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Load Frequency Control of Power System using Grey Wolf Optimization

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***Abstract*: This article presents an effort to use the gray wolf optimization (GWO) approach to tackle the load frequency control (LFC) issue in an interconnected power system network equipped with a standard PI/PID controller. The suggested method is used to a networked two-area non-reheat thermal-thermal power system. Using a fitness function based on integral time multiplied absolute error (l TAE), the GWO algorithm optimizes the gains of the controller. The suggested GWO algorithm's performance has been compared to other comparable meta-heuristic optimization methods for comparable test systems that are available in the literature, including ensemble of mutation and crossover strategies and parameters in differential evolution (EPSDE), comprehensive learning particle swarm optimization (CLPSO), and others. Moreover, sensitivity analysis is carried out by adjusting the system characteristics and operating circumstances within a -+50% range in order to show the robustness of the suggested GWO method. The findings of the simulation demonstrate that GWO is more capable of tweaking than other comparable population-based optimization methods.**

***Keywords*: Load Frequency Control, Grey Wolf Optimization.**

1. Introduction

The power companies have the responsibility of supplying their clients with a power supply that is satisfactory in quality, dependable, efficient, and uninterrupted, given the significance of electrical power distribution. Numerous controlled areas make up a modern power system network. In order for power system units to operate steadily, the total generation of each controlled area must meet the total load demands plus any related system losses. This allows the system to manage frequency and interchange tie-line power appropriately. This is known as automated generation control (AGC) or load frequency control (LFC), and it is crucial to the operation and management of power systems [1]. IFC continually monitors the tie-line power and system frequency. It then computes the net variations of these variables from their nominal values (known as area control error, or ACE), and adjusts the generator valve settings to maintain ACE at a minimum. Both frequency and tie-line power will immediately shift to zero when AGC pushes ACE to zero [2].

To date, a number of control techniques have been put forward in the field of LFC to enhance system dynamics when load perturbations occur. A critical evaluation of the literature on distributed and conventional power system networks' LIC may be found in [3]. Iris noted from the literature that the majority of research publications deal with proportional integral derivative (PID) controllers or their alternatives to tackle LFC problems because of its straightforward and user-friendly structure [4]. To handle the L.FC issue in a multi-area thermal power system, writers in [4] offered a number of classical controllers, including integral (I), proportional integral (PI), integral derivative (ID), PID, and integral double derivative (IDD). Using the bacteria foraging optimization algorithm (BFOA), controller gains were optimized, demonstrating the advantage of the suggested approach. A variable structure fuzzy gain scheduling based linear intelligence controller (LIC) is suggested in [5] for a network of linked multi-area multi-source hot water heating systems. For four-area [IC], an interval type-2 fuzzy controller is provided in [6]. Using the big-bang big crunch (BB-BC) optimization approach, the scaling factor and footprint uncertainty in interval type-2 fuzzy controllers were improved. Other controllers, such as the p-synthesis controller [7], sliding mode controller [8], ANFIS controller [9], non-integer controller [10], observer-based controller [11], neural network controller [12], predictive controller [13], fuzzy logic controller [14], etc., were also proposed in the field of ¡YC based on modem control theory to improve system performances under the occurrence of load perturbation.

In light of the above explanation, the primary goal of the current work is to develop and put into practice a novel evolutionary algorithm (EA) for the optimum design of PI/PID controllers to tackle LFC problems, known as gray wolf optimization (GWO). To assess the efficacy of the suggested GWO algorithm, four distinct linked power system networks with steam turbine nonlinearity are taken into consideration, and simulation results are examined. To fine-tune the gains of the PIJPID controller, the integral rime multiplication of absolute error (ITAE) based fitness function is taken into consideration. By comparing transient responses with other population-based meta-heuristic optimization techniques reported in the literature, such as PSO based fuzzy controller, pattern search (PS) based fuzzy controller, BFOA, DE, GA, hybrid BFOA-PSO, FA, hybrid FA-PS, TIJ3O, Zeigler—Nichols (ZN) for the similar test system with the same controller structure, the superiority and effectiveness of the

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proposed algorithm are established. Lastly, the resilience of the controller created using GWO is verified under various loading scenarios and system parameter changes.

2. Dual Area Power System

An overview of AGC and LFC systems in two-area power systems is given in [15]. [15] investigates tie-lines models and how they affect two-area power systems' LFC. The LFC models for two-area power systems that include the effects of voltage control loops on frequency response are developed in [16]. [17] proposes frequency response models that include the nonlinearities of the governor dead-band (GDB) and the generation rate constraints (GRC) for two-area power systems. A discussion of ways to lessen the complexity of the frequency response model is presented in [18]. [19] highlights the multi-source, two-area LFC models that account for nonlinearities. Reference [18] discusses LFC models of two-area power systems with parametric and nonparametric uncertainty. A technique of LFC for two linked power systems using HVDC/DC transmission lines is provided in [20]. Two-area power system frequency response models consisting of reheat-thermal turbines connected by AC/DC cables are shown in [20]. offers load frequency control strategies that account for communication channel delay in thermal-thermal two-area power systems [16], [21]. [16] provides a frequency model for two area power systems' reheat thermal turbine with a governor dead-band zone. GRC non-linearity is considered in [22] for the reheat thermal turbine-governor system in two-area power systems. According to [23], the LFC method for hydro-hydro connected power systems takes into consideration the non-linearities of hydro power plants. For two-area power systems, superconducting magnetic energy storage (SMES) system LFC models are proposed in [24]. A frequency control model for two-area power systems that considers the role of SMES and batteries is described in [25]. A reference [26] proposes the LFC model of conventional two-area power networks with the addition of energy storage devices and electric cars. The stochastic character of the electrical demand is considered in [27]. For the LFC model in [28], uncertainties about renewable energy sources are considered.

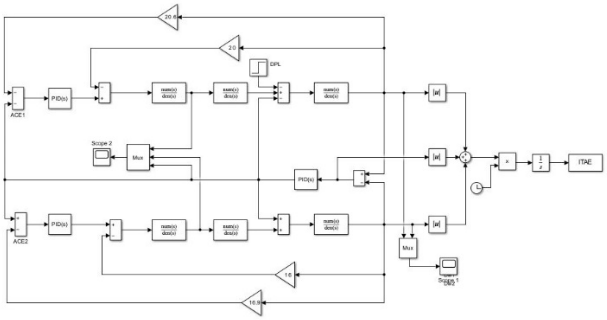


Fig. 1. Simulink model of two area network

3. Grey Wolf Optimization

In this section, the social hierarchy of wolves, tracking, encircling and attacking prey are discussed followed by the mathematical modeling of GWO algorithm.

A. *Social Hierarchy*

Alpha is seen to be the best option for simulating the social behavior of the grey wolf, with beta and delta following suit, and the other options falling under the category of omega. In GWO, alpha, beta, and delta lead the hunting (optimization) process, whereas omega always follows these three wolves.

B. *Encircling*

To model the encircling behavior of grey wolves around the prey, following equations are considered.

$$\vec{D} = |\vec{C}.\vec{x}_p(t) - \vec{x}(t)|$$

$$\vec{x}(t+1) = \vec{x}_p(t) - \vec{A}\vec{D}$$

where, t is the current iteration, X_p denotes the current position of the victim, and the coefficient vectors A and C are computed.

$$\vec{A} = 2\vec{a} * \vec{r}_1 - \vec{a}$$

$$\vec{C} = 2\vec{r}_2$$

where, r_1 and r_2 are two random vectors between [0, 1] and the component of a is linearly decreasing from 2 to 0 over each course of the iteration.

C. *Hunting*

In hunting phase which is basically guided by the alphas, the positions of the grey wolves are updated. Though alphas are the main agents in hunting phase, still occasionally betas and deltas also participate in the hunting process. So far we have the candidate solutions of grey wolves in terms of alphas, betas and deltas but we don't know the exact or optimum position of prey. To find the optimum positions, three best solutions (obtained so far) in terms of alpha, beta and delta are saved and remaining solutions including omega compete. Following formulas are used to update the wolf positions around the prey.

$$\vec{D}_\alpha = |\vec{C}_1\vec{X}_\alpha - \vec{X}|, \vec{D}_\beta = |\vec{C}_2\vec{X}_\beta - \vec{X}|, \vec{D}_\delta = |\vec{C}_3\vec{X}_\delta - \vec{X}|$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1(\vec{D}_\alpha), \vec{X}_2 = \vec{X}_\beta - \vec{A}_2(\vec{D}_\beta), \vec{X}_3 = \vec{X}_\delta - \vec{A}_3(\vec{D}_\delta)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3}$$

It would be observed that final position is random in nature within the circle which is completely defined by the alpha, beta and delta in the search space, whereas other wolves update their position by estimating the prey position.

D. *Attacking Prey*

Exploitation refers to local search capability around the promising regions obtained in the exploration phase. In the above sections, it is discussed that how the grey wolves finish the hunt by attacking prey when it stops moving. In order to mathematically express the model approaching the prey, two parameters, as described below are considered. a is linearly decreasing from 2 to 0 and fluctuations of A is also decreased with a. In other words A is a random value between ½_a; a_: When random value of A is between [-1, 1], the next position of search agent can be any position between current position and prey position.

E. Search for Prey

The exploration phase refers to the course of investigating the promising area of the search space as broadly as possible. Optimum search in grey wolf algorithm is based on the positions of alpha, beta and delta. They diverge from each other when they search for prey and converge during attacking the prey. Mathematically, when random value of A is greater than 1 or less than -1, search agent diverges to prey. This emphasizes exploration behavior in GWO algorithm. One more variable in GWO technique helps exploration process is C. The random value of C varies between [0,2], as evident from (8), which affects the prey of defining the distance as in (5). Thus, GWO shows more random behavior throughout the optimization and favoring exploration and local optima avoidance.

Finally, the algorithmic steps of GWO may be summarized as follows:

a) The search process is started with random initialization of candidate solutions (wolves) in the search space.
b) Alpha, beta and delta wolves are estimated based on the position of prey.
c) To find the optimum location of prey, each wolf updates its position.
d) A control parameter a linearly decreases from 2 to 0 for better exploitation and exploration of candidate solutions.
e) Candidate solutions tend to diverge when A > 1 and to converge when A < 1 and at the end GWO gives the optimum solution.

4. Simulation and Results

The purpose of this research is to compare the superiority and efficacy of the proposed algorithm using two distinct area networks with varying parameter values. The test system's transfer-function model is created in the MATLAB/SIMULINK environment, and the optimization method (GWO) is entered into the m file. To determine the optimal gains of controller settings, the GWO method minimizes the ITAE criteria based objective function (ACE). Simulations were run in the MATLALB 9.5.0 (2023a) environment on an Intel Core (TM) i3 CPU running at 2.4 GHz with 4 GB of RAM. In the current research, maximum loo iterations and population size are taken to 15, which is necessary for the proper execution of the GWO method.

To demonstrate the robustness of the proposed GWO-based PID controller, sensitivity analysis is conducted on each generator and turbine time constant change within a ± 50% range. The PID-controller used in both regions is optimized concurrently using the GWO method; the accompanying figures show the optimal controller gain values, minimal ITAE values, frequency overshoots and settling times, and tie-line power variances under various loading scenarios. It is evident that when the generator and turbine time constants are adjusted by ± 5O/ from their nominal values, system performances are little affected; this is notably true for the tie-line power oscillations and frequency setup times.

The PID gains calculated by the proposed algorithm is summarised in the table 1.

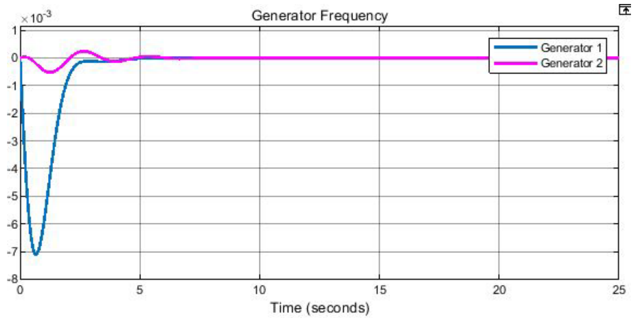
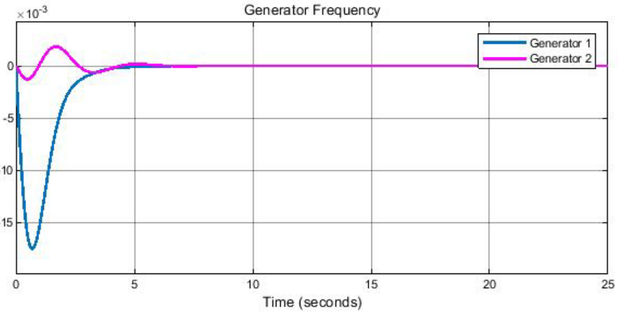


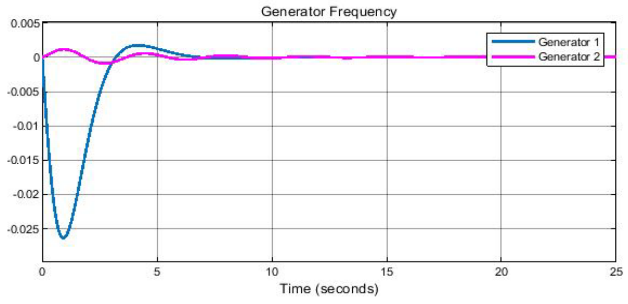
Fig. 2. Generator frequencies for base case



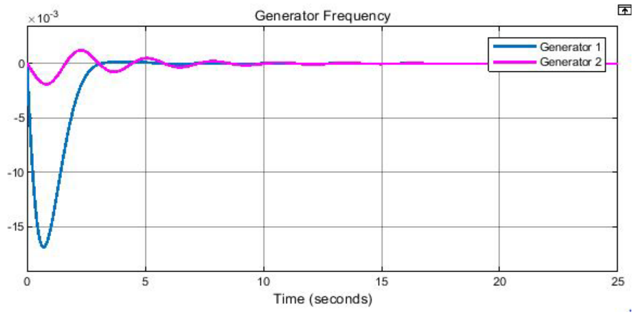
(a)

Table 1
Optimized PID parameters

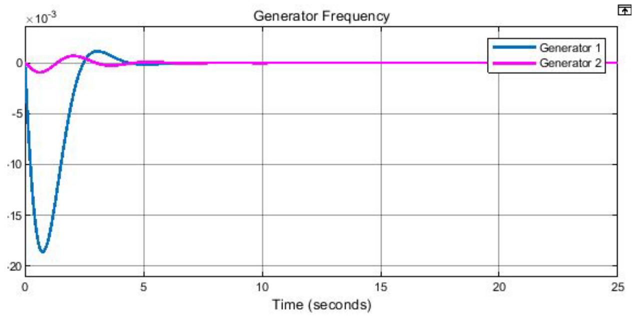
Case	PID 1 (Area 1)			PID 2 (Area 2)			PID 3 (Tie Line)		
	K_p	K_i	K_d	K_p	K_i	K_d	K_p	K_i	K_d
Base	0.67952	1	0.51608	0.88818	0.03003	0.31159	0.78828	0.00424	-0.1569
T_g +25%	0.84057	1	0.70355	0.62761	0.73457	0.64934	-0.4576	0.00646	0.7226
T_g +50%	0.06952	0.60283	0.47268	0.47341	0.26769	0.2062	-0.2782	-0.0059	-0.2123
T_g-25%	0.60073	1	0.52569	0.90046	-0.1418	-0.0574	0.909	0.00225	0.5859
T_g -50%	0.465	1	0.38473	0.56162	0.29949	0.16532	0.20934	0.00149	0.36788
T_t +25%	0.82297	1	0.74537	0.80593	-0.1412	1	-0.5342	-0.0008	-0.0084
T_t +50%	0.47338	0.77225	0.77608	0.47165	0.92061	1	-0.3154	0.0111	0.25453
T_t-25%	0.64161	1	0.51479	0.31278	0.03954	0.16959	0.22106	-0.0045	-0.2084
T_t -50%	0.39478	1	0.29521	0.6729	0.08932	0.81661	0.15925	0.0003	0.45397



(b)

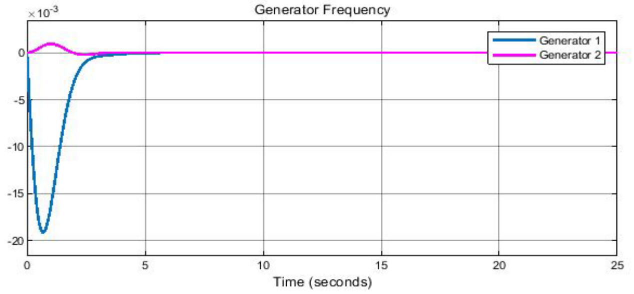


(c)

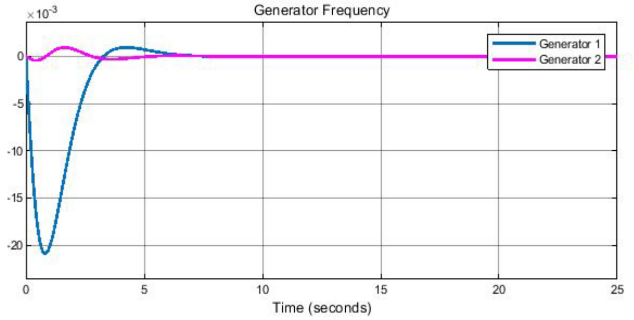


(d)

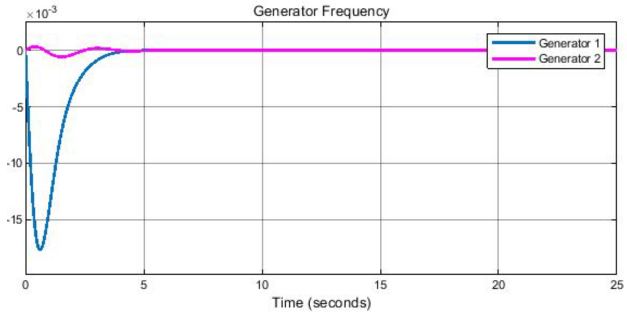
Fig. 3. Generator frequencies for different generator time constants (a) +25% (b) +50% (c) -25% (d) -50%



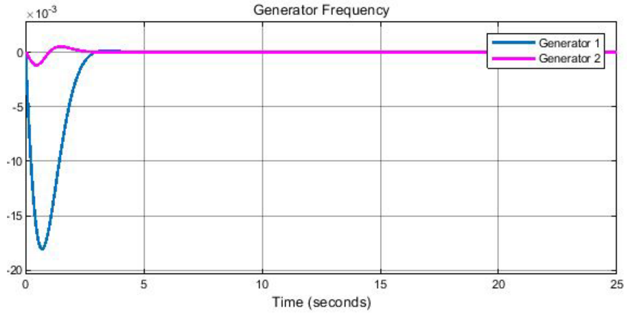
(a)



(b)



(c)



(d)

Fig. 4. Generator frequencies for different turbine time constants (a) +25% (b) +50% (c) -25% (d) -50%

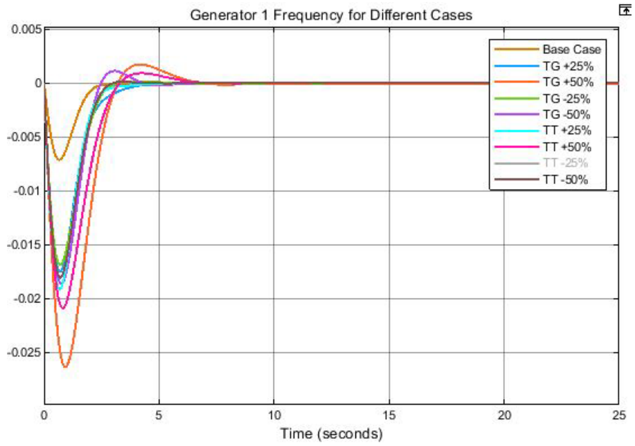


Fig. 5. Generator 1 frequency for all cases

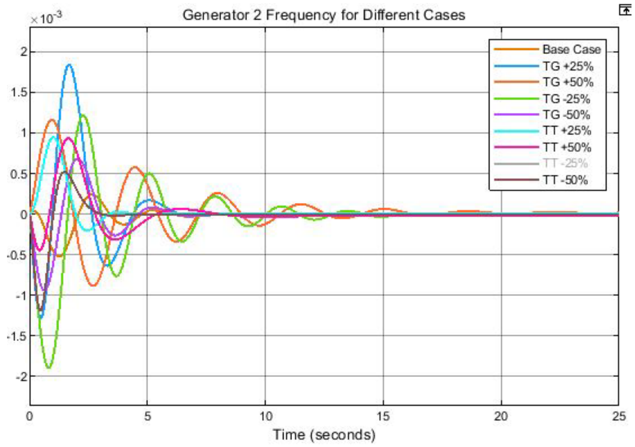


Fig. 6. Generator 2 frequency for all cases

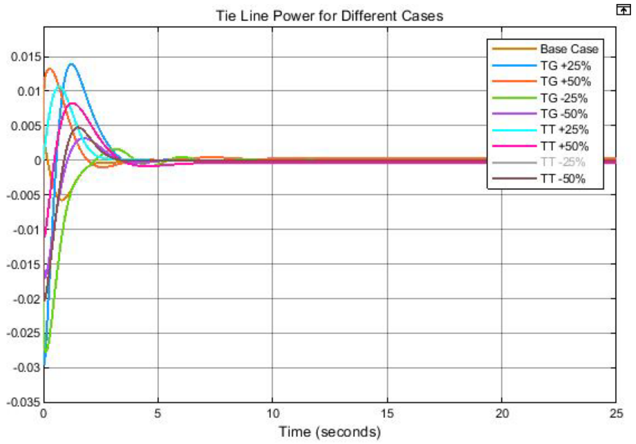


Fig. 7. Tie Line power for all cases

5. Conclusion

For the first time, a novel evolutionary algorithm called GWO is designed and implemented in this research to solve the LFC issue in the power system in an efficient and ideal manner. PI/PID controller settings are adjusted utilizing the GWO method using an ITAE-based objective function in a widely utilized two-area non-reheat thermal power system without the steam turbine's GRC. Sensitivity analysis is performed to show how the robustness of the controller design is maintained under various operating situations and system characteristics. According to results from time domain simulation, the suggested controller is quite reliable and performs well in unpredictable situations.

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