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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

TUNING OF PID CONTROLLER FOR FOUR-AREA LOAD FREQUENCY CONTROL USING ELEPHANT HERDING OPTIMIZATION

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Abstract

The power system quality and reliability depend on many factors; one of the most important terms is the Load Frequency Control (LFC). The goal of the LFC is to balance the power outputs of the generation to induce the varying load demands with zero variation in the frequency. PID controller contains three parameters which have all the necessary dynamics to eliminate the oscillation, increase the signal control, lead the error approach to zero and fast response on changing the controller input, especially peak undershoot, overshoot and settling time. This study presents the use of one of the optimization methods to optimize the parameters of the PID controller, which controls the four-area interconnected power systems. The PID controller Parameters are tuned using Elephant Herding Optimization (EHO) method. A comparison among multi-methods of PID tuning via multi-disturbance values and time. The results show the advantage of the proposed method compared to other PID tuning techniques.

Keywords: Load Frequency Control, PID Controller, Elephant Herding Optimization, Particle Swarm Optimization

FIL SÜRÜ OPTIMIZASYONU KULLANILARAK DÖRT ALANLI YÜK FREKANS PID KONTROLÖRÜ AYARLANMASI

Özet

Güç sistemi kalitesi ve güvenilirliği birçok faktöre bağlıdır. Bunların en önemli olanlarından biri, "Yük Frekans Kontrolü"dür (YFC). YFK'nün amacı, değişken yük ihtiyaçlarını frekansta sıfır varyasyonla indüklemek için üretimin sonrasındaki güç çıkışlarını dengelemektir. PID kontrolörü, titreşimi gidermek, sinyal kontrolünü arttırmak, hata yaklaşımını sıfıra indirmek ve kontrolör girişini değiştirmede hızlı tepki, özellikle geç kalma, aşma ve yatışma sürelerini maksimuma çıkarma için gereken tüm dinamikleri barındıran üç parametreye sahiptir. Bu çalışmada, dört alanlı ara bağlantılı güç sistemlerini kontrol eden PID kontrolörünün parametrelerini optimize etmek için optimizasyon yöntemlerinden birinin kullanımını gösterilmektedir. PID kontrolör parametreleri, Fil Sürü Optimizasyonu (Elephant Herding Optimization) (EHO) metodu kullanılarak ayarlanmıştır. Çoklu arıza değerleri ve zaman kullanarak diğer PID ayarlama için kullanılan optimizasyon yöntemlerinden biri olan Parçacık Sürü Optimizasyonu yöntemine ile arasında bir karşılaştırma ve sonuçlar ortaya koymaktadır.

Anahtar Kelimeler: Yük Frekans Kontrolüdür (YFC), PID kontrolörü, Fil Sürü Optimizasyonu, Parçacık Sürü Optimizasyonu

1. INTRODUCTION

The large size, quality, reliability, stability, and the balancing between demand and generation make the power system is one of the most complex issues in scientific researches. LFC is one very important method of the power system, which provides generator load control via zero frequency in "steady-state deviations" (Kumar, 2016). The frequency of a system depends on the balance of the active power in generation and load plus losses. If a substantial disturbance suddenly happens in a power system, generation units and demand will be affected by the difference in the energy between both two sides. Initially, this imbalance managed by the kinetic energy of the rotating elements in the system. Thus, LFC will handle the restoring of the system operation after reducing total kinetic energy (Soheilirad et al., 2012).

On the other hand, the PID controller is widely used for damping the oscillation of frequency in the power system. The classical controllers can be robust if it provides some specific gain and phase margin in case of a suitable selection for the values of the controller parameters (Sharma et al., 2018). Many classical and intelligent methods have been suggested to select PID parameters. Ziegler-Nichols, Cohen-Coon, and Fertik methods are the same examples of PID tuning methods, which are used to control the frequency in the power system (Sambariya and Fagna, 2018). The Proportional Integral (PI) control was also used in LFC and successful in one and two areas (Patel and Bhusan Jain, 2013). Partial Swarm Optimization (PSO), Genetic Algorithm (GA), Firefly Algorithm (FA), and Ant Colony (AC) methods were used to optimize the parameters of classical controllers (Patel and Bhusan Jain, 2013). Elephant Herding Optimization (EHO) was validated to select parameters of the PID controller of a low complexity power system of a single area in two types of power systems shown by Sambariya and Fagna (2018 and 2017).

All the previous methods validated with one disturbance on even single area or multi-identical areas (Jaber et al., 2013). Fuzzy logic is one of the best intelligent controllers, but it increases the complexity of any plan due to the selection of number, range of memberships and the perfect rules (Jaber et al., 2012). Therefore, the challenge of finding a simple and powerful controller still existing in most of high complex LFC.

In this paper, Elephant Herding Optimization (EHO) is applied to tune the PID controller on four area power system. Four areas with different parameters of a power system are simulated using MATLAB (MathWorks, Natick, Massachusetts, United States). A scenario of multi-double disturbances is suggested to investigate the proposed method. Integral Absolute Error (IAE) from zero frequency has been chosen to be the objective function of the EHO method. A comparison between PSO and EHO have done via the undershoot and the settling time. The results show the advance in controlling by using the proposed EHO algorithm.

2. SYSTEM MODEL

The tested system is a four-area with different parameters; the electric power system is shown in Figure 1., while Figure 2. represents the block diagram of each area (Liu et al., 2019) and the parameters of the four areas are shown in Table 1.

Table 1. The areas parameters

Area	T_t	T_G	R	B	D	H
1	0.030	0.08	2.4	0.401	0.0083	0.0834
2	0.025	0.091	2.1	0.3	0.0090	0.0776
3	0.044	0.072	2.9	0.48	0.0074	0.0850
4	0.044	0.044	1.995	0.391	0.0094	0.2500

where T_t is the turbine time constant, T_G is the speed governor time constant, R is the speed drop, B is the bias factor, D is the change in load, H is the inertia constant.

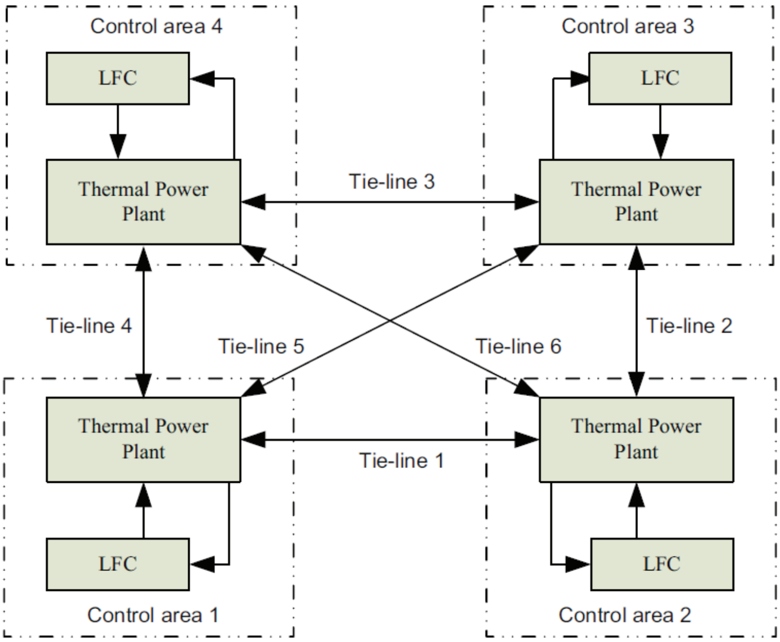

Figure 1. Four area networks

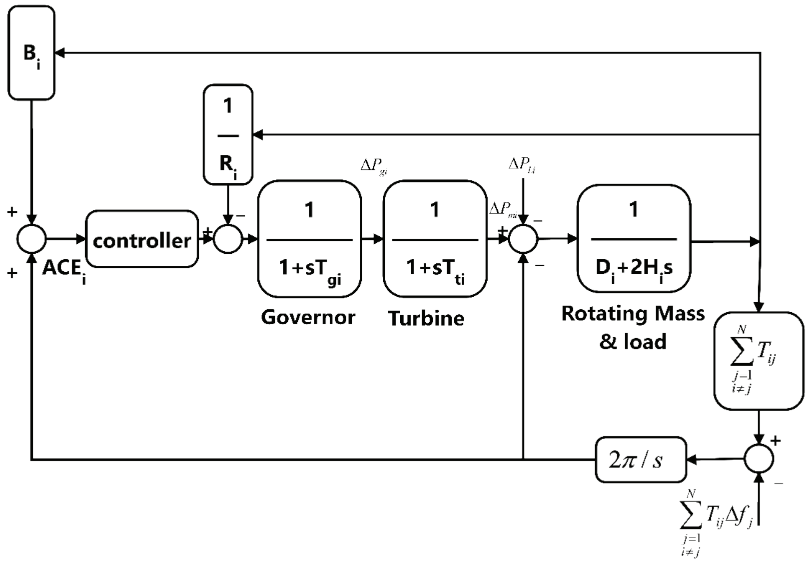

Figure 2. Block diagram for a single area of system with i^th connection

3. HERDING BEHAVIOR

Elephant Herding Optimization (EHO) is a novel metaheuristic nature-inspired optimization algorithm introduced by Wan**.** One of the largest animals on Earth are elephants, which belongs to the classification of mammals (Sambariya and Fagna, 2018)**.** The elephants divided into two traditional recognized types African and Asian. According to the elephant nature, they structured in a big size, but at the same character, these elephants are living in related groups such as a female elephant with her calves (Sambariya and Fagna, 2017). So, the elephant clans together named as a group, and all these groups are leaded by a matriarch, as shown in figure 3. Each clan among three to two dozen (Gupta et al., 2016). The females live with their family, while some males tend to live lonely until they leave their family group when they are getting older (Wang et al., 2015). The male elephant can still in contact with his family group by low-frequency vibrations (Sambariya and Fagna, 2017). The behavior of an elephant herding divided into two operations; one which in clan updating and other in separating, that used to solve the global optimization problem.

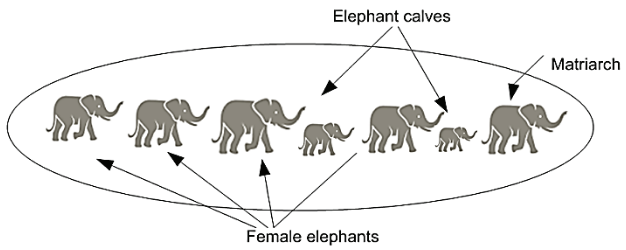

Figure 3. Generation of clan (Sambariya and Fagna, 2017)

3.1 Assumption of Optimization

- The worst behavior of male elephants is when leaving their family group, due to the fact it decided to live far away at a constant distance from their elephant groups for each generation.
- The total population of elephants can be classified in clans that have a fixed number of elephants.
- The matriarch is the alpha male of all elephants that live in a clan.

3.1.1 Clan updating operator

The matriarch is the leader of the clan, ci the total number of clans of elephants, j the total number of elephants in each clan, the current position of the elephant is updated by (Gupta et al., 2016),

$$x_{new,ci,j} = x_{ci,j} + \alpha \times (x_{best,ci} - x_{ci,j}) \times r \quad (1)$$

$x_{new,ci,j}$ and $x_{ci,j}$ constantly update as new values, and old position for elephant j in clan ci α scale factor of a matriarch on clan such that $\alpha \in [0,1]$, $\mathbf{r}$ is the random number in range r $\in [0,1]$, The best elephant in clan updated by (Wang et al., 2016),

$$x_{ci,j} = x_{best,ci,j} \quad (2)$$

$x_{best,ci}$ is the best position of the matriarch. ci is the movement, which is updated by.

$$x_{best,ci} = \beta \times x_{center,ci} \quad (3)$$

where β is a factor such that $\beta \in [0,1]$, and d is the dimension of the problem, according to above; the clan operation can be represented by:

$$x_{center,ci,d} = \frac{1}{n_{c_i}} \times \sum_{j=1}^{n_{c_i}} x_{ci,j,d} \quad (4)$$

3.1.2 Clan separating operation

As we mentioned before the elephant male leave his family and stay alone

$$x_{worst,ci} = x_{min} + (x_{max} - x_{min} + 1) \times r \quad (5)$$

The $x_{worst,ci}$ represents the worst elephant in a clan. The x_{max}, x_{min} represent the maximum and minimum position of the elephants, respectively. r $\in$ [0.1] the stochastic distribution between [0,1].

3.2 Objective Function

The LFC performance can be adequately specified in terms of settling time, peak undershoot and steady-state error (Kumari et al., 2017). Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral Time

Absolute Error (ITAE) are some of the most common indices to determine the objective functions. The function of the IAE is selected to determine the performance index for each iteration, which is shown in Eq (6).

$$IAE = \int_0^t ACEi\, dt \tag{6}$$

3.3 Tuning Of PID

The Tuning of PID is to control the frequency according to the load disturbances, which is used by EHO for a high-complex power system. The proposed method is by sending random values of four PID parameters (K_P, K_I, K_D) and recalculating the suggested values of those parameters according to the EHO algorithm (like a negative feedback system). This algorithm is shown in Figure 4.,

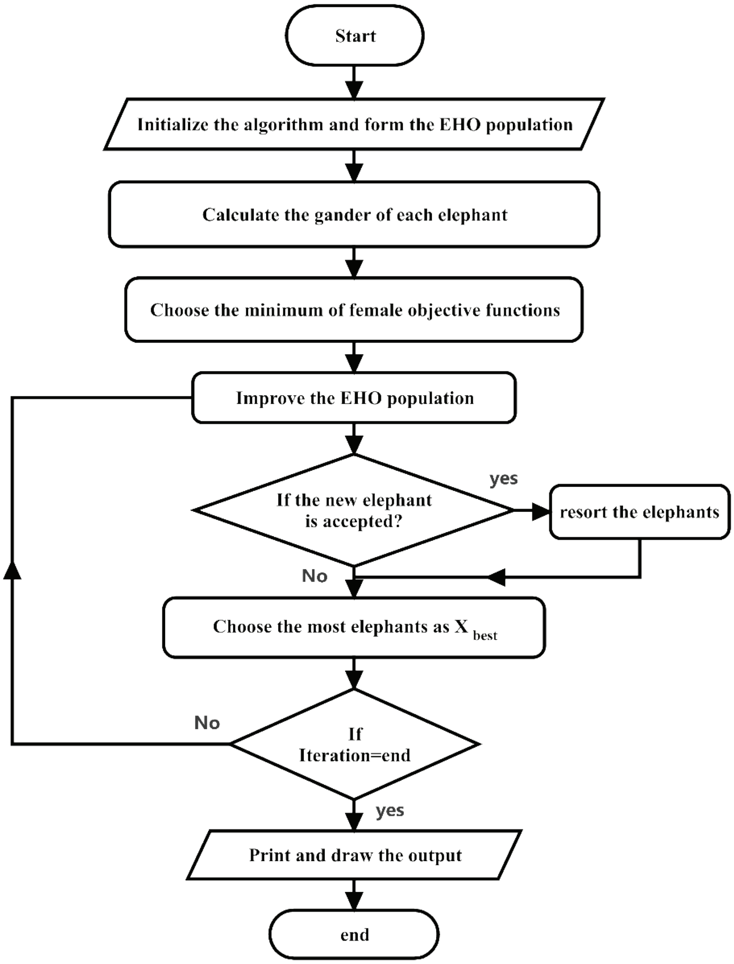

Figure 4. EHO algorithm

Moreover, the tuning of PID parameters using EHO shown in Figure 5.

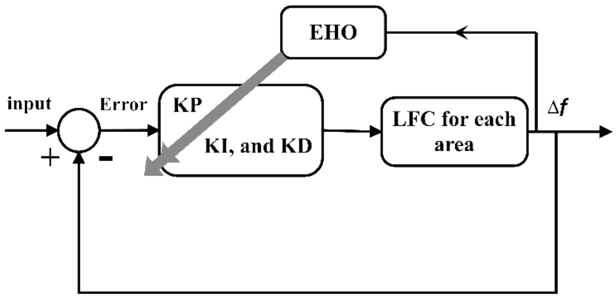

Figure 5. Tuning of PID by EHO

4. RESULTS and DISCUSSION

Load frequency control behavior of four different areas of a power system is simulated using MATLAB. EHO and PSO are used to tune the controller to get the minimum objective function. A disturbance of 0.1 p.u on the first area is selected to determine the PID parameters for both of the tuning methods. Ten samples run for each of EHO and PSO have been processed, and the resulted mean values of K_P, K_I, K_D are determined, and the resultant values of the parameters can see in Table 2.

Table 2. PID parameters

Area	EHO			PSO		
	K_P	K_I	K_D	K_P	K_I	K_D
1	1.1237	1.0422	0.9172	0.51	0.7	0.82
2	0.8361	0.7665	0.9595	0.5	0.7	0.8
3	0.7945	0.8142	0.9039	0.505	0.701	0.791
4	0.0750	0.0785	0.0342	0.499	0.698	0.803

The deviation response for four areas in 30 seconds shown in Figure 6.

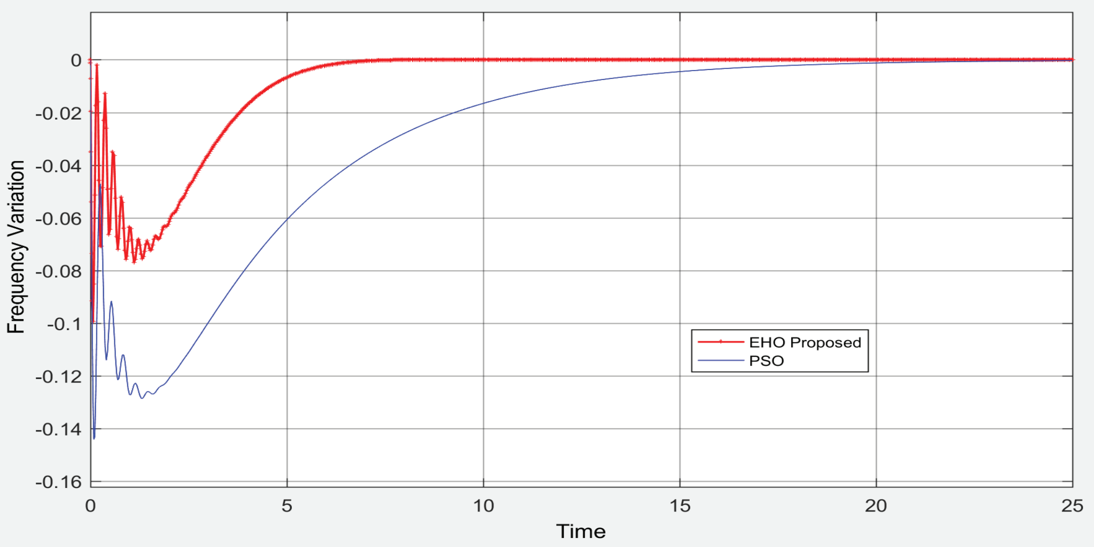

Figure 6. LFC response for single disturbance

To validate the system, double disturbance with multi values and moments were taken after the main disturbance. Figure 7., Figure 9. show the effectiveness of the proposed method via peak undershot and time steady state. However, the steady-state achieved by reducing the frequency deviation after a few seconds of controller action in both methods.

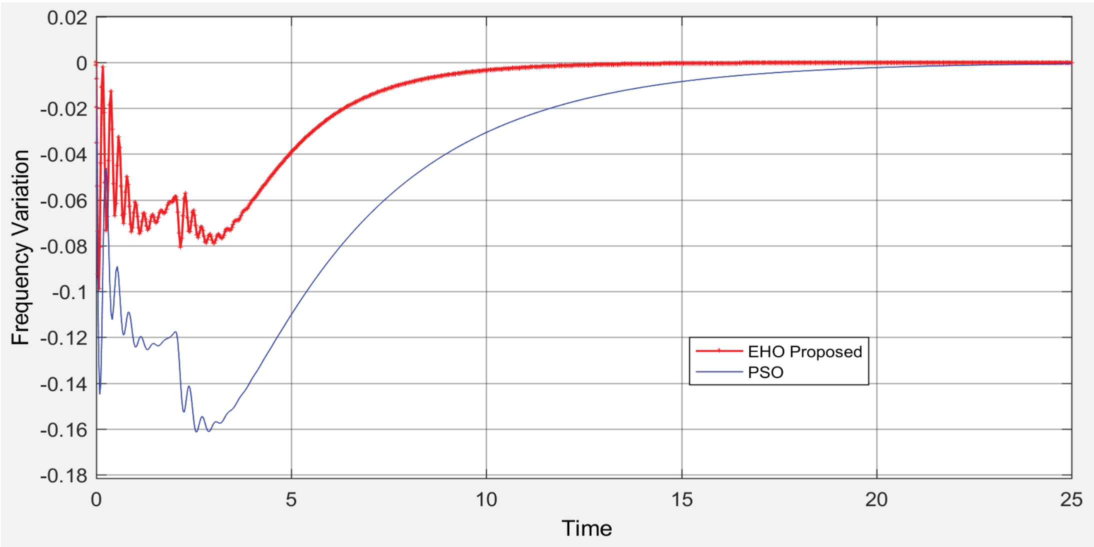

Figure 7. LFC response for double disturbance, 0.2 p.u, and 2 sec

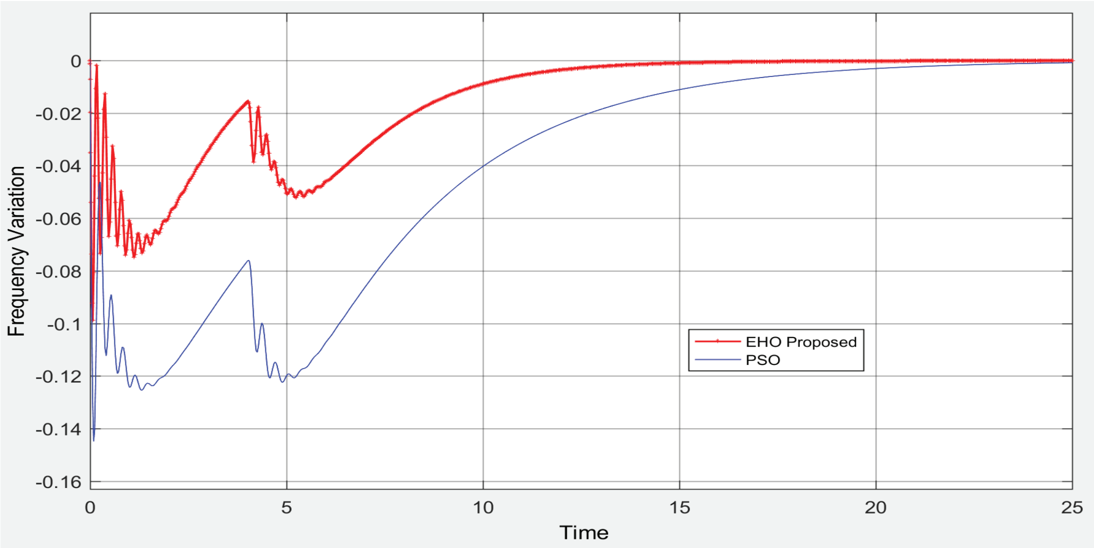

Figure 8. LFC response for double disturbance, 0.2 p.u, and 4 sec

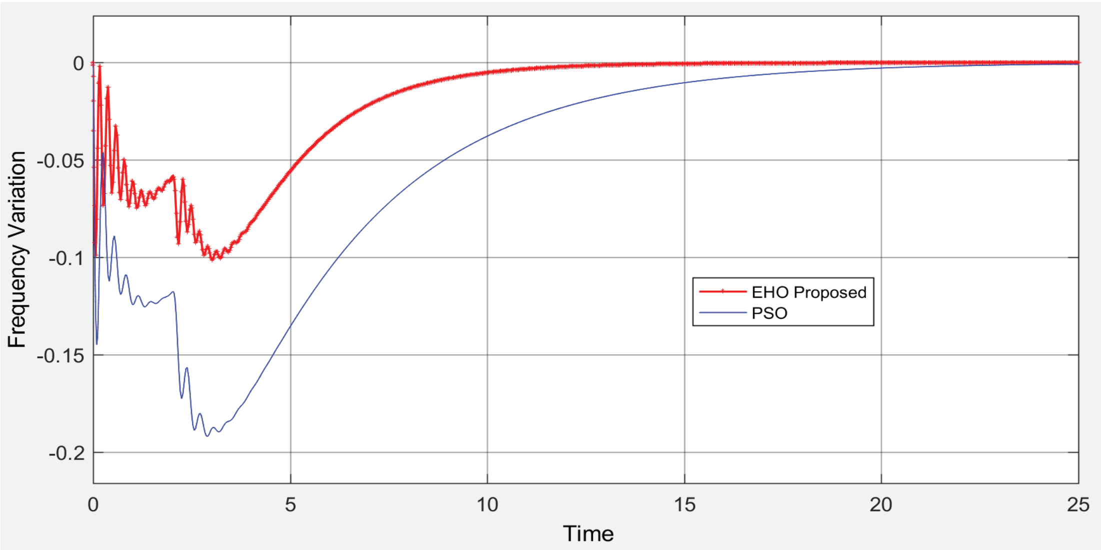

Figure 9. LFC response for double disturbance, 0.3 p.u, and 2 sec

After the first disturbance in the first area by two, three, four, and five seconds, another disturbance has been suggested in the second area. Table 3. shows the values of peak undershot and the approximate settling time for multi cases of disturbances.

Table 3. Dynamic performance for LFC

Dis (Area2)	Dis_time	EHO		PSO	
		PU-Sh	Sett_time	PU-Sh	Sett_time
0.1	2	-0.0988	10	-0.1449	21
0.2	2	-0.0988	11	-0.1614	21
0.3	2	-0.1015	11	-0.1920	20
0.4	2	-0.1241	11	-0.2228	20
0.1	3	-0.0988	11	-0.1449	20
0.2	3	-0.0988	11	-0.1449	20
0.3	3	-0.0988	15	-0.1708	25
0.4	3	-0.1079	25	-0.2018	25
0.1	4	-0.0988	25	-0.1449	25
0.2	4	-0.0988	25	-0.1449	25
0.3	4	-0.0988	25	-0.1533	25
0.4	4	-0.0997	25	-0.1852	25
0.1	5	-0.0988	24	-0.1449	24
0.2	5	-0.0988	25	-0.1449	25
0.3	5	-0.0988	25	-0.1449	25
0.4	5	-0.0988	25	-0.1725	25

where Dis (Area2) is the disturbance value of the second area, PU-Sh is peak undershoot, Sett_time is settling time, Dis_time is the disturbance time of the second area.

From Table 3., Figure7. Method Figure 9. can notice the advance of the tuning of the controller using EHO, especially in case of a short duration after the first disturbance.

5. CONCLUSION

In this study, a tuning of the PID controller used for the load frequency controller of the four areas interconnected power system has been suggested using Elephant Herding Optimization. A disturbance on the first area is chosen to tune the PID parameter. Four values of disturbance and four values of time have been implemented as a second disturbance in the second area to validate the system. The results show better dynamic responses of LFC by the EHO method in terms of the settling time, undershoots compared to the PSO approach.

Conflict of Interests/Çıkar Çatışması

Authors declare no conflict of interests/Yazarlar çıkar çatışması olmadığını belirtmişlerdir

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