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Electrical and Computer Engineering

# TUNING OF PID LOAD FREQUENCY CONTROL USING ELEPHANT HERDING OPTIMIZATION METHOD FOR FOUR AREA POWER SYSTEM

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Master Thesis

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by

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Electrical and Computer Engineering

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2019

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Firas Ayad Yaseen Alhayani

# DEDICATION

This thesis dedicated to my dear family, especially Dad & Mom.

## ACKNOWLEDGEMENTS

I would like to thank everyone who helps me in my scientific study, many thanks to my great parents, who always support me all my life and guide me. I am grateful to my friends, who helped and stayed with me.

# ABSTRACT

## TUNING OF PID LOAD FREQUENCY CONTROL USING ELEPHANT HERDING OPTIMIZATION METHOD FOR FOUR AREA POWER SYSTEM


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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 undershot, 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

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| LFC | : Load Frequency Control |
| PSO | : Particle Swarm Optimization |
| EHO | : Elephant Herding Optimization |
| PID | : Proportional Integral Derivative |
| AGC | : Automatic Generation Control |
| GA | : Genetic Algorithm |
| BFO | : Bacterial Foraging Optimization |
| ACE | : Area Control Error |
| ISE | : Integral Square Error |
| IAE | : Integral Absolute Error |
| ITAE | : Integral Time Absolute Error |
| ANN | : Artificial Neural Network |

# 1. INTRODUCTION

## 1.1 GENERAL OVERVIEW

In the power grid, the electricity is transmitted from the power plant to the end-user via transmission lines. The transmitted electricity is oscillating, which means the voltages cycling from positive to negative with the optimum number of cycles is 50 per second, also called frequency. In most countries, like Iraq and Turkey. The frequency of the transmitted electricity is 50 Hertz. When the home appliance is concerned. the Frequency is one of the important indicators of power quality since the appliance is operated with a certain frequency value, and if the supplied frequency is different than the required frequency by the appliance than these would not operate efficiently or even. To keep the frequency within a tight tolerance bounds is not easy when the load demand is high, the frequency decreased to a value below 50 Hertz, which put stress on the grid. While too much energy is fed into the power grid, the frequency increased to a value bigger than 50 Hertz which again put stress on the grid. Hence, the implementation of frequency regulation is necessary in order to keep the grid stable. The balancing process between the real power and the system frequency is known as Load Frequency Control (LFC).

On the other hand, due to the multi-variable conditions and complexity in the power systems, the classical and non-flexible LFC models are unable to withstand for worthy solutions. Thus, flexible procedures have been a matter of research throughout the modern years. Fuzzy Logic, Artificial Neural Networks (ANN), Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) all these have the advantages of modern intelligent control methods, which have solved the frequency control problems in an improved scale. Although numerous efforts have been projected implying fuzzy logic in solving LFC problems, the enhancement and modification of fuzzy logic still can be prepared so as the optimal performance could be achieved.

Elephant Herding Optimization (EHO) is the proposed method to solve the LFC issue to tune the PID parameter for four areas by sending random values of PID parameters ($K_P$, $K_I$, $K_D$) and recalculating the suggested values of those parameters according to the EHO algorithm.

## 1.2 PROBLEM DISCUSSION

In the previous section, the technical problem of LFC in the power system described. The foremost advantages of the LFC system are to preserve the frequency of system at the intended value, by keeping the power flows on the tie-lines at present value, and to share the amount of required generation among generating units as scheduled.

The large size, quality, reliability, stability, and the balancing between desired and generated power will result in making the power system is one of the most complex issues in scientific researches. Load Frequency Control is a common and important method of the power system, which provides generator load control via zero frequency in "steady-state deviations" [1]. The frequency depends on the balance of real power in generation and load plus losses. If a substantial disturbance suddenly happens in the system, the generation units and demand will be influenced by the difference in the energy between both two sides. Initially, this imbalance is managing 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 [2].

On the other hand, the PID controller is widely used to damping the frequency variation in the power system. The classical controller can be robust if it supplies some specific gain and phase margin in case of a suitable selection for the values of the controller parameters [3].

Many controllers have been proposed for different areas in the last decades, but due to the complexity of the multi-area power system, these methods are not efficient to control the frequency for four areas since all the previous methods were validated with one disturbance on even single area or multi-identical areas.

The conventional controller is used to solve the LFC issue. However, recently, PSO, Firefly, Bacterial Forging (BF), Spider Monkey (SP), Ants Colony (AC), Genetic Algorithm (GA), and Artificial Neural Network optimization methods investigated to set the PID parameters. The main weak point of these methods is the dynamic response usually disturbs when the complexity is increasing in the system, especially in three or four areas power system. Even fuzzy control considered a suitable system in case of choosing the memberships and rules, which are very difficult to determine in a highly complex power system [4].

At least it can be summarized that the good control performance for LFC will significantly increase the power system operation. Hence, in this thesis, the improvements to approach these problems mentioned are presented by proposing a new control approach.

## 1.3 OBJECTIVE

The thesis aims to calculate the parameter of the PID controller by using one of the optimization methods called Elephant Herding Optimization (EHO) resolving the Load Frequency Control (LFC) and compare with Particle Swarm Optimization (PSO). The method proposed to show efficient control strategies to control the 4- area power system.

## 1.4 THESIS OUTLINE

This thesis contains five chapters. The second chapter is a general overview of Load Frequency Control and the PID controller and related works with ours. The third chapter includes the methodology obtained through the tested system. In the first section, the model of interconnected power system areas presented and reviews. The second section is to explain the EHO methodology as a tuning method for the PID controller. In the fourth chapter, we explained the results of optimization with the PID controller. In the fifth chapter are the conclusion and future works of the thesis.

# 2. LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter presents the basic strategies of LFC and the related works in literature. In the first section, we discussed the basic controller type PI and PID controller and the reason for choosing the PID controller to determine the solution of Load Frequency Control (LFC) for power system and the reasons that lead the power system instability. The second section explains the type of control strategies, the classical control techniques and artificial intelligence techniques.

## 2.2 LOAD FREQUENCY CONTROL

The frequency regulation in the power system is a function of Automatic Generation Control (AGC). The deviation in frequency leads to a negative effect on the power system, which makes one of the most common and important problems in control of power system operation and design. Figure 2.1 is showing the systematic diagram of LFC [5]. The high deviation in frequency will reduce life cycle of the device, decrease load performance and make overload in via tie-line and intermediate with system protection schemes, thus making the power system unstable. Theoretically, the problem with LFC will become more common and important due to the fact of increasing in size, varying in construction, new emerging problem and environmental constraints. The power system has become more complex and in to preserve the frequency and maintain power interchange with another near control area; two main goals of the power system LFC have developed. Measuring the Area Control Error (ACE) is an approach to these goals. ACE defines as the instability in the system between the generation side and the load side.

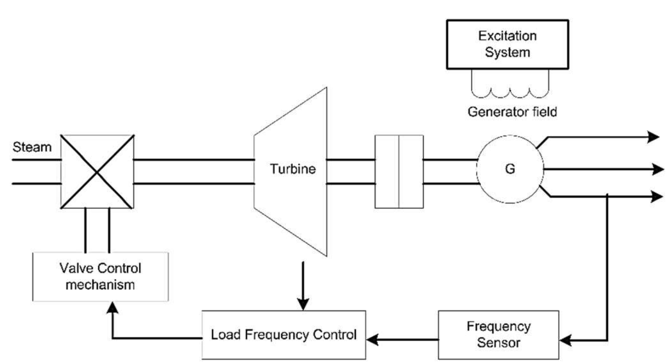


**Figure 2.1 :** Systematic diagram representation LFC [5].

## 2.3 INSTABILITY PHENOMENA

It defines as the power system unable to maintain the synchronize after the disturbance has accord in case of a transient angle and steady-state angle instability due to an increase or decrease of voltage in Busbar. Moreover, frequency instability makes an imbalance between the generator and load. All these reasons result in system instability, as seen in figure 2.2.

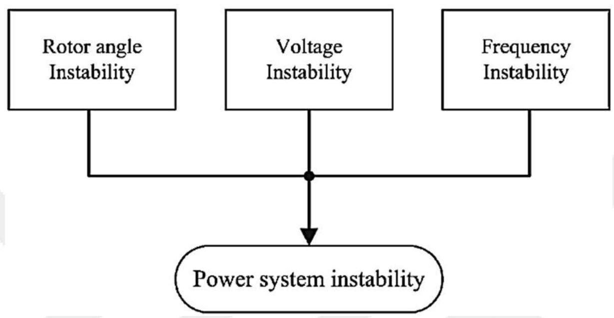


**Figure 2.2 :** Power System Instability

## 2.4 BASIC CONTROL TYPE

A controller is a device which is used as mechanical, hydraulic and electronic techniques in early applications. Although, it recently used in the form of a microscope or computer which adjusts and changes the operation condition of a given dynamical system. The typical application of controllers is to control the setting of temperature, pressure, flow and speed [6].

### 2.4.1 PI Controller

In case of the On-Off controller and P controller, the PI controller induces oscillation and reduces frequency variation also maintains a zero steady-state error. However, inserting the integral mode will affect the response time and the stability of the system due to the fact PI controller unable to forecast what will happen in future error. On the other hand, by inserting derivative mode to the controller, it will able to predict errors in the future. Thus, it will decrease the reaction time of the controller and make the system more stable [7]. The response system of the PI controller is low, which makes this an issue, resulting in a system disturbance and noise. Meanwhile, it will create one energy storage, which further delaying the transport of the system [8].

### 2.4.2 PID Controller

PID controller which refers to Proportional-Integral-Derivative, is a device to adjusts process variables using loop control feedback. Also, it is very accurate and stable. It was developed in 1911 by Elmer Sperry [9]. All dynamic processes such as fast reaction when a change introduces to the input control, zero steady-state error and the stability of the system will occur. Thus, increasing the speed of controller response [8]. PID control uses loop feedback control to sustain the actual output from the process as close as possible to the target or setpoint output [10]. The purpose of the PID controller is to force the feedback to match a set point. Figure 2.3 is showing the systematic diagram which represents the parameter of the PID controller.

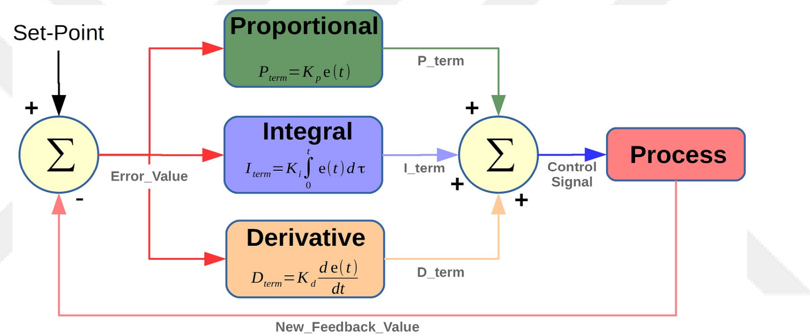


**Figure 2.3 :** Block diagram of PID controller [9]

Equation 2.1 represents the general transfer function of the PID controller.

$$G_c(S) = K_p + \frac{K_i}{s} + K_{d^S} \qquad (2.1)$$

## 2.5 TUNE PID CONTROLLER

Many rules have developed over the years, but the most important of all is Zeigler-Nichols (ZN) rules. Zeigler and Nichols described two methods of tuning a PID loop [10]. The primary method involves estimating the lag or delay time accordingly and then measuring the time taken to achieve the new output value. The secondary method depends on selecting the period of a steady-state oscillation.

- **Proportional tuning:** "P" correcting the value equal with a difference. thus, the value never gained because of the different approach to zero

- **Integral tuning**: "I" try to make the cumulative error to zero,
- **Derivative tuning**: "D" try to limit the overshoot by reducing the correction factor applied when the value approached

There are a lot of researchers who proposed the control techniques of design Load Frequency Control (LFC) has Tune the PID and PI controller using different control optimization. The controllers can be classified into classical and intelligent techniques [11].

## 2.6 CLASSICAL CONTROL TECHNIQUES

The classical control can be divided into robust control and adaptive control techniques. The first control to adjust with variation of parameters it is very important to make the system more stable in case of a transient. Robust control contains the parameter variations that cannot change at the variance of adaptive control will change when the condition is changing [12]. The group of engineers, namely Tripath et al., [13] suggested an adaptive controller, which is a process on a microprocessor for LFC. Wajk et al., [14] proposed an adaptive controller that uses the information and satisfies the multi-objective to control the Hungarian power system.

## 2.7 ARTIFICIAL INTELLIGENCE TECHNIQUES

### 2.7.1 Particle Swarm Based Techniques

A lot of researchers proposed a different study of Particle Swarm Optimization (PSO) to find a solution for LFC. Haluk Gode et al., 2008 [15] Proposed PSO calculate the ($K_P$, $K_I$, $K_D$) which are parameters of the PID controller. Such as one area, a power system contains a turbine, governor, and generator with negative feedback to gain high-quality solutions with a short time as compare with other stochastic methods Comparing with the conventional PI, the simulation is programming by MATLAB. Finally, the proposed PSO-PID controller is substantially shorter and gives better performance than the conventional PI. Lakshmi et al., 2014 [16] proposed Particle Swarm Optimization (PSO) to solve the LFC issue for the two-area power system. The Proportional-Integral (PI) controller is used to tune the LFC. The dynamic response of the system improved by reducing the ISE. The reaction of the PSO tuned PI controller which compared with the response of the conventional PI controller for the system considered. The result obtained from the proposed PSO tuned PI controller is better. Also, the simulation in MATLAB-Simulink. Hong et al., 2015

[17] Have been proposed the comparison between Bacterial Foraging (BFO) and Particle Swarm Optimization (PSO) and tuned PI-PID controller of Load Frequency Control for single area resulting in good outcomes in PID –BFO controller is gained. Sawinne et al., 2016 [17] present an improved PID to solve the problem of LFC gain by Particle Swarm Optimization (PSO) for two areas with a change in the system. The frequency response is calculating by using MSE. The optimal PID controller is more powerful for adjusting the system. Future work of the research will design hybrid controllers to obtain high performance for two area power systems.

### 2.7.2 Genetic Algorithm Based Techniques

These technique is consisted of different computational steps. The first step is initialization, that makes the chromosomes being generated randomly for the range of possible solutions. The second step is selection to select a certain ratio of the present populations to produce a new generation for choosing the chromosomes with higher fitness. The third step is reproduction; the genetic results in a population of chromosomes are different from the first generation. In the fourth step, evaluation is being conducted to keep a constant number of populations. The fifth step is termination; the Genetic Algorithm process is terminated if the chromosomes achieved the target fitness score. Otherwise, the steps 2-4 would be repeated to produce the next generation. Tawfik Elmenfy., 2012 [26] proposed also determined the PID controller for a single area power system but used the Genetic Algorithm (GA) to tune the conventional PID since the parameters are constantly changing. MATLAB develops the simulation and it takes a good result, such as reduce settling time and maintaining a free steady-state error, although it has been suggested in the future work to apply the same optimization but for two power systems. Tammam et al., 2012 [19] have been proposed LFC in a two-area interconnected with a PID controller by using the Genetic Algorithm (GA). The proposed controller compared with Bacteria Foraging Optimization (BFO) based PID controller. It has been demonstrating that the proposed calculation is powerful and gives huge execution in the framework. Along these lines, the proposed multi-target GA based PID controller is prescribed to create a decent worth. Hussein et al., 2012 [20] studies to find the parameters of the PID controller for the area to control the LFC system using GA. The simulation in MATLAB provided good and showed decent performance under various disturbances.

### 2.7.3 Neural Network-Based Techniques

Dianwei et al., 2016 [21] obtained Neural Network-Based to resolve the load frequency control problem; the control process is more stable with the interconnected power system. Surya et al., 2011 [22] proposed ANN and LFC. It is very complicated because it used for 3-area power system but used thermal re-heated for 1,2 area and the third area consists of the hydro station. Finally obtained an increase in the performance of fuzzy, PI and neural control as compare of PI and Fuzzy controller in the same condition

### 2.7.4 Fuzzy Logic-Based Techniques

This technique is widely using in control problem. A lot of related problems work on this technique for the power system. Fuzzy logic control found the solution for problem based on experience and knowledge in the system. [23]. Denna et al., [23] have proposed the use of the search algorithm for the automatic definition of the fuzzy rules. Meena et al., 2014 [24] obtained a comparing between fuzzy-PID and PSO-PID controller LFC of two power plants. The PSO algorithm was employed to tune PID control parameters when compared with the conventional PID controller. The performance of settling time and peak overshoot is improved under PSO-PID. Tridipta et al., 2015 [25] obtained an FPID controller and conventical PID used AGC in each area and applied for 3-area of the thermal power system; a good performance obtained as compared with other previous two methods. Debasis et al., 2018 [25] presented a new optimization called Spider Monkey Optimization (SMO) to tune fuzzy PID parameters for LFC. The result is gained in term peak undershoot, peak overshoot and settling time. This optimization for a multi-area power system in the first area is thermal and wind unit, but the second area is hydro and diesel unit.

### 2.7.5 Hybrid and Other Techniques

D K Sambariya et al., 2017 [26] proposed Elephant Herding Optimization (EHO) to find a solution for the problem of LFC by tune PID controller of optimization to reduce the variation in the frequency for a single area of a thermal power system. The results represent the effectiveness and improve performance of the power system in a specific time via undershoot, overshoot and settling time of the proposed controller simulated by MATLAB. Sahu et al., 2014 [23] tuned PI/PID controller of (LFC) optimized by hybrid Differential Evolution (hDE), Bacterial Foraging

Algorithm (BFO) based PID for a single area of an electric power system. An obtained good result by shown the proposed. Duman et al., 2012 [24] proposed the determination of the PID controller used Gravitational Search Algorithm (GSA) for two areas thermal non-reheated power plant, by used MATLAB-Simulink. GSA is applied to the PID controller to reduce various performance. M. Farahani., 2012 [22] studies tune PID controller adjustment using a chaotic optimization algorithm. He presented optimized the PID by the Lozi map-based Chaotic Algorithm (LCOA) to solve the LFC problem. The PID tuned by the LCOA used. The simulation results are used to demonstrate the effectiveness and performance of the proposed controller lead to the disturbance of frequency to reduce peak overshoot and oscillation. Sahu et al., 2016 [25] proposed Hybrid LUS-TLBO optimization to tune the PID controller for a three area LFC.

## 2.8 SUMMARY

The enormous power system is one of the reasons the Load Frequency Control and to make reliability and stability to system. So many optimizations have been applied to damping the frequency deviation.

This chapter has provided the proposed method for the PID or PI, which have shown undesirable results despite the diverse ways of optimization. Nerveless, these advanced approaches are complicated and not efficient to control the frequency and rather less effective for the output responses.

# 3. METHODOLOGY

## 3.1 INTRODUCTION

This chapter is included the methodology of the thesis obtained through the tested system. In the first section, the model of interconnected power system areas are presented and reviewed. The second section is to explain the EHO methodology as a tuning method for the PID controller.

## 3.2 SYSTEM MODEL

### 3.2.1 The Tested System

The tested model of this thesis is a four-area thermal power system with different parameters, and the connection of the four electric power system is shown in Figure 3.1.

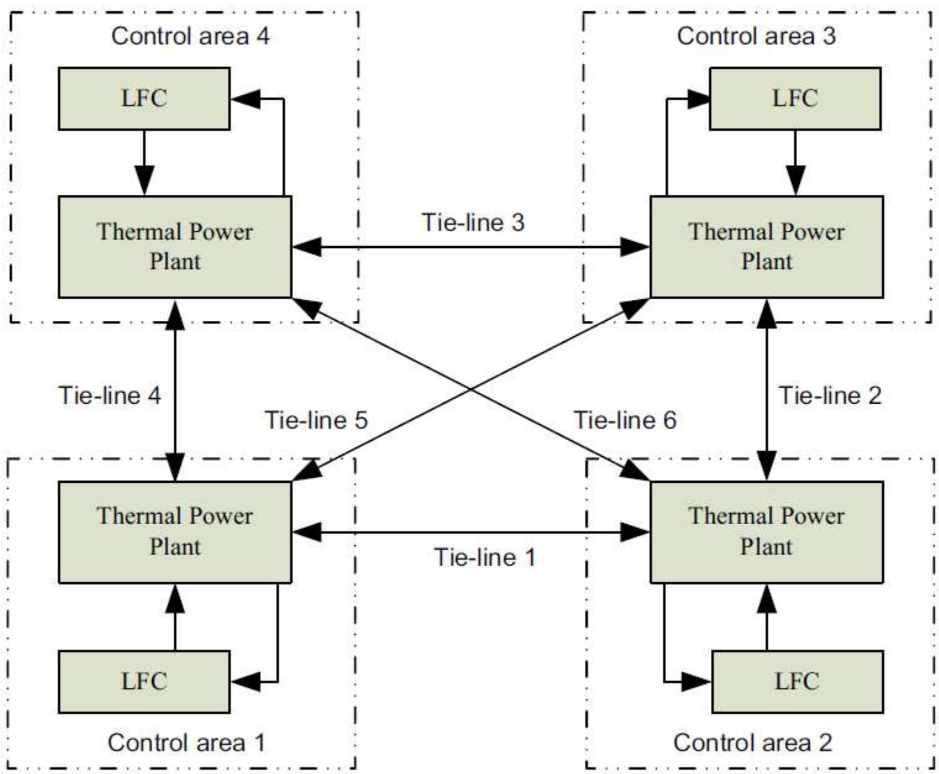


**Figure 3.1 :** Four Area Network

### 3.2.2 Governor Turbine Model

The governor function is to adjust the turbine input valve or gate. Therefore, to improve the mechanical power output to a new steady-state stable of speed since every change in the load leads to a change in the speed of generator, which senses by a speed governor [23].

Moreover, the prime mover is driving the generator in the power station by the steam, hydraulic, gas turbine, or wind turbine. In a thermal power station, the prime mover model must take account of steam supply and control system characteristics. IEE working groups were suggested the block diagrams for all types of governor and turbine systems. The diagram of the Governor Turbine Model is shown in Figure 3.2. Also, the transfer function of thermal generator governor, and turbine ($G_{tg}$) of the area *i* represent in Eq3.1.[23]

$$G_{tg} = \frac{1}{(1+sT_{Gi})(1+sT_{Ti})} \tag{3.1}$$

where, $T_G$ speed governor time, $T_T$ turbine time constant.

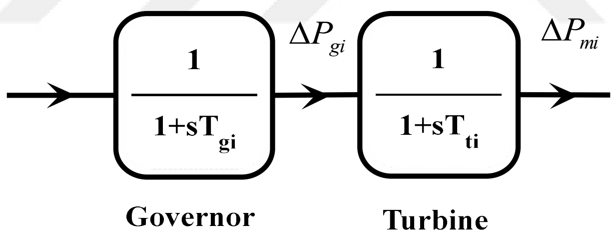


**Figure 3.2 :** Governor Turbine Model.

### 3.2.3 Tie Line Model

Area tie line is a transmission line which connects two or more area power system. The total power exported from each area is equal to the summation of all-out following line powers $\Delta P_{tie\ ij}$ to adjoining area *i*.

$$\Delta P_{tie\ i} = \sum_{j=0} \Delta P_{tie\ ij} \tag{3.2}$$

In normal operation, the power in per unit transmitted across a lossless line of reactance $X_{ij}$ is

$$P_{tieij} = \frac{|Vi||Vj|}{X_{ij}P_{ri}} sin(\delta i - \delta j) \tag{3.3}$$

where, δ is load angle.

Considering the relationship between area power angle and frequency can be written as Eq 3.4

$$P_{tieij} = 2\pi T_{ij} \int \Delta f_i dt - \int \Delta f_j dt \tag{3.4}$$

The total tie-line power change between areas $i$ and the other two areas calculated as

$$P_{tiei} = \frac{2\pi}{s} \sum_j T_{ij} \, \Delta f_i - \sum_j T_{ij} \, \Delta f_j \tag{3.5}$$

The representing of Eq 3.5 in terms of block diagram symbols yields the diagram shown in Figure 3.3.

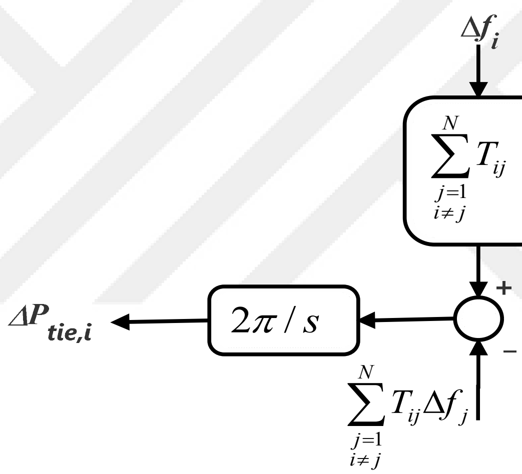


**Figure 3.3 :** Model of Tie-Line Power System Area.

### 3.2.4 Control Area Modeling

The kinetic energy is proportional to the square of speed. Therefore, area kinetic energy and the changing can be expressed as:

$$W_{kin,i} = W^{*}_{kin,i} \left(\frac{f}{f^{*}}\right)^2 \tag{3.6}$$

Therefore;

$$\frac{d}{dt} W_{kin,i} = \frac{d}{dt} W^{*}_{kin,i} \left(\frac{f}{f^{*}}\right)^2 \tag{3.7}$$

$$= \frac{d}{dt}\left(W_{kin,i}^{*}\left(\frac{f^{*}+\Delta f}{f^{*}}\right)^{2}\right) \; W_{kin,i}^{*} \tag{3.8}$$

$$= 2\, W_{kin,i}^{*}\, f^{*} \frac{d}{dt}(\Delta f) \tag{3.9}$$

Also, the change in load, due to frequency variation is:

$$D_i = \frac{dPL_i}{dt} = B_i - \frac{1}{Ri} \; Pu.MW/Hz \tag{3.10}$$

In the event of changes in area load by a disturbance ($\Delta P_{Di}$), the area changes its generation by $\Delta P_{Gi}$, and due to the action of the turbine controller. The net power ($\Delta P_i$) the surplus in the area following the disturbance is equal to ($\Delta P_{Gi} - \Delta P_{Di}$)and compensated by changing in ($W_{kini}$), and ($\Delta P_{tiei}$), Then $\Delta P$ for $i_{th}$ area is as follows;

$$\Delta P_i = 2\frac{W_{kin}}{f}\frac{\partial}{\partial t}(\Delta f) + D_i \Delta f_i + \Delta P_{tiei} \tag{3.11}$$

where, $D$ is a damping coefficient and equal to $\Delta P/\Delta f$. And by Laplace transformation:

$$[\Delta P_{Gi}(s) - \Delta P_{Di}(s) - \Delta P_{tiei}(s)]\frac{K_{Pi}}{1+sT_{Pi}} = \Delta F_i(s) \tag{3.12}$$

$$T_{Pi} = \frac{2H_i}{fD_i} sec \tag{3.13}$$

where, $f$ is the frequency, $H$ is inertia constant.

Then the parameters of one area power system LFC can represent in the block diagram as follows:

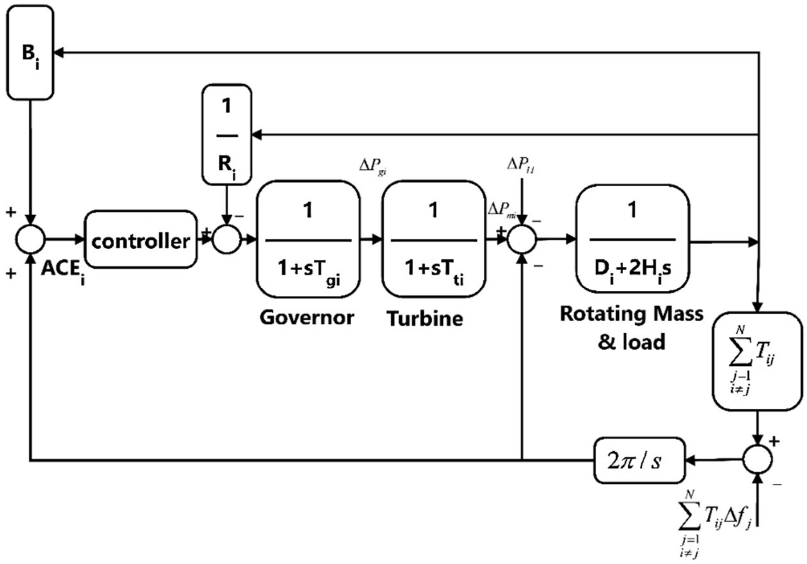


**Figure 3.4 :** Block diagram for a single area of system with ith connection.

The parameters of the four areas can show in Table 3.1

**Table 3.1:** The Area 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, $T_t$ the turbine time constant, $T_G$ the speed Governor time constant, R the speed drop, B the bias factor, D the change in load, H the inertia constant.

### 3.3 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[5]. The elephants can be 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 [12]. So, the elephant clans together named as a group, and all these groups are leaded by a matriarch as shown in Figure 3.5. Each clan among three to two dozen [5]. The females live with their family, while some males tend to live lonely until they leave their family group when they are getting older [13]. The male elephant can still in contact with his family group by low-frequency vibrations [6]. 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.

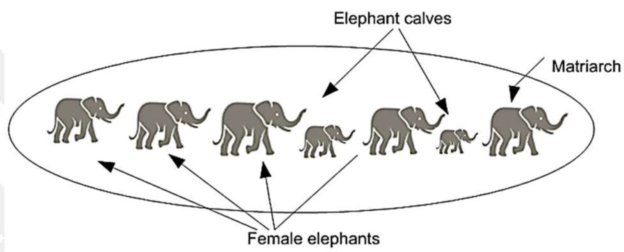


**Figure 3.5 :** Generation of Clan [5]

### 3.3.1 Assumption of Optimization

1- 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.

2- The total population of elephants can be classified in clans that have a fixed number of elephants.

3- The matriarch is the leader of all elephants that live in a clan

### 3.3.2 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 [5]:

$$x_{new,ci,j} = x_{ci,j} + \alpha \times \left(x_{best,ci} - x_{ci,j}\right) \times r \tag{3.14}$$

$x_{new,ci,j}$ and $x_{ci,j}$ constantly update as new values, and old position for elephant j in clan $ci$ , $\alpha$ scale factor of a matriarch on clan such that $\alpha \in [0,1]$, r is the random number in range r ∈ [0,1], The better elephant in clan updated by:[12]

$$x_{ci,j} = x_{best,ci,j} \tag{3.15}$$

where, $x_{best,ci}$ is the best position of the matriarch, $ci$ is the movement.

The best position of the matriarch is updated by Eq 3.16.

$$x_{best,ci} = \beta \times x_{center,ci} \tag{3.16}$$

where, $\beta$ is a factor such that $\beta \in [0,1]$, d is the dimension of the problem.

according to above, the clan operation can be represented by:

$$x_{center,ci,d} = \frac{1}{n_{c_i}} \times \sum_{j=1}^{n_{c_i}} x_{ci,j,d} \tag{3.17}$$

### 3.3.3 Clan Separating Operator

As we mentioned before, the elephant male leaves his family and stay alone.

$$x_{worst,ci} = x_{min} + (x_{max} - x_{min} + 1) \times r \tag{3.18}$$

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 ∈ [0.1] the stochastic distribution between [0,1]

## 3.4 OBJECTIVE FUNCTION

The LFC performance can adequately specify in terms of settling time, peak undershoots and steady-state error [12]. 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 3.19.

$$IAE = \int_0^t ACEi\, dt \tag{3.19}$$

## 3.5 EHO VALIDATION

A comparison of three values of the PID parameters has done using a single area power system. The parameters of PID controller values, which were determined by some researchers of the EHO method is shown in Table 3.2.

**Table 3.2 :** Values of PID parameters of researchers

| Technique | Kp | Ki | Kd |
|---|---|---|---|
| Proposed | 0.9606 | 1.2329 | 0.0094 |
| Shariq, 2015 | 0.732 | 0.987 | 0.136 |
| Tan, 2010 | 0.4036 | 0.6356 | 0.1832 |

Three values of disturbance are suggested to study the proposed method. The disturbance values are simulated via MATLAB. So, according to Figure 3.6, we can clearly see the peak undershoot and settling time for the proposed method is much better than the previous researchers.

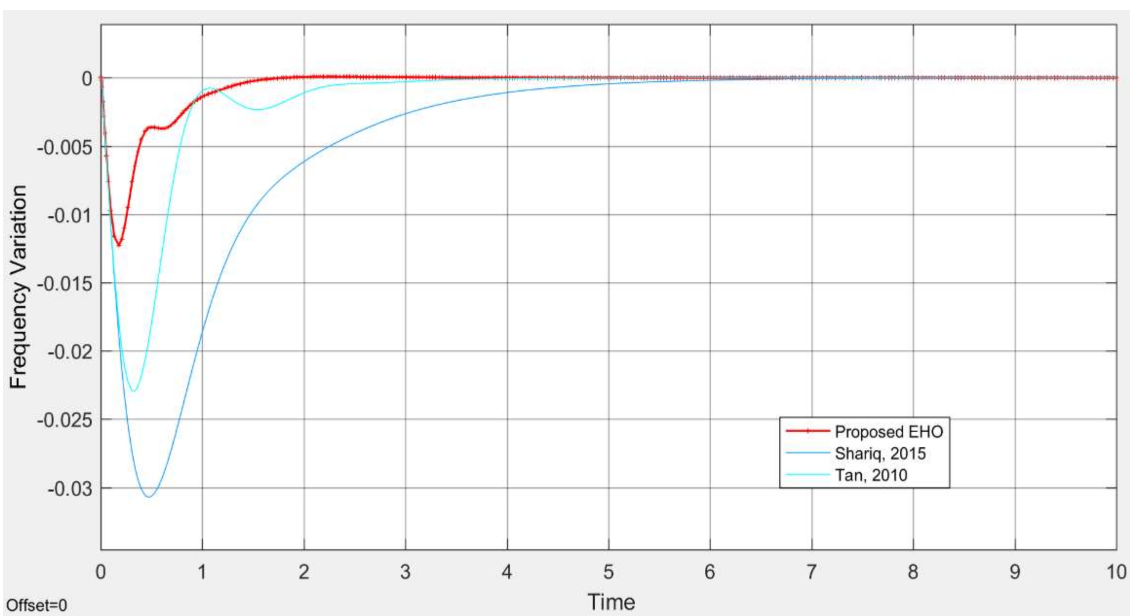


**Figure 3.6 :** Frequency variation compare with others

### 3.6 TUNE OF PID

The tuning of PID controller parameters 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 three PID parameters ($K_P$, $K_I$, $K_D$) and recalculating the suggested values of those parameters according to the EHO algorithm. The tuning of PID parameters using the EHO method shown in Figure 3.7.

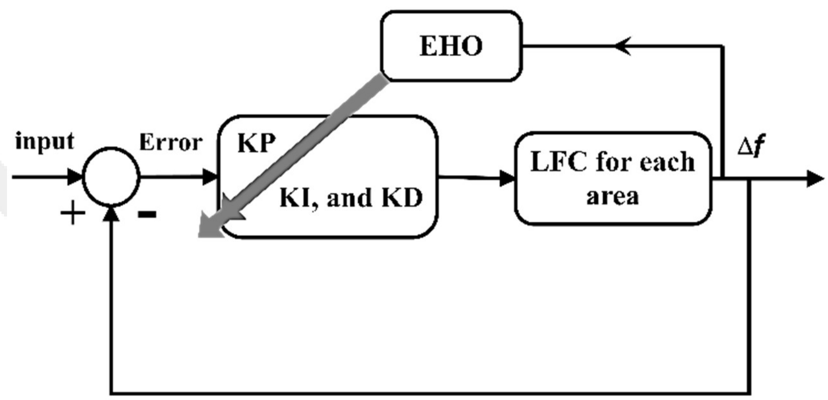


**Figure 3.7 :** Tuning of PID by EHO.

Also, the EHO algorithm can see in Figure 3.8

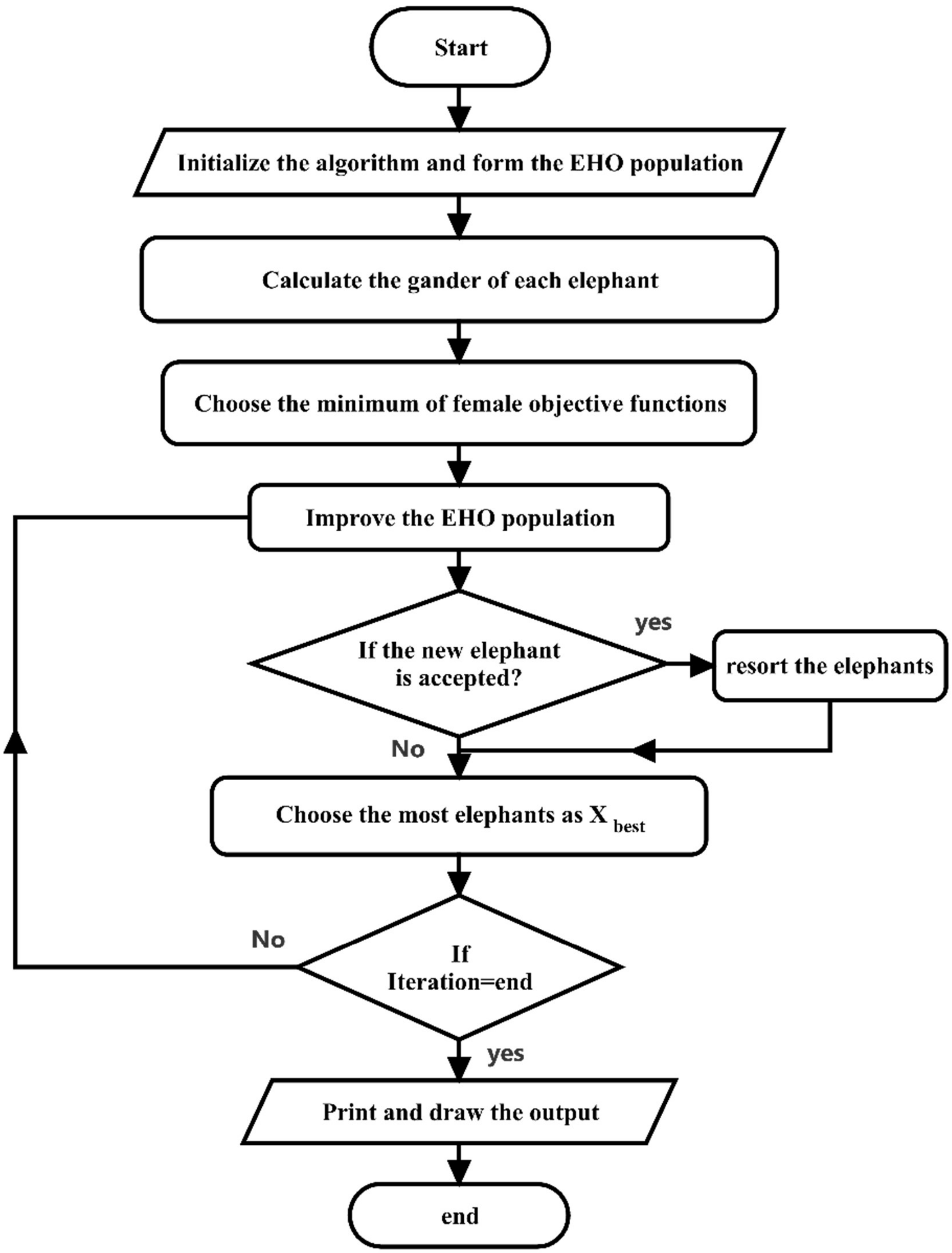


**Figure 3.8 :** EHO algorithm**.**

### 3.7 SUMMARY

The stochastic behavior of EHO and PSO algorithms may reduce the accuracy of optimizing the search for any problem, especially the power system, which high complexity and large size system. So, to increase efficiency should increase the number of iterations.

In this chapter, the proposed EHO gives an orientation to find the optimum global point by finding the desirable PID parameter values.

On the other hand, a single and multi-areas model of a power system has studied and derived each area consists of three first order; transfer functions, modeling the turbine, governor and power system.

# 4. SIMULATION RESULTS

## 4.1 INTRODUCTION

In this part of the thesis, we are going to show the result of PID parameters that we got from the EHO behavior of Load Frequency Control and compared with PSO for four different areas of the thermal power system. The simulation result via MATLAB.

## 4.2 DETERMINATION OF PID PARAMETERS

Elephant Herding Optimization (EHO) and Particle Swarm Optimization (PSO) are used to tune the PID parameters 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 tuning methods. Ten samples run for each of EHO and PSO have been processed, and the resulted mean values of $K_P$, $K_I$, $K_D$ is determined, and the resultant values of the parameters are shown in Table 4.1.

**Table 4.1 :** The 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 | 0.075 | 0.0785 | 0.0342 | 0.499 | 0.698 | 0.803 |

The deviation response for four areas in 30 seconds shown in Figure 4.1.

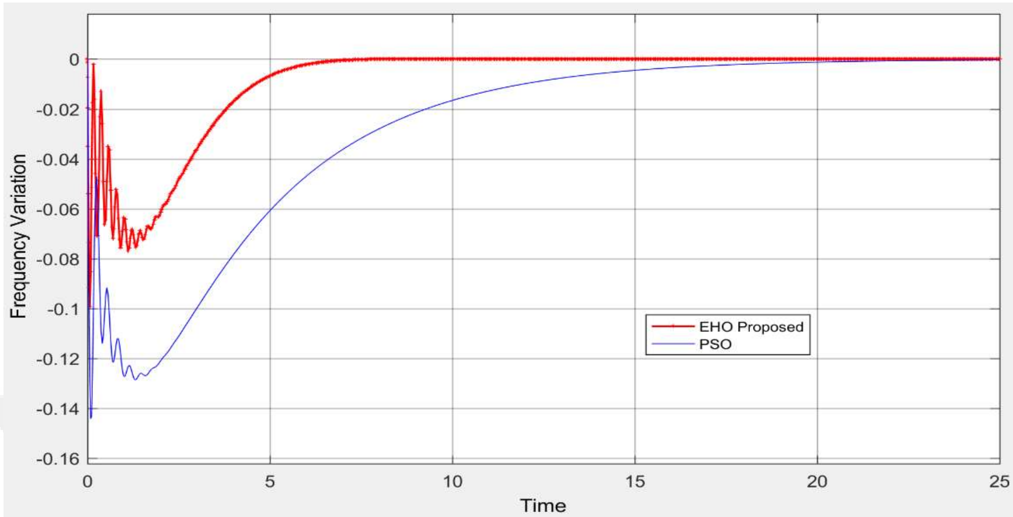


**Figure 4.1 :** LFC response for a single disturbance.

## 4.3 SYSTEM VALIDATION

To validate the system, we suggest double disturbance with multi values and moments taken after the main disturbance. Figures 4.2 - 4.21 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.

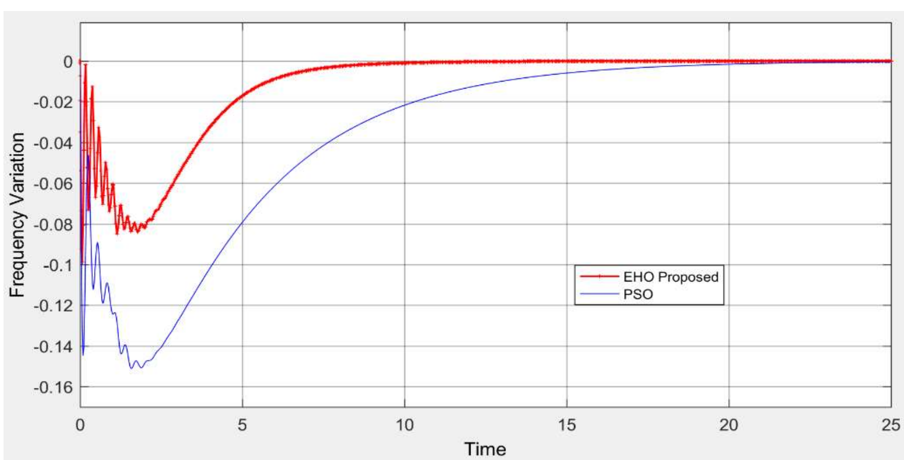


**Figure 4.2 :** LFC response for double disturbance 0.1 p.u, and 1 sec.

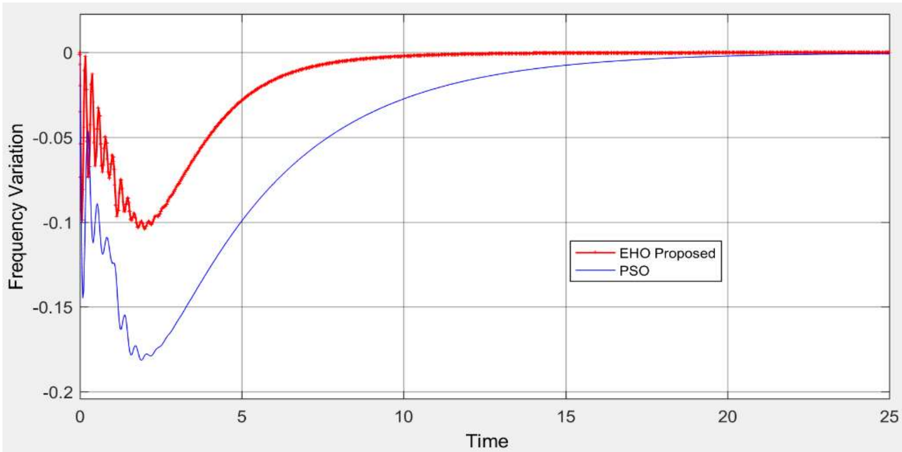


**Figure 4.3 :** LFC response for double disturbance 0.2 p.u, and 1 sec

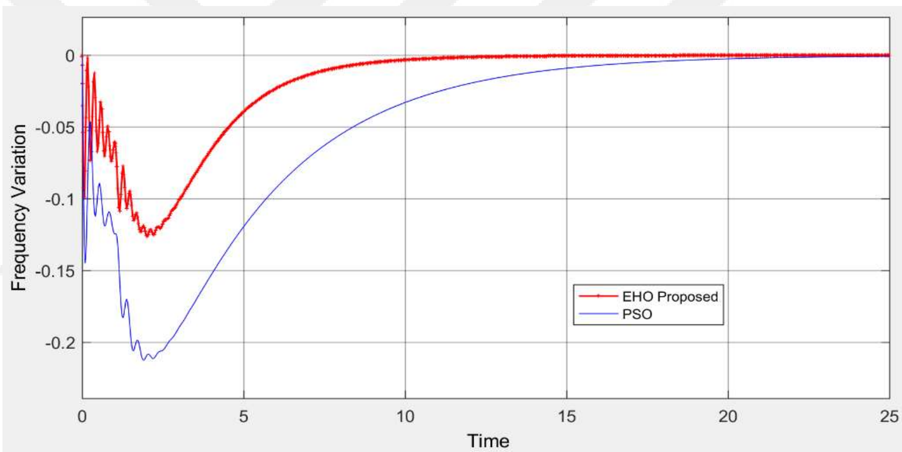


**Figure 4.4 :** LFC response for double disturbance 0.3 p.u, and 1 sec

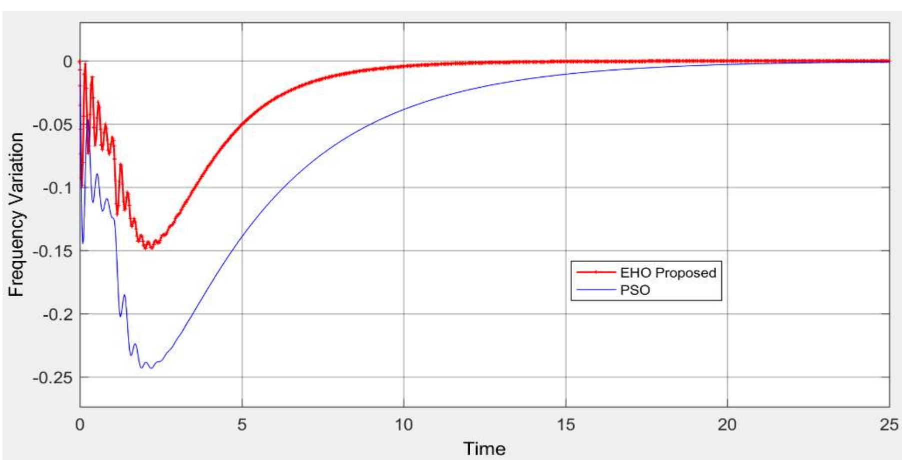


**Figure 4.5 :** LFC response for double disturbance 0.4 p.u, and 1 sec

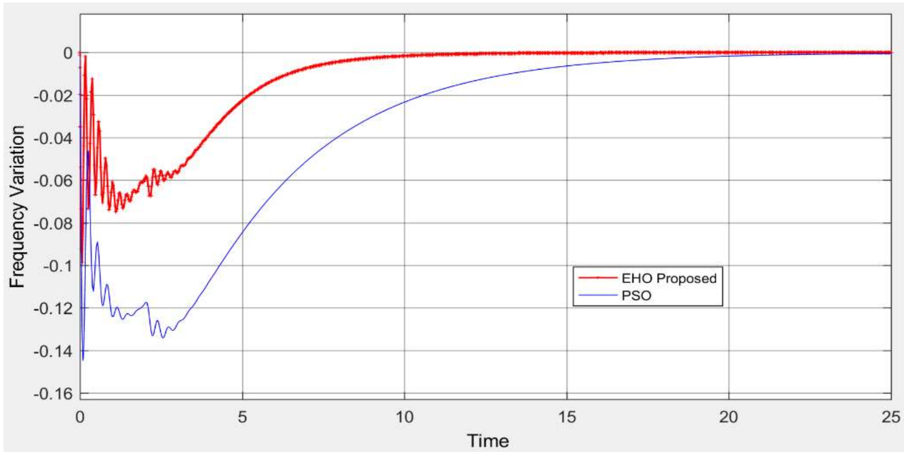


**Figure 4.6 :** LFC response for double disturbance 0.1 p.u, and 2 sec

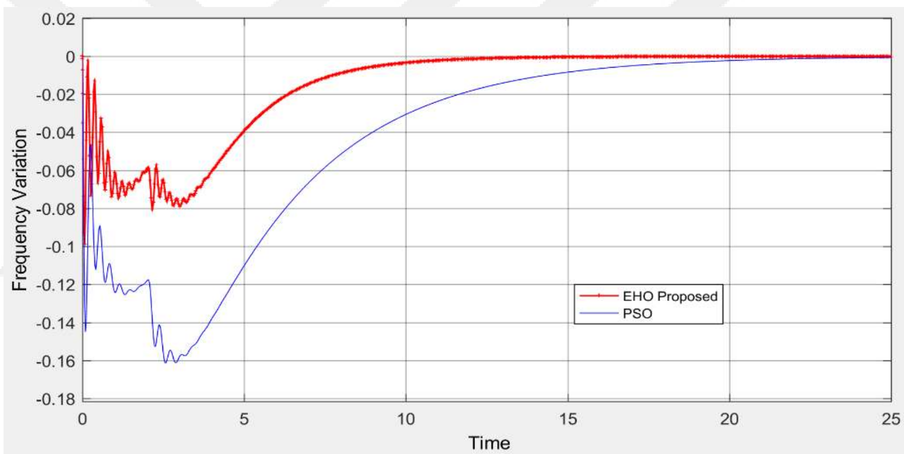


**Figure 4.7 :** LFC response for double disturbance 0.2 p.u, and 2 sec

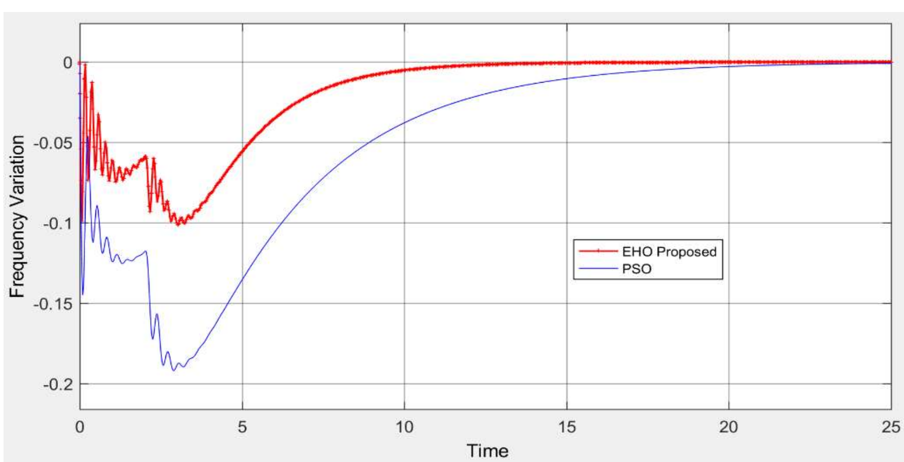


**Figure 4.8 :** LFC response for double disturbance 0.3 p.u, and 2 sec

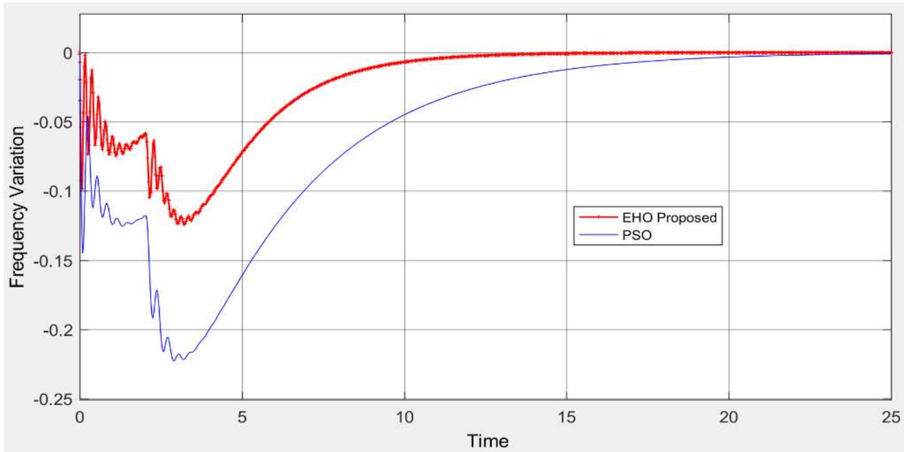


**Figure 4.9 :** LFC response for double disturbance 0.4 p.u, and 2 sec

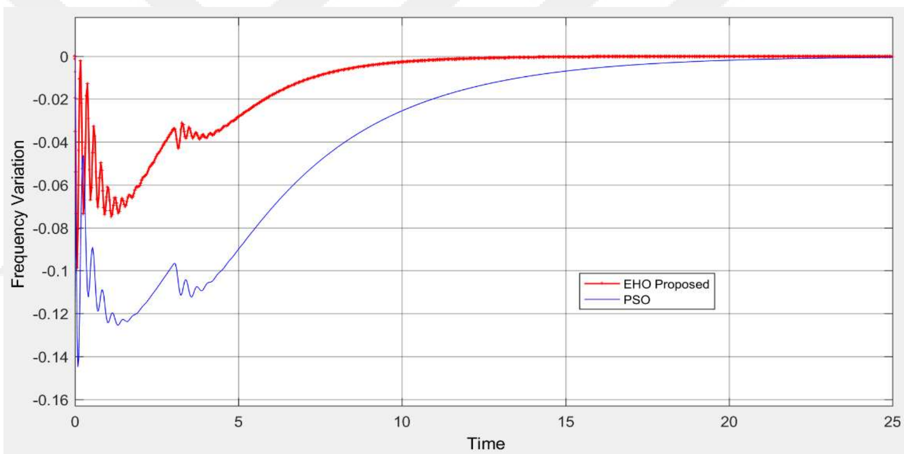


**Figure 4.10 :** LFC response for double disturbance 0.1 p.u, and 3 sec

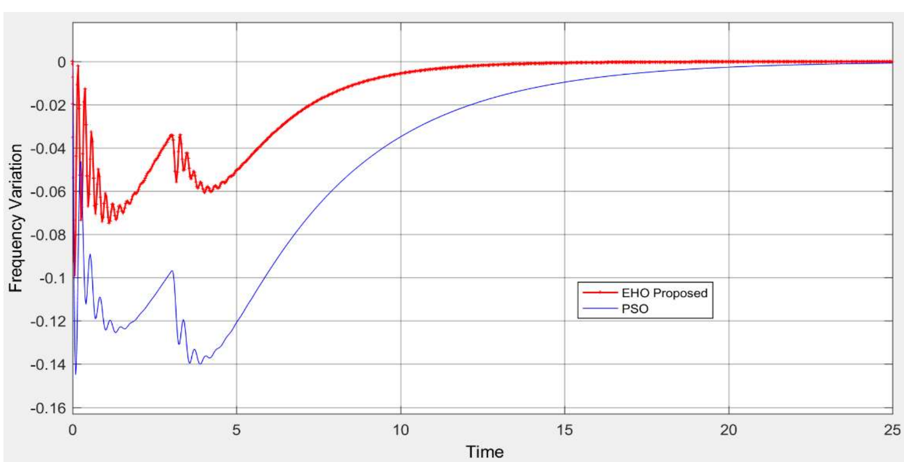


**Figure 4.11 :** LFC response for double disturbance 0.2 p.u, and 3 sec

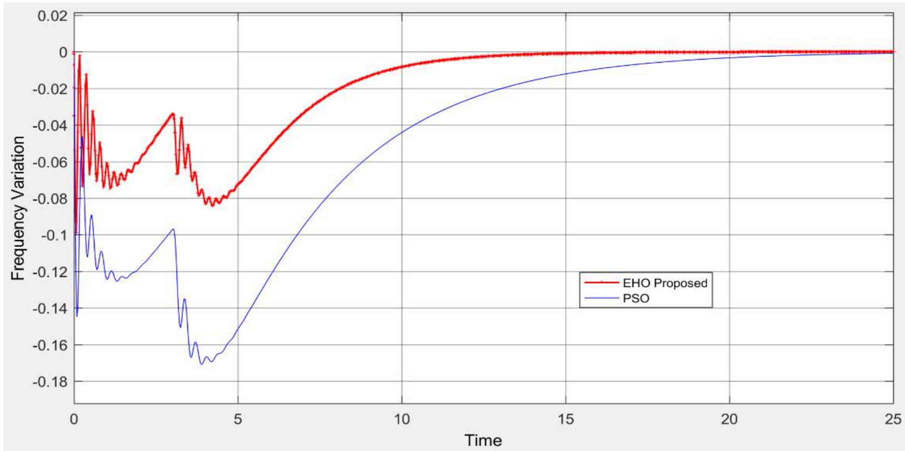


**Figure 4.12 :** LFC response for double disturbance 0.3 p.u, and 3 sec

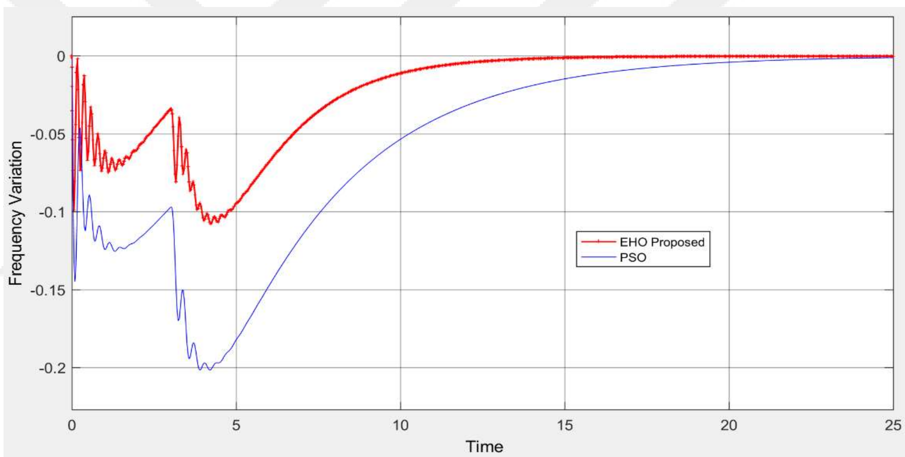


**Figure 4.13 :** LFC response for double disturbance 0.4 p.u, and 3 sec

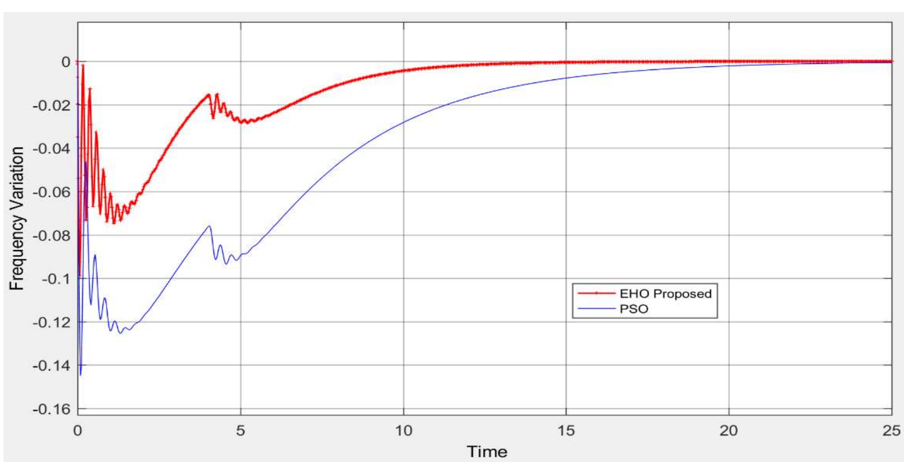


**Figure 4.14 :** LFC response for double disturbance 0.1 p.u, and 4 sec

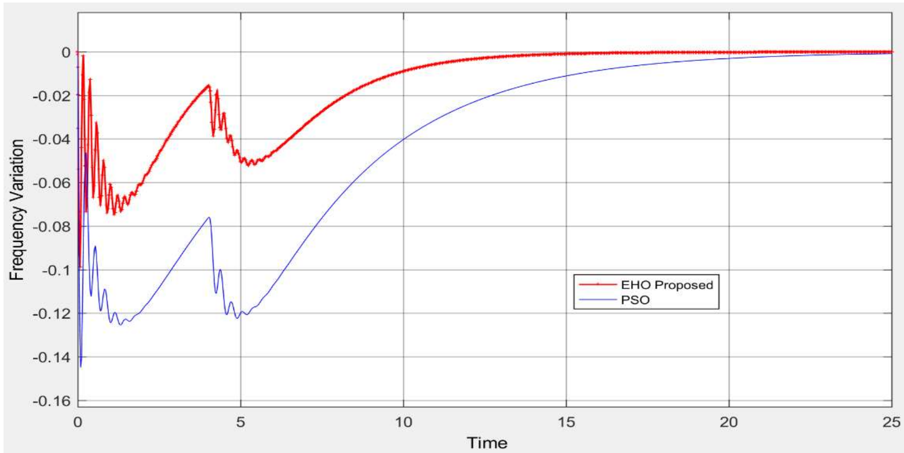


**Figure 4.15 :** LFC response for double disturbance 0.2 p.u, and 4 sec

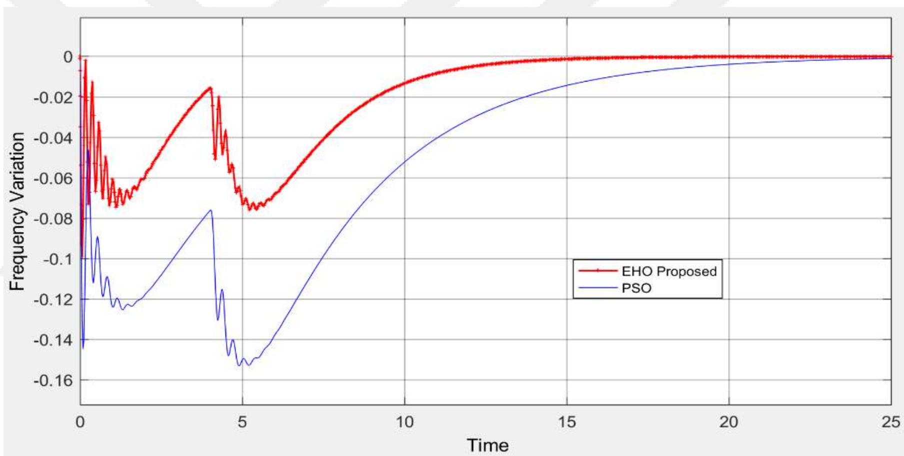


**Figure 4.16 :** LFC response for double disturbance 0.3 p.u, and 4 sec

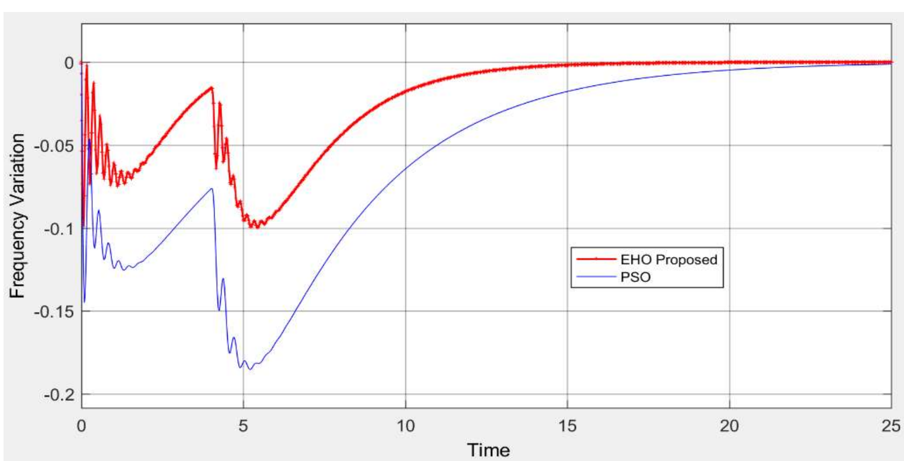


**Figure 4.17 :** LFC response for double disturbance 0.4 p.u, and 4 sec

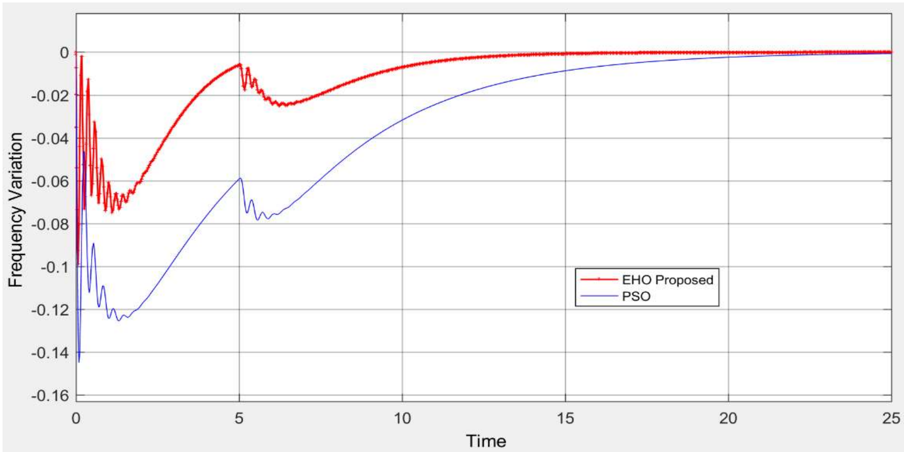


**Figure 4.18 :** LFC response for double disturbance 0.1 p.u, and 5 sec

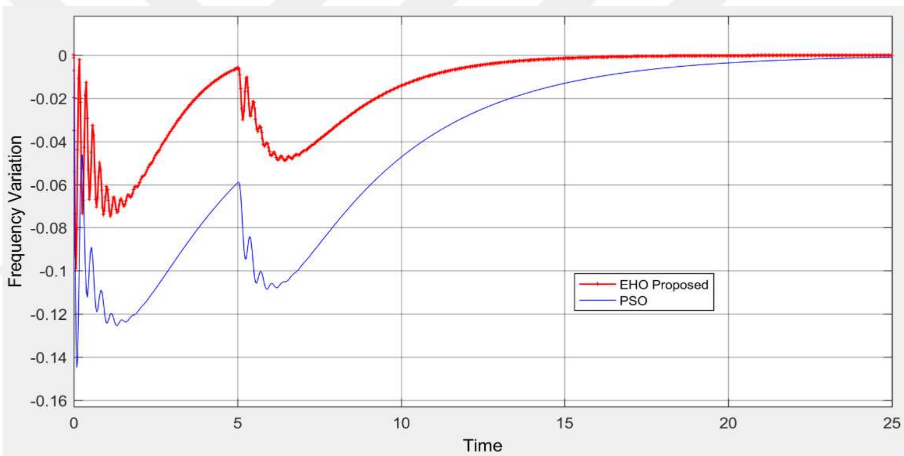


**Figure 4.19 :** LFC response for double disturbance 0.2 p.u, and 5 sec

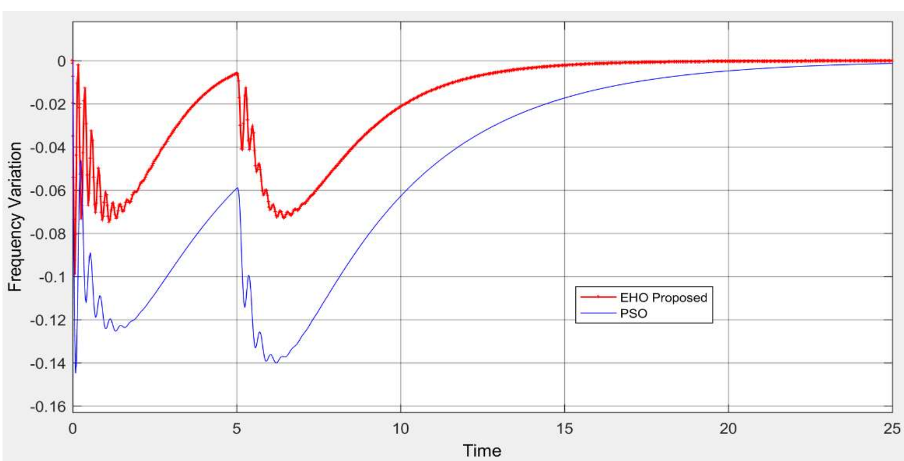


**Figure 4.20 :** LFC response for double disturbance 0.3 p.u, and 5 sec

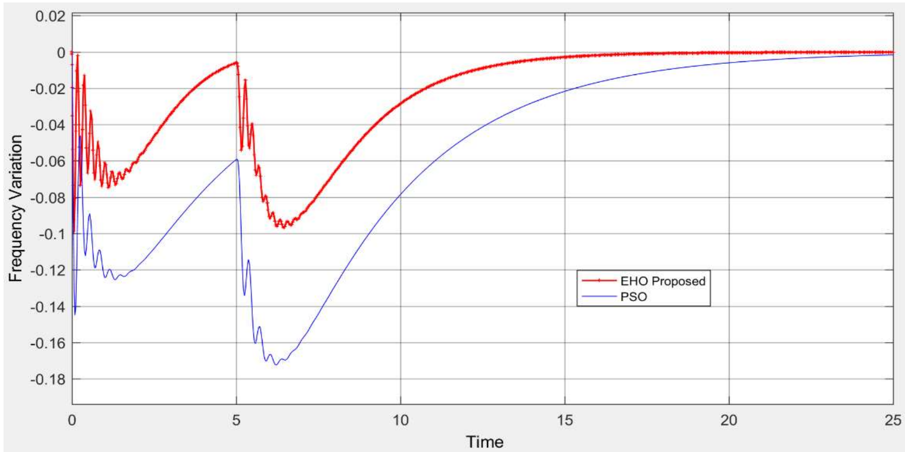


**Figure 4.21 :** LFC response for double disturbance 0.4 p.u, and 5 sec

**Table 4.2 :** Dynamic performance for LFC

| Dis(Area 2) | Dis_time | EHO | | PSO | |
|---|---|---|---|---|---|
| | | PU-Sh | Sett_time | PU-Sh | Sett_time |
| 0.01 | 0 | -0.0988 | 6 | -0.1449 | 20 |
| 0.1 | 1 | -0.0988 | 10 | -0.1511 | 20 |
| 0.2 | 1 | -0.1038 | 10 | -0.1815 | 20 |
| 0.3 | 1 | -0.1263 | 10 | -0.2124 | 20 |
| 0.4 | 1 | -0.1486 | 10 | -0.2434 | 20 |
| 0.1 | 2 | -0.0988 | 10 | -0.1449 | 21 |
| 0.2 | 2 | -0.0988 | 11 | -0.1614 | 21 |
| 0.3 | 2 | -0.1015 | 11 | -0.192 | 20 |
| 0.4 | 2 | -0.1241 | 11 | -0.2228 | 20 |
| 0.1 | 3 | -0.0988 | 11 | -0.1449 | 20 |
| 0.2 | 3 | -0.0988 | 13 | -0.1449 | 20 |
| 0.3 | 3 | -0.0988 | 13 | -0.1708 | 25 |
| 0.4 | 3 | -0.1079 | 13 | -0.2018 | 25 |
| 0.1 | 4 | -0.0988 | 13 | -0.1449 | 25 |
| 0.2 | 4 | -0.0988 | 15 | -0.1449 | 25 |
| 0.3 | 4 | -0.0988 | 15 | -0.1533 | 25 |
| 0.4 | 4 | -0.0997 | 15 | -0.1852 | 25 |
| 0.1 | 5 | -0.0988 | 15 | -0.1449 | 23 |
| 0.2 | 5 | -0.0988 | 16 | -0.1449 | 25 |
| 0.3 | 5 | -0.0988 | 16 | -0.1449 | 25 |
| 0.4 | 5 | -0.0988 | 16 | -0.1725 | 25 |

where, Dis(Area 2) the disturbance value of the second area, PU-Sh is peak undershoot, Sett_time is settling time, Dis_time the disturbance time of the second area.

From Table 4.2 and Figure 4.7, 4.15, 4.8 can notice the advance of the tuning of the controller using EHO, especially in case of short duration after the first disturbance.

# 5. CONCLUSION & FUTURE WORK

## 5.1 CONCLUSION

This thesis described Load Frequency Control (LFC) Which is one of the important issues in the high-power system. The goal of the LFC is to balance the frequency of outputs power at the generator end with the load since the load end requires zero variation on frequency. In order to achieve this, a PID controller is needed to be used as a load frequency controller of the interconnected four power systems. Furthermore, Elephant Herding Optimization has been suggested for tuning the parameter of the PID controller. 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 with the PSO approach.

## 5.2 FUTURE WORK

In the future, the following research on both EHO and the Load Frequency Control in the power system is expected to conduct.

1. Improve the EHO to define the parameters of the power system itself such as R, B, D, $T_g$, H, and $T_t$.
2. For the LFC problem, all the areas took a thermal plant. In the future, the controller may include many other plants which are existing in power systems.
3. Using the EHO to identify the fuzzy membership of control single and two areas of the power system.
4. Using EHO to control another power system problem, for example, voltage control.

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