Automatic Generation Control of Single Area Hybrid Power System

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Abstract

In the power system, the load demand is continuously changing as per system requirement and the power system controller should efficiently compensate for the load requirement. The frequency instability may lead to equipment damage, load shedding, and possible blackouts, as a reason frequency is the most important design parameter to achieve the stability of a power system. The stable operation of an interconnected Hybrid Power System depends on a balance between production and consumption centers. To ensure system stability, different control techniques or control algorithms to compensate for the deviations in the system are employed but selecting the proper controller and its correct gain is tedious. In this research paper, the load frequency control of a single area hybrid power system is carried out using the Proportional-Integral and Derivative (PID) controller. The hybrid power system may consist of a renewable energy system (Wind/Solar) and a conventional interconnected power system (Thermal/Hydro).To obtain the optimal tuning of the PID controller, this research utilizes the PID Tuner from MATLAB. The performance of the PID controller for a single area hybrid power system will be analyzed for various load variation cases to show its effectiveness. The proposed PID-based governor provides better frequency control during load variations with smaller overshoot, undershoot, and short settling time of 10 seconds, as compared to P and PI.

Keywords—PID Controller, PID Tuner, Hybrid power system, Automatic generation control, DG, SM's Method.

1 Introduction

THE power system is a significant element that plays a major part in humans' daily lives. Due to rapid growth in technology, the power system has evolved from the conventional system to a more advanced power system net-work that incorporates intelligent algorithms that allow the system to be more robust and adaptive. The power system can be divided into three major parts namely the power system generation, power system transmission, and power system distribution. Power system control and stability are a field of study that mainly deals with the issue of how the transmitted power can be controlled as the generated power is normally subjected to various factors that can cause disturbance or imbalance in the electrical network [1]. One of the most important considerations that need to be taken into account during the operation of the power system is that the system should be able to cater to active power and reactive power load demand. The load demand is continuously changing as per system requirements and the power system controller should efficiently compensate for the load requirement. The changes in real or active power will directly affect the system frequency whereas the changes in reactive power will cause a change in the voltage magnitude [2]. The active and reactive powers are controlled separately using different controllers. The primary reason for the change in the frequency of the power system is due to:

1) Rapid increase in load demand than supply generator to meet demand.
2) Unexpectedly high demands caused by unusual changes or certain special events (sudden increase

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in load and load environment) resulting in significant losses in a variety of consumer loads.

3) Overload or Failure of other components or components of the equipment such as Generator failure and transformer failure [3]. It is clear from the above discussion that an accurate and fast Load frequency control method is highly important for the successful operation of power system networks. To address this issue, commonly load Frequency Control (LFC) is used to restore the frequency [4],[4] of the system to its nominal value[5]. The voltage is controlled by an excitation control and the frequency is controlled by making the output equal to the load requirement using a controller. Governor is a mechanical tool used to control engine speed, where there is a variation of load. If the engine load varies, the configuration of the governor changes, and it controls the supply of fuel to the engine, therefore the basic function of the governor is to control the speed of the generator [6] to keep its frequency constant.

Up to now, different types of governors have been used to control frequency. Typically, the mechanical controller [7], Electro-hydraulic PI, and the PID controller are hired to control [8] the load frequency of hybrid power systems [9].

The algorithm of the PID controller employs the control signal in a feedback loop. It consists of three parameters to calculate the corrections. The Proportional parameter corrects the present value of the error[10]. It multiplies the current error by a gain P. However, the proportional controller has the limitation[11] that it over-reacts to small variations producing swinging in the system[12]. These oscillations can be eliminated eventually but can be avoided. But for steady-state conditions of the proportional controller, it is impossible to avoid such small errors also. For ideal conditions, the controller should have no error at steady-state conditions. At this integral stage comes into existence [13].

The Integral gain eliminates the steady-state error. At this stage, the integration term subtracts a fraction of the mean error. Therefore, this average difference between the output and the set point is constantly decreasing. This helps in reducing the oscillations of a Proportional controller [14].

The slow response in the system may overcome the derivative term, which predicts the future performance of the system. By the combination of all these three functions in a controller, errors can be reduced to zero in a stable state and response can be fast. However, due to non-optimum P, I, and D parameters setting the PID controller may fail in controlling the hybrid power system.

The correct tuning of the PID-based governor helps to provide satisfactory frequency control during transient condi-tions and maintain flawless operation. PID controllers are employed to provide optimum speed control by properly tuning parameters. Their strength to solve these problems can be an option. The power system network may also have to deal with generation loss or sudden load surge cases. To combat this [15], the PID needs a proper tuning setting [16] to stabilize [17] the frequency and prevent the power system [18] from black outing [19].

Different techniques are employed for tuning PID controllers to solve such problems[20], [21], [22]. PID controller tuning is a complicated issue if the plants to be controlled are nonlinear and unstable.

Rani et al. [13] have proposed a genetic Algorithm for the tuning of PID controller parameters. He used a modified technique, called the Global Ranking Genetic Algorithm. The results show that the proposed technology is capable of fine-tuning PID controllers. Dormido et al. presented the design of a Fractional Order Proportional Integral Derivative controller. In this, he used two interactive tools. The First tool deals with the time and frequency domain design of FOPID controllers. This allows the user to analyze the effects of changing their chosen parameters. In the second tool, a loop shaping technique is used, which allows the user to automatically determine the controller parameters.

The response of the PID controller is employed by employing these techniques [20], [23]. However, these techniques make PID more complex. This also makes the controller a time-consuming process. In this research, the PID tuner block available in the MATLAB/SIMULINK software is used to tune the PID controller for automatic generation control of a single area hybrid power system.

2 Research Methodology

2.1 Test System for Load Frequency Control

The test system used for analyzing the proposed PID-based load frequency control (LFC) of a Hybrid power genera-tion system having a Thermal power plant and Wind Farm Modelled in MATLAB/Simulink software. The thermal power plant has a rated power of 250MW, and the Wind power plant has a rated power of 2MW. Both systems are connected to the load.

2.2 Thermal Power Plant

As discussed earlier, the capacity of the thermal power plant is 250MW. The components of a thermal power

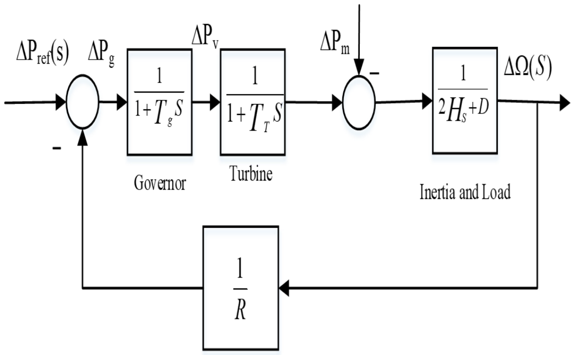

Fig. 1: Thermal Power system model transfer function

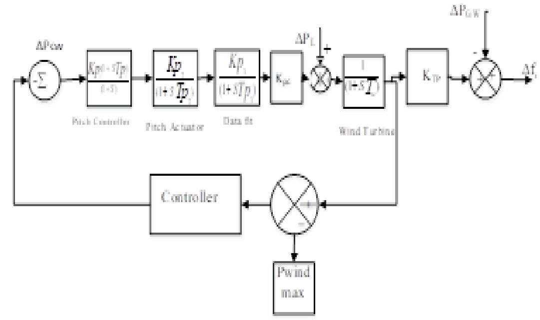

Fig. 2: Wind power system block diagram

TABLE 1: Power system parameters

Parameter	Value
Turbine time constant	0.5
Governor time constant	0.2
Governor inertia constant	05
Governor speed regulation	0.05
Damping constant	0.8

TABLE 2: Wind generation parameters

Wind Power System Parameters	
Kp1	0.75
Kp2	1
Kp3	1.3
Tp1	0.6
Tp2	0.04
Tp3	1
TW	4
H	5
D	6
KPc	0.00567
Ktp	0.99999

plant are the speed control mechanism which includes the speed governor, governor control valves, speed control mechanism and speed changer, turbine, rotating mass, and load. The power system is designed using the transfer function. Table 1 shows the detailed parameters of the thermal power plant used in the paper. The Block diagram of the power system based on the transfer function is shown in fig.1.

2.3 Wind Power System

The wind power generation system includes an actuator, pitch control, and data fit pitch feedback. The entire wind system is controlled by using a PID controller. The integration of wind power in any hybrid system may affect the power quality of the whole system. The blade pitch control mechanism is employed for controlling the deviations in the generating power. This mechanism also controls frequency fluctuations. This control system also monitors wind turbine speeds and operates on an active feedback control system attached to the turbine. The block diagram of the transfer function of the wind generating system along with the blade pitch controller is illustrated in fig.2.

The function of the blade pitch controller in a wind turbine generating unit is to maintain continuously the power generation of wind. Conflicts of wind power generation can impact the electrical quality of the wind thermal hybrid power system. It also introduces variations in power generation and frequency fluctuations. They are removed by the blade pitch control mechanism. Transfer function parameters of a wind power system: The actual change in power load P1 is different from the specific level of power output experienced by the Pgw hybrid system. The time constant of the hydraulic blade pitch actuator and data fit pitch response unit are TP1, TP2, and Tp3 respectively. Kp1, Kp2, and Kp3 are the gain constants of the hydraulic pitch actuator and data fit pitch response unit respectively. Kpc and Tw are the blade characteristic constant and wind-turbine power generation system time constant in seconds. The first-order function can be employed for the transfer function of wind when the nonlinearities are neglected. It is shown in equation.1.

$$G_w = \Delta P_w + Kw/(1 + sT_w) \quad (1)$$

where ΔPWG is the change in wind generator output,

ΔPW is the change in wind power, KW is the gain of wind generator The parameters of the Wind generation system are given in Table 2.

2.4 Blade Pitch Control

Wind turbine blade angle pitch control has an effective impact on the dynamic behavior of the

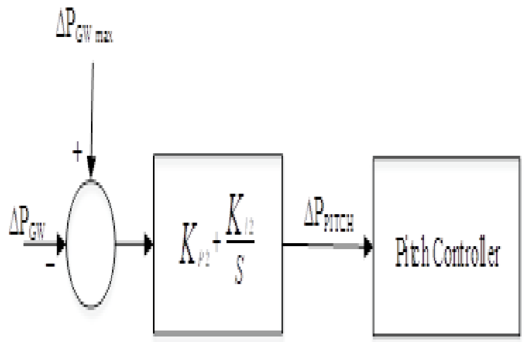

Fig. 3: Block Diagram of Pitch Controller

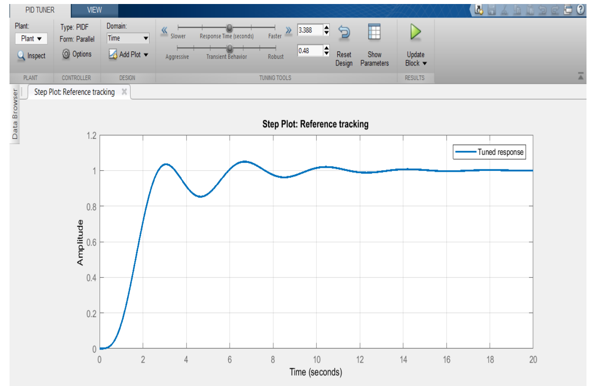

Fig. 4: PID Tuner app in MATLAB/SIMULINK

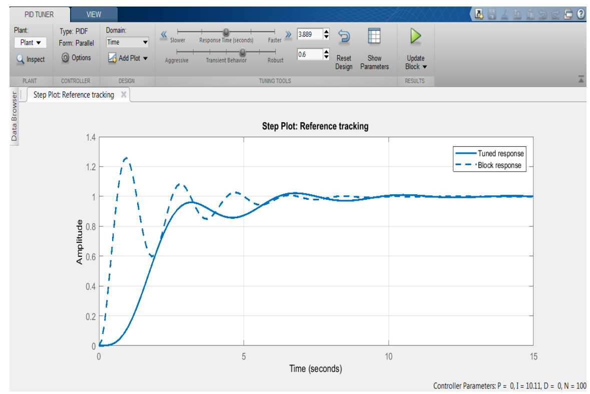

Fig. 5: Re-tuning of PID controller-1

system. The regulation of the power delivered to the rotor is achieved through turbine blade pitch control. As shown in the figure below the pitch controller (KPITCH) of the 1st-order PI controller is used to reduce the frequency deviation (△ fs). This controller works by using the output power of a wind generator (△PGW) as an input feedback signal.

Here the pitch control system controls the wind power input into the system and limits the power during high wind speeds in the autonomous system. The pitch control system limits the power input to handle power when load demands are lower than the potential output of the wind turbine.

2.5 Tuning of PID Controller Model

By adjusting the parameters of the PID controller in MATLAB SIMULINK, the various values of Kp, Ki and Kd can be found to achieve the required performance, whereas the gains of the PID tuner can be tuned automatically in SIMULINK control design in the control model. The rise time in frequency response can be reduced by varying the Kp. The setting time and response overshoot both depends on the variation of Kd. By changing Ki steady-state error can be eliminated. The PID controller tuning process involves various steps.

Click on the PID Tuner App in MATLAB/SIMULINK and then import your model into the PID tuner app or simply just open the Simulink model and go to the PID controller parameters to be tuned and then click on the tune button so that a new window is opened as given below.

Fig.4 shows that whenever we open the PID tuner in MATLAB/SIMULINK, it will automatically tune the parameters of the PID controller up to some suitable extent, however, it is not enough, therefore, to meet your desired values slide the slider bar again and again. Once you get some values, update the block parameters, and then open the tuner app again for further tuning if required for this purpose continue this process again until you meet your desired values. Similarly, tune the other PID controller given in your MATLAB/SIMULINK plant model of load frequency control. After several tries, I have to get my desired response which shows minimum overshoot and undershoot issues, less settling time, and rise time. At this stage, the tuned values of the PID controller parameters are required for optimal tuning of the PID controller. It has been observed that PID based governor shows good response and take minimum time to stabilize the frequency. Fig.5. Shows the re-tuning of PID controller-1 and similarly repeats the whole process for the tuning of the 2nd PID controller used in the plant.
This process is too time-consuming because at every time of tuning the plant is auto-tuned and some random values are set for PID parameters then i have manually performed tuning by using the slider tool or simply by putting the random values of Kp, Ki, and Kd. Which is called the Hit and Trial method of

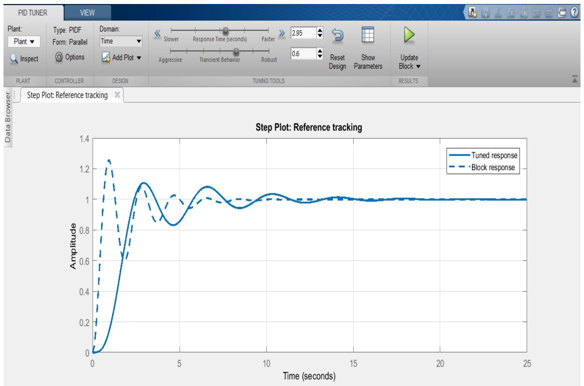

Fig. 6: overall tuned values of the PID controller

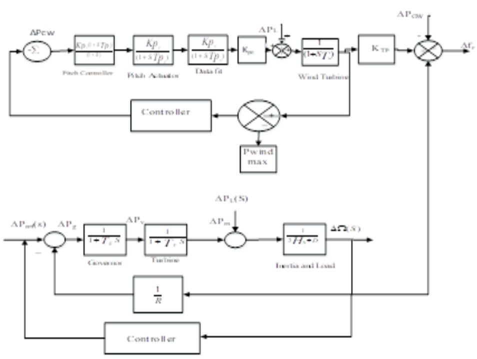

Fig. 7: Shows the overall transfer Function block diagram of the Hybrid Power system

PID tuning. Once the tuning process is completed, parameters are updated, and the power system is simulated again to obtain the desired outputs. In the end, a comparison is made between the tuned and untuned parameters through the parameters table or the graph of the output response of the PID controller which shows a clear difference between tuned and untuned values. Fig.6. Shows the overall tuned values of the PID controller.

2.6 Tuning of PID Controller Model

In figure.7, the block diagram of a hybrid (Wind-Thermal) power system based on transfer function is illustrated. To control the load frequency PID controllers are used in the model of a hybrid (Wind-Thermal) power system. These controllers eliminate the error caused by either a small change in active power load demand or a change in generated power.

TABLE 3: Shows the different case studies

Case Studies	Description	
CASE NO.01	A	05% load is suddenly increased at peak load.
	B	05% load is suddenly decreased at peak load.
CASE NO.02	A	10% load is suddenly increased at peak load.
	B	10% load is suddenly decreased at peak load.

3 Result and Discussion

The system is made to check the response of tuned and untuned PID controllers for load frequency control. MATLAB/Simulink Software is used to model and simulate the test system.

3.1 Case Studies

The response of PID-based governor for load frequency control in different cases at base load on the power system. Table 3. Shows different cases for the sudden increase and decrease in load to observe the significant response of PID-based governor.

3.2 Simulation Results

3.2.1 Case1-a: When 05%load is increased at peak load:

The power plants are operating at the maximum load (peak load) of their capacity and suddenly a 05% load is added. As the load is increased so the frequency will decrease. The deviation in frequency through tuning and without tuning of the PID controller is shown in fig.8.

Due to load increment frequency is dropped from its nominal value (50 Hz) to 49.7 Hz and it is necessary to bring the frequency to its original value. It can be observed that the PID controller-based governor has restored the frequency to its nominal value in approximately 20 sec. By using the tuning function of MATLAB, the PID controller is tuned and it gives a fast response, restored in 15 seconds, and also undershoot problems are restored.

3.2.2 When 05% load is decreased at peak load:

The response of the PID-based governor at peak load for a decrease of 05% load is shown in figure 9.
It can be observed from fig.9, that load is decreased so frequency has increased and then again reduces to its original value after some time. Approximately 0.5 Hz frequency is increased due to 5% reduction of load. PID-based governor showing good response has recovered the frequency to its nominal value in 15 sec. Thus by tuning PID controllers, the frequency is recovered in almost 15 sec and overshoot problems are also reduced to acceptable limits.

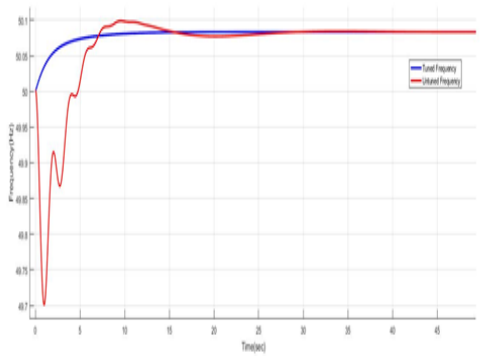

Fig. 8: PID-based governor response for 05% addition of load

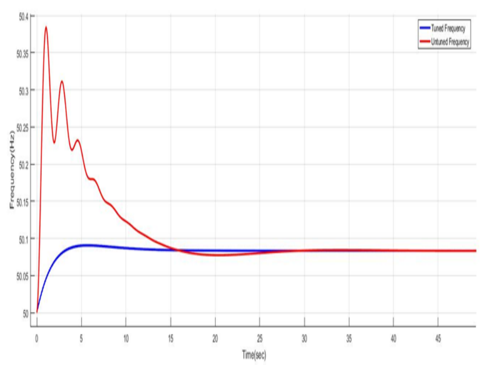

Fig. 9: PID-based governor response for 05% reduction of load

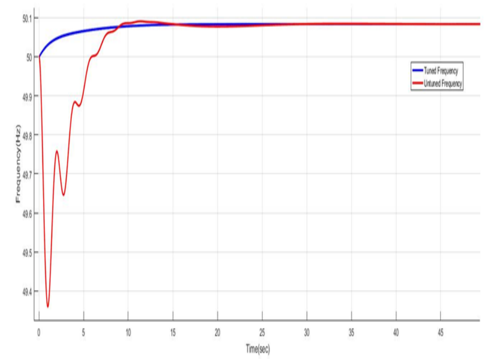

Fig. 10: PID-based governor response for 10% addition of load

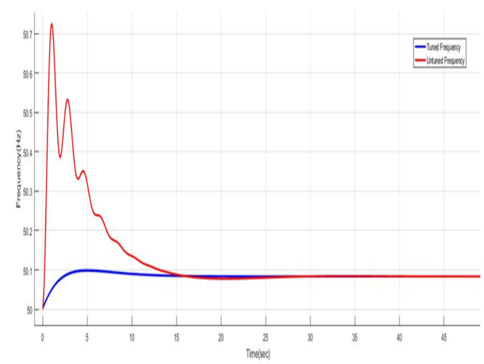

Fig. 11: PID-based governor response for 10% reduction of load

3.2.3 Case2-a: When 10% load is increased at peak load:

The power plants are operating at the maximum load of their capacity and suddenly a 10% load is added. As the load is increased so the frequency will decrease. The deviation in frequency through tuning and without tuning of the PID controller is shown in figure 10. It can be seen in fig.10 that the frequency has dropped from 50Hz to 49.4 Hz due to the sudden addition of the load. It can also be observed that PID-based governor has less undershot and frequency takes 10 seconds to reach gain at its original 50 Hz value. Whereas another curve shows that the tuned frequency is settled in less than 5 seconds.

3.2.4 Case2-b: When 10% load is decreased at peak load:

The power plants are operating at the maximum load of their capacity and suddenly a 10% load is reduced. As the load decrease so frequency will increase. The response of the PID-based governor is shown in figure 11. Due to the addition of the load to the system, the frequency has overshot to 50.7 Hz, and it is necessary to keep the frequency within safe limits. It can be observed in Fig. 11 that the PID-based governor has brought the frequency to its original value of 50 Hz in 10 sec. The tuned PID controller in LFC controls the frequency and brings it back to 50 Hz in minimum time without overshooting.

3.3 Discussion

The load frequency control (LFC) based on a PID-based governor has been analyzed on a single-area Hybrid Thermal-Wind power generation system at various load variations operating at maximum capacity. The frequency response of the proposed PID-based governor is analyzed in terms of frequency undershoot, frequency overshoot, and time is taken to stabilize the frequency for various load variations. It has been observed that PID-based governor shows good response and takes minimum time to stabilize the frequency, having less undershoot and overshoot. Thus, it is proved that the proposed PID-based governor is efficient and reliable to control the frequency deviations. Load frequency control has to perform its action within the safe range of frequency. Failure to do so will initiate the automatic load-shedding strategies to prevent power system blackouts.

4 Numerical Methods

There are various methods can be applied on the engineering model, where the short-term balance of power and fre-quency of the power system discussed. There are three different models, and their conditions can be defined to simu-late mathematically. The oldest and easiest method is finite discretization using finite difference method[24], SM's method[25], Finite element[25] and finite volume method[26], conjugate gradient method[24] and so on[11, 28]. The Mesh generation process[25], [23], [26] is described for regular (Uniform) [24] and random spacing. This method[25], [24] , [29] helps us to solve tuning of proportional-integral-derivative controller for LFC[29], which is implemented in the mathematical software, namely MATLAB[27], [28] Method can also calculate the effectiveness and robustness of proposed PID based governor with load addition and reduction[30].

5 Conclusion

Frequency control is one of the most effective ancillary services for a power system. It maintains a short-term balance of power and frequency of the power system. Frequency control is usually achieved through Generator Governor Feedback (Primary Frequency Regulation) and Load Frequency Control (LFC). The control of generation and frequency is commonly termed load frequency control (LFC). This research is focused on the tuning of a proportional-integral-derivative (PID) controller for LFC, implemented in MATLAB. The effectiveness and robustness of the proposed PID-based governor are investigated on load addition and reduction of 5% to 10% at base capacity. The simulation results show that the PID base governor provides better frequency control during load variations with smaller overshoot, undershoot, and short settling time. Hence, it has been proved that the proposed PID-based governor is efficient and reliable in the safe and stable operation of the power

6 Nomenclature

Table 4 shows the nomenclature use in paper.

TABLE 4: Nomenclature

LFC	**Load frequency control**
PID	Proportional-integral-derivative
SM's Method	Sanaullah Mastoi's Method
BFO	Bacterial Foraging Optimization
PSO	Particle Swam Optimization
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization

7 Future Recommendations

The response of PID-based governor can be further improved by implementing the optimization techniques such as Bacterial Foraging Optimization (BFO), Particle Swam Optimization (PSO), Artificial Bee Colony (ABC), and Ant Colony Optimization (ACO) techniques.

The Numerical simulation using SM's Method is proposed to apply to a fictious model and can get better

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