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Research Article

Design a PID controller based on grey wolf optimization algorithm for single-area load frequency control

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Abstract. This article, focuses on the load frequency control (LFC) of a single-area system with a grey wolf optimization metaheuristic approach. This approach is applied to optimize the PID controller parameters for the effective operation of the system. The grey wolf Algorithm (GWO) has been utilized to optimize the controller's parameters and minimize the error. SIMULINK Model is used to simulate the Single-area load frequency control (SALFC) with GWO to mitigate the error and frequency fluctuations. The integral time absolute error (ITAE) has been considered as an objective function for optimal search of PID parameters. The frequency performance of the system has been observed without a controller, or any other methods in literature and with the proposed grey wolf optimization (GWO). The simulation response shows in terms of rise time, settling time, and peak time. The performance of the power system has been compared with other approaches namely Particle Swarm Optimization (PSO), and Firefly Algorithm (FFA). The Proposed optimization technique provides a much better response than other strategies.

Keywords: Single Area, Load frequency, Firefly Algorithm (FFA), Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), PI Controller, PID Controller.

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1. Introduction

A power system is a sophisticated network of electrical components that is specifically intended to generate, transfer, and distribute electrical energy to end users (Akter, K. *et al.* 2022). The main components of a power system include power generators, transformers, transmission lines, distribution lines, and various control and protection equipment. Power generators, such as hydroelectric plants, wind turbines, and thermal power plants, are responsible for converting mechanical energy into electrical energy (Chaine S. *et al.* 2015). The generators' electrical energy is transmitted over long distances through transmission lines. These lines may be overhead or underground, and they are designed to transport high-voltage electricity with minimal losses (Fayek, H. H. *et al.* 2019). At the receiving end of the transmission lines, the high-voltage electricity is stepped down through transformers to a lower voltage suitable for distribution to consumers. Distribution lines then transport the electricity to homes, businesses, and other consumers through power lines and cables. Power systems are designed to provide reliable and stable electrical power to consumers. This requires careful planning and coordination of various components of the system, including generation, transmission, and distribution (Gupta, M. et. al.2017). To ensure the security, safety, and stability of the system, various control and protection mechanisms are employed, including protective relays, circuit breakers, and voltage regulators (Deo, J. et. al.2017).

The LFC is an approach that is used in power systems to regulate the stability between the production/generation of the system and the load in real time. LFC is essential to maintaining a stable power system frequency within the acceptable range of 50Hz or 60Hz (Nath, V. *et al.* 2015). In a power system, the balance between the generation and load is crucial for the system's frequency stability. Any inconsistency between the production and load can cause the frequency to deviate from the actual value (Murdan, A. P. et. al. 2019). This change in frequency can have a significant influence on the stability and reliability of the electrical power system, it can also damage the equipment and appliances connected to it and cause blackout conditions (Parvaneh, H. et. al2016).

The major purpose of the load frequency control is:

1. Frequency Regulation
2. Power system stability
3. Economic operation
4. Load sharing

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Automatic Load Frequency Control (ALFC), also called as Automatic Generation Control (AGC), is a control mechanism used in power systems to automatically adjust the output of generators in response to deviation demand for load (Debbarma, S. et. al. 2013). Its primary objective is to keep maintain the system frequency within permissible limits by balancing the generation and load.

The basic key tasks of ALFC are:

1. It is used to keep the desired megawatt output power of a generator adapting with the changing load.
2. It helps to establish controlling the frequency of larger interconnection.
3. To sustain the net interchange power across the pool members, at the predetermined values.
4. The ALFC loop will preserve control only during small and slow deflection in frequency and load (Nath, V. et. al. 2015).

(Kumar, A. et al. 2023). in this paper PSO is proposed algorithm which has been compared Genetic Algorithm (GA), and Firefly Algorithm (FA). ITAE has considered as objective function in two-area hybrid power system. The performance comparison is done in terms of setting time, objective function. The proposed PSO provide best results.

(Sambariya, D. K. Jangid, P et al. 2023) this article has single area thermal power system. The proposed firefly algorithm has been used for effective operation of the system. ISE has been used as an objective function for optimization process. The Proposed method result has been compared with other methods and get proposed method provides better results compared to others.

Numerous methods traditional, conventional, PID controller, fuzzy, artificial intelligence, and metaheuristics strategies (GA, FA, HBA, ABC, PSO, etc.) are used to optimize the controller and search best result for effective and reliable operation of the system (Sambariya, D. K. Jangid, P et al. 2023). The suggested method GWO is a very simple and flexible method to optimize the system parameters to enhance the system performance and make operation reliable. The GWO provides a good frequency deviation response (Yadav, H. P et al. 2019 & (Nagar, V. *et al.* 2023).

2. System of load frequency control

A Power System of a Single-Area Model is a simplified representation of an electrical power system that focuses on a specific area or region (Nath, V. et. al. 2015). It typically consists of a generator, connected loads, and a transmission network that interconnects them. This model is widely used for analyzing the behaviors and performance of power systems within a specific geographical region (Sambariya, D.D. et al. 2017).

2.1 Governor Model

A speed governor, also known as a governor control system or speed control system, is a device used in power plants and other rotating machinery to regulate and maintain the speed of the equipment within a desired range (Abdel-Halim, M. A. et al. 1985). Eq. 1 and Fig.1 represent the Governor model of the system.

$$\frac{\Delta X_E(S)}{\Delta P_C(S) - \frac{1}{R}\Delta F(S)} = \frac{K_G}{1+ST_G} \tag{1}$$

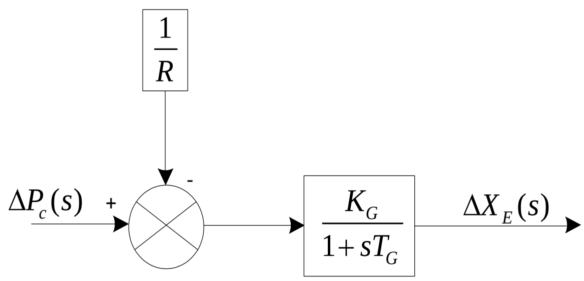

Fig. 1. Governor model

2.2 Turbine Model

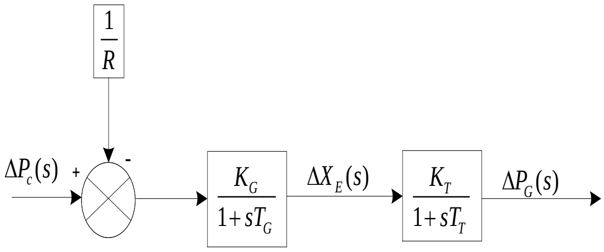

Fig. 2. Governor-Turbine model

A turbine is a type of machine used in power plants to convert energy into rotational mechanical energy. This mechanical energy can then be used to drive a generator to produce electrical power (Gupta, D. et al. 2021). The Fig. 2 shows the block diagram of the turbine.

$$\frac{\Delta P_G(S)}{\Delta X_E(S)} = \frac{K_T}{1+ST_T} \quad (2)$$

2.3 Power System/Generator Model

A generator is an electrical equipment that mutate mechanical energy into electrical energy. It is a crucial component in most types of power plants, including thermal power plants, hydroelectric power plants, and wind farms. The generator in a power plant typically constructs of two main parts (Singh, A. K. et. al. 2019): a rotor and a stator. Fig. 3 shows generator model.

$$\Delta P_G - \Delta P_D = \left(\frac{2H_i S}{f_i} + D_i\right)\Delta F_i - \Delta P_{tie}(S) \quad (3)$$

$$\Delta P_G - \Delta P_D = \left(\frac{K_P}{1+T_P}\right)\Delta F_i - \Delta P_{tie}(S) \quad (4)$$

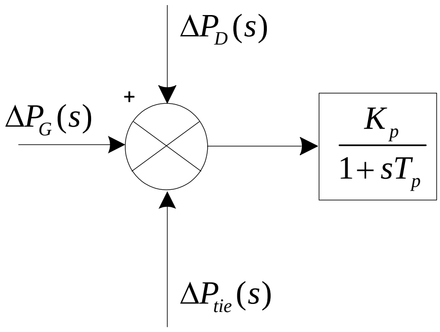

Fig. 3. Generator/ Power system model

2.4 Controller

A PID controller is a feedback control mechanism widely used in various control systems to regulate a process or system (Singh, K. and Shankar, G. et. al 2016 & Sambariya, D. K. and Shringi, S. et. al 2017). PID stands for Proportional-Integral-Derivative. The Fig. 4 present PID controller.

PID Controller is define as:

$$H(s) = K_p + \frac{K_i}{s} + K_D s \quad (5)$$

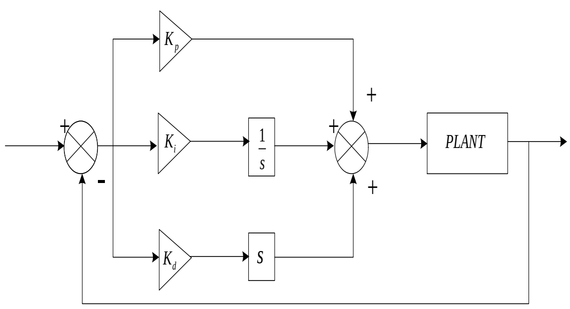

Fig. 4. PID Controller

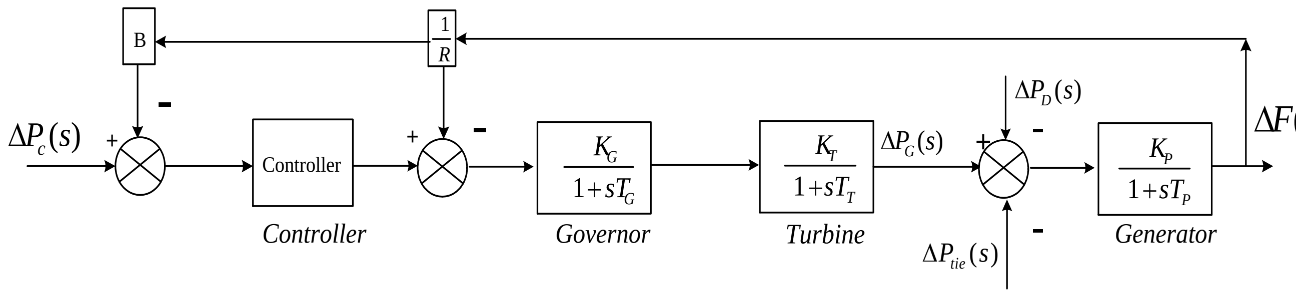

Fig. 5. Basic Single Area Load Frequency Control Model

The Single Area non-reheated thermal power plant model is displayed in Fig. 5.

3. Methodology

Several metaheuristic optimization strategies like Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Firefly Algorithm (FFA), Honey Badger Algorithm (HBA), Gravitational Search Algorithm (GSA) etc. are very popular in artificial intelligent area due to their different behaviors and approach (Gupta, D. K. et al. 2021). There are many factors as flexibility, easy to use, durability, efficient and reliable which is make it success in research area. All these algorithms are utilized to optimize the input parameters of the system to reliable operation and make system efficient (Ramjug-Ballgobin, R. et al. 2021).
The Particle Swarm Optimization (PSO) algorithm is a population-based optimization technique encouraged by the social behavior of fish schooling and bird flocking. It aims to detect the optimal solution to a given optimization issues by iteratively searching and updating a swarm of particles in the search space. The PSO algorithm utilizes the collective intelligence and cooperation among particles to guide the search towards better solutions. By balancing exploration and exploitation, it aims to find the global optimum in the search space. PSO has been effectively applied to various optimization issues, including function optimization, feature selection, and parameter tuning, among others (Lakshmi, D. Fathima, A. P. and Muthu, R. et al. 2014).
Xin-She Yang offered Firefly Algorithm in 2008. It is a methodology based on population. It is a metaheuristic approach used to resolve optimization problems. By using this approach, we may fix continuous and discrete issues. This technique is inspired by patterns and lighting actions of firefly. Fireflies glow because of the effect of bioluminescence and by their lighting behavior, we may identify them. This approach is a group of bugs that can radiate natural light to attract prey. Three variables of firefly method are intensity (I), constant of absorption, and coefficient of attraction (β). The attractiveness is directly proportional to brightness. brightness rise as the distance reduces (Sambariya, D. K. Jangid, P et al. 2023).

This algorithm has three idealized actions for the design of the algorithm, these are derived from the behaviours of fireflies.

a. Fireflies are attracted to others no matter what their gender. because they are bisexual.
b. A less bright bug moves toward brighter because to attraction is directly related to the lightning.
c. The brightness & attractiveness are mitigated as the distance among the two fireflies is rises.
d. Fireflies move without restriction when there is no glowing firefly.
e. The lighting of a firefly is characterized as the target function geography.

GWO is inspired by the social activity of the wolves. It depends on the hunting process and leadership behavior of the wolf in searching the prey. It is used to resolve complicated optimization issues and problems. It has been used for LFC problems. Mirjalili et al. suggested this technique in year 2014. This technique has categorized into four types of leadership behaviors which is known as α, β, δ, Ω alpha, beta, delta and omega respectively. They have decision making ability about hunting and search prey (Paliwal, N. Srivastava, L. and Pandit, M. et. al. 2022).

Alpha, beta and delta display the position of the wolves. These wolves are most dominant wolves in this algorithm alpha is most dominant, beta is second most dominant and delta is third according to its ability.
Alpha category wolves are leader of the whole group. They have the power of taking all decision for group like sleeping place, hunting etc. They can be man and female. They are not strongest wolves in the group but they are best in decision and arrangement.

$$\alpha\text{new} = \alpha\text{old} - \Omega \times \text{distance}\ (\alpha\text{old, Current Position}) \qquad (6)$$

Beat is the second level of leader in hierarchy of grey wolf. It is the helper of alpha grey wolf. They help the alpha group of wolves to take decision. They are the best wolves in this group when alpha categories members are getting old and can make decisions and arrangements in place of alpha.

$$\beta\text{new} = \beta\text{old} - \Omega \times \text{distance}\ (\beta\text{old, Current Position}) \qquad (7)$$

Delta is third group of wolves and have ability to take decision over in omega.

$$\delta\text{new} = \delta\text{old} - \Omega \times \text{distance}\ (\delta\text{old, Current Position}) \qquad (8)$$

Omega is the fourth lowest level of grey wolf. They are not main part and not have right to take decision. It is the control parameters of the algorithm which motivate the process of exploration of the optimization (Guha, D. Roy, P. K. and Banerjee, S. et. al. 2016).

Tables should have a title which makes the general meaning understandable without reference to the text. Tables should be presented in the form shown in Table 1, with all text, including title 8pt. Their layout should be consistent throughout.

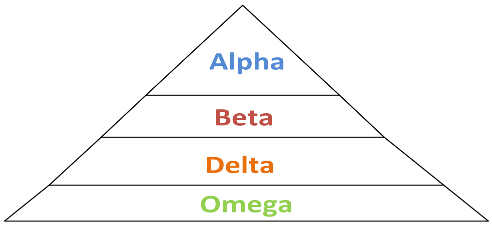

Fig.6. Grey wolves' hierarchy

Three main steps of this algorithm of GWO are:

a. Tracking the prey
b. Encircling of the prey
c. Attack on the prey

Grey wolf algorithm is quite simple than another algorithm. It is relatively simple to understand and implemented to optimize the problem. It is design to local search, exploration and attack to the prey.

The Flowchart represent the complete process of the optimization. The first step of the process is initialization the position of alpha, beta, delta wolves. Define the objective function of system and evaluate the fitness function. The omega factor is a control parameter by which update the position of the alpha, beta and delta. Others wolves' position is renew based on the alpha, beta, delta position in the defined boundary. The process of iteration is repeat until the desired values reached. At the end algorithm is terminate when get desired optimal parameters.

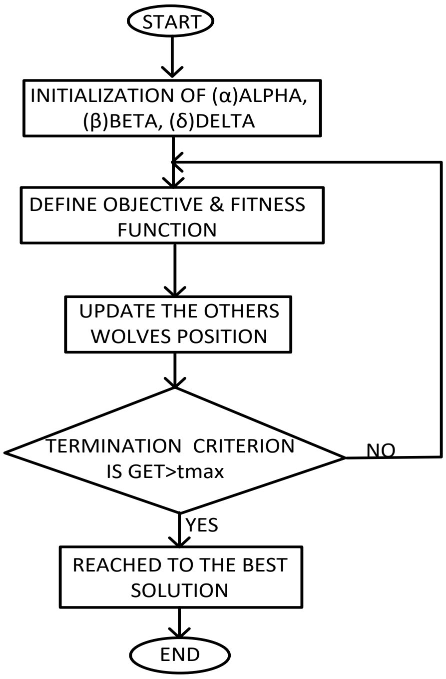

Fig.7. Flow-chart of Grey wolf Optimization

The integral time absolute error (ITAE) has been used as an objective function in the load frequency control system. This objective function is used in GWO algorithm to overcome the error (ITAE).

$$\text{ITAE} = \int_0^t t(\Delta F)^2\, dt \quad (9)$$

4. Result & Discussion

This section has a single Area system has been considered to calculate the ITAE and frequency oscillation. Sigle-area system has been created and simulate by using SIMULINK Software version R2018b. The grey wolf optimization algorithm has been implemented to the model to optimize the PID controller parameters to reduce/mitigate error.

Table 1. Parameters of The Pid Controller of Numerious Strateges

Controller/ Parameter	K_P	K_I	K_D
Proposed GWO	3.6332	5	0.7413
PSO, 2015 (Hong, M. S. et. al..)	1.7065	2.4623	0.9721
FFA, 2018 (Boddepalli, M. K. K. et. al.)	1.8719	1.3677	1.2673
FFA, 2023 (Sambariya, D. K. Jangid, P. et. al.)	5.7586	4.5378	1.5689

The Grey wolf optimization (GWO) has been suggested to optimize the controllers gain. The PID Controller gains have been tuned by this approach to reach suitable and desired values for system. The parameters of the model of area-1 are presented in appendix. The Ref. Table I has been represented the tuned PID values which is tuned with GWO and other literature methods like Particle Swarm Optimization (PSO), Firefly Algorithm (FFA). The optimized parameters of the controller by GWO are KP = 3.6332, KI = 5, and KD = 0.7413. The performance of the system frequency fluctuation has been compared with PSO-PID, FFA-PID,2018 and FFA-PID,2023 in literature. The (ITAE) integral time absolute error has been used as an objective and fitness function to carried out to optimize the controller. The Fig. shows the response of frequency without controller. The frequency response of the proposed and other methodology has been displayed in Fig. A comparison terms of the settling time, rise time, and peak time are shown in Table II. The proposed GWO technique produces better results than others methods. The traditional, PI, and PID Controller with other metaheuristics method outputs has been compare with innovative GWO strategy to modify the results of the Area-1 system. The system response has been produced in a duration of 10 seconds. GWO provides preferable result compare to other optimization algorithm PSO, FFA, GA etc. due to its simple and understanding coding, easy implementation, less parameters, and simple principle. Its quick response provides good solution and improve efficiency of the system and boost the system performance.

Table 2. Comparative Parameters of The Frequency Deviation

Parameter/ Literature	Rise Time	Settling Time	Peak Time
Proposed GWO	4.0591	5.6280	0.9996
PSO, 2015	3.7047	7.2483	0.9996
FFA, 2018	3.7047	12.7996	0.9993
FFA, 2023	2.19×10^{-6}	7.36×10^{-7}	2.03×10^{-6}

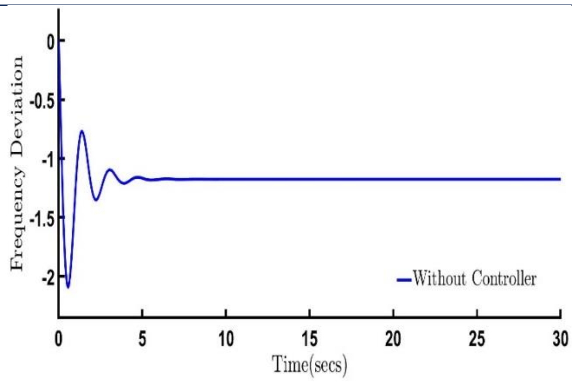

Fig. 8. Single area Frequency response without controller

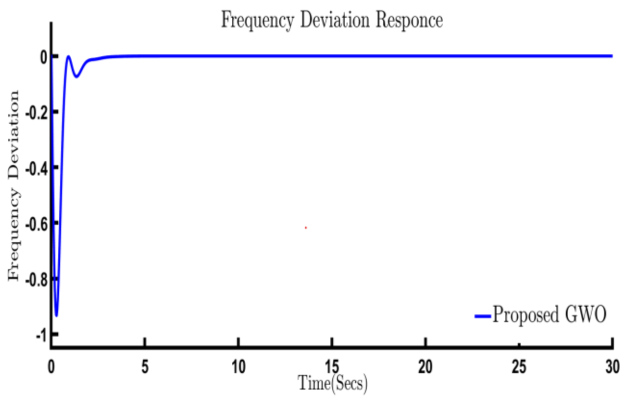

Fig. 9. Frequency response of area-1 with GWO

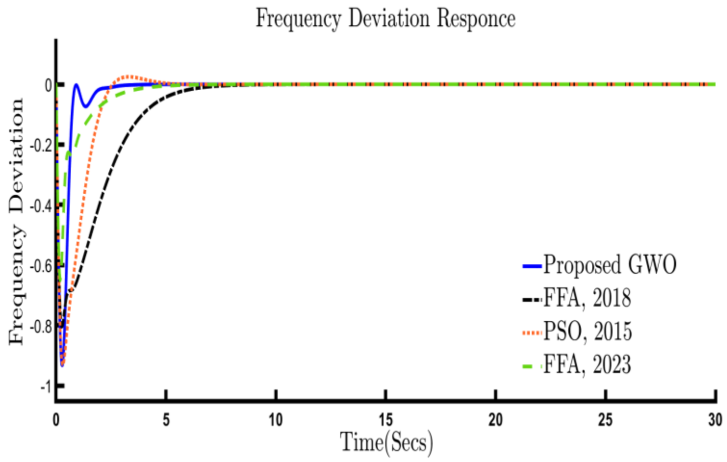

Fig.10. Comparative Frequency response of area-1 with different methods

5. Conclusion

In this Single-area system has been considered a thermal power plant to an analysis of load frequency control. The PID controller has been used to investigate. The controller parameter is optimized with GWO metaheuristics algorithm to get better values of the parameters and minimum error in the system. ITAE has been used as an objective function to mitigate the error and find superior results of the frequency deviation. The optimized result by using GWO algorithm has been compared with other approaches and has found better results.

GWO has been applied to the system model to get suitable optimized parameter values to reduce error and reached minimum setting time and minimum steady state error in the system. GWO is very simple and flexible algorithm easy to use and implemented in system. It provides desirable outcomes and boost the system operation.

Appendix

Model data for single-area system:
Time constant of Governor (TG) = 0.08, Turbine (TT) = 0.3, power system (TP) = 20, Governor gain (KG) = 1, Turbine gain (KT) = 1, power system gain (KP) = 120, Speed regulation (R) = 2.4, Frequency Bias (B) = 0.425.

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