FREQUENCY STABILITY ANALYSIS OF THERMAL POWER SYSTEM WITH DIFFERENT STEAM CONFIGURATIONS

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Abstract:

The load frequency control (LFC) of a single-area thermal power system is provided in this study. An evolutionary method known as ant colony planning is used to enhance the features of the proportional-integral-derivative (PID) controller, a typical industrial auxiliary controller (ACO). Three cost functions are looked at to raise controller gain values. This study takes into account three different stem configurations in addition to integral absolute error (IAE), integral temporal absolute error (ITAE), and integral square error (ISE) (non-reheat turbine, single-stage reheat turbine, and double-stage reheat turbine).The effectiveness of the suggested approach is further demonstrated by including non-linearity (Generation Rate Constraint, Governor Dead Band, and Boiler Dynamics) into the same power system and changing the value of Step Load Perturbation (SLP) in each of the three steam configurations. The operation of electricity systems under diverse conditions is investigated using time domain analysis.

Keywords: Load Frequency Control (LFC), Proportional-Integral-Derivative (PID), Integral Square Error (ISE), Step Load Perturbation (SLP)

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1. INTRODUCTION

The Load Frequency Control (LFC) approach is used in electric power networks to control tie-line exchange schedules, spread the load among some of the generators, and keep the frequency generally steady. The power system urgently needs load frequency management because if the duty cycle drops below 47.5 Hertz or rises over 52.5 Hertz while the average frequency is 50 Hertz, the turbine blades might be harmed and the generator could stall. The models below illustrate how to regulate load frequency in a power system. Two significant components that alter when transient power demand is applied (Load Frequency Control (LFC)) are area frequency and tie-line power exchange.

Since the goal of load frequency control (LFC) is to lessen this variation, it is strongly connected to the aforementioned components. It's important to keep the stable condition at the null position. As a result, practical solutions were created, such as Active Disturbance Rejection Control (ADRC), which makes usable control easier. Active and reactive power are primarily responsible for the major split between frequency and voltage in the power system. Voltage depends on reactive power, whereas frequency depends on active power. Load frequency management is the umbrella term for the coordination of active power and frequency regulation. There are various different forms of modern power systems. There are a number of facilities in Bangladesh, including the Ashugonj Power Plant.

Using Bheramara Power Plant as an example Most of these places have connections to the area around them. One area is connected to another through transmission wires called tie-lines. Power is distributed between two locations via these tie wires. Load frequency management, as its name implies, regulates power flow while maintaining frequency. When two generating stations operate in parallel to meet a load change, the system becomes more complicated. One way to split the load between two machines is by employing a tie line to connect two producing stations.

This type of control is known as flat frequency regulation if the load changes at either A or B and the output of A is changed to have a constant frequency. Another way to divide up the work is to have A and B manage their individual generations to keep the frequency constant. Parallel voltage regulation is the term for it.

The third alternative, the generator there, will manage the frequency change and keep the tie-line loading. The flat tie-line loading control is the name given to this technique. During the use of selective frequency management, each system in a group is responsible for controlling load variations on its own system and does not provide help to the other systems in the group for changes that are outside of their control.All of the power systems in the interconnection assist in controlling frequency in tie-line loads, regardless of the source of frequency variations.

2. LITERATURESURVEY

Several studies have been done on single- and multi-area thermal and hydroelectric systems for supplying clients with high-quality power, according to a study of the literature [1-33]. LFC is essential for the high quality and dependability with which power systems function [1-3]. LFC attempts to maintain frequency deviations and power flow between control zones within the permitted range by altering the output of generators to match power generation with varying load demand. A power plant that is well-designed and operated can balance power generation with peak load by maintaining system frequency and the voltage between the generator terminals. The LFC problem in a power system is solved by using the appropriate controller.The controller's input into the power system is typically Area Control Error (ACE). The controller then uses this input to generate a suitable control output signal and transmit it to the power system as an input signal.

Classical controllers [4], Proportional-Integral Controllers (PI) [30], proportional-integral-derivative control system (PID) [5, 6], Integral-Double Derivative Controllers (IDD) [7], fractional-order proportional-integral-derivative controllers (FOPID) [8, 9], and 2DOF [10] are just a few of the controllers that have been developed and successfully used in recent years. The selection of the controller is the main effort, but the proper selection of the controller gain and goal function is more crucial for the design of a better-regulated power system.Numerous bio-inspired algorithms have been created recently to optimally balance different controller gain values in LFC/AGC issues in power systems. The Artificial Bee Colony (ABC) [20], Stochastic Particle Swarm Optimization (SPSO) [5], Imperialist Competitive Algorithm (ICA) [21], Firefly Algorithm (FA) [22], Quasi-Oppositional Harmony Search algorithm (QOHS) [23], Cuckoo search [24, 31], and Particle Swarm Optimization based optimal Type fuzzy Fuzzy Logic Control [24, 31] are a few descriptions (PSO-SFLC)

When changing the LFC/AGC of a multi-area power system's controller system parameters, choosing an appropriate cost/objective function is crucial [30–33]. Integral absolute error (IAE), integral temporal absolute error (ITAE), and integral square error (ISE) are three frequently used cost functions (ISE). The remainder of the text is structured as follows: The LFC and other computing efficiency employing cost functions are covered in the "Introduction" section.Using the provided methodology, the "Single Area Thermal Power System" section presents the suggested single-area power system with various steam arrangements and components. The performance of different value and steam combinations is discussed and compared in the section titled "Computational Outcomes and Evaluations."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 [35-39]. An enhanced distributed certificate authority scheme for authentication in mobile ad hoc networks and trust based cross-layer security protocol malicious node detection was proposed. The modified security scheme for data integrity for manet was suggested for security in network communication.Enhanced data accuracy-based PATH discovery using backing route selection algorithm in MANET was proposed for better network communication [41-42].Effective timer count scheduling with spectator routing using stifle restriction algorithm in manet for timely scheduling packets and rapidly communication at emergency situations [43].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[44].

2.1 Needfor SecondaryController

A major controller exists in every power system, as specified by the system design. Rapid fluctuations in load are one condition that the primary controller is equipped to handle. Frequency oscillation must be stopped, however doing so destroys electrical equipment and takes additional time. The power system uses the LFC mechanism to address the issue. In order to include the LFC into the power supply, we need a secondary controller. In this application, the PID controller serves as a backup controller.

3. ***Materials And Method***

To solve the Load Frequency Control (LFC) problem, Particle Swarm Optimization (PSO) is advised for single-area multi-source power-producing systems. The power generating system uses a proportional-integral-derivative (PID) controller as a secondary regulator. Thermal, hydro, gas, nuclear, and photovoltaic (PV) systems with energy storage are all included in the proposed power network. When unexpected load fluctuations cause the system frequency to depart from ideal values, the LFC approach is employed to preserve power system quality**.**

The PSO-based regulator is developed and tested for the multi-source power system that was previously suggested. The effectiveness of the proposed technique is shown to be superior by comparing its performance to that of a conventional tuned PID controller. Analysis of the time domain specification parameters demonstrates the higher performance of the suggested controller. The difference shows how effectively the PSO-PID controller operates in terms of speedy frequency oscillation settling and limited peak overshoot values and undershoots.

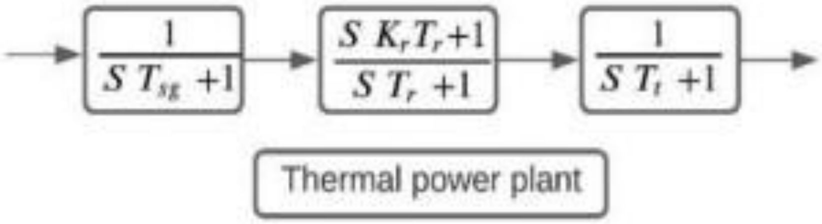


Figure 1:ExistingSystemModel

3.1 ConventionalController

In reality, several controllers are used to keeping the power system operating normally. As the demand deviates from its normal operating value, the system state changes. Numerous controller types built on the conventional linear control theory have been developed over the years.

3.2ProportionalControllers

Each controller has a particular use case that it is best suited for. Some requirements must be met before you can just add any controller type to any system and expect a positive outcome. There are two requirements for a proportional controller, and these are listed below. Now that we are in a position to examine proportional controllers, the deviation should not be significant, or there should not be a significant difference between the input and output.As the name implies, the output (also known as the actuating signal) of a proportional controller is inversely proportional to the error signal. Let's now perform a mathematical analysis of the proportional controller. As we already know, the output of a proportional controller is exactly proportional to the error signal.Removingthesignofproportionalitywehave,

$$A(t) \propto e(t)$$

$$A(t) = K_p \times e(t)$$

3.3 IntegralController

The output of integral controllers, also known as the actuating signal, is, as the name implies, exactly proportional to the integral of the error signal. Let's now perform a mathematical analysis of integral controllers. In stating this analytically, we have, where Ki is an integral constant also known as controller gain. As we know, the output of an integral controller is exactly proportional to the integration of the error signal. The reset controller is another name for the integrated controller.

3.3.1 DerivativeControllers

Derivative controllers are never used in isolation. Due to the minor drawbacks listed below, it should be used in conjunction with other controller modes:

$$A(t) \propto \int_0^t e(t)dt$$

$$A(t) = K_i \times \int_0^t e(t)dt$$

3.3.1.1 Itneverimprovesthesteady-stateerror.

3.3.1.2 Itproducessaturationeffectsandalsoamplifiesthenoisesignalsproducedinthe system.

The output (sometimes referred to as the actuating signal) in a derivative controller is now perfectly proportional to the derivative of the error signal, as the name indicates. Let's now evaluate the derivative controller mathematically. Designers can phrase this analytically by eliminating the proportionality sign since we now know that the output of a derivative controller is precisely proportional to the derivative of the error signal.

Where KDis a proportional constant also known as controller gain. The derivativecontrolleris

$$A(t) \propto \frac{de(t)}{dt}$$

$$A(t) = K_d \times \frac{de(t)}{dt}$$

alsoknownastheratecontroller.

3.3.2 ProportionalandIntegralController

As the name of the controller implies, the output, also known as the actuated signal, is equal to the sum of the integral and proportional components of the error signal. Now let's evaluate proportional and integral controllers mathematically. As you are undoubtedly aware, the output of a proportional and integral controller is identical to the integration of the error signal plus the fractional error added together.

$$A(t) \propto \int_0^t e(t)dt + A(t) \propto e(t)$$

Removingthesignofproportionalitywehave,

$$A(t) = K_i \int_0^t e(t)dt + K_p e(t)$$

Where$K_i$and$k_p$are proportionalconstants and integralconstants respectively.

The benefits and drawbacks of proportional and integral controllers are combinations of their positives and negatives. Using the PI controller, designers add one pole at the origin and one zero away from the origin (on the left-hand side of the complex plane). The steady-state error is drastically decreased, making the PI controller one of the most popular ones, even if it may have less stability since the pole is closer to the origin and has a higher impact. The schematic for the PI controller is shown in Fig. 6. Fig. 7 shows the temporal response for step input with K=5.8 and Ki=0.2 values.At K=5.8, it was about to become unstable as a P- controller; all that was needed to make it unstable was to add the little value of an Integral part. Even though the Integral component reduces stability, the system is not necessarily going to remain unstable forever. In this case, humans introduced a vital element, causing the system to become unbalanced.

3.3.3 LoadFrequencyControl

Load frequency management is essential for the modern power system to ensure power quality from generation to consumption. Due to the rise of the economy and the population, loads are more and more needed nowadays. If a rapid load disturbance occurs, the power system should be able to maintain stability and power quality while also balancing the power demand with generation. A little load change, which also results in damping resonance, has an impact on the established operating frequency of a single-area power system. It results in an imbalance of electricity between supply and demand.The elimination of kinetic energy from the system, which results in a decrease in system frequency, is the initial fix for this mismatch problem. To maintain the lowest possible damping oscillation, lowest possible peak overshoot, and lowest possible miscalculation during a rapid load change, load frequency control is utilized in the power system.

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 wastage. A change in speed or frequency instantly signals any difference (Nagrath and Kothari, 1994; Kundur, 1994). (Elgerd, 1970).

3.4 SingleAreaThermalPowerSystem

3.4.1 ThermalPowerSystem

A speed regulator unit, a boiler dynamics unit, a generator, a turbine with an evaporator unit, and a suitable governor unit are all included in the analysed single-area reheat thermal power system shown in Fig. 1. Figure 1 shows the transfer function model for the assessed power system using nominal values from [28–30]. where Tg stands for the speed governor time constant, Kr for the reheat gain, Tt for the steam chest, and Tp and Kp for the load frequency constant (Tp = 2H/f * D and Kp = 1/D), respectively. R is the governor's self-speed control parameter in p.u. Hz. gradual adjustments to the governor valve position, generation, and frequency are denoted by the letters delXE, dealing, and delF, respectively.

In a thermal power system, water is converted to steam, which is then converted into usable mechanical energy with the aid of a turbine from its high-pressure, high-temperature state. Based on the steam stages, the turbine units are separated into three fundamental kinds. such as the non-reheat turbine, the two-stage reheat turbine, and the single-stage reheat generator [28–30]. The governor dead band limitation and the generation rate restriction are two physical restrictions in this system. The formula for the transfer function of the governor's dead band non-linearity is shown below, along with the GRC constraint for the thermal power system, which is 0.0017 puMW/s.

This examination looks at drum-type boilers and demonstrates that they can generate steam under pressure. Power systems have load demands, which cause system characteristics (such as frequency and power flow across connected regions) to diverge from the desired value and affect the stability of the system. The appropriate selection of a second power system controller is a vital consideration to overcome the aforementioned deficiencies. A supporting controller in this work is the proportional-integral-derivative controller.

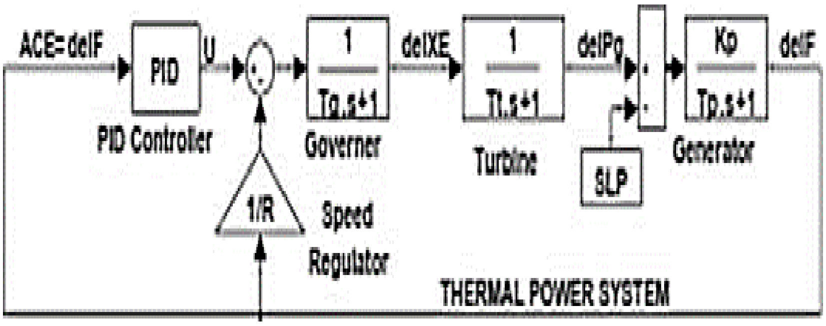
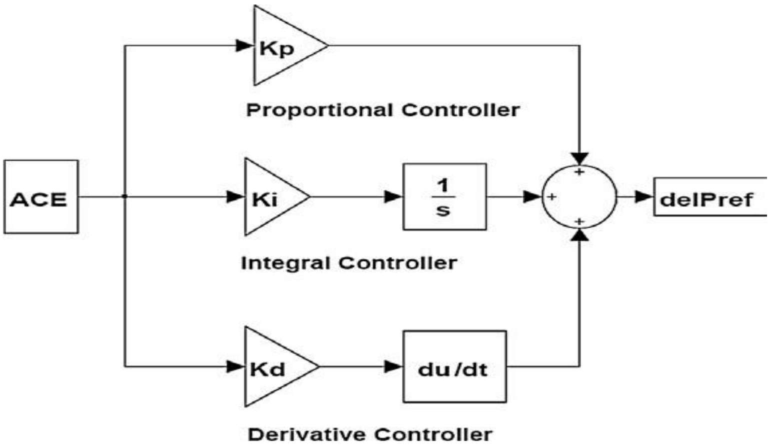


Figure 2 Transferfunctionmodelofnon-reheat thermalpowersystem

3.4.2 PIDControllerDesign

The suggested PID controller's input and output signal values are explained and presented, along with the necessary equations. To increase controller output responsiveness during unexpected load disturbance, the choice of controller gain settings is essential. Traditional methods are used to change the PID controller gain values while accounting for various cost functions. The structural arrangement of the PID controller is shown in Figure 3. Its three key terms are "integral controller," "proportional controller," and "derivative controller" (Gopal, 2002; Gopal, 2004; Nagrath and Gopal, 2007; Gopal, 2008).

Figure 3StructureofPIDcontroller



3.4.3 *GeneralGuidelinesfordesigning aPIDController*

Anyone may build a PID controller for a given system and achieve the desired response by following the general advice provided below: Obtain the transient response of the closed-loop transfer function to determine what has to be improved. There, attach the proportional controller. Find the value of "K" using Routh- Hurwitz or other suitable software. Add an essential piece to reduce steady-state error. Include the derivative component to increase damping (damping should be between 0.6- 0.9). The derivative component will lessen overshoots and transitional time. The MATLAB application Diagnostic tools can also be used for precise tinkering and getting the desired outcome. Please be advised that the methods given above are only suggestions for parameter tuning (forming a control system).

3.4.4 *AntColonyOptimizationTechnique(ACO)*

The PID controller successfully controls the system's frequency when there is an unexpected load requirement. Traditional objective functions are used to modify the proportional gain (Kp), integral gain (Ki), and derivative gain (Kd) gain parameters in the PID console's structure. The suggested PID controller consists of three basic controllers. It is possible to regulate excessive overshoot and undershoot in the response with a proportional regulation, and the steady state error in the output frequency with an integral controller. A derivative controller is also available to reduce the damping oscillation in the system frequency. The proportional integral derivative regulator generates a mixture of the output from the proportional, integral, and derivative controllers.

The use of evolutionary computational approaches to algorithms for solving has grown in significance in recent years. The Ant Colony Optimization (ACO) method is used in this work to address the LFC issue in the power system. Marco Dorigo initially described the Ant Colony Optimization (ACO) technique in his PhD thesis in 1992 [6, 32, and 33]. When searching for food, real ants behave as follows: they initially scatter randomly across the colony. They then choose different paths. During the ant movement, the pheromone chemical is stored in the ground. Each ant hunts for a different type and quantity of food supply, which determines the effectiveness of the chemical round.

The great quality and quantity road has a large pheromone concentration above the poor path, however, the chemical included in the bad path evaporates very rapidly compared to the fastest way possible. These real activities inspired several academics to develop the ACO technique [6, 32, 33]. A constant that establishes the time gap between the effect of pheromones and heuristic evaluations on ant decision-making is followed by the flow rates to compute the kth ant's transition probability between towns I and j. The Ant Colony Optimization (ACO) optimization approach was used to modify the proportional, integral, and derivative gain values of the PID controllers for the following different steam turbines:

Each ant is in its nest in stage one. There are no pheromones in the surroundings. (Algorithmic design may consider residual pheromone amount without changing probability.)

Stage 2: Ants begin their search with an equal (0.5) likelihood along each path. The curved path is longer, and as a result, it takes longer for ants to reach the nutrition.

Stage 3: As a result of the reduced journey, the ants reach the food source earlier. It appears that they are now faced with a similar selection dilemma, but this time, the selection is more probable as a result of the pheromone trail down the shorter, already-accessible path.

Stage 4: Pheromone concentrations increase as more ants take the quicker way back. Additionally, due to evaporation, the pheromone concentration in the longer path drops, decreasing the chance that this path will be used in later phases. The entire colony thus uses the quicker route more frequently. Thus, a path solution is obtained.

3.4.5 PSEUDOCODE:

Ant Colony Optimization Technique: Initialize the proper parameters and pheromone trials; then, without stopping the experiment, create the ant population. Identify each ant's fitness ratings, choose the best alternative by applying selection methods; Update the pheromone experiment, and then wrap things up.

3.4.6.CostFunctionDetails

Non-ReheatTurbine

ISE-Kp= 0.88,Ki= 0.86,Kd= 0.95;

IAE-Kp = 0.96,Ki= 1,Kd= 0.2;

ITAE-Kp= 0.51,Ki= 0.97,Kd= 0.18

SingleReheat Turbine

ISE-Kp = 0.95, Ki = 0.56, Kd = 0.89;IAE-Kp = 1, Ki = 0.97,Kd = 0.1;ITAE-Kp= 0.98,Ki= 0.93,Kd=0.01

DoubleReheatTurbine

ISE-Kp= 0.61,Ki= 0.34,Kd= 0.75;

IAE-Kp = 1,Ki= 1,Kd = 0.09;

ITAE-Kp = 0.44,Ki= 0.98,Kd = 0.13.

SimulationDiagram

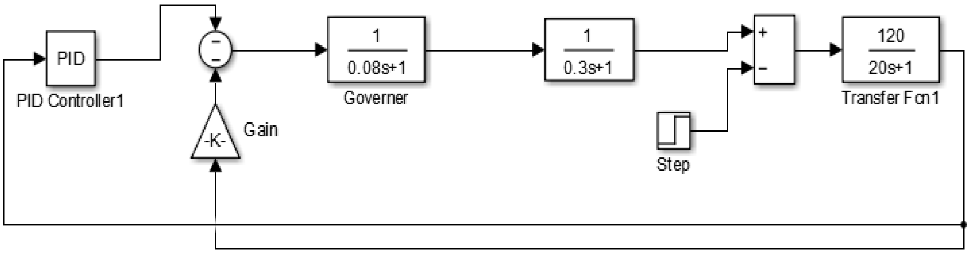


Figure 3 Singleareathermalmodel

4. ResultsandDiscussion

In Fig. 2, the power system response for a turbine-equipped system with no reheat, one reheat, and two reheats is depicted. The response makes it evident that, for all turbine units, the ITAE cost function-based PID controller responds more quickly than the IAE and ISE-improved PID controllers. However, the ISE cost function optimum PID controller performs much better at decreasing peak undershoots in system responsiveness than the IAE and ITAE cost function optimal PID controllers. The settling time numbers for various cost and seam combinations are presented in Table 1.

The performance of the suggested population-based optimization approach is used to enhance PID controller settings for several scenarios with various target functions and steam configurations in a single-area power system. The first case is a thermal power system with 1% SLP and several nonlinear cost functions. The 1% Step Load Perturbation (1% SLP) load requirement is taken into consideration while designing the thermal power plant's non-reheat, single-reheat, and double-reheat turbines with PID controls. The recommended controller's gain values are decreased by combining ACO with the cost functions ISE, IAE, and ITAE.

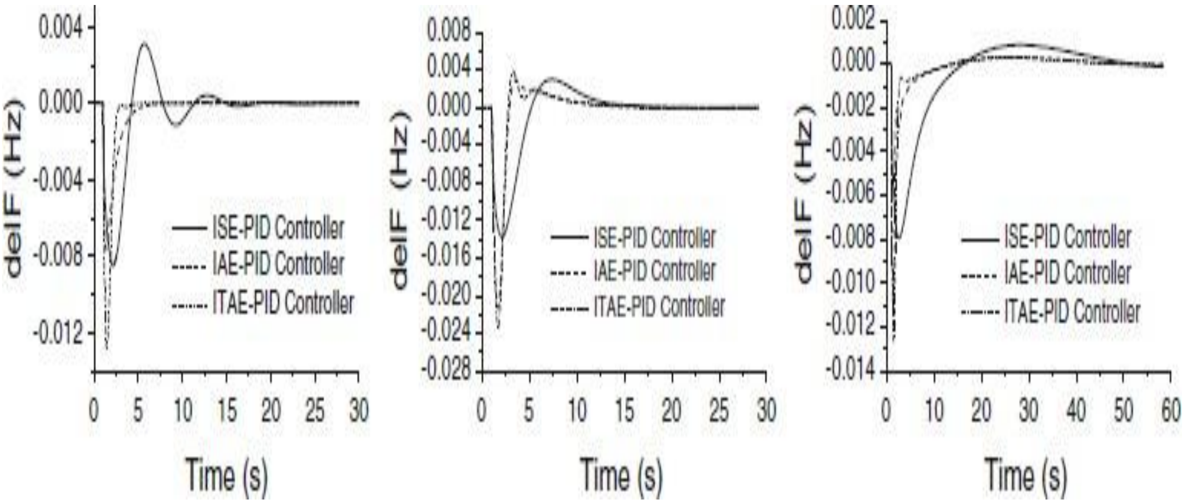


Figure 4 Frequencydeviationsofthe non-reheatturbine,single-stagereheatturbineanddouble-stagereheatturbinethermalpowersystemwithdifferentcostfunctions

Table 1 Performance comparison of settling time for scenario-1

	Steam configuration	Objective function	Settling time (s)	Peak overshoot (Hz)	Peak undershoot (Hz)
Thermal power system without non-linearity by considering 1 % SLP	Non-reheat turbine	ISE	22.15	0.003	−0.0084
		IAE	9.79	0	−0.0076
		ITAE	5.75	0	−0.0127
	Single reheat turbine	ISE	21.88	0.0029	−0.013
		IAE	16.2	0.0027	−0.0212
		ITAE	15.83	0.0035	−0.023
	Double reheat turbine	ISE	84	0.00087	−0.0079
		IAE	47.12	0.00029	−0.011
		ITAE	47.07	0.0003	−0.0125

Table1 Scenario2:ThermalPowerSystemnon-linearity,boilerdynamicsanddifferentcostfunctionsbyconsidering1%SLP.

The power system in this case considers the boiler dynamics, governor dead band non-linearity, and generation rate constraint. When nonlinearity is introduced, the power system undergoes larger damping oscillations with overshoots, undershoots, and longer settling periods. Variable steam turbine-equipped power systems' frequency variations and different objective processes' frequency deviations Figure 3 displays the responses to the controller settings. The convergence speed of the thermal power system frequency variation is significantly reduced by using an ITAE cost function-optimized PID controller.

In terms of settling time, the response of the ITAE cost function-based PID controller is superior to that of the ISE and IAE-based PID controllers. As can be seen from the response in Fig. 4, the ISE cost function maximized PID controller settles more slowly than the IAE and ITAE cost function based PID controllers, but it produces very less peak undershoot in comparison to the other controllers for all possible steam settings.

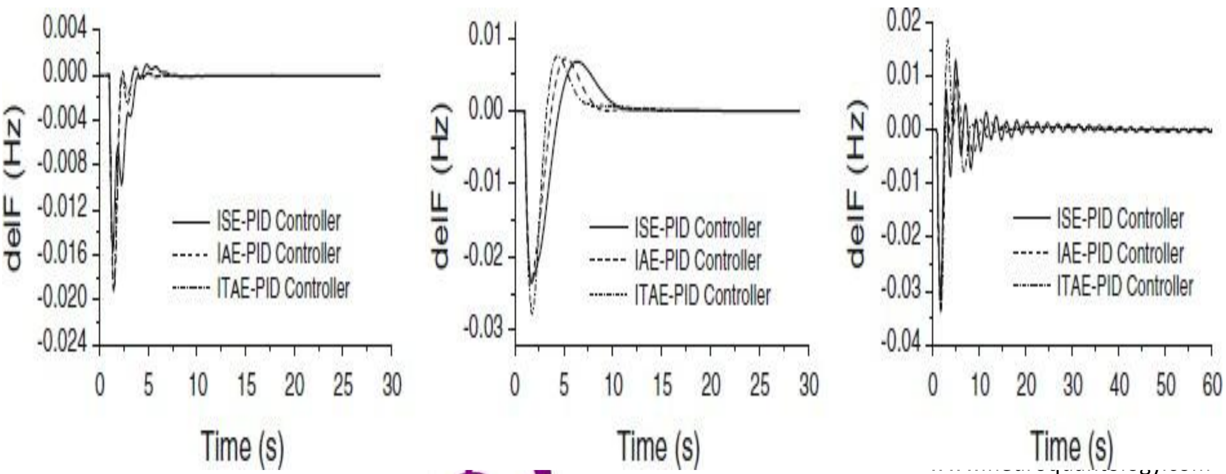


Figure 5Frequency deviations of a non-reheat turbine, single-stage reheat turbineand double-stage reheat turbine thermal power system with different cost functions,non-linearityandboilerdynamics

5. CONCLUSION

The load frequency management of a single area with a thermal power system and a Proportional-Integral-Derivative (PID) controller was the focus of this work. The controller parameters are set using the evolutionary computing method called ant colony optimizations (ACO). The PID controller is built using three unique cost functions. Integral Time Absolute Error (ITAE), Integral Square Error, and Integral Absolute Error (IAE), instance (ISE). Power systems with turbines that have different stem designs employ these distinct cost-function-optimized PID controllers. The non-reheat, single-stage reheat, and double-stage finish cooking are the three different types of steam arrangements.

The simulation findings show that the ITAE cost function-based PID controller delivers a rapid settled reply in all three circumstances when compared to IAE and ISE cost function-based PID controller response (Scenario 1: non-reheat turbine: 5.75 9.79 22.15; Single reheat turbine: 15.83 16.2 21.88; Double reheat turbine: 47.07 47.12 84). The system responsible for all three different situations was much improved by using the ISE cost function-based Control approach in contrast to the IAE and ITAE cost function efficient PID controller response.

5.1 Future Scope

The automated generation control (AGC) or load frequency control (LFC) of an integrated three-area thermal power system (AGC). The steam turbine in the thermal power system uses many steam stages. Tandem compound-type steam turbines take into account several steam phases. Based on how the steam system is set up, steam turbines can be characterized as non-reheat, single-stage reheat, or double-stage reheat turbines. The consequences of different steam stages are explored both with and without taking into consideration the effects of boiler dynamics and nonlinearity.

REFERENCES

[1] Nagrath, I.J., Kothari, D.P.: Power System Engineering. Tata Mc-Graw Hill Publishing Company Limited, New Delhi (1994).

[2] Kundur, P.: Power system stability and control. Tata Mc-Graw Hill Publishing Company Limited, New Delhi (1994).

[3] Elgerd, O.I.: Electric Energy System Theory: An Introduction. Tata Mc-Graw Hill Publishing Company Limited. New York (1970).

[4] Nandha, J., Mishra, S.: A novel classical controller for Automatic generation control in thermal and hydrothermal systems. PEDES, 1–6, 2010.

[5] Jagatheesan, K. Anand, B. and Ebrahim, M.A.: Stochastic Particle Swarm Optimization for tuning of PID Controller in Load Frequency Control of Single Area Reheat Thermal Power System. International Journal of Electrical and Power Engineering, 8(2), 33–40, 2014.

[6] Jagatheesan, K., Anand, B., and Dey, N.: Automatic generation control of Thermal-Thermal-Hydro power systems with PID controller using ant colony optimization. International Journal of Service Science, Management, Engineering, and Technology, 6(2),18–34, 2015.

[7] Lalit Chandra saikia, Nidul Sinha, Nanda, J.: Maiden application of bacterial foraging based fuzzy IDD controller in AGC of a multi-area hydrothermal system. Electric Power and Energy Systems, 45, 98–106, 2013.

[8] Seyed Abbas Taher, Masoud HajiakbariFini, Saber FalahatiAliabadi.: Fractional order PID controller design for LFC in electric power systems using the imperialist competitive algorithm.Ain Shams Engineering Journal, 5, 121–135, 2014.

[9] Indranil Pan, Saptarshi Das, Fractional-order load frequency control of interconnected power systems using chaotic multi-objective optimization. Applied Soft Computing, 29, 328–344,2015.

[10] Puja Dash, Lalit Chandra Saikia, Nidul Sinha: Comparison of performance of several FACTS devices using Cuckoo search algorithm optimized 2DOF controllers in multi-area AGC.Electric power and Energy systems, 65, 316–324, 2015. 26

[11] Ashmole PH, Battebury DR, Bowdler RK.: Power-system model for large frequency disturbances. Proceedings of the IEEE, 121(7), 601–608, 1974.

[12] Pan CT, Liaw CM.: An adaptive controller for power system load–frequency control," IEEE Transactions on Power Systems. 4(1), 122–128, 1989.

[13] Wang Y, Zhou R, Wen C. Robust, "load–frequency controller design for power systems," IEE Proceeding-C 1993, Vol. 140, No. 1, 1993.

[14] Wang Y, Zhou R, Wen C.: New robust adaptive load-frequency control with system parametric uncertainties. IEEE Proceedings—Generation Transmission and Distribution, 141 (3), 1994.

[15] Jiang, En L, Yao W, Wu QH, Wen JY, Cheng SJ.: Delay-dependent stability for load frequency control with constant and time-varying delays. IEEE Transactions on Power Systems, 27(2), 932–94, 2012.

[16] Singh Parmar KP, Majhi S, Kothari DP.: Load frequency control of a realistic power system with multi-source power generation. Electrical Power and Energy Systems, 42, 426–433, 2012.

[17] Foord TR.: Step response of a governed hydro-generator. Proceedings of the IEEE, 125(11),1978.

[18] Music GL, Sutterfield, J.A.; Caprez, A.R.; Haneline, J.L.; Bergman, B.R.: Automatic generation control for hydro systems. IEEE Transactions on Energy Conversion, 3(1), 33–39, 1988.

[19] Doolla S, Bhatti TS.: Load frequency control of an isolated small-hydro power plant with a reduced dumped load. IEEE Transactions on Power Systems, 21(4), 1912–1919, 2006.

[20] Halukgozde, M.cengizTaplamacioglu, Ilhan kocaarslan.: Comparative performance analysis of artificial bee colony algorithm in automatic generation control for interconnected reheat thermal power system. Electric power and energy systems, 42,167–178, 2012.

[21] Seyed Abbas Taher, Masoud HajiakbariFini, Saber FalahatiAliabadi.: Fractional order PID controller design for LFC in electric power systems using the imperialist competitive algorithm.Ain Shams Engineering Journal, 5, 121–135, 2014.

[22] K.Naidu, H.Mokhlis, A.H.A.Bakar.: Application of Firefly Algorithm (FA) based optimization in load frequency control for interconnected reheat thermal 27 power system. IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies, 2013.

[23] Chandan Kumar Shiva, G. Shankar, V.Mukherjee.: Automatic generation control of power system using a novel quasi-oppositional harmony search algorithm. Electric power and energy systems, 73, 767–804, 2015.

[24] Puja Dash, Lalit Chandra Saikia, Nidul Sinha: Comparison of performance of several FACTS devices using Cuckoo search algorithm optimized 2DOF controllers in multi-area AGC. Electric Power and Energy Systems, 65, 316–324, 2015.

[25] Nattapol S-ngwong, IssarachaiNgamroo.: Intelligent photovoltaic farms for robust frequency stabilization in multi-area interconnected power system based on PSO-based optimal sugeno fuzzy logic control. Renewable Energy, Vol. 72, pp: 555–567, 2015.

[26] Md Nishat Anwar, Somnath Pan.: A new PID load frequency controller design method in frequency domain through a direct synthesis approach. Electrical power and Energy Systems, 67, 560–569, 2015.

[27] TulasichandraSekarGorripotu, Rabindra Kumar Sahu, SidharthaPand.: AGC of a multi-area power system deregulated environment using redox flow batteries and interline power flow controller. Engineering Science and Technology, an International Journal, 1–24, 2015 (In press).

[28] Jagatheesan, K. and Anand, B.: Dynamic Performance of Multi-Area Hydro-Thermal Power Systems with integral Controller Considering Various Performance Indices Methods. IEEE International Conference on Emerging Trends in Science, Engineering and Technology, Tiruchirappalli, December 13–14, 2012.

[29] Evolutionary Algorithm Based LFC of Single Area Thermal Power … 193

[30] Jagatheesan, K. and Anand, B.: Performance Analysis of Three Area Thermal Power Systems with Different Steam System Configurations considering Non-Linearity and Boiler Dynamics using Conventional Controller. Proceedings of 2015 International Conference on Computer Communication and Informatics (ICCCI-2015), 130–137, Jan. 08–10, 2015, Coimbatore, India.

[31] Jagatheesan, K. and Anand, B.: Load frequency control of an interconnected three-area reheat thermal power systems considering non-linearity and boiler 28 dynamics with a conventional controller. Advances in

Natural and Applied Science, 8(20), 16–24, 2014. ISSN: 1998-1090.

[32] Dey N, Samanta S, Yang XS, Chaudhri SS, Das A.: Optimization of Scaling Factors in Electrocardiogram Signal Watermarking using Cuckoo Search," International Journal of Bio-Inspired Computation (IJBIC), 5(5), 315–326, 2014.

[33] M. Omar, M. Solimn, A.M. Abdel ghany, F. Bendary: Optimal tuning of PID controllers for hydrothermal load frequency control using ant colony optimization. International Journal on Electrical Engineering and Informatics, 5(3), 348–356, 2013.

[34] Jagatheesan, K. and Anand, B.: Automatic Generation Control of Three Area Hydro-Thermal Power Systems considering Electric and Mechanical Governor with conventional and Ant Colony Optimization technique. Advances in Natural and Applied Science, 8 (20), 25–33, 2014. ISSN: 1998-1090

[35] Rajaram, A., &Palaniswami, D. S. (2010). Malicious node detection system for mobile ad hoc networks. International Journal of Computer Science and Information Technologies, 1(2), 77-85.

[36] Palaniswami, S., & Rajaram, A. (2012). An enhanced distributed certificate authority scheme for authentication in mobile ad hoc networks. The International Arab Journal of Information Technology (IAJIT), 9(3), 291-298.

[37] Rajaram, A., &Sugesh, J. (2011). Power aware routing for MANET using on-demand multipath routing protocol. International Journal of Computer Science Issues (IJCSI), 8(4), 517.

[38] Premanand, R. P., & Rajaram, A. (2020). Enhanced data accuracy based PATH discovery using backing route selection algorithm in MANET. Peer-to-Peer Networking and Applications, 13(6), 2089-2098.

[39] Anand, R. P., & Rajaram, A. (2020, December). Effective timer count scheduling with spectator routing using stifle restriction algorithm in manet. In IOP Conference Series: Materials Science and Engineering (Vol. 994, No. 1, p. 012031). IOP Publishing.

[40] Rajaram, A., &Palaniswami, S. (2010). Detecting malicious node in MANET using trust based cross-layer security protocol. Intern J Comput Science Information Technologies, 2, 130-137.

[41] Rajaram, A., &Palaniswami, S. (2010). A high certificate authority scheme for authentication in mobile ad hoc networks. International Journal of Computer Science Issues (IJCSI), 7(4), 37.

[42] Kannan, S., & Rajaram, A. (2017). Enhanced Stable Path Routing Approach for Improving Packet Delivery in MANET. Journal of Computational and Theoretical Nanoscience, 14(9), 4545-4552.

[43] Rajaram, A., &Palaniswami, S. (2010). The modified security scheme for data integrity in Manet. International Journal of Engineering Science and Technology, 2(7), 3111-3119.

[44] Kumar, K. V., & Rajaram, A. (2019). Energy efficient and node mobility based data replication algorithm for MANET.