Optimal Tuning of FOPID with GWO Algorithm for Multi-Source Power System

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***Abstract*: Automatic Generation Control (AGC) ensures the frequency and tie-line power errors to maintain the nominal frequency and tie-line schedules. This can be achieved by employing FOPID controllers. But FOPID has some limitations in practical applications that includes the selection of control parameters of the controller, which directly impacts the system stability. The tuning of fractional order PID parameters depends upon required specifications of peak-overshoot, settling time, rise-time, and steady-state error. Conventionally, Cuckoo search Algorithm (CSA) is used to determine the parameters so that minimum overshoot can be obtained. By applying the cuckoo search the overshoot was reduced but not to a satisfactory level. It suffers from lot of problems thus, in this paper, the CSA algorithm is replaced with GWO algorithm. It is used to tune the parameters of the controller. Simulation results are obtained using MATLAB. From the obtained experimental results, the proposed approach is proved to be efficient and offers less settling, rise times and comparable overshoot in comparison to existing approaches.**

***Keywords*: FOPID, GWO, 2DOF-FOPID, Optimization**

1. Introduction

The process of AGC control is a significant process to continuously balance the load and generation in the power systems at the low cost. AGC is responsible for controlling the power exchange, frequency. AGC is implemented into an interconnected power system which is referred as being divided into control area where all the generators are predicted to form a coherent group. In any kind of power system, instead of maintaining speed governing system, it is required to attain better frequency constancy. While, in an interconnected power system, maintaining the tie line flow at a given level irrespective of the load change in any area is a significant task [1]. This is achieved by using (AGC) which provides balance between generation and consumption of active power. It also provides a method to control the generation in order to decline the deviation of frequency and to control the flow of tie-line power within the prescribed boundaries. [2]. An optimal controller was introduced by Elgerd and Fosha that enhanced the stability and dynamic response of a two-area interconnected power system to a great extent. [3] However, AGC faces some problems which make it inefficient to use. Many researchers have worked to cope with the problems of AGC [4].

In order to control the frequency and tie-line power errors, mostly used controllers are proportional, Integral and derivative in parallel and/ or series combinations so far [5]. The PID controller is better than all the combinations of P, I, D controllers and can be easily implemented to achieve effective and dynamic responses, but the increase in the complexity due to disturbances like load variation boiler dynamics in the system results in educed performance of PID. Other controllers are also utilized such as Artificial Intelligent controllers like Fuzzy and Neural control. These approaches are deployed to deal with the load frequency control problems and to attain better results [6]. The fuzzy controller offered superior performance over the conventional controllers, particularly, in complex and nonlinearities associated. However, the limitation of using fuzzy is that it provided good dynamics only when the specific number of membership function is selected to make decisions. A new technique- Degree of freedom of a control system is also introduced which is the number of closed-loop [6].

Designing control systems is a multi-objective concern which is solved by developing the two-degree-of-freedom (2DOF) control system. This system is able to acquire the better performance than one-degree-of-freedom (lDOF) system [7], [8]. The conventional PI/PID and FOPI/PID controllers are of one degree of freedom (1-DOF) type i.e. they are available with only one closed loop. This makes the simultaneous management of set point tracking and disturbance rejection a difficult task. Due to this ambiguity, researchers developed two degree of freedom (2-DOF) control algorithm [9]. This control structure is explored in different domains of engineering by a significant number of authors [10], [11]. With the implementation of Fractional order mathematics with 2-DOF PID controller, its flexibility can be increased. However, it makes the tuning of controller complex. This problem can be efficiently tackled by implementing nature inspired meta-heuristics such as genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO), artificial bee colony (ABC) and DE etc. in the recent times, there are number of algorithms which are proposed by getting inspired from nature., one of them is Cuckoo search algorithm that is used for efficient tuning of 2-DOF FOPID controller [12]. This lacks in the efficiency of the performance. This paper presents a new model of AGC by implementing an optimization algorithm for 2-DOF control of AGC in an interconnected power system. This paper is divided into different sections and the next section is the literature survey performed for the works done in this field.

2. Related work

Many studies are performed to control the AGC for interconnected system which are mentioned below:

Sanjoy Debbarma1, et.al, the main concern of the paper [13] was the application and design of 2-DOF-FOPID (2- Degree-of-Freedom - Fractional Order PID) controller in order to resolve the problem of AGC (automatic generation control) of hydrothermal and multi-area system consisting of various sources like, thermal, gas and hydro units. With the help of CSA (Cuckoo search Algorithm) algorithm, every controller's optimal factors were selected.

L. C. Saikia and S. Debbarma.: In the paper [14], the FOPID controller in 2-equal area thermal system's AGC under bilateral policy approach based deregulated environment was presented. In the system, suitable GRC (generation rate constraint) was taken into account. Bacterial Foraging (BF) approach is used in this paper in order to optimize various parameters. It was analyzed from the study that fractional order proportional-integral-derivative controller gives optimal performance with regards to magnitude oscillation, settling time in contrast to other ten controllers.

Preeti, et.al, paper [15] proposed the solution of 4-area interconnected power system's AGC problem consisting doubly fed induction generator wind turbine with the help of GSA (gravitational search algorithm). For tuning the gains of speed and DFIG wind turbines' pitch angle controller with PID (proportional integrated derivative) controlled interconnected system, Gravitational Search Algorithm was utilized.

Kumar, et.al, [16] proposed General Relativity Search Algorithm (GRSA) based new technique, for 2-area interconnected thermal power system's AGC. He analyzes the power system's AGC by Proportional Integral (PI) controller and Proportional Integral Derivative (PID) controller.

It is revealed from the related work that improved performance of 2-DOF FOPID controller is required to be enhanced by applying optimization technique on the controller parameters.

3. Optimization

This section presents the intelligent optimization technique to design the fractional order PID controller (FOPID) based on. Optimization is the process of applying different number of algorithm to choose the optimal solution for the system [17]. here, GO is chosen for FOPID to enhance its performance. The algorithm is explained below:

GWO: The GWO [18]-[20] imitates gray wolves ' chasing and social hierarchy. Apart from the social structure of gray wolves, pack hunting is another attractive social activity of gray wolves. Circling, hunting, and attacking the prey are the primary sections of GWO.

GWO algorithm consists of only few parameters and its implementation is simple due to which it becomes greater as compared to conventional ones. This algorithm is applied for resolving the optimization issues because it has versatile features.

In GWO, the optimum solution is searched by encircling the prey, hunting it, attacking it and eventually search for the new prey consecutively if any exists.

A grey wolf optimizer is a meta-heuristic algorithm, and the wolves belong to a Canidae family. The leaders are male or females, called alpha (α) and have a rigid social leading ruling structure and mostly they are the choice maker. The dominant wolf's commands should be followed. The Betas (β) are subordinate wolves that assist the alpha to make choices. The beta is an alpha consultant and pack discipliner. The grey wolf of the reduced classification is Omega, who must present all other wolves of dominance. If a wolf is not alpha, beta and omega then, it's named delta. Delta (δ) dominates the Omega and accounts to alpha and beta. In order to create and optimize GWO, wolves ' hunting methods and social Hierarchy are mathematically modeled.

In addition, the GWO was effectively implemented to solve multiple issues of engineering optimization.

The GWO algorithm is being followed by the various steps which have explained below.

Algorithmic steps and Pseudocode

The GWO algorithm is explained below:

Step 1: Initialize the parameters of GWO like, design variable size (Gd), search agents (Gs), vectors a, A, C and highest count of iteration (itermax).

$$\overrightarrow{A.} = 2\overrightarrow{a.}rand_1 - \vec{a} \quad (1)$$
$$\overrightarrow{C.} = 2.rand_2 \quad (2)$$

During the iterations, the values of → a reduced linearly from 2 to 0.

Step 2: Generate random wolves on the basis of pack size. Those wolves can be articulated mathematically as:

$$Wolves = \begin{bmatrix} G_1^1 & G_2^1 & G_3^1 & \cdots\cdots G_{Gd-1}^1 & G_{Gd}^1 \\ G_1^2 & G_2^2 & G_3^2 & \cdots\cdots G_{Gd-1}^2 & G_{Gd}^2 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ G_1^{Gs} & G_2^{Gs} & G_3^{Gs} & \cdots\cdots G_{Gd-1}^{Gd} & G_{Gd}^{Gs} \end{bmatrix} \quad (3)$$

In which, G_j^i is the first value of j^{th} pack of i^{th} wolves.

Step 3: with the help of equation (4) and (5), calculate the value of every hunt agent.

$$\vec{D} = \left|\overrightarrow{C.}\,\overrightarrow{G_p}(t) - \vec{G}(t)\right| \quad (4)$$
$$\vec{G}(t+1) = \overrightarrow{G_p}(t) - \overrightarrow{A.}\,\overrightarrow{D} \quad (5)$$

Step 4: find the optimal hunt agent (G_α), second optimal hunt agent (G_β) and third optimal hunt agent (G_δ), with the help of equation (6)-(11).

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$$\vec{D}_\alpha = |\vec{C}_1.\vec{G}_\alpha - \vec{G}| \quad (6)$$
$$\vec{D}_\beta = |\vec{C}_2.\vec{G}_\beta - \vec{G}| \quad (7)$$
$$\vec{D}_\delta = |\vec{C}_3.\vec{G}_\delta - \vec{G}| \quad (8)$$
$$\vec{G}_1 = \vec{G}_\alpha - \vec{A}_1.(\vec{D}_\alpha) \quad (9)$$
$$\vec{G}_2 = \vec{G}_\beta - \vec{A}_2.(\vec{D}_\beta) \quad (10)$$
$$\vec{G}_3 = \vec{G}_\delta - \vec{A}_3.(\vec{D}_\delta) \quad (11)$$

Step 5: With the help of equation (12), renew the current hunt agent's location.

$$\vec{G}(t+1) = \frac{\vec{G}_1 + \vec{G}_2 + \vec{G}_3}{3} \quad (12)$$

Step 6: Estimate every hunt's fitness value.

Step 7: Update the value of $\vec{G}_1, \vec{G}_2 and\ \vec{G}_3$

Step 8: Ensure for stopping condition that is, if Iter reaches Itermax, then print the best value of solution, else go to step 5.

4. Present work

The conventional algorithm is not appropriate for the system due to some problems faced by cuckoo algorithm in the conventional work. This algorithm does not offer the system to obtain the required minimum value for the parameters. Thus, a novel approach for FOPID system is developed by implementing the optimization algorithm. The model is optimized by deploying Grey Wolf Optimization (GWO). The GWO technique is used to optimize the parameters of different controllers along with fuzzy-PID controller. The key advantages are rapid convergence at a very initial stage by exchanging from exploration to exploitation. This feature enables this algorithm for the scenarios where fast solutions are required. It performs the convergence with high accuracy. It is able to globally optimize the problem for week dimensional function. Accuracy of GWO algorithm is higher than Cuckoo search algorithm. GWO algorithm is robust, performs fast conversion and consists of global optimization as compared to other optimization algorithms.

A. Objective

The objectives of the proposed work are as follows:

- Replacement of cuckoo search algorithm with Grey Wolf Optimization (GWO) algorithm in order to reduce the overshoot in FOPID based power systems.
- Comparative analysis between the performance of cuckoo search optimization algorithm and GWO algorithm.

The algorithm used for GWO is as follows:

1. *Generate initial search agents Gi (i=1, 2,….,n)*
2. *Initialize the vector's a, A and C*
3. *Estimate the fitness value of each hunt agent*
   Gα=the best hunt agent
   Gβ=the second best hunt agent
   Gδ=the third best hunt agent
4. *Iter=1*
5. *repeat*
6. *for i=1: Gs (grey wolf pack size)*
   Renew the location of the current hunt agent using Equation (3.12).
   End for
7. *Estimate the fitness value of all hunt agents*
8. *Update the value of Gα, Gβ, Gδ*
9. *Update the vectors a, A and C*
10. *Iter=Iter+1*
11. *until Iter>= maximum number of iterations {Stopping criteria}*
12. *output Gα*

5. Results

The proposed system aims to reduce the overshoot in the output of the FOPID based power systems. The proposed work tunes the GWO algorithm with FOPID controller. The experimental analysis acquired from the simulation is shown below:

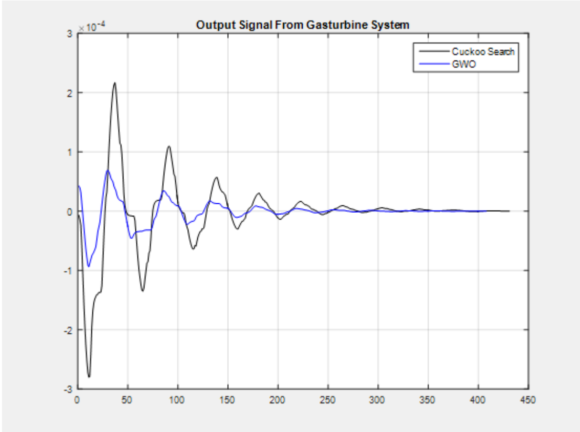

Fig. 1. Comparison of Gas turbine system using conventional and proposed technique

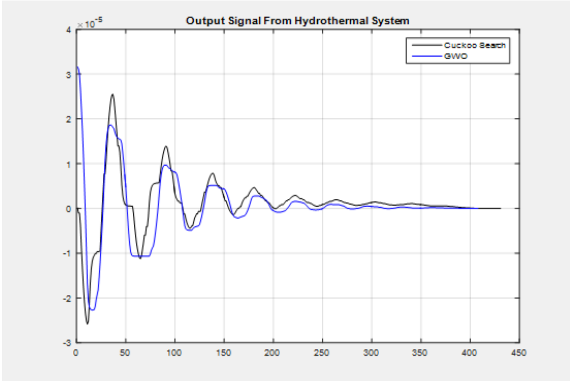

Fig. 2. Comparison of Hydrothermal system using traditional and proposed technique

The figure 1, exemplifies the effect of overshoot in the gas turbine PID controller by using both the approaches i.e. traditional and proposed approach. From the graph above it can observed that the output curve of the proposed work has little fluctuations as compare to the output curve of the traditional work, which faces the sudden raise in the frequency and similarly suddenly it gets down at next time interval. The effect of overshoot has reduced in the GWO algorithm in comparison with the traditional approach which indicates that by using the proposed system, the efficient output in the Gas turbine systems can be achieved.

The comparison graph of hydrothermal system has shown in the Figure 2, in which the effect of overshoot is seen by applying both the algorithms i.e. traditional and proposed. it is observed that the tuning using GWO algorithm outperforms than conventional approach and the effect of overshoot has been reduced in the hydrothermal system which demonstrated that proposed scheme is optimal as compared to traditional approach.

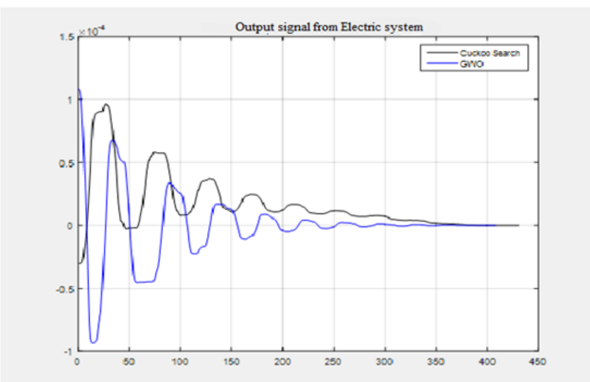

Fig. 3. Comparison of Electric system using proposed and traditional approach

The figure 3, illustrates a comparison graph of the proposed and traditional work for controlling the output of the electric PID system. The cuckoo search algorithm was used with PID controller in the earlier technique to control the output which does not reduced the overshoot to the satisfactory level. However, the results of proposed system are much better than that of traditional system. The proposed technique in the considered system remarkably improves the settling time with more reduced overshoots and oscillations.

6. Conclusion

FOPID controller is introduced to cope with AGC problem of hydrothermal, electric and gas unit based system. Tuning of controller is required for obtaining the reduced overshoot, settling time and oscillations for which different algorithms are studied. The cuckoo algorithm in the traditional approach is not able to reduce the overshoot. Therefore, a Grey Wolf Optimization based PID controller is proposed to control output of three power grid systems. The simulation is done by considering the output of three power systems such as hydrothermal power system, gas turbine and electric power system. Results represents the tuning of the PID controller using proposed approach and also comparison is made between the traditional (cuckoo search algorithm) approach and proposed (GWO) approach which shows that the tuning of PID controller with GWO is better than the tuning of PID with cuckoo search algorithm. GWO conveniently minimizes the setting time as well as achieved the reduced overshoot and oscillations. Simulation results validate the effectiveness of the proposed technique.

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