frac{K_S}{1+sT_S} \quad (18)$$

RESULT AND DISCUSSIONS

In this study, MATLAB has been utilized to model the two-area hybrid power system in order to assess the effectiveness of PI, PD and PID controllers for variable loads. The system comprises renewable and fossil generation devices installed in the two connected areas. The first area includes thermal, hydro, and gas plants, while the second area is comprised of diesel, wind, and solar plants. The aim of these controllers is to control frequency and voltage changes due to varying loads and changing amounts of renewable energy. The hybrid power system response has been evaluated by applying appropriate disturbances at each area. The controller effectiveness has been evaluated on the time domain performance indexes such as frequency deviation, voltage deviation, and overshoot, and undershoot. The frequency deviation shows how efficient the controller is in bringing the frequency back to the specified value after a disturbance has occurred, while the voltage deviation shows how effective the controller is in keeping the voltage within the desirable range. Both overshoot and undershoot allow estimating the level of the oscillations in transient mode, while the settling time gives an estimate of the time needed for the system to start functioning in steady-state mode. The results of the simulation experiments done using MATLAB/Simulink evaluation software were utilized to determine the controller that gave the best dynamic response as well as stability in the system. Based on the evaluation done on the PI controller, PD controller and the PID controller, their advantages and shortcomings were established in terms of using them in the frequency and voltage regulation on the proposed hybrid power system.

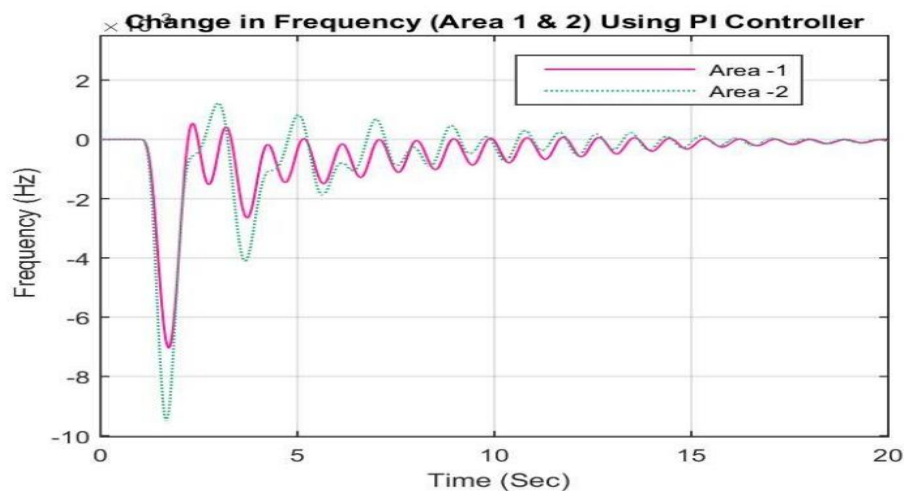


Fig 3. Change in Frequency in Area 1 & 2 using PI Controller

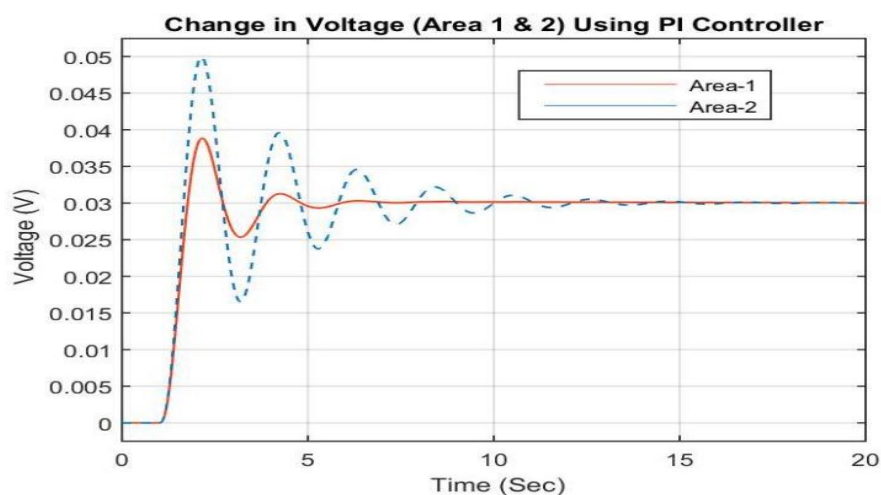


Fig 4. Change in Voltage in Area 1 & 2 using PI Controller

From Fig.3 and Fig.4 present both the frequency and voltage responses for two-area hybrid power system controlled by PI controller. The usage of this controller minimizes the deviations in frequency and voltage affected by disturbance in loads and brings the system toward steady-state operation. The performance of the controller is evaluated through oscillations, settling time, overshoot, and undershoot.

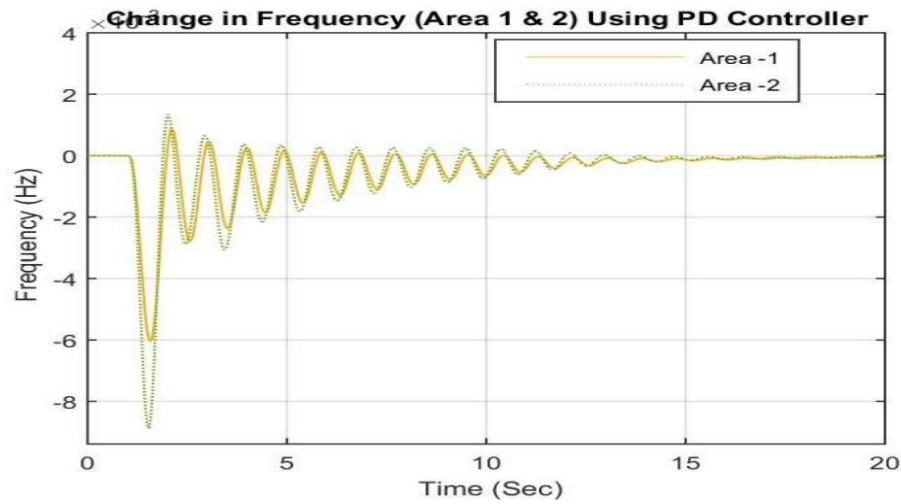


Fig 5. Change in Frequency in Area 1 & 2 using PD Controller

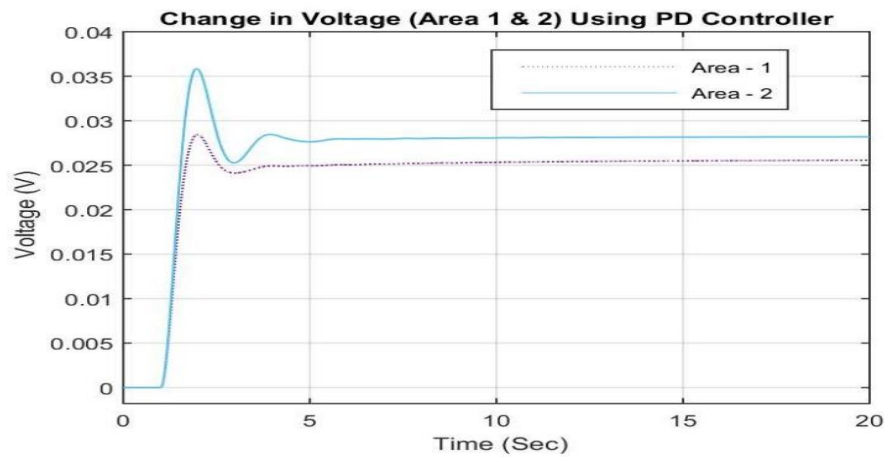


Fig 6. Change in Voltage in Area 1 & 2 using PD Controller

From Fig.5 and Fig.6, presents the frequency and voltage responses using the PD controller. The derivative action improves the transient response and reduces deviations caused by load disturbances. Its performance is evaluated using frequency and voltage deviations, oscillations, overshoot, undershoot, and settling time.

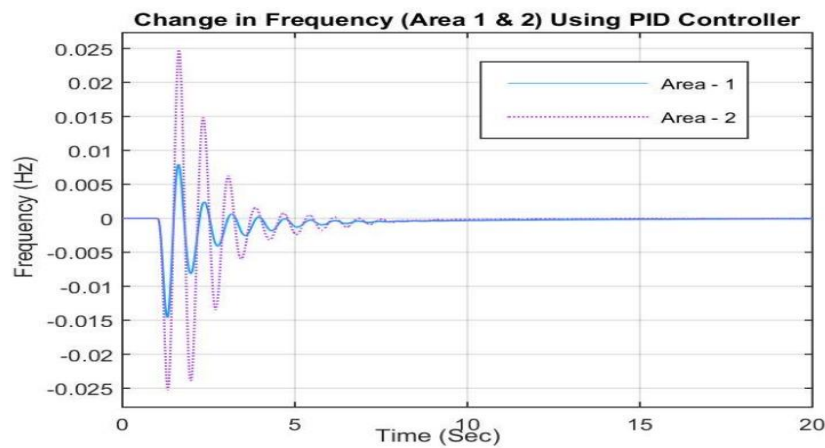


Fig 7. Change in Frequency in Area 1 & 2 using PID Controller

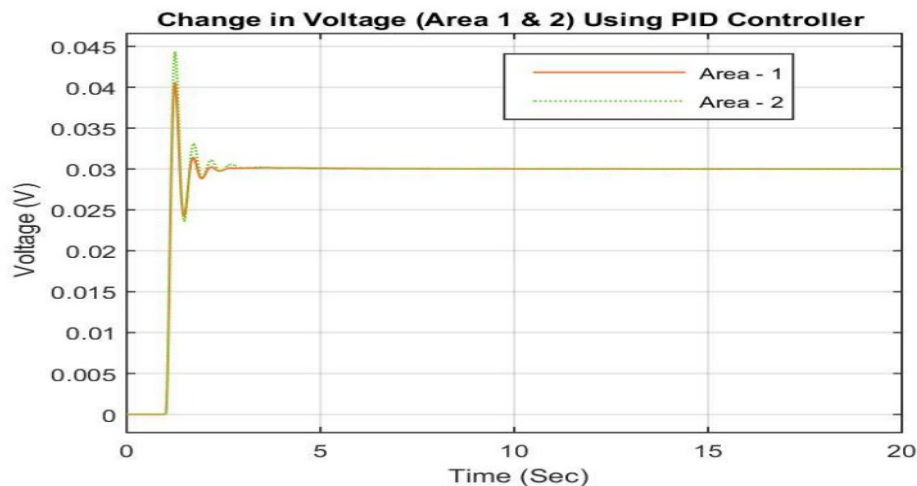


Fig 8. Change in Voltage in Area 1 & 2 using PID Controller

From Fig.7 and Fig.8, shows the frequency and voltage responses using the PID controller. The combined proportional, integral, and derivative actions effectively reduce system deviations and provide faster stabilization following load disturbances.

Frequency Response:

The analysis of frequency response assesses how successfully each controller is able to return frequency of system to its equilibrium values after load disturbance has occurred. An effective controller causes lower variations in frequency, lower oscillation levels and results in settling time being shorter [4], [16].

Voltage Response:

The analysis of voltage response is done through monitoring the output of AVR loop. The working of controller is determined by analysing the level of voltage changes [1], [10].

Controller Comparison:

According to the results of simulation experiments, PID controller shows better dynamic response if compared to PI, PD, and even PID controllers. It stabilizes the system better and eliminates fluctuations caused by changes in frequency and voltage faster than any other device [1], [8], [15].

Overall Discussion:

It is analysed that the comparison shows that the proper coordination of LFC with AVR is important in maintaining frequency and voltage stability in renewable integrated hybrid power systems. The transient performance has been improved with the PID controller, which makes it the best controller for the two-area system under consideration. The abstract of the paper also confirms PID as the best controller based on its effectiveness and speed [3], [10].

CONCLUSION

In the two-area power system, renewable energy production is coordinated to establish stability, reliability, and dynamics in a system. This process disrupts electricity generation to a certain extent because of intermittent characteristics of renewable energy generation systems such as solar and wind energy production. Thus, fluctuations in generation and variations caused by electricity demand cause frequency fluctuations, voltage deviations, and power oscillations. Therefore, control systems should be implemented in order to keep the frequency and voltage of the system at a satisfactory level.

In order to enhancing the voltage and frequency stability of the hybrid power system, one can evaluate the performance of PI, PD and PID control techniques under MATALB/Simulink environment. These controllers are programmed in such a way that they respond to the system errors and take necessary actions for normalising the system after disturbance. The PI controller uses both proportional and integral actions to provide swift response and to eliminate steady state errors. The PD controller uses both proportional and derivative actions to enhance the transient response. The PID controller uses all the three actions in order to achieve the better transient response results.

Controllers can be tested under different load variations and disturbances in the two-area hybrid power system. The frequency and voltage response after any loading disturbance is checked for every controller to compare their effectiveness through different indices. Frequency deviation is used to check the capability of the controller in restoring the frequency of the system after the disturbance of the load, while the voltage deviation is employed to see the ability of the controller in voltage regulation. Furthermore, the maximum overshoot and under-shoot values are calculated to check how severe the fluctuation is while the settling time is determined to find how quickly the system reaches the steady state.

The results from the simulation have shown that the PID controller is faster in stabilization and provides better dynamic performance compared to the PI and PD controllers. The proportional part of the controller is responsible for fast response to the error, while the integral action is there to remove the steady-state error, and the derivative part improves the transient response by reacting to the change rate of the error. Thus, the PID controller performs the operation of stabilizing frequency and voltage disturbances and avoiding oscillations because of load variations.

The analysis of the results from using the three controllers has proved the necessity to select an adequate control system of power generation. Among the proposed controllers, the PID controller allows achieving better frequency and voltage control, less oscillations, less overshoot, and smaller time taken to stabilize. Thus, design of the properly tuned PID controller is important for ensuring stable operation of a hybrid power system in two areas.

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