

# Load Frequency Control of Multi-Area Hydro Thermal Power System Using Elephant Herding Optimization Technique

D. K. Sambariya\*, Rajendra Fagana

Department of Electrical Engineering, Rajasthan Technical University, Kota, India

\*Corresponding author: dsambariya\_2003@yahoo.com

**Abstract** This paper presents a novel approach to design a PID controller for load frequency control (LFC) of a hydro-thermal power plant. In the modern power system, the load frequency control of hydro-thermal power plants has widely used in frequency control due to having the fast responses. The PID controller parameters are designed using the elephant herding optimization (EHO) as an optimization technique under the minimization of error. The objective function is considered as minimization of the Integral Squared Error (ISE) for optimal design of PID parameters of the system. The prototype of hydro-thermal power plant with PID controller is simulated in MATLAB/SIMULINK platform. The dynamic responses of load frequency control using proposed controller is compared with the responses of LFC without controller and the other method of frequency control of hydro-thermal power plant in literature. The effectiveness of the proposed methodology is better in terms of settling time, rise time, peak and peak time.

**Keywords:** load frequency control, proportional integral derivative (PID) controller, Thermal power plant, hydro power plant, elephant herding optimization (EHO)

**Cite This Article:** D. K. Sambariya, and Rajendra Fagana, "Load Frequency Control of Multi-Area Hydro Thermal Power System Using Elephant Herding Optimization Technique." *Journal of Automation and Control*, vol. 5, no. 1 (2017): 25-36. doi: 10.12691/automation-5-1-5.

## 1. Introduction

A power system comprises of a generation, transmission and distribution of electrical energy. Large interconnected number of elements results to a complicated power system which is generally connected through tie lines. In recent decades, it is becoming a difficult task to power engineer for maintaining the increased power demand from the modern power system. The secure and reliable operation of a large interconnected multi-area power system requires the balancing between the generating power and load demand [1]. The unbalancing in generation and load demand is met by optimally designed controllers for the load frequency controlling loop in the power system.

The main motive of a power system is to supply electric energy with nominal terminal voltages and system frequency. It is desirous to efficient and stable operation of the power system by maintaining system frequency under required tolerances. This frequency deviation can be minimized by using optimally designed PID controller. The Load frequency control is one of the mechanisms that balance the active and reactive power demand, on the other hand, the controller mechanism is to control the change in system frequency.

The conventional method of PID controller such as Ziegler-Nichols [2] method, Tyreus-Luyben method, Cohen-Coon method, Fertik method and Integral Model Control method are used for controlling the load

frequency of power system. Fuzzy-PID, ANN [3,4] and NARMA L2 [5] are the intelligent techniques for maintaining the system frequency when load demand changes. The responses of intelligent controller give better result as compared to conventional method for controlling the system frequency.

During the last year researchers, all over the world are proposed many soft computing techniques for load frequency control of power system in order to maintain the system frequency and tie line flow at their nominal values. These computing techniques such as Bacterial Foraging Optimization Algorithm (BFOA) [6], Genetic Algorithm (GA) [6], Particle Swarm Optimization [7], Quasi-Oppositional Grey Wolf Optimization Algorithm (QOGWOA) [8], Teaching Learning Based Optimization Algorithm (TLBO) [9], Firefly Algorithm [10], Cuckoo Search algorithm [11]. These soft computing based tuned controllers give better results as compared to the conventional controllers. The controller not only maintains constant frequency but also achieves zero steady state errors.

The load frequency control for multi-source multi area hydro thermal system using fuzzy controllers and the responses are compared with the ZN tuned PI controller and GA PI controller in [12]. Kaewkaosai et al. [13] have designed a robust controller for load frequency control of hydro thermal power system using Genetic Algorithm. Shivaie et al. [14] have presented a load frequency control of hydro thermal power system using PID controller. The parameters of the PID controller are tuned by modified

Harmony Search Algorithm. Guha et al. [8] have developed a quasi-oppositional grey wolf optimization algorithm for solving the load frequency problem of an interconnected hydro thermal power system.

An intelligent controllers for controlling the load frequency of hydro thermal power system is presented in [2]. The LFC performances with ZN tuned PID controller is compared with fuzzy tuned PID and ANN controller. Prakash et. al. [15] have reported on the load frequency control of hydro thermal power system using Neuro-Fuzzy Computational Techniques controllers. Jagatheesan et. al. [16] have presented the dynamic performances of LFC of interconnected three area hydro thermal power system.

The load frequency control of four area interconnected power system using NARMA L2 controller and comparing their result with ZN-PID and PSO-PID is presented in [5]. Nath et. al. [4] have proposed an adaptive neuro fuzzy controller approach for load frequency control of three area power system. The optimal design of a PID controller for load frequency control using Harmony Search algorithm is reported in [17]. A load frequency control of three area Hydro-thermal power system using Hybrid Fuzzy Tilt-Integral Derivative is reported in [18].

This paper presents a study of load frequency control of two area hydro-thermal power plant. The tuning of PID controller gains plays an important role to achieve better performances. In this paper, Elephant Herding Optimization techniques have been applied to tune the gains of the controller to fulfill the design aspects.

This paper is prepared in five sections. The problem formulation with system description, PID controller and objective function are presented in section 2. The parameters of PID controller are tuned using elephant herding optimization is presented in section 3. The performances of system in terms of peak overshoot, settling time of frequency deviation of hydro and thermal power plant are

compared with the conventional ZN PID is described in section 4. The conclusion of this work is presented in section 5 and consists of nomenclature and references.

## 2. Problem Formulation

### 2.1. System Description

The basic diagram of hydro-power plant is shown in Figure 1. The controlled components of Hydro power plant can be divided into four parts: Penstock, Electric-hydraulic servo system, Turbine and Generator [17,19].

The block diagram of speed governing turbine system of thermal power plant is shown in Figure 2. The load frequency is controlled when the steam input of the Turbine is controlled. The steam input of the turbine is control when the steam valve is opened or closed.

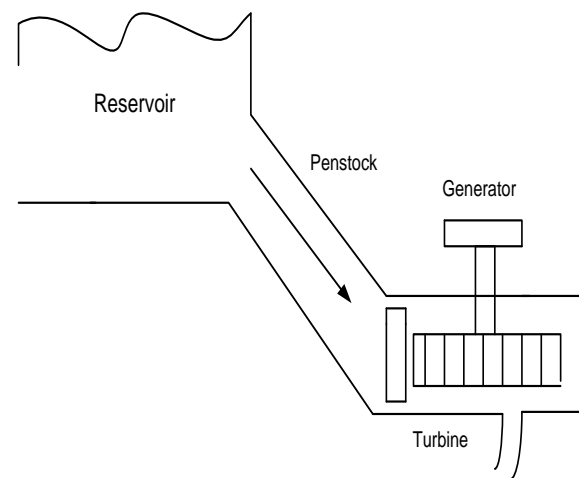


Figure 1. Schematic diagram of Hydro Power Plant

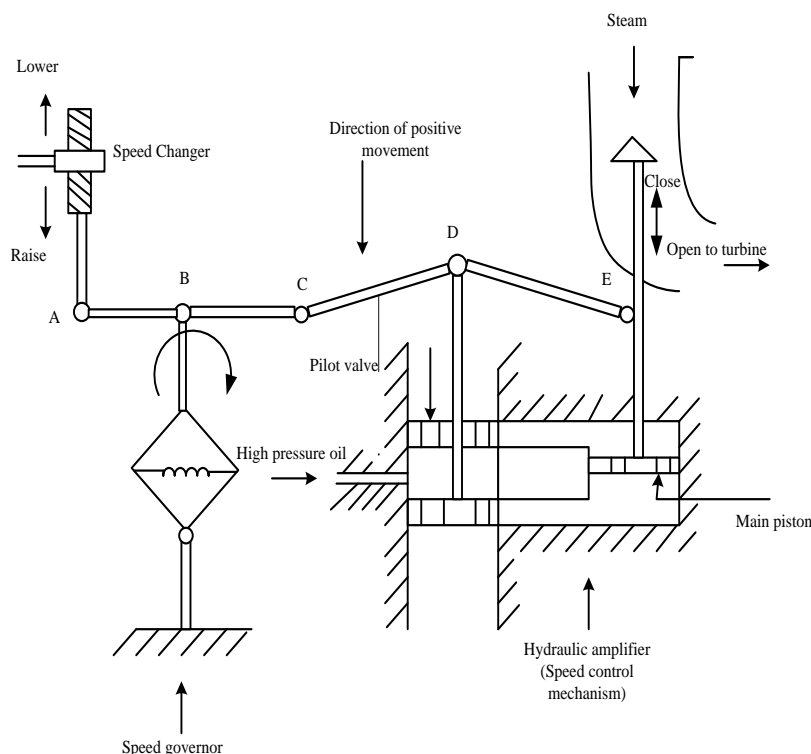


Figure 2. Schematic diagram of speed governing turbine system

In two area load frequency control, the two-different power plant interconnected to each other through tie-lines. One is hydro power plant and other is thermal power plant. The input and operation of both power plant is different [20,21]. In hydro power plant, the hydro turbine is rotating to the potential energy of the water flow. In thermal power plant, the electric power is generated to the steam expanded on the turbine. For these different powers plant the operation and controlling are different to each other. The transfer function of the hydro- thermal power plant as equated in Eq. 1-Eq. 8.

In two area LFC of hydro-thermal power plants can be interconnected through tie lines. The main objective is to control the frequency of each power plant and tie line power as per inter area contacts. The hydro-thermal power plant consists of components such as governor, reheat turbine, re-heater, hydro governor, hydro turbine and power system [21,22,23]. The model of the transfer function block of hydro-thermal power plant is as shown in Figure 3.

### 2.2.1. Speed Governor

The Eq. 1 describes the speed governor model of the load frequency control system. Time constant of speed governor is indicated by  $T_G$ . The parameter value which is used  $T_G=0.08$  seconds.

$$G_G(s) = \frac{1}{1 + sT_G}. \quad (1)$$

### 2.2.2. Steam Turbine

The Eq. 2 describes the transfer function of the turbine model. The time constant of the turbine is indicated by  $T_T$ . The parameter value which are used in the turbine  $T_T = 0.3$  seconds.

$$G_T(s) = \frac{1}{1 + sT_T}. \quad (2)$$

### 2.2.3. Re-heater

The function of the re-heater in the system is improved the efficiency of a power plant. The working of reheating turbines is steam is returned after partial expansion to the boiler for superheating and then allowable to expand the back pressure. The Eq. 3 presents the transfer function of the re-heater model. The  $K_R$  and  $T_R$  are the gain and time constant of a re-heater respectively. The used values of the parameters are  $K_R = 0.5$  and  $T_R = 10$  seconds.

$$G_R(s) = \frac{1 + sK_RT_R}{1 + sT_R}. \quad (3)$$

### 2.2.4. Hydraulic Amplifier and Turbines:

The Eq. 4 – Eq. 6 describes the transfer function of hydraulic amplifier and hydraulic turbine model. The  $T_1$  and  $T_2$  are the time constant of hydro governor of stage - I and hydro turbine of stage - II, respectively. The time constant of the hydro turbine is indicated by  $T_w$  and its value is 1.0 second. The parametric value of the  $T_1$  and  $T_2$  is 48.7 and 0.513 seconds, respectively.

$$G_{H1}(s) = \frac{1}{1 + sT_2} \quad (4)$$

$$G_{H2}(s) = \frac{1 + sT_R}{1 + sT_2} \quad (5)$$

$$G_{HT}(s) = \frac{1 - sT_w}{1 + 0.5sT_w}. \quad (6)$$

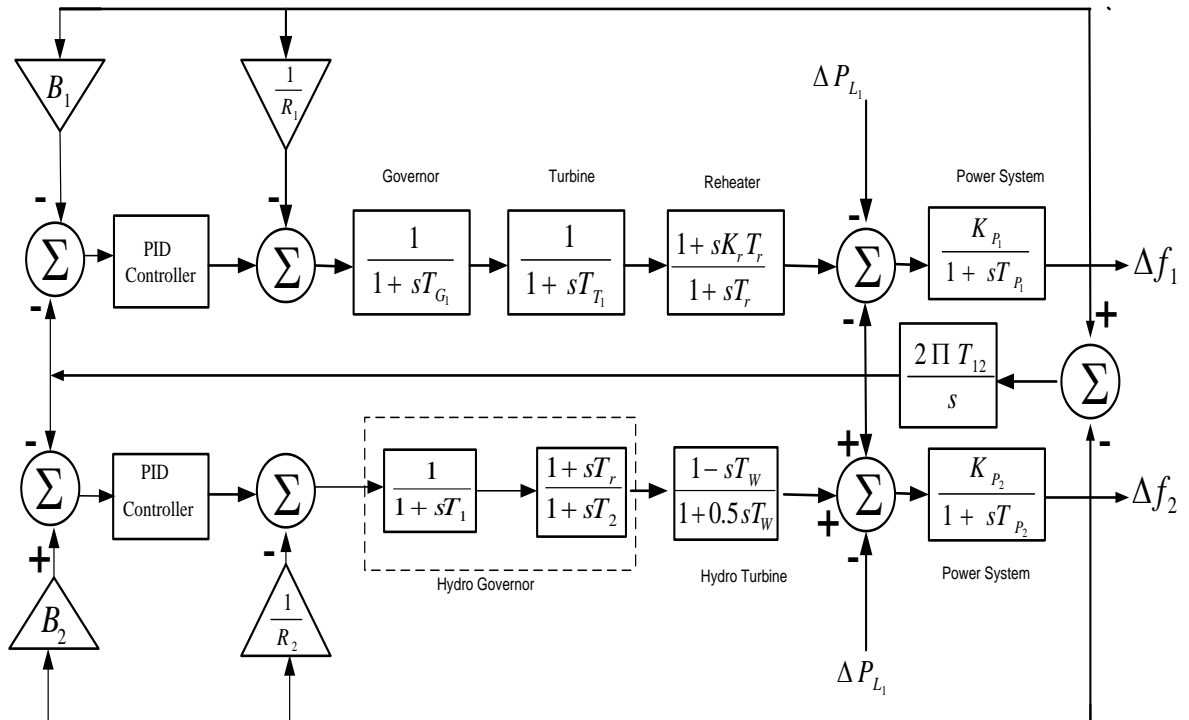


Figure 3. Block diagram of two area Hydro-Thermal Power System with PID controller

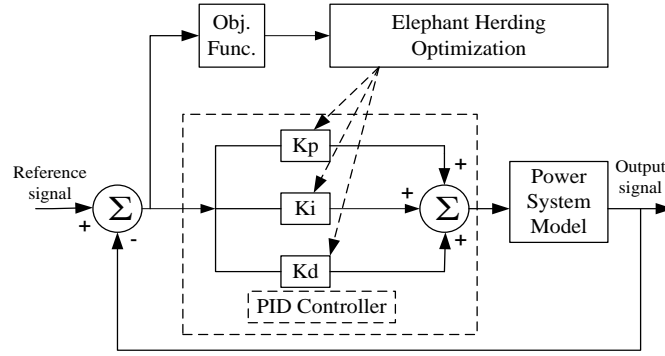


Figure 4. Block diagram of PID controller

### 2.2.5. Rotating Mass and Load Inertia of the Power System

The Eq. 7 describes the transfer function of a rotating load of the power system. Gain and time constant of the power system are indicated by  $K_P$  and  $T_P$  respectively. The used value of the parameters are  $K_P = 100$  and  $T_P = 20$  seconds.

$$G_P(s) = \frac{K_P}{1 + sT_P} \quad (7)$$

$$\text{Speed regulation constant } \frac{1}{R}. \quad (8)$$

In two area Hydro-thermal power plants  $T_{G_1}$  is the governor time constant,  $T_{T_1}$  is the turbine time constant,  $T_R$  is the re-heater time constant,  $K_R$  is the gain of re-heater,  $K_{P_1}$  and  $K_{P_2}$  are the gains of power system of thermal and hydro plant respectively.  $T_{P_1}$  and  $T_{P_2}$  are the power system time constant of power plant 1 and plant 2,  $R_1$  and  $R_2$  are the speed regulation of governor.  $B_1$  and  $B_2$  are the frequency bias factor,  $\Delta P_{L_1}$  and  $\Delta P_{L_2}$  are the power change in load demand of plant 1 and plant 2 respectively. The time constant of hydro turbine is represented by  $T_W$ . The output of the system is change in frequency  $\Delta f_1$  and  $\Delta f_2$  of plant 1 and plant 2 respectively.

### 2.2. PID Controller

The Proportional-Integral-Derivative (PID) controller structure is the most widely used in control applications. The PID controller has three parameters  $K_p$ ,  $K_I$  and  $K_D$ . These parameters are tuned by using optimization techniques. The PID controllers are used when the system stability and fast responses are needed. The PID controller transfer function as in Eq. 9. The block diagram of PID controller is shown in Figure 4.

$$PID = K_p + \frac{K_i}{s} + K_d s. \quad (9)$$

### 2.3. Objective Function

The methodology to determine the unknown parameters of PID controller ( $K_p, K_i, K_d$ ) is considered as an

optimization problem. The optimization problem is considered as minimization of the error signal as in Eq.10. The objective function defines the integral of squared error as shown in Eq 10. The parameters are subjected to lower and upper bounds with the proposed algorithm as shown in Eq. 11

$$J = \int_0^{t_{sim}} (|\Delta F_1|^2 + |\Delta F_2|^2 + |\Delta P_{tie}|^2). dt \quad (10)$$

$$K_p(\text{initial}) \leq K_p \leq K_p(\text{final})$$

$$K_i(\text{initial}) \leq K_i \leq K_i(\text{final}) \quad (11)$$

$$K_d(\text{initial}) \leq K_d \leq K_d(\text{final}).$$

## 3. On Elephanterding Optimization

Due to increasing complication, the real-world problem is very difficult. So, it cannot be solved by using traditional method. Some of the meta heuristics techniques cannot give exact answers. Recently researcher's studies on various kind of meta heuristics algorithm such as elephant herding optimization (EHO) and successfully applied to solved number of problem of real world.

### 3.1. Herding Behaviour of Elephant

Elephants are the largest animals come in category of mammals on the earth [24]. Elephants have social structures, more size and disciplined character. An elephant lives in compound group such as female elephant with her calves or certain related female elephants. This group is called as clan. A clan of the generation is as shown in Figure 6. An elephant group consists of several clans. A clan consists of a three up to maximum two dozen elephants. The leader of a clan is called matriarch. An elephant group headed by a matriarch is in concentric circles. Female elephant like to live in joint family but male elephant tends to live alone and they leave their family group when growing up. After leaving the male elephant mixes with few other adult male elephants in small group. Male elephant can live in contact with elephants in their clan through low frequency vibrations. The population of all elephants is as shown in Figure 5.



Figure 5. Population of elephants

The herding behaviour of elephant is divided as two operators. These operators such as clan updating and clan separating operators are used to solve the global optimization problem.

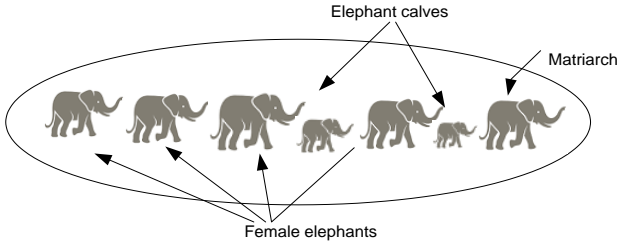


Figure 6. Clan of a generation

### 3.2. Assumption of Optimization

A global optimization problem solved by using the herding behaviour of elephant [25,26]. We use these rules for solving the problem [27]

- It is assumed that the total population of elephant is divided into groups such as clans. These clans have a definite number of elephant.
- It is also assumed that the worst performing male elephant will leave their family group. It live alone on a remarkable distance from the elephant group on occurrence of each generation.
- Matriarch is the leader of all elephants live in a clan.

### 3.3. Clan Updating Operator

Each clan is headed by matriarch.  $C_p$  is the total no. of clans of elephants and  $q$  is the total no. of elephants in each clan [25]. The current position of all elephants are updated as Eq.9

$$x_{new,C_p,q} = x_{C_p,q} + \alpha \times (x_{best,C_p} - x_{C_p,q}) \times r \quad (12)$$

Where  $x_{new,C_p,q}$  and  $x_{C_p,q}$  are new update and old position for elephant  $q$  in clan  $C_p$  respectively.  $\alpha$  is a scale factor that determines the influences of matriarch on clan such that  $\alpha = [0,1]$ . The  $x_{best,C_p}$  denotes the best position of matriarch  $C_p$ .  $r \in [0,1]$  is the random no. in the range. The best elephant in each clan cannot be updated by eq. (9)

$$x_{C_p,q} = x_{best,C_p,q} \quad (13)$$

The matriarch movement is updated by

$$x_{best,C_p} = \beta \times x_{center,C_p} \quad (14)$$

Where  $\beta$  is factor such that  $\beta = [0,1]$

$$x_{center,C_p,d} = \frac{1}{n_{C_p}} \times \sum_{q=1}^{n_{C_p}} x_{C_p,q,d} \quad (15)$$

Where  $\beta$  is factor such that  $\beta = [0,1]$  For the  $d^{th}$  – dimension it can be calculated as

$$x_{center,C_p,d} = \frac{1}{n_{C_p}} \times \sum_{q=1}^{n_{C_p}} x_{C_p,q,d} \quad (16)$$

Where  $1 \leq d \leq D$  indicates the  $d^{th}$  – dimension.  $D$  is the total dimension.

The clan updating operator can be calculated on the basis of herding behaviour of elephants.

### Pseudo-code of Elephant Herding Optimization Algorithm

1. Initialization
2. Set generation counter  $t=1$ , set maximum generation  $max.gen$ .
3. Initialize the population, global variables, dimension (6),  $max.gen. = 100$ , set  $elism$  as 2, objective function,  $\alpha=0.5$ ,  $\beta=0.1$ .
4. While  $t=1: max.gen$ .
5. Start and save  $elism$  strategy for cost and population
6. Division of elephant population into clans
7. Clan updating operator as in Eq. 13 and Eq. 15
8. Evaluate separating operator as in Eq. 17
9. Evaluate new clan
10. Save fitness function for each iteration
11. Save parameter for newly update position
12. Update iteration count by  $t=t+1$
13. end

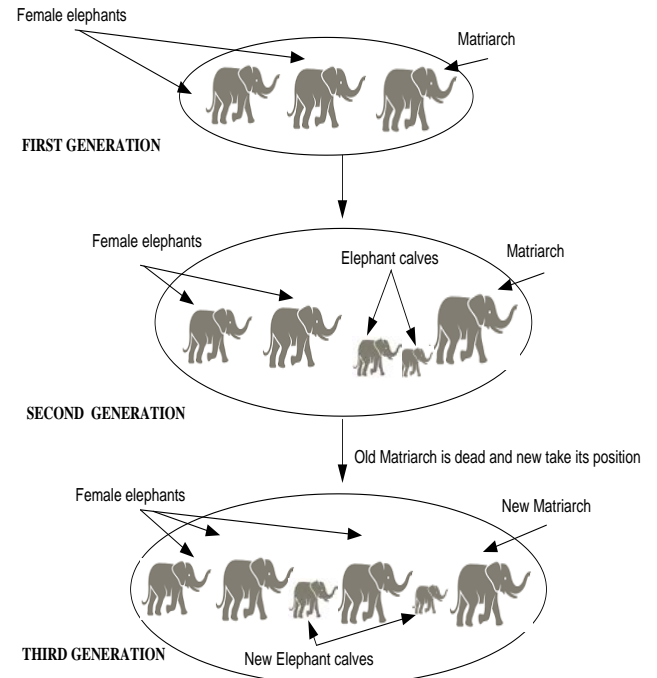


Figure 7. Clan Updating Operator

### 3.4. Clan Separating Operator

Male elephant leaves their family group when they growing up. Let we consider the elephant individual with the worst performing will implement the separating operator at each generation.

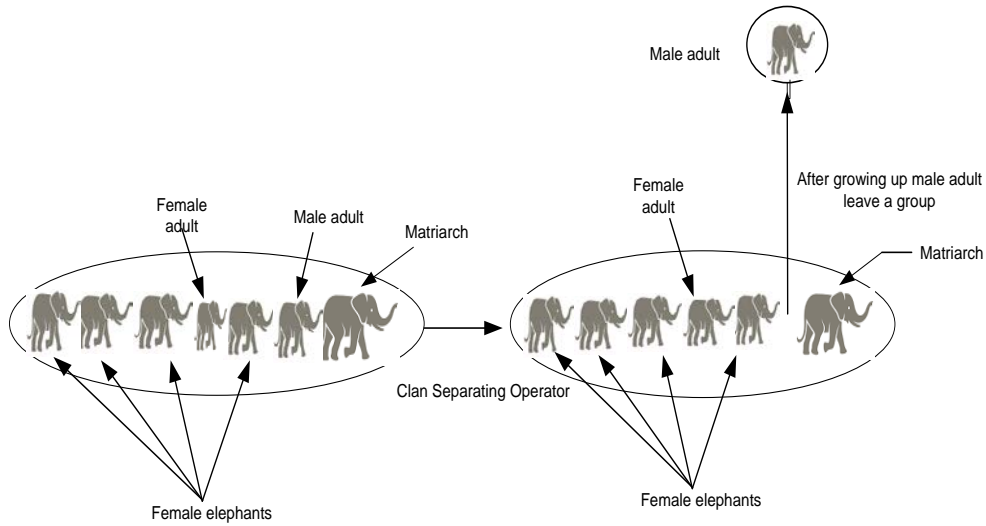


Figure 8. Clan Separating Operator

$$x_{worst,Cp} = x_{min} + (x_{max} - x_{min} + 1) \times rand \quad (17)$$

Where  $x_{max}$  and  $x_{min}$  represent the maximum and minimum position of elephant.  $rand$  is random number  $\in [0,1]$ .  $rand$  is a stochastic distribution.

### 3.5. Implementation of EHO Algorithm

The proposed PID controller parameters are determined by the use of Elephant Herding Optimization Algorithm. The optimization problem is considered for minimizing the ISE. The number of PID parameters employed is 6.

Using the proposed Elephant Herding Optimization techniques, we have easily found the minimize solution of ISE. First, we set the maximum number of iteration is 100 for termination of optimization. The current best solution can be collected during iteration. The best result comes in the 28 iterations. So, the EHO algorithm give best result for low no. of iterations. We can also see that proposed algorithm approaches the optimal solution exponentially is shown in Figure 9. The lower and upper bound to the PID parameters during optimization are set as shown in Eq.

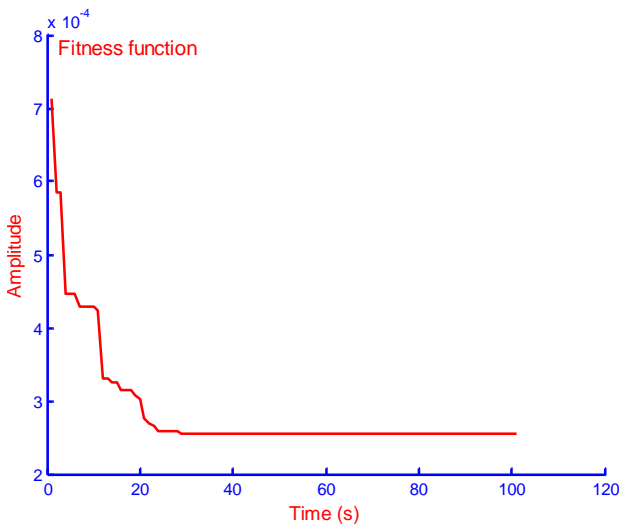


Figure 9. convergence characteristics of EHO-PID controller

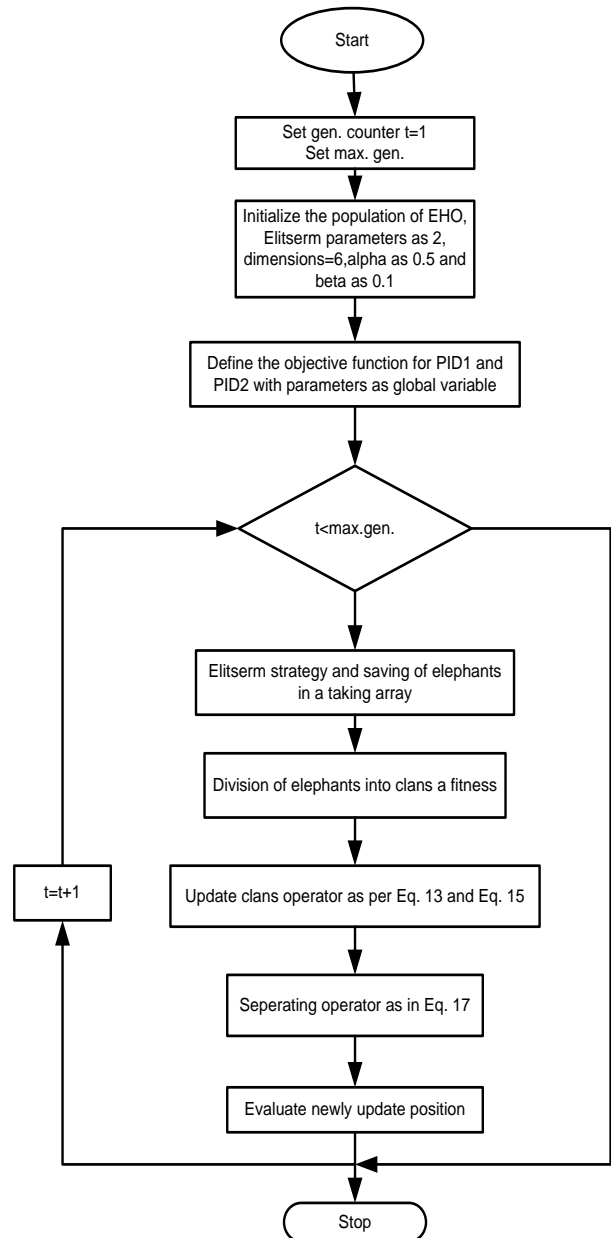


Figure 10. Flow chart of Elephant Herding Optimization Algorithm



## 4. Simulation and Discussion

In simulation study, we simulate the two-area hydro-thermal power plant with PID controller using Elephant Herding Optimization techniques. In this paper, the optimal tuning of the gains of PID controller using EHO is presented. We compared the performances of hydro-thermal power plant using EHO PID controller with ZN tuned PID controllers. In simulation result a 1% step load perturbation is applied on the change of load demand in thermal power plant. Compare the responses of frequency deviation of thermal power plant, frequency deviation of hydro power plant and power deviation in tie line.

The model of two area load frequency control with different power plant using PID controller tuning EHO techniques is developed in MATLAB/SIMULINK platform. The parameters of the transfer function block used in the model are tabulated in Table 1.

**Table 1. Parameter of Two Area Load Frequency Control of Different Power Plant**

Parameters	symbols	Value
Time constant of Governor	$T_{G1}$	0.08 Sec
Time constant of Turbine	$T_{T1}$	0.4 Sec.
Gain constant of Power system	$K_{P1}, K_{P2}$	120Hz/pu MW
Time constant of Power system	$T_{P1}, T_{P2}$	20 Sec.
Speed regulation	$R_1, R_2$	2.4 Hz/pu MW
Frequency Bias	$B_1, B_2$	0.425 PU MW/Hz
Synchronizing co-efficient	$T_{12}$	0.0707
Time constant of Hydro turbine	$T_W$	1 Sec.
Time constant of Re-heater	$T_r$	10 Sec.
Gain of Re-heater	$K_r$	0.33
Time constant of Hydro-Governor	$T_1$	48.7 Sec.
Time constant of Hydro-Governor	$T_2$	0.513 Sec.

### 4.1. Analysis of Results

A multi-area hydro-thermal power plant is considered for load frequency problem. A 1% step load perturbation is given to the change in load demand of thermal power plant.

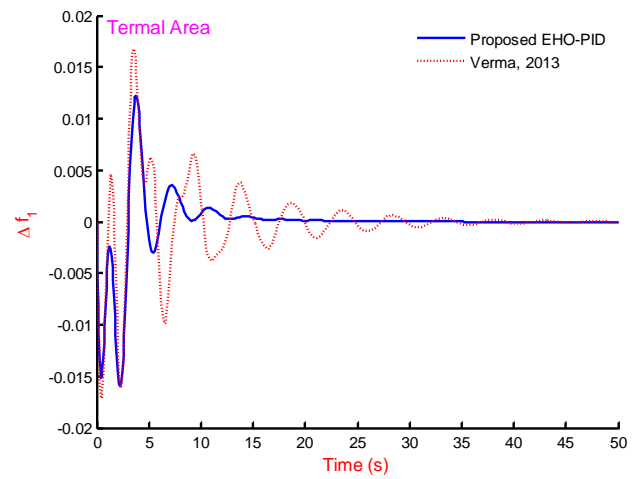
**Table 2. Optimum values of the gains of PID controller**

PARAMETERS	PROPOSED EHO-PID	R. VERMA ZN-PID [2]
$K_{P1}$	2.6984	2.700
$K_{I1}$	1.5508	3.121
$K_{D1}$	0.9910	0.5838
$K_{P2}$	0.4242	0.270
$K_{I2}$	0.0935	0.3121
$K_{D2}$	0.4053	0.05838

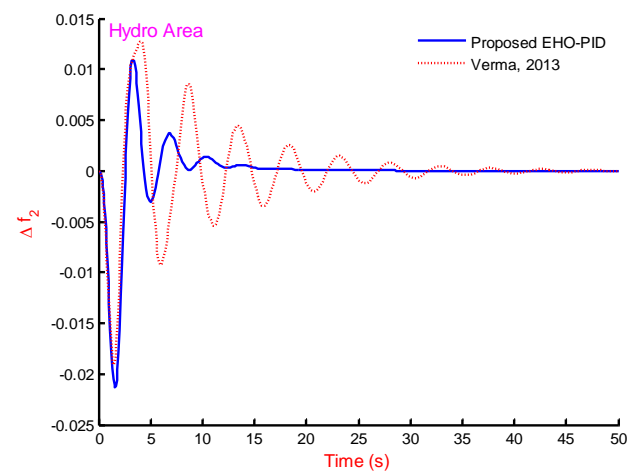
**Table 3. Comparative Performance of Settling Time, Overshoot, Undershoot**

Author	technique	Areas	Settling time Sec.	Undershoot
Proposed	EHO-PID	$\Delta F_1$	22.564	-0.016
		$\Delta F_2$	18.983	-0.021
		$\Delta P_{tie}$	22.989	$-3.325 \times 10^{-3}$
R. Verma	ZN-PID	$\Delta F_1$	46.538	-0.017
		$\Delta F_2$	46.299	-0.019
		$\Delta P_{tie}$	42.540	$-3.601 \times 10^{-3}$

The proposed parameters of the PID controller of thermal power plant as  $K_{P1}$ ,  $K_{I1}$ ,  $K_{D1}$  are 2.6984, 1.5508, 0.9910 respectively. Similarly, the parameters of PID controller of hydro power plant as  $K_{P2}$ ,  $K_{I2}$ ,  $K_{D2}$  are 0.4242, 0.0935, 0.4053 respectively. The parameters are tabulated in Table 2.



**Figure 11.** Frequency deviation in thermal power plant due to 0.01 p.u. load change in thermal power plant



**Figure 12.** Frequency deviation in hydro power plant due to 0.01 p.u. load change in thermal power plant

So, the output responses of proposed EHO-PID controlled system is compared with the reference ZN-PID as shown in Figure 11-Figure 13. The setting time of proposed model is less as compared to the reference ZN-PID. The peak overshoot and undershoot of proposed

model is less as compared to the reference ZN-PID. The comparative performances are depicted in Table 3. So, the EHO tuned PID controller improves the overall time specification of power system.

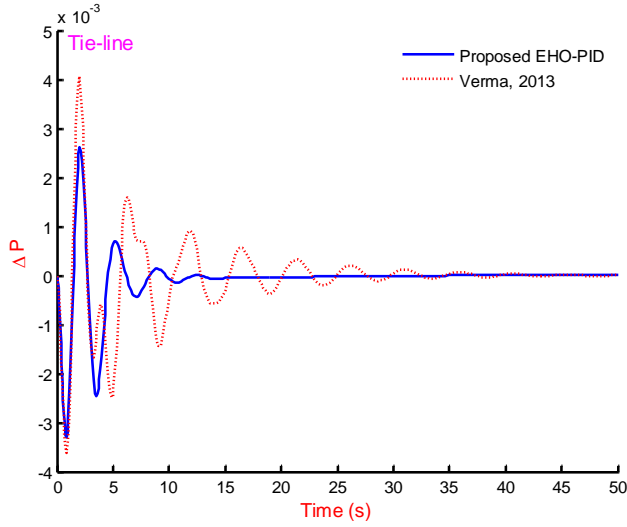


Figure 13. Power deviation in tie line

The change in frequency in thermal power plant of proposed controller due to 1% step load disturbance in thermal power plant is compared with ZN tuned PID controller as shown in Figure 11. The frequency deviation in Hydro power plant of proposed controller due to 1% step load disturbance in thermal power plant is compared with ZN tuned PID controller as shown in Figure 12 and the change in power of tie line of proposed and ZN-PID as shown in Figure 13.

## 4.2. Comparison of Performance indices

The performance of the proposed PID controller of hydro-thermal power system is discussed in terms of performance indices such as ITAE, IAE and ISE as well described in Eq.18-Eq. 20.

$$ITAE = \int_0^{t_{sim}} (\Delta f_1 + \Delta f_2 + \Delta P_{tie}) . dt \quad (18)$$

$$ISE = \int_0^{t_{sim}} (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2) . dt \quad (19)$$

$$IAE = \int_0^{t_{sim}} (\Delta f_1 + \Delta f_2 + \Delta P_{tie}) dt. \quad (20)$$

### 4.2.1. Based on ITAE

The proposed PID controller gives better performance to the ZN tuned PID controller. The ITAE value of proposed PID is 0.52297 resulting as better as compared to the ITAE value of ZN tuned PID is 1.9951.

### 4.2.2. Based on IAE

In this analysis, according to best solutions in Table 4, the proposed PID gives better results in terms of IAE as compared to the PID controller in literature. The IAE

value of proposed PID and ZN-PID are 0.119831 and 0.22691 respectively.

### 4.2.3. Based on ISE

The EHO tuned PID controller with ISE value is 0.00107099. In Table 4 shown the worst performing controller are based on ZN method with ISE value is 0.00162219.

Table 4. Comparative Performance of ITAE, IAE and ISE

Error	ITAE	IAE	ISE
Proposed PID	0.52297	0.119831	0.00107099
ZN-PID	1.9951	0.22691	0.00162219

## 4.3. Robustness Test

The robustness of controller shows the capability of a power system to perform effectively when the parameters of a system are changed within a certain range +25% to -25% [28]. The sensitivity of the power system is tested by varying the power system parameters from their tolerance values in the range of +25% to -25% without changing the gain of the PID controller. The Table 5 shows performances of the power system for a 1% step load change in thermal area under varying parameters of the system with proposed EHO-PID controller. It is clear from Table 5 that the proposed PID controller is a robust controller, there is no need of other tuned parameters of controller when the system parameters are varying from their tolerance values in the range of +25% to -25%. The robustness test of the controller is doing by changing the system parameter one by one with their nominal values in the range of +25% to -25%. Firstly, we increase the 25% of their nominal values of the governor time constant  $T_{G1}$  and the remaining parameters of the system remain of their nominal values and the model of system with these parameters without changing the optimum gain of the PID controller is simulated in MATLAB/SIMULINK. Similarly, we change the system parameter one by one changing within their nominal value in the range of +25% to -25% and the responses of each changing parameters as shown in Figure 14 - Figure 22. The settling time, peak overshoot and undershoot of the change in frequency in area 1, change in frequency in area 2 and change in tie line power is compared with the nominal value, +25% of nominal value and -25% of nominal of the system parameters. So, the Figure 14 to Figure 22 shows there is minor change in the settling time, peak overshoot and undershoots.

To take the effect of uncertainty into account, the system parameters are written in the interval manner. The lower limit of any parameter is -25% and upper limit is +25% of the nominal values. For the power system with re-heat hydro-thermal power plant [28] the parameters are  $T_{G1} = [0.06, 1.00]$ ,  $T_{T1} = [0.3, 0.5]$ ,  $T_r = [7.5, 12.5]$ ,  $K_r = [0.2475, 0.4125]$ ,  $K_{P1} = [90, 150]$ ,  $T_{P1} = [15, 25]$ ,  $T_W = [0.75, 1.25]$ ,  $K_{P2} = [90, 150]$ ,  $T_{P2} = [15, 25]$  For robustness test of the controller we change the system parameters value one by one from +25% to -25% with the system parameters nominal values and measures the settling time, peak overshoot and undershoot for every system

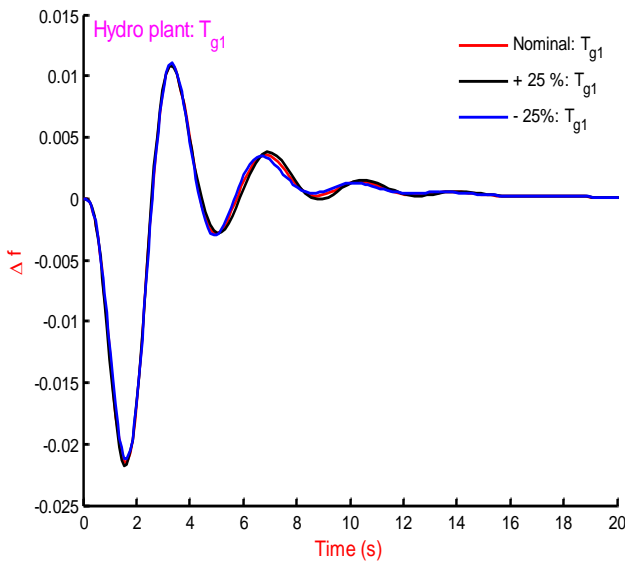


parameters varied value. We record the results in terms of time specification for every variation is tabulated in Table 5. Now we compared the result of nominal system parameter value with the varied system parameter. So, the 30 graphs are impossible to present in the paper. Now

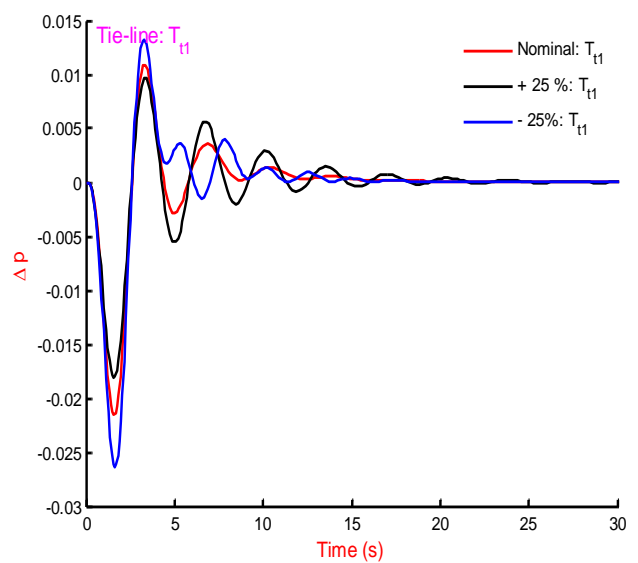
some samples related to these graphs as shown in Figure 14- Figure 22 and settling time, peak overshoot and undershoot of both area with system variation as tabulated in Table 5. The comparison of settling time is shown in Figure 23.

**Table 5. Comparative Performance of Change in System parameter variation**

Parameter	% change	Frequency deviation in area 1		Frequency deviation in area 2		Power deviation in tie-line	
		Settling time	Undershoot	Settling time	Undershoot	Settling time	Undershoot
Nominal	0	22.564	-0.016	18.983	-0.021	22.989	$-3.325 \times 10^{-3}$
$T_{G1}$	+25%	19.719	-0.017	19.244	-0.022	20.527	$-3.393 \times 10^{-3}$
	-25%	21.242	-0.015	19.339	-0.021	22.856	$-3.2626 \times 10^{-3}$
$T_{T1}$	+25%	20.338	-0.018	19.624	-0.023	20.573	$-3.650 \times 10^{-3}$
	-25%	21.051	-0.014	20.671	-0.020	23.975	$-2.958 \times 10^{-3}$
$T_r$	+25%	22.431	-0.017	21.337	-0.022	22.297	$-3.321 \times 10^{-3}$
	-25%	19.719	-0.015	19.148	-0.021	27.004	$-3.285 \times 10^{-3}$
$K_r$	+25%	28.901	-0.014	28.045	-0.018	28.821	$-2.822 \times 10^{-3}$
	-25%	21.099	-0.020	18.292	-0.026	20.899	$-3.933 \times 10^{-3}$
$K_{P1}$	+25%	26.528	-0.017	25.764	-0.021	26.731	$-3.376 \times 10^{-3}$
	-25%	30.540	-0.015	27.292	-0.022	29.864	$-3.578 \times 10^{-3}$
$T_{P1}$	+25%	22.755	-0.016	22.135	-0.022	22.568	$-3.314 \times 10^{-3}$
	-25%	26.862	-0.017	26.194	-0.021	29.864	$-3.357 \times 10^{-3}$
$T_W$	+25%	28.104	-0.018	27.483	-0.023	27.993	$-3.320 \times 10^{-3}$
	-25%	22.278	-0.015	22.899	-0.020	26.123	$-3.320 \times 10^{-3}$
$T_{P2}$	+25%	24.140	-0.015	22.947	-0.019	23.129	$-3.482 \times 10^{-3}$
	-25%	23.520	-0.018	22.612	-0.026	23.363	$-4.432 \times 10^{-3}$
$K_{P2}$	+25%	21.753	-0.018	21.227	-0.025	21.866	$-4.021 \times 10^{-3}$
	-25%	21.896	-0.015	21.66	-0.018	24.906	$-3.325 \times 10^{-3}$



**Figure 14.** Robustness analysis of controller with change of  $T_{G1}$



**Figure 15.** Robustness analysis of controller with change of  $T_{T1}$

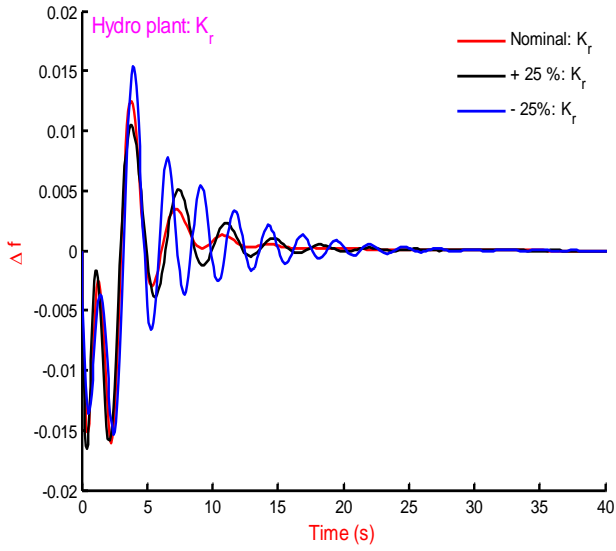


Figure 16. Robustness analysis of  $+K_r$

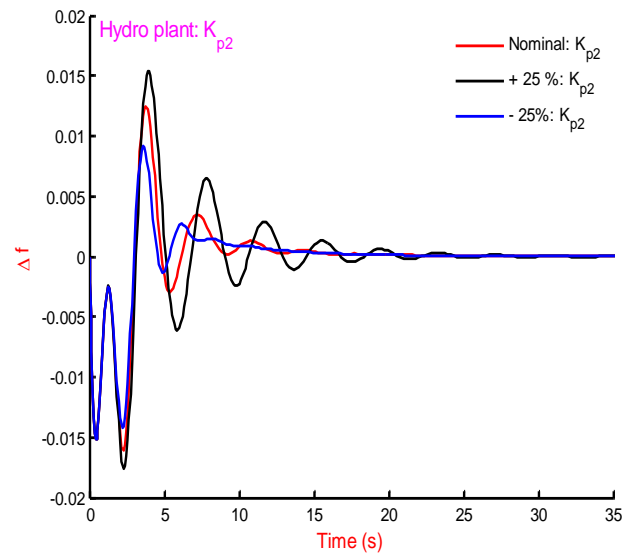


Figure 19. Robustness analysis of  $K_{p2}$

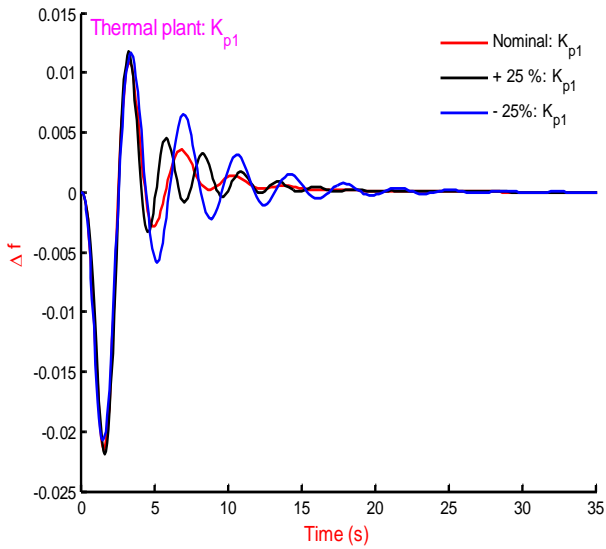


Figure 17. Robustness analysis of controller with change of  $K_{p1}$

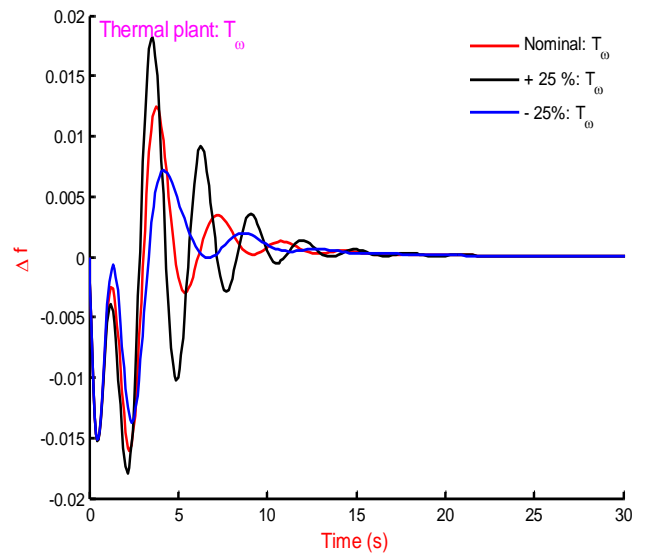


Figure 20. Robustness analysis of  $T_{\omega}$

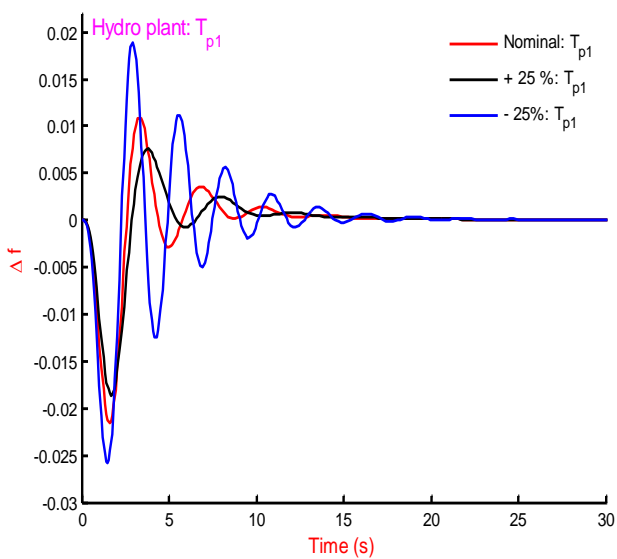


Figure 18. Robustness analysis of controller with change of  $T_{p1}$

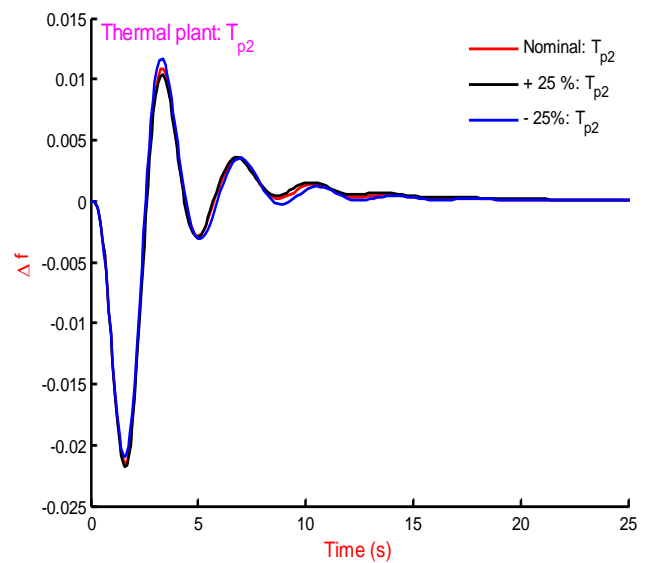


Figure 21. Robustness analysis of  $T_{p2}$

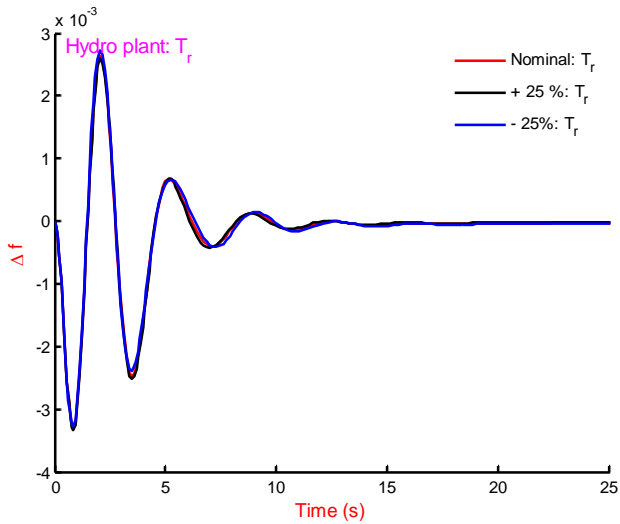


Figure 22. Robustness analysis of  $T_r$

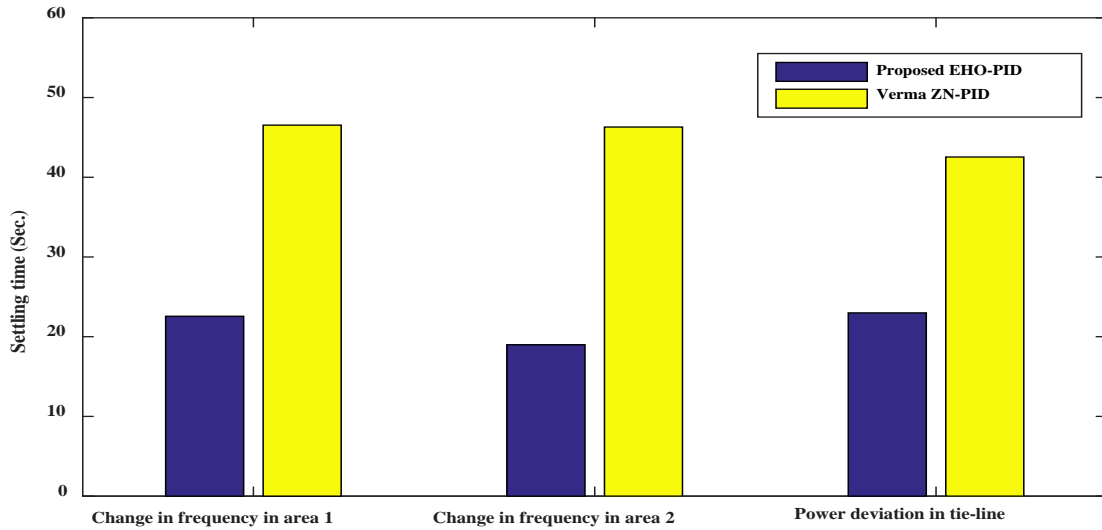


Figure 23. Bar graph representation of settling time

The simulation results show that the proposed PID controller has better performances than the reference ZN-PID. The settling time, peak overshoot and undershoot of the hydrothermal power system controlled by EHO-PID gives better result.

## Nomenclature

$T_{G1}$  : time constant of Steam governor

$T_{T1}$  : time constant of Steam turbine

$K_{P1}, K_{P2}$  : Gain constant of Power system for area 1 and area 2

$T_{P1}, T_{P2}$  : time constant of Power system for area 1 and area 2

$R_1, R_2$  : Governor speed regulation constant

$B_1, B_2$  : Frequency bias constant

$T_{12}$  : Synchronizing co-efficient

$T_W$  : Time constant of Hydro turbine

$T_r$  : Time constant of Re-heater

## 5. Conclusion

In this paper, the parameters of PID controllers are tuned by Elephant Herding Optimization for solving the load frequency problem. A comparative study was presented using a EHO-PID with ZN-PID. Both controller parameters are applied to a two area Hydro-thermal power plant. The main aim of this paper is to improve the dynamic performances of the power system. The superiority of EHO technique over Ziegler-Nichols method has been demonstrated. The robustness test of the controller is performed by changing the system parameters and it is observed that the parameter of the gain of the PID controller need not be changed even if the system is subjected to varied the parameters from +25% to -25% of the nominal value. The performances of the changing loading condition of the system are nearly equal to the nominal values responses of the system.

$K_r$  : Gain of Re-heater

$T_1$  : Time constant of Hydro-Governor

$T_2$  : Time constant of Hydro-Governor

## References

- [1] B. Mohanty and P. K. Hota, "Load Frequency Control of Nonlinear Interconnected Hydro-Thermal System Using Differential Evolution Technique," World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, vol. 8, pp. 453-460, 2014.
- [2] R. Verma and S. Pal, "Intelligent automatic generation control of two-area hydrothermal power system using ANN and fuzzy logic," in Communication Systems and Network Technologies (CSNT), 2013 International Conference on, pp. 552-556, 2013.
- [3] J. R. Nayak, T. K. Pati, B. K. Sahu, and S. K. Kar, "Fuzzy-PID controller optimized TLBO algorithm on automatic generation control of a two-area interconnected power system," in 2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015], pp. 1-4, 2015.
- [4] V. Nath and D. K. Sambariya, "Design and performance analysis of adaptive neuro fuzzy controller for load frequency control of multi-power system," in 2016 10th International Conference on Intelligent Systems and Control (ISCO), pp. 1-7, 2016.

- [5] D. K. Sambariya and R. Prasad, "Design of Optimal Proportional Integral Derivative Based Power System Stabilizer Using Bat Algorithm," *Applied Computational Intelligence and Soft Computing*, vol. 2016, p. 22, Feb. 1, 2016.
- [6] E. S. Ali and S. M. Abd-Elazim, "BFOA based design of PID controller for two area Load Frequency Control with nonlinearities," *International Journal of Electrical Power & Energy Systems*, vol. 51, pp. 224-231, 2013.
- [7] D. Lakshmi, A. P. Fathima, and R. Muthu, "PSO Based Load Frequency Control For Single Area Power System," *International Journal of Scientific & Engineering Research*, vol. 5, pp. 12-17, 2014.
- [8] D. Guha, P. K. Roy, and S. Banerjee, "Load frequency control of large scale power system using quasi-oppositional grey wolf optimization algorithm," *Engineering Science and Technology, an International Journal*, vol. 19, pp. 1693-1713, 2016.
- [9] R. K. Sahu, S. Panda, U. K. Rout, and D. K. Sahoo, "Teaching learning based optimization algorithm for automatic generation control of power system using 2-DOF PID controller," *International Journal of Electrical Power and Energy Systems*, vol. 77, pp. 287-301, 2016.
- [10] K. Naidu, H. Mokhlis, and A. Bakar, "Application of Firefly Algorithm (FA) based optimization in load frequency control for interconnected reheat thermal power system," in *Applied Electrical Engineering and Computing Technologies (AEECT), 2013 IEEE Jordan Conference on*, 2013, pp. 1-5.
- [11] S. Debbarma, A. Nath, U. Sarma, and L. C. Saikia, "Cuckoo search algorithm based two degree of freedom controller for multi-area thermal system," in *2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE)*, 2015, pp. 1-6.
- [12] K. V. Chandrakala, S. Balamurugan, and K. Sankaranarayanan, "Variable structure fuzzy gain scheduling based load frequency controller for multi source multi area hydro thermal system," *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 375-381, 2013.
- [13] P. Kaewkaosai, K. Hongesombut, and C. Mitsantisuk, "Robust hydro-thermal power system controller considering Energy Capacitor System," in *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2014 11th International Conference on*, 2014, pp. 1-6.
- [14] M. Shivaie, M. G. Kazemi, and M. T. Ameli, "A modified harmony search algorithm for solving load-frequency control of non-linear interconnected hydrothermal power systems," *Sustainable Energy Technologies and Assessments*, vol. 10, pp. 53-62, 2015.
- [15] S. Prakash and S. Sinha, "Neuro-Fuzzy Computational Technique to Control Load Frequency in Hydro-Thermal Interconnected Power System," *Journal of The Institution of Engineers (India): Series B*, vol. 96, pp. 273-282, 2015.
- [16] K. Jagatheesan and B. Anand, "Dynamic performance of multi-area hydro thermal power systems with integral controller considering various performance indices methods," in *Emerging Trends in Science, Engineering and Technology (INCOSET), 2012 International Conference on*, 2012, pp. 474-484.
- [17] D. K. Sambariya and S. Shringi, "Optimal Design of PID Controller for Load Frequency Control using Harmony Search Algorithm," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 5, pp. 19-32, 2017.
- [18] A. Kumar and R. Dahiya, "Load Frequency Control of three area hydro thermal power system with HFTID Controller," in *2014 IEEE 6th India International Conference on Power Electronics (IICPE)*, 2014, pp. 1-6.
- [19] X. Ding and A. Sinha, "Sliding mode/ $H_\infty$  control of a hydro-power plant," in *Proceedings of the 2011 American Control Conference*, 2011, pp. 5201-5206.
- [20] V. Nath and D. K. Sambariya, "Design and performance analysis of adaptive neuro fuzzy controller for load frequency control of multiarea power system," in *10th International Conference on Intelligent Systems and Control (ISCO 2016)*, Karpagam College of Engineering, Tamilnadu, India, 2016, pp. 359-365.
- [21] D. K. Sambariya and V. Nath, "Load Frequency Control Using Fuzzy Logic Based Controller for Multi-area Power System," *British Journal of Mathematics & Computer Science*, vol. 13, pp. 1-19, December 28, 2015.
- [22] D. K. Sambariya and V. Nath, "Optimal Control of Automatic Generation with Automatic Voltage Regulator Using Particle Swarm Optimization," *Universal Journal of Control and Automation*, vol. 3, pp. 63-71, December 2015.
- [23] V. Nath and D. K. Sambariya, "Analysis of AGC and AVR for Single Area and Double Area Power System Using Fuzzy Logic Control," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 4, pp. 6501-6511, July 2015.
- [24] S. Deb, S. Fong, and Z. Tian, "Elephant Search Algorithm for optimization problems," in *2015 Tenth International Conference on Digital Information Management (ICDIM)*, pp. 249-255, 2015.
- [25] G.-G. Wang, S. Deb, and L. d. S. Coelho, "Elephant herding optimization," in *Computational and Business Intelligence (ISCBI), 2015 3rd International Symposium on*, pp. 1-5, 2015.
- [26] D. K. Sambariya and R. Fagna, "A novel Elephant Herding Optimization based PID controller design for Load frequency control in power system," in *2017 International Conference on Computer, Communications and Electronics (Comptelix)*, pp. 595-600, 2017.
- [27] S. Gupta, V. Singh, S. Singh, T. Prakash, and N. Rathore, "Elephant herding optimization based PID controller tuning," *International Journal of Advanced Technology and Engineering Exploration*, vol. 3, p. 194, 2016.
- [28] R. K. Sahu, S. Panda, and N. K. Yegireddy, "A novel hybrid DEPS optimized fuzzy PI/PID controller for load frequency control of multi-area interconnected power systems," *Journal of Process Control*, vol. 24, pp. 1596-1608, 2014.