

Stability Control Analysis Of Standalone Nuclear Power System With Pid Controller

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Abstract

This project discussed about the performance analysis of Load Frequency Control (LFC) of single-area nuclear power systems. The LFC is achieved by the support of a Proportional Integral Derivative (PID) controller as implemented as a secondary controller. The controller gain values are tuned by the conventional tuning method (trial and error). During unexpected power demand occurs in the power system, the frequency in the system is oscillated from the standard limit. The PID controller helps to control the oscillation and bring back the frequency to standard. The gain values are tuned with different cost functions (Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE) and Integral Square Error (ISE)). The conventional – PID controller provides better time domain specification.

1. INTRODUCTION

Any power generating plant's power systems are operated and controlled in large part by automatic generation control, often known as load frequency control (LFC) or AGC. Examining the effectiveness and consistency of the power supply carefully is crucial when there is a sudden or ongoing load disruption in the process. Power plants are coupled by tie-line to get acceptable power quality, including nuclear power systems, to satisfy the aforementioned standards.

The two main objectives of Load Frequency Control (LFC) are

1. To maintain the real frequency and the desired power output (megawatt) in the interconnected power system.
2. To control the change in tie line power between control areas.

2. PREVIOUS RESEARCH WORK

For load frequency control of an empowered power generation system that includes numerous autonomous generation facilities such as diesel energy generators, solar energy modules, wind turbine generators, and fuel cells, along with energy storing units, an improved Sine Cosine Algorithm (SCA) based Adaptive Fuzzy Aided Proportional Integral Derivative (AFPID) controller is proposed. Flywheel and battery energy storage systems are the available devices for storing energy. The suggested controller's response is contrasted with that of a proportional integral derivative controller calibrated using a sine-cosine algorithm and an integral time total error

target value. The comparison makes it quite evident that the suggested controller yielded the least amount of settling time. 2019 (Rajesh and Dash).

Using the Kharitonov theorem For the load frequency regulation of a single area power system, a proportional integral controller constructed using fuzzy logic was presented. The suggested controller's simulation results are contrasted with the output of a traditional PID controller. The suggested controller has a better resonant frequency with less damping oscillation (Golshannavaz et al. 2018).

PID controller based on the population-based optimization approach is presented for autonomous generation control of thermal power systems with one, two, three, and four areas. With different cost functions in mind, the response was compared with GA PID and PSO PID controllers. In comparison to existing techniques, the suggested controller provides the fewest time domain-defined parameters (Jagatheesan et al. 2017).

To control the load frequency of a multi-area linked power system with various function optimization, a robust proportional-integral controller is developed, and its parameters are built via limited population extremal minimization. Integral standard deviation, integral time absolute error, integral time square error, and integral square error are the cost measures. A genetically adjusted proportional integral derivative controller and an optimization algorithm for bacterial foraging are used to compare the performance of the proposed system. Performance comparisons make it abundantly obvious that the suggested controller excels in terms of lowering frequency stability (Zhou et al. 2019).

For the load frequency regulation of a multi-area thermal power system with an integral squared error objective function, a proportional integral derivative controller based on the Flower Pollination Algorithm (FPA) was built. The suggested controller's simulation results were compared to those of the genetic algorithm and the tuned proportional integral derivative controller response from Particle Swarm Optimization (PSO). Peak overshoot (0.0085 sec), Peak undershoot (0.0021 sec), and settling time in response (0.0085 sec) are all improved by the suggested minimization technique-based controller (Jagatheesan et al. 2017).

Fuzzy proportional integral derivative controllers that are tuned for the Firefly Algorithm (FA) have been developed and explored for use in autonomous generation control of multi-area, multi-source, linked power systems. The performance of the suggested controller is compared to simulation results for proportional integral derivative controllers based on genetic algorithms and differential evolution gravitational search algorithms. The proposed controller demonstrates its advantages through enhanced dynamic responsiveness (Pradhan et al., 2016).

For load frequency control of three area-linked power systems (two areas reheat thermal systems and hydro system), tuned proportional integral controllers using the Cuckoo Search (CS) algorithm are examined. The effectiveness of the suggested method is evaluated in comparison to genetic algorithms, evolutionary algorithms customized integral controllers, and objective functions for integral absolute error, integral time absolute error, integral squared error, and integral time squared error. The suggested controller displays a faster settling time in an emergency. (2015) Abdulaziz and Ali

In a deregulated environment, the proportional integral derivative with filter (PIDF) is suggested for autonomous generation regulation of a multi-area thermal power system. When compared to fuzzy logic controllers in simulation results, the suggested controller's peak overshoot and settling time are reduced by using the integral time absolute error objective function (Gorripotu et al. 2015).

In a two-area hydrothermal power system operating in a deregulated environment, the adaptive neural fuzzy system controller is employed to justify the different load frequency control problems. The simulation's results were compared to controllers using fuzzy logic and standard proportional integrals. The suggested controller responds more quickly and requires less settling time (Abhijith Pappachen & Peer Fathima 2016).

For automated generation management of two area thermal systems, a 2-Degree of Freedom proportional integral derivative controller based on teaching-learning was presented. The response is contrasted with ziegler-Nicols, genetic, bacteria-foraging optimized, differential, and hybrid BFOA and PSO-based proportional integral controller responses with integral time absolute error objective functions. The outcome amply demonstrates that the suggested controller provides superior dynamic responsiveness (Sahu et al. 2016).

A detection system for identifying malicious node in mobile ad hoc networks and also proposed power-aware routing system using on-demand multipath routing protocol for efficient packet transfer without any packet loss and for better communication in MANET (Rajaram, K et.al 2010).

An enhanced distributed certificate authority scheme for authentication in mobile ad hoc networks and trust based cross-layer security protocol malicious node detection. The modified security scheme for data integrity for manet was suggested for security in network communication (Palaniswami, S et.al 2012).

Enhanced data accuracy-based PATH discovery using backing route selection algorithm in MANET was proposed for better network communication (Premanand, R. P et.al 2020).

Effective timer count scheduling with spectator routing using stifle restriction algorithm in manet for timely scheduling packets and rapidly communication at emergency situations (Anand, R. P et.al 2020).

Energy efficient and node mobility-based data replication algorithm and a high certificate authority scheme for authentication for MANET an approach for stable path routing scheme for improving packet delivery (Rajaram, A. et.al 2019).

The literature analysis mentioned above makes it abundantly evident that transient and rapid load changes have an impact on the quality of single- and multi-area power systems. The suggested evolutionary programming approach tuned PID controller is built and used as a secondary controller in the power system during rapid load demand to resolve the multiple input.

Every power system has a principal controller according to the system design. The primary controller is capable of managing situations involving abrupt changes in load. The frequency oscillation must be controlled, but it damages electrical equipment and consumes extra time. LFC mechanism is implemented in the power system to address the issue. We require a secondary controller to integrate the LFC into the power supply. The PID controller was used as a supplementary controller in this design.

3. MATERIALS AND METHOD

To resolve the Load Frequency Control (LFC) issue, single-area multi-source power-producing systems are advised to use the Optimization Algorithm (PSO) approach. The power-producing system uses a Proportional-Integral-Derivative (PID) controller as a secondary regulator. The planned power network consists of photovoltaic (PV) systems with an energy storage system as well as thermal, hydro, gas, and nuclear power sources.

The LFC method is used to preserve the quality of the power system when unanticipated load change situations cause the system frequency to diverge from the standard values. For the aforementioned suggested multi-source power system, a regulator based on the PSO approach is created and tested. By contrasting the performance of the suggested method with that of a traditional tuned PID controller, the superiority of the proposed method is demonstrated. Analyzing the time domain specification parameters reveals the superiority of the proposed controller performance. The distinction demonstrates that the PSO-PID controller performs the best in terms of quick frequency oscillation settling, constrained peak overshoot values, and undershoots.

3.1 Load Frequency control

For the contemporary power system to maintain power quality from generation to the consumer, load frequency regulation is crucial. The need for loads nowadays is growing as a result of both industry and demographic expansion. The power system should be able to maintain stability and power quality in the event of a rapid load disruption while also balancing the power demand and generation.

A single-area power system's established operating frequency is affected by a modest load variation, which also causes damping oscillation. It causes a power imbalance between supply and demand. The initial solution to this mismatch issue is the removal of kinetic energy from the system, which leads to a decline in system frequency. Therefore, load frequency control is used in the power system to maintain the lowest possible damping oscillation, the lowest possible peak overshoot, and the lowest possible undershoot during a fast load shift.

The frequency and other system specifications are automatically met when the power balance between generation and demand is established. Similar to how electricity generation and demand are balanced, the voltage profile is kept within the established bounds. When the system is in a stable state, its total power generation matches its entire demand + power losses. A change in speed or frequency instantly signals any difference (Nagrath and Kothari, 1994; Kundur, 1994). (Elgerd, 1970).

The following basic requirements are to be fulfilled for the successful operation of the power system:

1. The generation must be adequate to meet all the load demands.
2. The system frequency must be maintained within narrow and rigid limits.
3. The system voltage profile must be maintained within reasonable limits.

3.2 Nuclear Power System Model

A nuclear power plant is a generator where nuclear energy is transformed into electrical energy. In a particular device called a reactor, heavy materials like uranium (U235) or thorium (TH232) are exposed to nuclear fission. Reactive materials emit heat energy, which is used to create steam at high pressure and temperature. Steam turbines use steam energy to create mechanical energy.

The most significant characteristic of a nuclear power plant is that, in contrast to other traditional types of power plants, a significant quantity of electrical energy can be generated from a very little amount of nuclear fuel. Since we are now consumed by energy, nuclear energy may be effectively used to provide low-cost electrical energy on a wide scale to fulfil rising commercial and industrial electrical load needs (Mehta and Rohit Mehta., 1982).

The major features of nuclear power plants are as follows:

- The amount of fuel required is quite small.
- A nuclear power plant requires less space.
- This is very economical for producing bulk electric power.
- It ensures the reliability of operation.

The hydraulic amplifier, speed regulator, a nuclear power plant with a governor, and generator make up the single-area nuclear power system model. For closed-loop control of a single-area nuclear power plant, a proportional integral derivative controller is taken into consideration together with the aforementioned components. Figure 1 below shows the block diagram of a single-area nuclear power system.

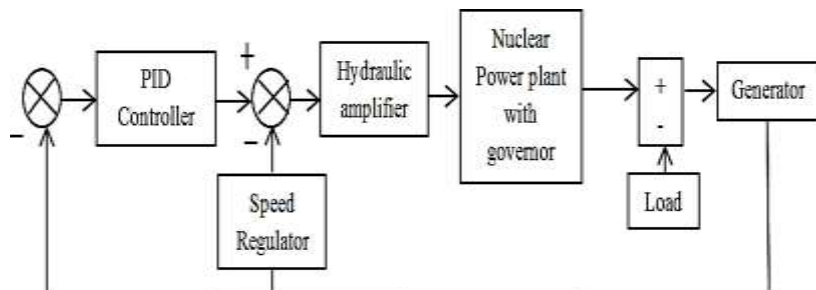


Figure 1. Single-area nuclear power system model with PID controller

3.3 Hydraulic Amplifier

A mechanical setup for managing power generation in a steam-powered generating unit is a hydraulic amplified. To balance power generation and load demand during a sudden change in load in the power system, the input of the generator should be modified right away following the load distribution. The input to the steam turbine, which determines the generator's speed, is adjusted. Hydraulic amplifiers are used in this procedure. It has a main piston and a pilot piston. This configuration transforms a low-power pilot value movement into a high-power level movement of the oil-servomotor piston. To operate a steam valve or gate against high-pressure steam, a hydraulic amplifier is required. The equation provides the hydraulic amplifier's transfer function equation 1.

$$G_H(s) = \frac{1}{1+sT_H} \quad (1)$$

$$T_H = \frac{1}{K_H} \quad (2)$$

Where

T_H = hydraulic time constant.

3.4 Nuclear Power Plant with Governor

The high-pressure and low-pressure turbine model is always key component in the development of a mathematical model of a nuclear power plant. The transfer function for the nuclear power plant is generated by taking into account those two turbine transfer functions given in the below equation (Mohanty, and Hota, 2015).

$$G_N(s) = \frac{1+sA+s^2B}{(1+sT_{RH1})+(1+sT_{r1})+(1+sT_{RH2})} \quad (3)$$

From the above transfer function of a nuclear power plant, a model of nuclear power plant with a governor is developed and shown in figure 2.

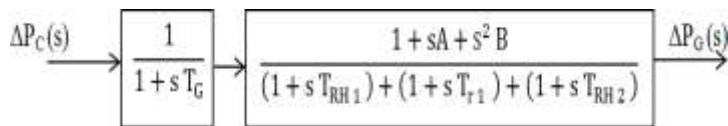


Figure 2. Model of Nuclear Power Plant with Governor

3.5 Speed Governor

A governor is a tool for regulating a primary mover's speed. A governor controls the primary mover's speed and prevents it from exceeding the specified rotational speed. A governor is necessary to maintain the prime mover at a speed that will provide the desired frequency when it drives an alternator that generates electricity at a specific frequency. It is a load frequency control device for error sensing. It contains all the components that are immediately influenced by speed and cause other system components to take action transferring speed governor function is given in equation 2.

$$\Delta X_C(s) = \left[\Delta P_C(s) - \frac{1}{R \Delta f(s)} \right] \frac{K_G}{1+sT_G} \quad (4)$$

From the transfer function of the speed governor, the basic Simulink model of the speed governor is shown in figure 3

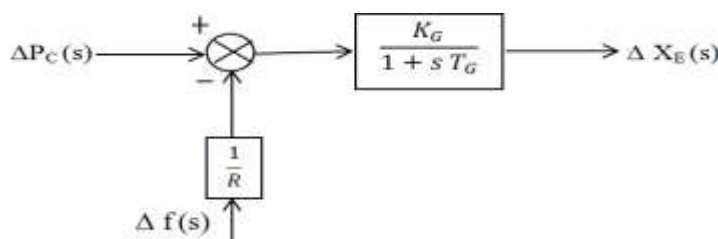


Figure 3 Model of speed governor

3.6 Power System

Using a generator, mechanical energy may be transformed into electrical energy. Given steam, energy is transformed into useable mechanical energy via the turbine. With the aid of a generator, this mechanical energy is transformed into electrical energy. To create a mathematical model of an isolated generator that only supplies local load and does not provide power to another region, and which raises its output by an amount ΔP_G in response to a real load change of ΔP_D caused by the operation of the turbine controllers. The total power surplus ($\Delta P_G - \Delta P_D$).

$$\Delta P_G - \Delta P_D = B \Delta f \quad (5)$$

Where B = Damping coefficient in MW/Hz.

Power balance equation,

$$\Delta P_G - \Delta P_D = \frac{2HPr}{f_0} \frac{d}{dt} \Delta f + B \Delta f \quad (6)$$

$$\Delta f(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{1 + sT_p} K_p \quad (7)$$

From the above transfer function, the basic generator load model is shown in figure 4

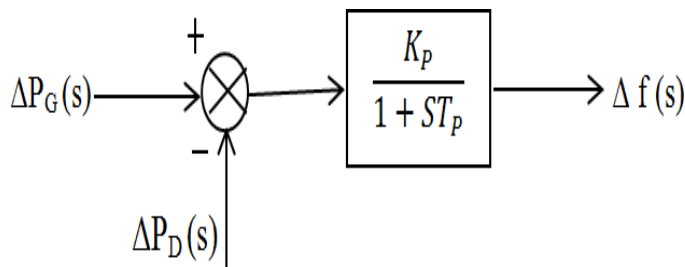


Figure 4 Generator model

3.7 Overall Arrangement

The overall arrangement of the proposed model for a single-area nuclear power system consists of a hydraulic amplifier, and speed regulator; a nuclear power plant with a governor, generator and PID controller is designed for analysis of the proposed technique performance. The overall Simulink model arrangement of single area nuclear power system is shown in figure 5

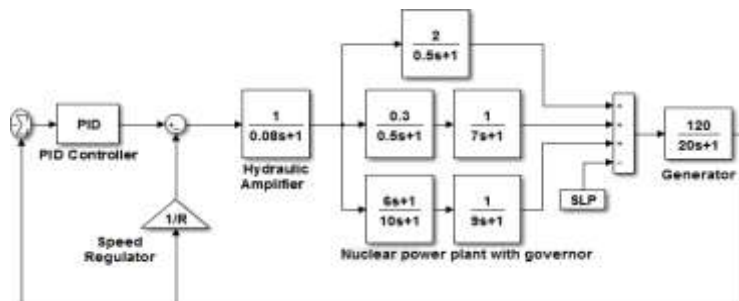


Figure 5 Overall arrangement of single area nuclear power system

4. Results and Discussion

4.1 Open Loop Response

Application of 1% SLP is used to simulate the performance of the proposed single-area nuclear power plant that is created in chapter 2 and shown in figure 2. The suggested system's parameters are listed in Appendix 1. The suggested power system's open-loop response comparison with and without load demand is shown in Figure 6. The black line in this example indicates no load, while the red line shows a distribution of 1% SLP load. From the response region, a steady state error value of 0.007Hz is found.

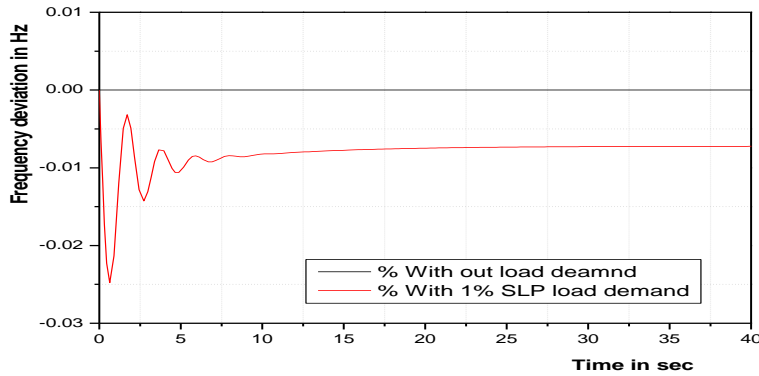


Figure 6 Open loop response comparison with and without load demand

Table 1 Time domain parameter of open loop response with and without load demand

Time domain-specific parameter/loading condition	Settling Time (s)	Peak Overshoot (Hz)	Peak Undershoot (Hz)
With load demand	32	0	0.025
Without load demand	0	0	0

4.2 PID Controller Design

In this section 3.3, the input and output signal values of the proposed PID controller, together with the appropriate equations, are explained and provided. The choice of controller gain levels is crucial for achieving improved controller output responsiveness during unexpected load disruption. The PID controller gain values are adjusted using a traditional way while taking into account various cost functions. Figure 7 depicts the PID controller's institutional framework. Integral controller (I), Proportional controller (P), and Derivative controller (D) are its three fundamental words (Gopal (2002), Gopal (2004), Nagrath and Gopal (2007), Gopal (2008)).

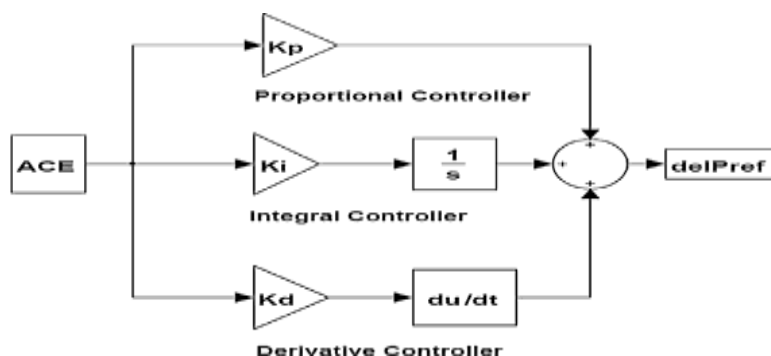


Figure 7 Structure of PID controller

When a sudden load demand occurs, the PID controller effectively regulates the system's frequency. The proportional gain (K_p), integral gain (K_i), and derivative gain (K_d) gain parameters in the PID controller's

structure are modified using traditional optimization methods. Three fundamental controllers make up the proposed PID controller. A derivative controller is provided to lessen the damping oscillation in the system frequency, a proportional controller to manage excessive overshoot and undershoot in the response, and an integral controller to control steady-state error in the operating frequency.

The proportional integral derivative controller produces an output, which is the combination of the outputs of proportional, integral and derivative controllers.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (8)$$

By taking Laplace transformation on equation 8, the mathematical form PID controller is derived. The transfer function of the PID controller is given in equation 9.

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \quad (9)$$

The input of the controller is Area Control Error (ACE) and the output of the controller is control signal (delPref). The output of the controller is given into the power system as a reference signal.

4.3 Cost Function

The performance metric to reduce reaction error and enhance performance in an emergency circumstance is a cost function. It comprises the overall amount of power used, integrated error, and signal deviance from a reference value. A functional equation called the cost function converts a collection of time-series data points into a single scalar value. Cost is represented by the scalar value.

According to a literature review, there are multiple ways to improve controller gain values using various cost functions. These cost functions include IAE, ISE, ITAE, and ITSE. To obtain the required power supply in the power system, the best control gain values are found using cost functions (Zhou et al., 2019; Ghasemi et al., 2016; Arya and Kumar, 2016; Barisal, 2015). The cost functions IAE, ISE, ITAE, and ITSE are mathematically expressed below in equations 10 to 13, respectively.

$$J_{IAE} = \int |ACE| dt \quad (10)$$

$$J_{ITAE} = \int t \cdot |ACE| dt \quad (11)$$

$$J_{ISE} = \int \{ACE\}^2 dt \quad (12)$$

$$J_{ITSE} = \int t \cdot |ACE|^2 dt \quad (13)$$

Where; ACE-Area Control Error, t-Time period.

The cost functions of IAE, ISE, and ITAE are employed in this proposed research project to adjust the gain values of PID controllers to achieve the required optimal gain value. by modifying the controller's gain value, which results in a decrease in J value. ITAE is employed in the suggested study effort to obtain the ideal gain value after comparing the performance of the aforementioned function optimization.

4.4 Conventional Method

In this approach, controller gain settings are adjusted through the use of a trial-and-error process to obtain the best values. To get the best gain value, gain values of integral, proportional, and derivative controllers like KI, KP, and KD are modified within the limit. Find the integral gain value first, which is adjusted by raising the integral controller gain values, and note the performance index values. After that, a graph is drawn plotting different integral gain values against performance index values. It demonstrates unequivocally that at some time, an index's value abruptly starts to rise from its declining value.

This related gain value is noted as the controller's ideal gain value. Following the process outlined above, the proportional gain value is tweaked while maintaining the integral gain value as a constant. The derivative gain value is modified by maintaining Ki and Kp constant after obtaining the best integral and proportional controller

gain values. Figures 8, 9, 10, and 11, respectively, display the performance indices curve for the ITAE, S, and A cost functions. By utilising the traditional tuning procedure with the various cost functions shown in table 1, the controller gain values were tweaked.

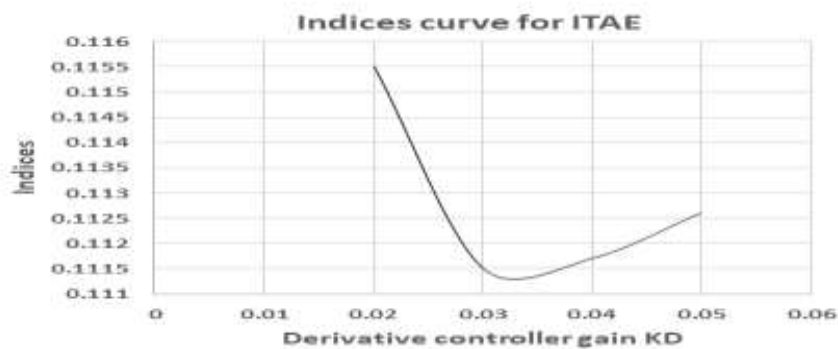


Figure 8 Performance indices curve for ITAE

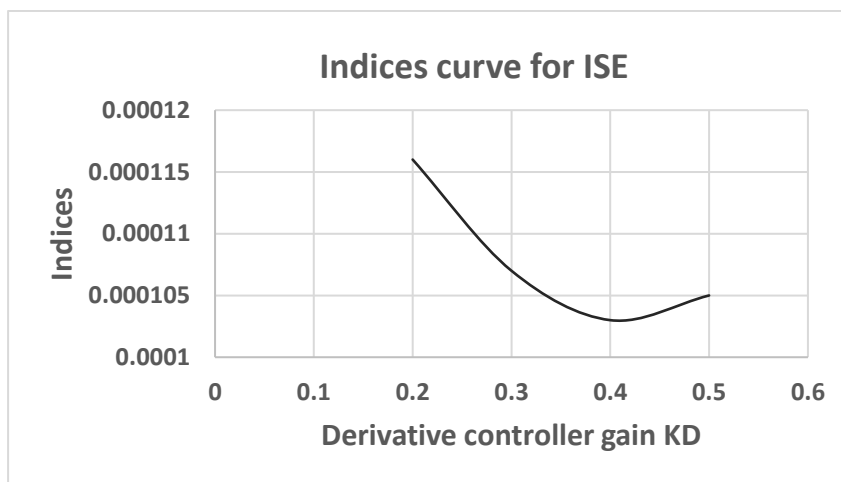


Figure 9 Performance indices curve for ISE

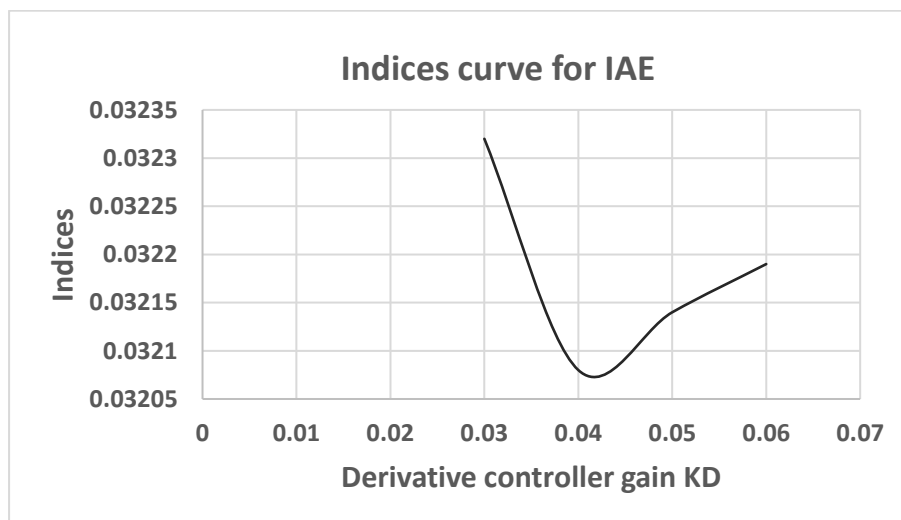


Figure 10 Performance indices curve for IAE

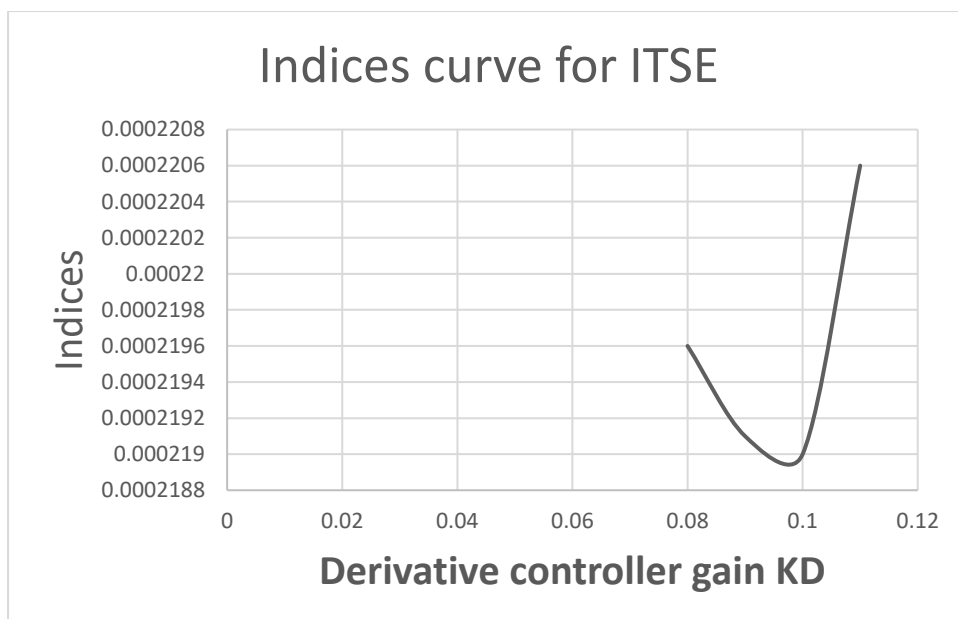


Figure 11 Performance indices curve for ITSE

Table 2 Controller gain values tuned by the conventional method

Cost function / Gain value	ISE	IAE	ITAE	ITSE
K_p	0.3	0.13	0.008	0.1
K_I	0.13	0.12	0.15	0.13
K_D	0.54	0.1	0.06	0.09

4.5 Performance Analysis of Conventional Tuned PID Controller

This section explains how a traditional tuned PID controller with a variety of cost functions performs. Figure 12 compares the system frequency deviations using various cost functions. Figure 13 displays the comparison of the area control error deviation for three distinct cost functions. Figures 14 and 15 show comparisons of the above responses. The black line depicts the response of the IAE-based cost function, the red line the response of the ITAE-based cost function, the green line is the response of the ISE-based controller response, and the blue line is the response of the ITSE-based circuit design.

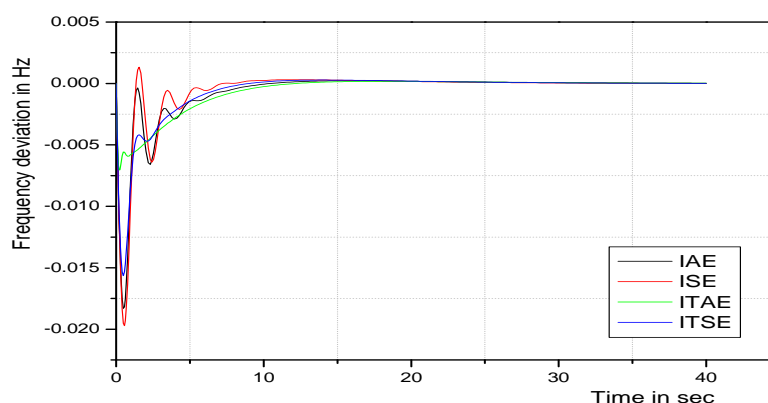


Figure 12 Comparison of frequency deviation with conventional tuned PID controller

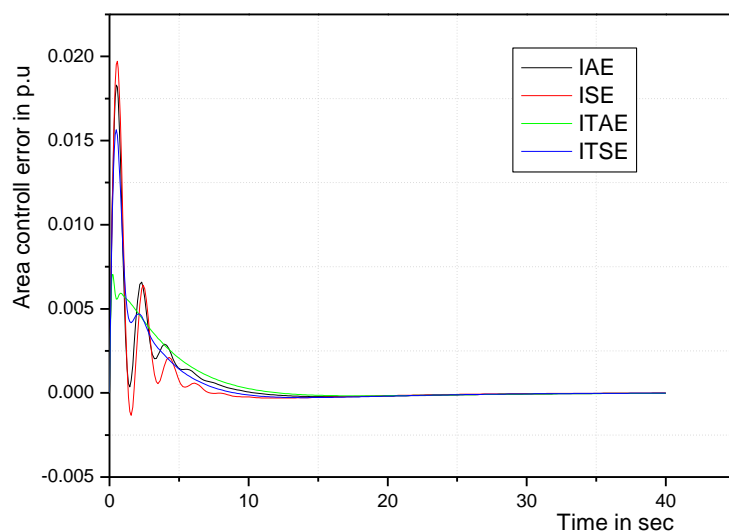


Figure 13 Comparison of area control error with conventional tuned PID controller

The frequency and area control error deviations, which are the time domain specification parameters for the response comparison discussed above, are shown in tables 3 and 4, respectively.

Table 3 Comparison of frequency deviation of conventional tuned PID controller with different cost functions

Time domain specification parameters / cost function	Settling time (s)	Peak overshoot (Hz)	Peak undershoot (Hz)
IAE	25	0.0015	0.02
ITAE	24	0.0005	0.016
ISE	35	0.0005	0.007
ITSE	28	0.0005	0.018

The numerical parameter results of table 4.2 and the similarity of the bars in the reaction comparisons made it abundantly clear that the ITAE cost function-based existing PID controller provides a better response than the IAE, ISE, and ITSE cost function-based conventional PID controllers when in factored using the standard approach.

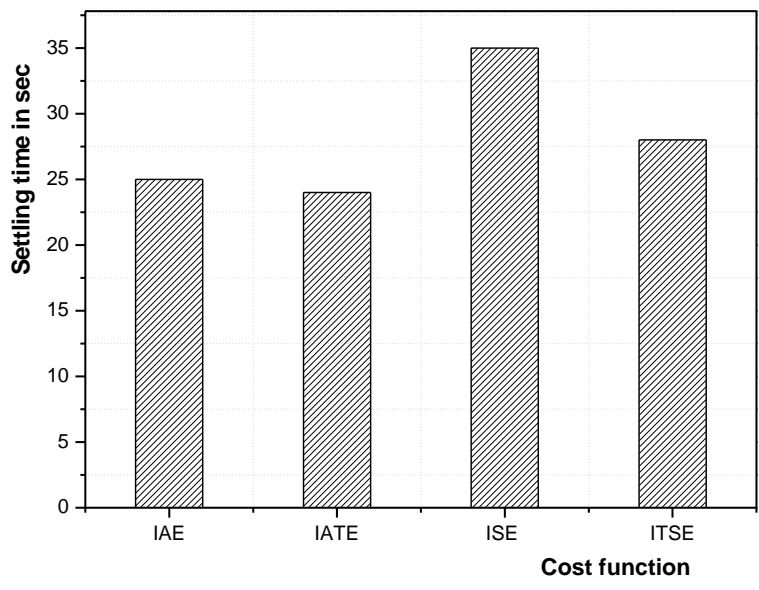


Figure 14 Bar chart comparison of conventional tuned PID controller for settling time of frequency deviation

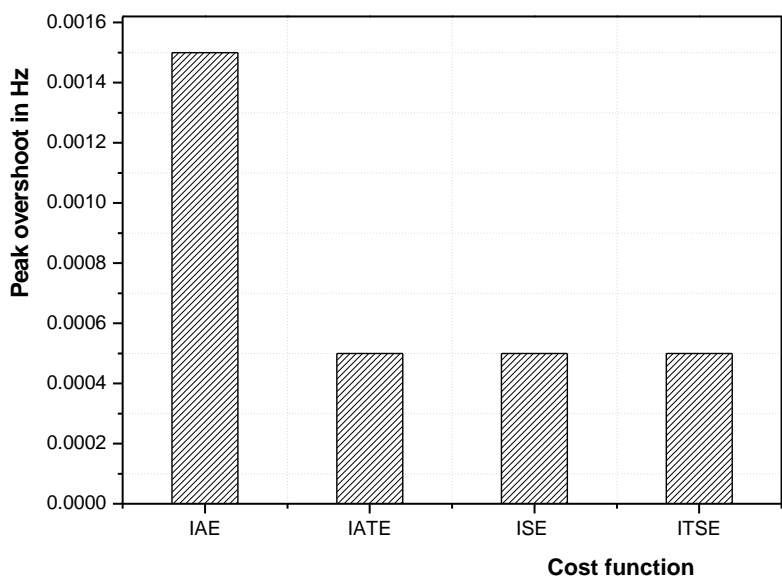


Figure 15 Bar chart comparison of conventional tuned PID controller for peak overshoot of frequency deviation

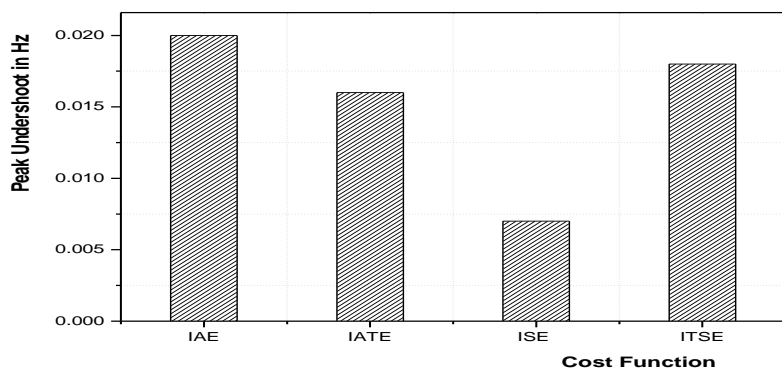


Figure 16 Bar chart comparison of conventional tuned PID controller for peak undershoot of frequency deviation

Table 4 Comparison of area control error of conventional tuned PID controller with different cost functions

Time domain parameter/cost function	Settling time (s)	Peak overshoot (Hz)	Peak undershoot (Hz)
IAE	30	0.02	0.0015
ITAE	32	0.016	0.0002
ISE	38	0.007	0.0002
ITSE	32	0.018	0.0002

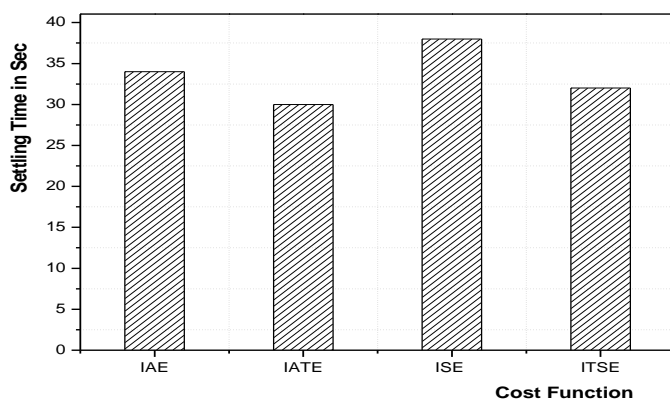


Figure 17 Bar chart comparison of conventional tuned PID controller for settling time of area control error

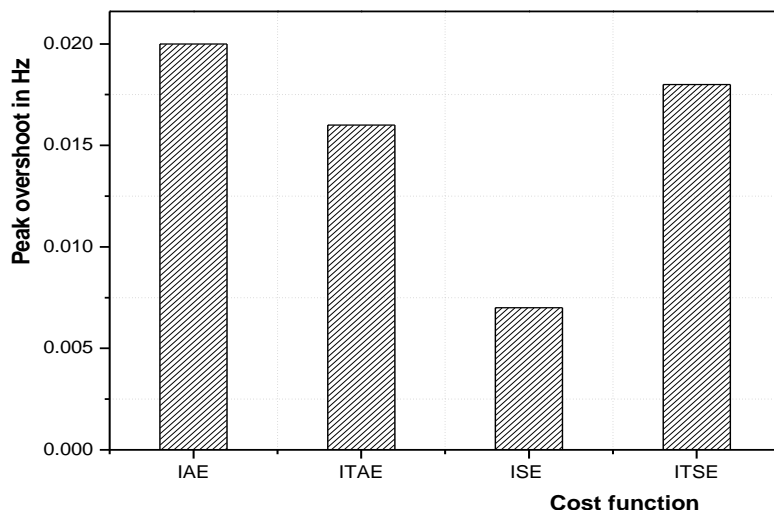


Figure 18 Bar chart comparison of conventional tuned PID controller for peak overshoot of area control error

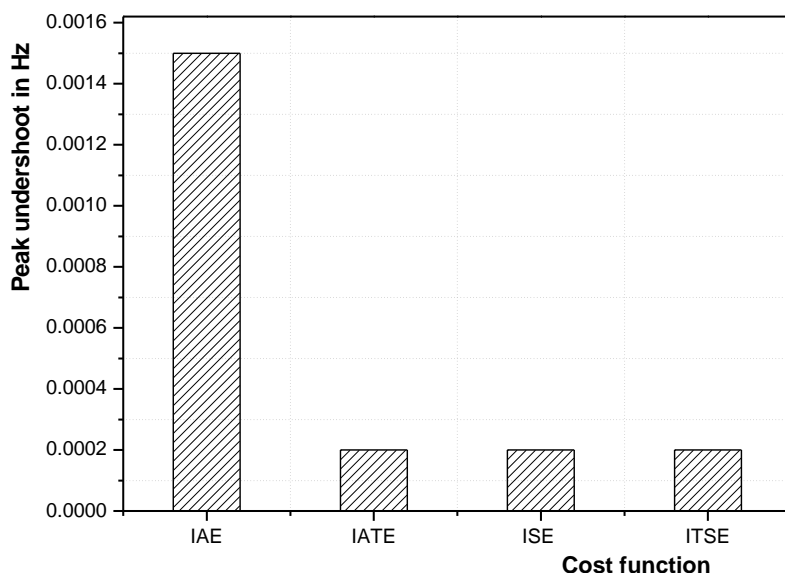


Figure 19 Bar chart comparison of conventional tuned PID controller for peak undershoot of area control error

When compared to the primary control loop, the secondary control loop in the power-producing unit is far more important during an emergency. PID controller makes up the secondary control loop for this work. The controller gain settings are wholly responsible for the secondary controller's efficacy. In this study, 1% SLP is used to use traditional and ant colony techniques with various cost functions to adjust controller gain values in the power system under investigation.

By using the traditional approach of trial and error and taking into account the IAE, ITAE, ISE, and ITSE cost functions, the controller gain values are adjusted. The comparison of the simulated data made it abundantly evident that the performance of the ITAE cost function-based conventional PID controller is superior to that of other cost function-based controllers. Time domain specifications parameters are used to evaluate the cost function's efficiency (Settling time, peak over and undershoot).

4. CONCLUSION

To provide all consumers with high-quality electricity and to balance the overall load demand with the generated power supply in the power-producing unit, the load frequency control scheme is used in the power system. It might be challenging to keep the power system stable and the quality of the power supply when the load is suddenly changing. LFC is used to address this power system problem. The primary goal of this research is to design a suitable secondary controller to maintain system stability during sudden load disturbance by implementing an efficient optimization method for the enhancement of controller gain values. A single-area nuclear power system is taken into consideration for this scientific work.

In this study, secondary PID controller gain values in the examined power system were calculated using the traditional approach. In the load frequency management of the researched single-area nuclear power system, the suggested optimization technique-based controller takes care of the time domain specification parameter values and maintains the stability of the system during the time of emergencies.

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LIST OF SYMBOLS AND ABBREVIATIONS

2-DOFPID	-	2-Degree Freedom of Proportional Integral Derivative
AFPID	-	Adaptive Fuzzy Aided Proportional Integral Derivative
ANFIS	-	Adaptive Neuro-fuzzy Inference System
ASPM	-	Adaptive Set Point Modulation
ACO	-	Ant Colony Optimization
ALO	-	Antlion Optimizer
ABC	-	Artificial Bee Colony
ANN	-	Artificial Neural Network
AGC	-	Automatic Generation Control
BFOPSO	-	Bacteria Foraging Optimization Particle Swarm Optimization
BFOA	-	Bacterial Foraging Optimization Algorithm
BF	-	Bacterial Foraging
BA	-	BAT Algorithm
BWNN	-	Beta Wavelet Neural Network
Δf	-	Change infrequency
CRAZYPSO-		Claimed Crazyness based Particle Swarm Optimization
CS	-	Cuckoo Search
D	-	Derivative
K_D	-	Derivative gain value
DE	-	Differential Evaluation

DPM	-	DISCO Participation Matrix
EV	-	Electrical Vehicle
EHOA	-	Elephant Herding Optimization Algorithm
FA	-	Firefly Algorithm
FPA	-	Flower Pollination Algorithm
FOFPID	-	Fractional Order Fuzzy PID
FOPID	-	Fractional Order Proportional Integral Derivative
FOPI-FOPID-		Fractional Order Proportional Integral Fractional Order Proportional Derivative
FFOA	-	Fruit Fly Optimization Algorithm
FGS	-	Fuzzy Gain Scheduling
FLPID	-	Fuzzy Logic Intelligent Proportional Integral Derivative
FLPI	-	Fuzzy Logic Proportional Integral
ΔP_G	-	Generator output
GA	-	Genetic Algorithm
GTP	-	Geothermal Plant
GSO	-	Glow Swarm Optimization
GSA	-	Gravitational Search Algorithm
GWO	-	Grey Wolf Optimization
HVDC	-	High Voltage Direct Current
HC	-	Hill Climbing
hFA-PS	-	Hybrid Firefly Algorithm-Pattern Search
HSCOA	-	Hybrid harmony search and cuckoo search optimization algorithm
hSFS	-	hybrid Stochastic Fractal Search
hSFS-PS	-	hybrid Stochastic Fractal Search plus Pattern Search
T_H	-	hydraulic time constant
HAE	-	Hydrogen Aqua Electrolyzer
ICA	-	Imperialist Competitive Algorithm
I	-	Integral
IAE	-	Integral Absolute Error
IDD	-	Integral Double Derivative
K_I	-	Integral gain value
ISE	-	Integral Square Error

ISTAE	-	Integral Square Time Absolute Error
ISTSE	-	Integral Square Time Square Error
ITAE	-	Integral Time Absolute Error
ITSE	-	Integral Time Square Error
IME	-	Ion exchange membrane
KHA	-	Krill Herd Algorithm
LFC	-	Load Frequency Control
MHSA	-	Modified Harmony Search Algorithm
MFO	-	Moth Flame Optimization
OHS	-	Opposition Based Harmonic Search
PSO	-	Particle Swarm Optimization
PS	-	Pattern Search
PEV	-	Plug in Electrical Vehicle
ΔX_E	-	Position of main piston in speed changer
K_P	-	Proportional gain value
PID	-	Proportional Integral Derivative
PIDF	-	Proportional Integral Derivative with Filter
PIDD	-	Proportional Integral Double Derivative