Design a PID controller for load frequency control of multi area thermal power system using Elephant Herding Optimization technique

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***Abstract*—In this paper, an application of Elephant Herding Optimization technique has been proposed for employing the parameter of PID controller for Load frequency control of two area non-reheat power system. This algorithm is one of the new meta-heuristic-based algorithms which have been developed in 2015. The parameter of PID controller is optimized by minimizing the objective function as Integral Square of Error. A 1% step load perturbation is applied in the load demand in area 1 for analyzing the dynamic performance of the power system. This paper utilizes the EHO tuned PID to improve the stability and dynamic response of the LFC of power system. The superiority of proposed EHO tuned PID controller has been proved by comparing the performances of change in frequency and change in power in tie-line of power system with PID controller in literature. In addition to these, the robust analysis of proposed controller is applied to the power system by changing the system parameters during loading conditions in the range of +25% to -25% of their standard values.**

***Index Terms*—Load Frequency Control, Proportional Integral Derivative (PID) controller, frequency deviation, Elephant Herding Optimization (EHO) technique, power system**

I. INTRODUCTION

A modern power system network consists of a number of network elements interconnected to each other via tie-lines. The structure and size of the power system network are complex due to growth of the power generation and power demand. Load Frequency Control (LFC) plays a vital role in the large-scale multi area interconnected modern power system to maintain the system frequency and tie-line power near to the standard throughout the power system. The goal of LFC is to maintain the system frequency within the standard values of the Energy Management System. The power system to a state of equilibrium is achieved by regulating the generated power and power demand. However, it is a very difficult task to sustain the whole power system to a state of equilibrium. The variation occurs in the frequency due to changing the active and reactive power demand of the system. The controller is used for damping the oscillation and frequency deviation of the power system. The controller is necessary for neglecting the effect of sudden load changes and to maintain the system frequency within their nominal values.

The classical methods of PID controllers such as Ziegler-Nichols method, Tyreus-luyben method, Cohen-Coon method, Fertik method, Integral Model Control method and Chien Hrones Reswick method are used for damping the oscillation of the frequency on the power system. However, the classical method-based controllers are not efficient for complicated power system.

In last decades, the researchers have proposed many control strategies based on soft computing techniques for LFC of the power system. These control strategies as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE), Quasi-Oppositional Grey Wolf Optimization Algorithm (QOGWOA) and Teaching Learning Based Optimization Algorithm (TLBO). These controllers not only maintain the constant frequency for the system but also achieve zero steady-state error operation within the power system.

Sambariya et al., 2017 [1] have designed a PID controller for load frequency control using Harmony Search algorithm. Padhy et al., 2017 [2] have reported on the hybrid stochastic fractal search and pattern search techniques to search the parameters of cascade PI-PD controller for AGC of the multi-source power system.

Elazim et al., 2016 [3] have employed a new technique such as BAT algorithm to enhance the parameters of the load frequency controller. Sambariya et al., 2016 [4] describes the load frequency control of four area interconnected power system using NARMA L2 controller and comparing their result with ZN-PID and PSO-PID. Nath et al., 2016 [5] have proposed an adaptive neuro fuzzy controller approach for load frequency control of three area power system. Dash et al., 2016[6] have designed a cascade PI-PD controller based on Flower Pollination Algorithm for controlling the load frequency of multi-area power system. Dhillon et al., 2016 [7] have studied on the multi objective load frequency controller parameters are optimized by BFOA and PSO algorithm and compare the responses of BFOA and PSO tuned PI controller. Nikmanesh et al., [8] 2016 has used Pareto optimization techniques for deriving the parameters of PID controller for LFC of the power system.

Anwar et al., 2015 [9] have designed the PID controller based on direct synthesis method for load frequency control of the power system. Sahu et al.,[10] 2015 has demonstrated that the hybrid Firefly algorithm and Pattern Search techniques for improving the performances of the power system.

Debbarma et al., 2014 [11] used two degree of freedom order PID controller to enhance the performance of PID controller for AGC of the power system. Sahu et al., 2014 [10] have been reported the fuzzy PI/PID controller tuned Hybrid Differential Evolution and Pattern Search algorithm improve the performance of the power system and show the controller is robust by varying the system parameters.

Author Chandrakala et al., 2013 [12] have estimated the fuzzy gain scheduling controller for controlling the oscillations of the power system frequency. Saikia et al., 2013 [8] have been reported on the application of bacterial foraging based Fuzzy IDD controller for controlling the frequency of hydro-thermal power system.

Farhangi et al., 2012 [13] have estimated the use of emotional learning based intelligent controller for LFC of two area reheat thermal system. Gozde et al., 2012 [14] suggested the Artificial Bee Colony for tuning the parameters of the controller for AGC of the power system. Khodabakshian et al., 2012 [15] have reported on the LFC of two area power system using Sequential Quadratic Programming techniques. Yazdizadeh et al., 2012 [6] have proposed a robust PID controller for LFC of multi-area power system.

Bhatt et al., 2010 [16] have proposed the application of Real coded Genetic Algorithm for deriving the parameters of PID controller for AGC of the power system. Ali et al., 2011 [17] have optimized the parameters of PI controller using Bacteria Foraging Optimization Algorithm (BFOA) for LFC of the power system.

II. PROBLEM FORMULATION

A. System Description

As described previously, for improving the time specification and stability of the interconnected power system. Under condition of steady load, the reactive power demands are never steady. LFC is a part of speed governor system controlling the input valve of the steam turbine. A two-area interconnected non-reheat thermal power system as shown in Fig. 1. The system is widely used in literature for solving load frequency problem. The non-reheat thermal power plant consists of components such as governor, turbine and power system. The mathematical modelling of the component of the two-area non-reheat thermal power plant are mentioned here.

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 are used T_G =0.08 seconds.

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

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.

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

Rotating mass and load inertia of the power system:

The Eq. 3 describe the transfer function of a rotating load on the power system. Gain and time constant throughout the power system are indicated by K_P and T_P respectively. The used values in the parameters are K_P = 120 and T_P =20 seconds.

$$G_P(s) = \frac{K_P}{1+sT_P} \qquad (3)$$

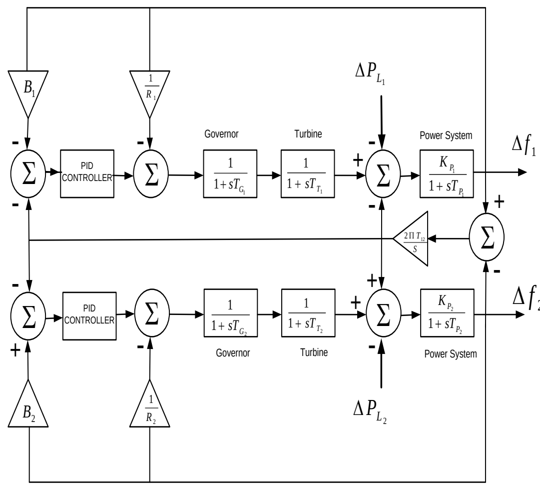

Fig. 1 Block diagram of two area non-reheat thermal power system

In two-area re-heat thermal power plant T_{G_1} and T_{G_2} are the time constants of the speed governor; T_{T_1} and T_{T_2} are the time constants of turbine; K_{P_1} and K_{P_2} are the gain of the power system; T_{P_1} and T_{P_2} are the time constant of the power system; R_1 and R_2 are the speed regulation constants; B_1 and B_2 are the frequency bias constant. The error inputs to the controller are Area Control Errors given by.

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie} \qquad (4)$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie} \qquad (5)$$

B.PID controller

PID controller is a parallel combination of proportional, integral and derivative controller. PID controller have been extensively used in industry due to their simple in design. The block diagram of PID controller is as shown in Fig. 3. PID controller combines the advantage of Proportional, Integral and Derivative control mode. The proportional controller gain is represented by K_P and the proportional parameter adjusts the size of the process error signal. Integral controller gain is indicated by K_i and the K_i improves the steady state offset from a constant reference signal value. The derivative gain of the controller introduces an element prediction into the control action. PID controller not only reduces the steady error but also reduces the settling time, undershoot and damping oscillation of the response of the power system. The transfer function of the PID controller is as shown in Eq. 6.

$$G_C(s) = K_p + \frac{K_i}{s} + K_d s \qquad (6)$$

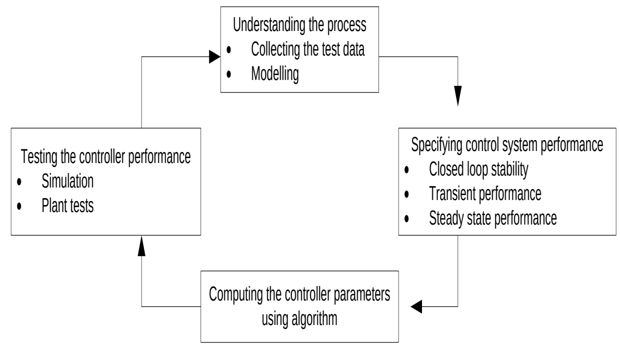

Fig. 1 Architecture of controller design

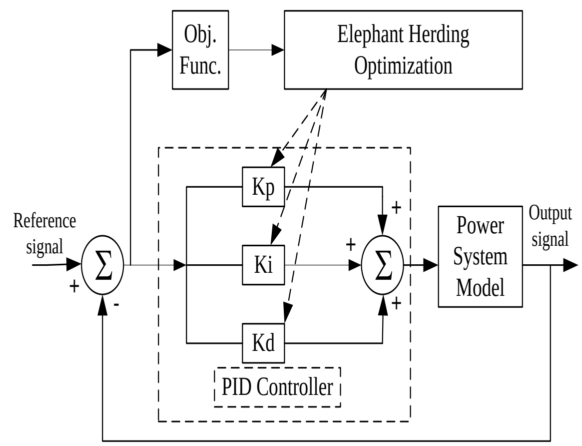

Fig. 2 structure of PID controller

C. Objective function

An Integral Square Error (ISE) is used as an objective function for deriving the parameter of PID controller. The Elephant Herding Optimization methodology is used to determine the unknown parameter of PID controller. The optimization problem is considered as minimization of the error signal as in Eq. The main aim of choosing ISE as objective function for EHO based PID controller design is that it gives better performance as compared to the other performance indices such as ITAE and IAE. The parameters of PID controller are subjected to lower and upper bounds with limits of proposed algorithm as shown in Eq.

$$ISE = \int_0^{t_{sim}} (\Delta f_1^{\,2} + \Delta f_2^{\,2} + \Delta P_{tie}^{\,2}).dt \qquad (7)$$

$$K_{p_1}(initial) \leq K_{p_1} \leq K_{p_1}(final)$$
$$K_{i_1}(initial) \leq K_{i_1} \leq K_{i_1}(final) \quad (8)$$
$$K_{d_1}(initial) \leq K_{d_1} \leq K_{d_1}(final)$$

$$K_{p_2}(initial) \leq K_{p_2} \leq K_{p_2}(final)$$
$$K_{i_2}(initial) \leq K_{i_2} \leq K_{i_2}(final) \quad (9)$$
$$K_{d_2}(initial) \leq K_{d_2} \leq K_{d_2}(final)$$

III. ELEPHANT HERDING OPTIMIZATION ALGORITHM

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

A. Assumption The of optimization:

A global optimization problem is solved by using the herding behaviour of an elephant [19]. We use these rules for solving the problem [20].

- It is assumed that total population of elephants is divided among a group called clans, and each clan have fixed number of elephants.
- It is also assumed that the worst performing male elephant will leave their family group. It lives alone far away from the elephant group at each generation.
- Matriarch is the leader of all elephants live in a clan.

B. Clan Updating Operator:

Each clan is headed by the matriarch. The total number of a clans of elephants (C_p) and q is the total number of elephants in each clan [19].The current position of all elephants are updated as Eq.10.

$$x_{new,C_p,q} = x_{C_p,q} + \alpha \times \left(x_{best,C_p} - x_{C_p,q}\right) \times r \quad (10)$$

Where $x_{new,Cp,q}$ and $x_{Cp,q}$ are newly updated and old position for elephant q in clan C_p respectively. The α 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 number in the range. The best elephant in each clan cannot be updated by eq. (11)

$$x_{Cp,q} = x_{best,C_p,q} \quad (11)$$

The matriarch movement is updated by

$$x_{best,Cp} = \beta \times x_{center,C_p} \quad (12)$$

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

$$x_{centre,Cp,d} = \frac{1}{n_{C_p}} \times \sum_{q=1}^{n_{Cp}} x_{Cp,q,d} \quad (13)$$

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

C. Clan Separating Operator

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

$$x_{worst,Cp} = x_{\min} + (x_{\max} - x_{\min} + 1) \times rand \quad (14)$$

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

Pseudo-code of Elephant Herding Optimization Algorithm
Initialization Set generation counter t=1, set maximum generation max.gen. Initialize the population, global variables, dimension (6), max.gen. =100, set elitism as 2, objective function, α=0.5,β=0.1. While t=1: max.gen. Start and save elitism strategy for cost and population Division of elephant population into clans Clan updating operator as in Eq. 10 and Eq. 12 Evaluate separating operator as in Eq. 14 Evaluate new clan Save fitness function for each iteration Save parameter for newly update position Update iteration count by t=t+1 end

IV. SIMULATION RESULTS AND DISCUSSION

In this section, we simulate the two-area load frequency control of non-reheat thermal power plant using EHO based PID controller. The parameters of the power system with proposed PID controller is tabulated in Table 1. The detail of the gain of proposed PID controller with PID controller in literature is described in Table 2.

Table 1 Parameter of Two Area non-reheat Thermal Power Plant

Parameter	Symbol	Values
Governor time constant	T_{G_1}, T_{G_2}	0.08 Sec.
Turbine time constant	T_{T_1}, T_{T_2}	0.3 Sec.
Power system gain constant	K_{P_1}, K_{P_2}	120 Hz/pu MW
Power system time constant	T_{P_1}, T_{P_2}	20 Sec.
Speed regulation	R_1, R_2	2.4 Hz/pu MW
Frequency Bias	B	0.425
Synchronizing co-efficient	T_{12}	0.086

A. PID controllers in literature

In this section, the PID controllers in literature are designed using different techniques for controlling the load frequency of power system is to be reviewed. The parameters of the PID controllers in literature is enlisted in Table 2.

Alomoush, 2010 [21] have use the application of Particle Swarm Optimization of LFC of interconnected power system. Nayak et. al., 2015 [22] have employed the parameter of PID controller for LFC of two area power system using DEPSO algorithm. Yesil et. al., 2014 [23] have used the Big Bang- Big Crunch 2 Algorithm for deriving the parameters of PID controller for LFC of power system compared the performance index between the BFOA and BB-BC 2 tuned PID controller. Tan, 2009 [24] has designed a PID controller for LFC of two area power system using 2 degree-of-freedom IMC method. Sahu et. al., 2016 [25] have used the TLBO algorithm to optimized the parameter of PID controller for AGC of an interconnected power system.

Nikmanesh et. al., 2016 [8] have recently applied the NSGA-II tuned PID controller for LFC of multi area power system. Guha et. al., 2016 [26] have applied Backtracking Search Algorithm to searching the gains of the PID controller for LFC of a two-area interconnected system. Ali et. al., 2013 [27] have introduced the BFOA tuned PID controller for LFC of two area power system and compared the responses of BFOA tuned PID with GA-PID, conventional PID controller. Khodabakhshian et. al., 2012 [15] have employed an artificial search technique to optimized the parameter of PID controller using SQP method.

Ikhe et. al., 2013 [28] have reported on the PID controller for LFC of two area power system. Farahani et. al., 2012 [29]have designed the four types of control strategies such as LCOA-PID, GA-PID, PS-PID and SA-PID for LFC of two area power system. The performance and settling time of LCOA-PID controller is better as compared to the GA, PS, SA tuned PID controller. Ikhe et. al., 2012 [30] have composed the fuzzy logic controller for two area power system and compared the response of FLC with PID controller. Sharma and Kumar, 2015 [31] have designed a PID controller using the application of PSO technique. In 2014, Jain et. al. [32] have studied on the comparative analysis of PID controllers tuned by different technique.

Saifi et. al., 2015 [33] have employed a PSO tuned PID controller for LFC of two area power system.

Table 2 The detail of the PID parameters

Author/technique	K_{P_1}	K_{I_1}	K_{D_1}	K_{P_2}	K_{I_2}	K_{D_2}
Proposed EHO	4.935	6.2349	0.9967	2.8345	0.7135	1.5567
Alomoush PSO, 2010 [21]	0.0452	0.4836	0.4350	0.4121	0.5027	0.863
Nayak DEPSO, 2015 [22]	0.6269	1.9402	0.2808	1.7268	1.1682	1.0944
Yesil BB-BC 2, 2014 [23]	0.8962	0.7779	0.3862	0.8962	0.7779	03862
Yesil BFOA, 2014 [23]	0.1317	0.4873	0.2506	0.1317	0.4873	0.2506
Tan, 2009 [24]	1.5692	2.3966	0.5259	1.5692	2.3966	0.5259
Sahu TLBO, 2016 [25]	1.1726	1.9370	1.1635	1.1726	1.9370	1.1635
Nikmanesh NSGA-II, 2016 [8]	0.453	0.94	0.473	0.453	0.94	0.473
Guha BSA, 2016 [26]	1.0663	1.9657	0.3462	1.5606	0.0164	0.4259
Ali GA, 2013 [27]	0.0955	0.4712	0.0679	0.0955	0.4712	0.0679
Ali BFOA, 2013 [27]	0.1317	0.4873	0.2506	0.1317	0.4873	0.2506
Ali conventional, 2013 [27]	0.5865	0.5100	0.1686	0.5865	0.5100	0.1686

Khodabakshian SQP, 2012 [15]	1.011	1.08	0.95	0.92	1.05	0.98
Lakshmi PSO, 2015 [34]	0.7900	1.4252	0.4652	0.7900	1.4252	0.4652
Lakshmi BFOA, 2015 [34]	0.7674	0.1776	0.1056	0.7674	0.1776	0.1056
Kouba ZN, 2014 [35]	0.06168	3.56	0.89	0.06168	3.56	0.89
Kouba PSO, 2014 [35]	2.16	0.45	0.6305	2.16	0.45	0.6305
Ikhe, 2013 [28]	0.1109	0.2742	0.1110	0.0121	0.2019	0.0030
Pain PSO, 2014 [36]	0.0010	0.5350	0.1831	1.4785	1.7496	1.0342
Farhani GA, 2012 [29]	0.6003	0.6204	0.5224	0.3000	0.7319	0.3654
Farhani LCOA, 2012 [29]	0.9390	0.7668	0.5636	0.5208	0.4775	0.7088
Farhani PS, 2012 [29]	0.9180	0.7439	0.5873	0.5479	0.6312	0.0980
Farhani SA, 2012 [29]	0.9470	0.7599	0.5681	0.2362	0.0108	0.0809
Ikhe, 2012 [30]	0.8036	0.6356	0.1832	0.8036	0.6356	0.1832
Lokanath PSO, 2014 [37]	0.1458	0.6458	1.5468	0.4121	0.5027	0.863
Sharma ZN, 2015 [31]	1.0286	1.2939	0.2044	1.0286	1.2939	0.2044
Sharma PSO, 2015 [31]	1.22	1.94	0.31	1.53	1.61	0.31
Salim BFOA [38]	0.0162	0.7656	0.1810	0.0162	0.7656	0.1810
Jain ZN, 2014 [32]	0.66	0.33	0.33	0.9	0.45	0.45
Jain Simplex, 2014 [32]	0.4221	1.2113	0.3295	0.9	0.45	0.45
Saifi PSO, 2015 [33]	0.094	0.61	0.49	0.924	0.6240	0.4806
Salma BAT [39]	0.850	1.480	0.31	1.53	1.61	0.31
Ragini PSO [40]	0.6412	0.9459	0.4866	1.4907	2.000	1.3701
Ragini BSA [40]	1.1154	0.9665	0.8358	1.1274	2.9687	1.3701

A. Implementation of EHO algorithm

The prototype of a two-area reheat thermal power plant is simulated in MATLAB/SIMULINK platform and Elephant Herding Optimization algorithm program is written in .m file. Different PID controllers are tuned for each area. The gains of the PID controller of area 1 are , , is respectively. Similarly, the gain of PID controller of area 2 are , , is respectively. A 1% step load perturbation is applied to the power demand of the area 1. The fitness value of the Elephant Herding Optimization algorithm is calculation and the fitness graph as shown in Fig. 4.

The parameter of EHO such as an elitism parameter by which the number of elephants are assigned for movement from one generation to the other generation is set to as 2.0 and the control operators are α=0.5 and β=0.1. Using the proposed EHO techniques, we have easily found the minimize solution of ISE. Firstly, we set the total number of iteration count is 100 for considering the termination of optimization, and algorithm is run for evaluated the best results. The current best solution can be collected during iterations. The total number of population is 10 and maximum generation size is 100 at number of clan is 1 for optimized the value of PID controller using the EHO techniques.

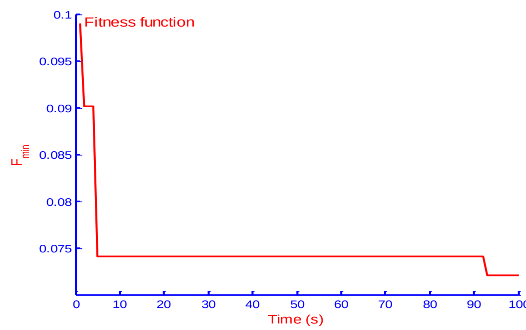

Fig. 4 Convergence characteristics of EHO

A.Analysis of result

The performance of proposed PID controller is compared with the responses of PID controller tuned by PSO, BFOA, TLBO, BSA and ZN method as shown in Table. The ISE objective function is employed for comparison the performances of proposed PID controller with the PID controllers in literature. The performance of the power system in terms of time specification is superior as compared to the controller in literature. The settling time and undershoot value of the change in frequency of area-1 with proposed EHO-PID is 3.750 second and -0.665, respectively and is shown in Table 3. Nayak have presented the performance of power system of area-1 in terms of settling time and undershoot value is 4.788 second and -1.325 respectively is better except Proposed PID as compared to the response of PID controller in literature. Guha, 2016 performs the BSA algorithm for tuning the parameter of PID controller and produces settling time for area- 1 and area- 2 are 4.929 and 5.778 respectively are also high as compared to proposed PID controller. Farhani, 2012 have used the four methodologies for controlling the load frequency such as GA, LCOA, PS and SA respectively and compare the performance with each other. Farhani proposed LCOA-PID gives settling time value for area- 1 is 10.495 second which is less as compared to the GA, PS and SA tuned PID controllers. The worst performing controller in terms of setting time is Lakshmi tuned BFOA controller and its settling time value for area- 1 is 45.307 second. The GA, BFOA and conventional techniques [27] are presented with system response as settling time and peak values of the response of the frequency deviation of area- 1 and area- 2 are mentioned in table 3.

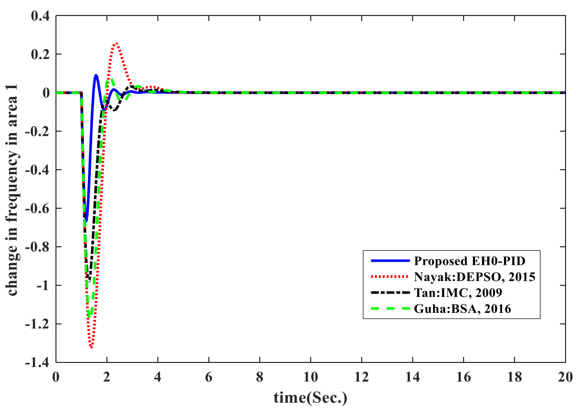

Fig. 5 Comparative analysis of frequency deviation in area- 1 of proposed PID with PID controller in literature

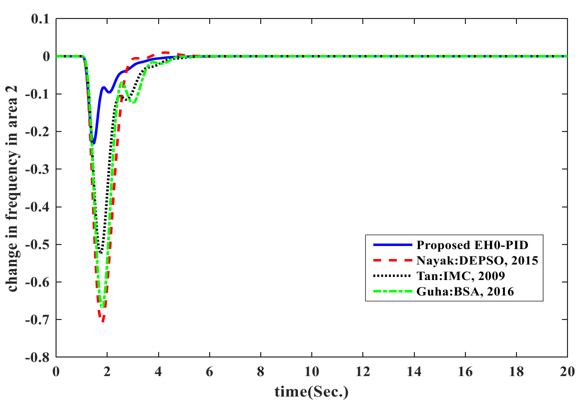

Fig. 6 Comparative analysis of frequency deviation in area- 2 of proposed PID with PID controller in literature

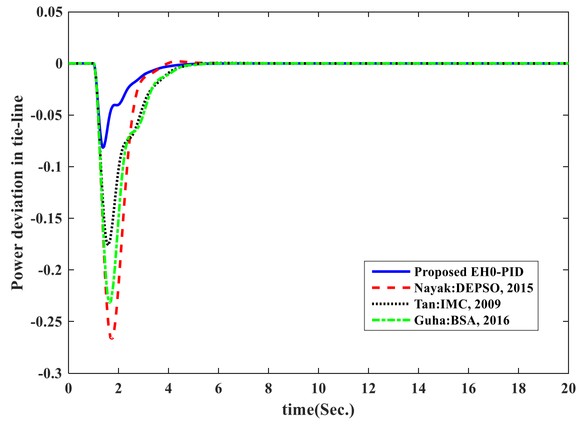

Fig. 7 Comparative analysis of Power deviation in tie-line of proposed PID with PID controller in literature

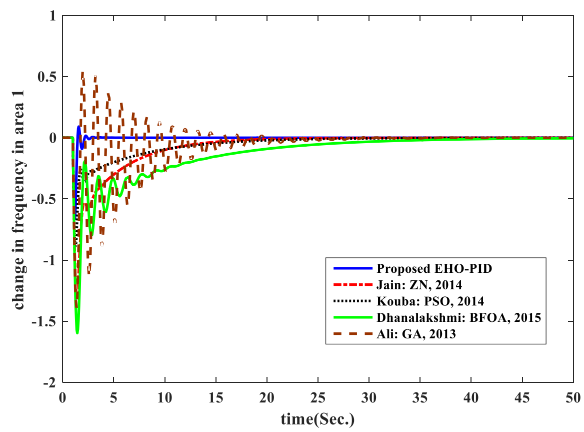

Fig. 8 Comparative analysis of frequency deviation in area- 1 of proposed PID with PID controller in literature

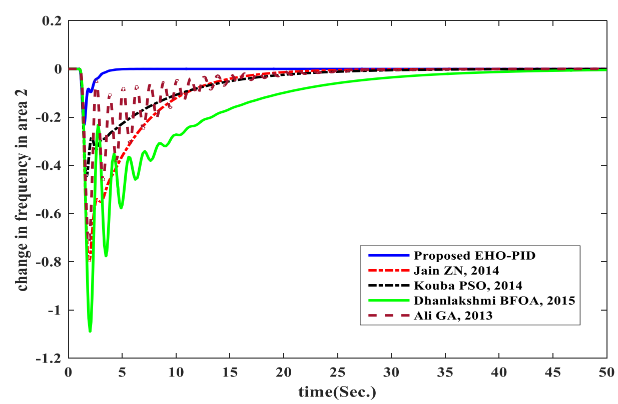

Fig. 9 Comparative analysis of frequency deviation in area- 2 of proposed PID with PID controller in literature

Table 2 Comparative analysis of PID controllers in terms of settling time and undershoot

Author/ technique	Change in frequency in area 1		Change in frequency in area 2		Power deviation in tie-line	
	Settling time	undershoot	Settling time	undershoot	Settling time	Undershoot
Proposed EHO	3.750	-0.665	5.342	-0.232	5.532	-0.082
Alomoush PSO, 2010 [21]	10.495	-1.264	11.769	-0.849	12.559	-0.341
Nayak & pati [22]	4.788	-1.325	5.401	-0.710	5.247	-0.267
Yesil BB-BC 2, 2014 [23]	11.061	-1.172	12.948	-0.711	13.699	-0.248
Yesil BFOA, 2014 [23]	10.307	-1.518	11.769	-1.077	11.800	-0.387
Tan, 2009 [24]	5.071	-0.980	5.590	-0.526	5.437	-0.176
Sahu TLBO, 2016 [25]	9.741	-0.691	10.518	-0.353	10.518	-0.139
Nikmanesh NSGA-II, 2016 [8]	7.571	-1.145	6.722	-0.717	9.283	-0.259
Guha BSA, 2016 [26]	4.929	-1.175	5.778	-0.671	5.674	-0.232
Ali GA, 2013 [27]	37.005	-1.385	34.788	-0.724	36.349	-0.281
Ali BFOA, 2013 [27]	9.882	-1.525	11.439	-1.077	11.697	-0.387
Ali conventional, 2013 [27]	14.458	-1.525	16.486	-1.034	16.643	-0.356
Khodabakshian SQP, 2012 [15]	8.986	-0.780	8.191	-0.427	9.995	-0.171
Lakshmi PSO, 2015 [34]	6.156	-1.104	5.778	-0.656	7.764	-0.228
Lakshmi BFOA, 2015 [34]	45.307	-1.603	49.991	-1.088	50	-0.368
Kouba ZN, 2014 [35]	17.618	-0.845	19.693	-0.483	14.079	-0.179
Kouba PSO, 2014 [35]	32.429	-0.888	37.618	-0.445	38.343	-0.152
Ikhe, 2013 [28]	19.222	-1.813	21.203	-1.397	21.627	-0.492
Pain PSO, 2014 [36]	6.580	-1.703	9.080	-1.087	8.713	-0.422
Farhani GA, 2012 [29]	11.392	-1.079	13.514	-0.687	13.414	-0.246
Farhani LCOA, 2012 [29]	10.495	-1.010	12.618	-0.554	13.272	-0.208
Farhani PS, 2012 [29]	11.486	-0.988	13.420	-0.661	14.221	-0.217
Farhani SA, 2012 [29]	11.769	-1.001	13.656	-0.636	13.794	-0.222
Ikhe, 2012 [30]	12.995	-1.441	15.024	-0.944	15.456	-0.321
Lokanath PSO, 2014 [37]	20.637	-0.645	21.014	-0.579	20.442	-0.238
Sharma ZN, 2015 [31]	10.637	-1.358	10.542	-0.857	10.565	-0.283
Sharma PSO, 2015 [31]	7.146	-1.201	7.901	-0.714	7.574	-0.233
Salim BFOA [38]	6.439	-1.685	6.203	-1.228	8.523	-0.435
Jain ZN, 2014 [32]	24.552	-1.281	27.665	-0.800	27.896	-0.286
Jain Simplex, 2014 [32]	6.061	-1.304	6.958	-0.816	7.431	-0.292
Saifi PSO, 2015 [33]	9.976	-1.186	10.825	-0.816	11.230	-0.304
Salma BAT [39]	6.203	-1.252	7.382	-0.794	6.861	-0.258
Ragini PSO [40]	5.684	-1.103	7.948	-0.595	7.764	-0.234
Ragini BTSA [40]	8.656	-0.832	10.470	-0.430	10.518	-0.171

A. On performance indices

The analyses of the performance of PID controller design for the LFC of two area power system with different types of performance indices like Integral Time Absolute Error (ITAE), Integral Absolute Error (IAE) and Integral Square Error (ISE) as described in this section. The minimum value of performance indices shows the PID controller is better as compared to others. The comparative analysis of performance indices of proposed PID with PID controller in literature as tabulated in table. The value of ITAE, IAE and ISE for proposed PID controller is 0.3486,0.2359 and 0.09785, respectively for frequency deviation in area 1. The values of the performance indices are measured at the simulation time is 50 seconds.

Based on ITAE

Tan, 2009 [24] gives better performance as compared to the PID controller in literature except proposed PID controller in terms of ITAE for conventional PID controller as well as IMC based controller whose value as 0.8623 for frequency deviation in area 1. The ITAE value of the frequency deviation of area 1, frequency deviation of area 2 and power deviation of tie-line are 0.3486, 0.3953 and 0.1683 respectively.

On comparing ITAE in table. the worst performing PID controller are Dhanalakshmi, 2015 [34] proposed controller using BFOA algorithm. The ITAE value of the worst performing controller is 65.12 for frequency deviation in area 1.

Based on IAE

In this analysis, according to best solution of IAE in table. Tan, 2009 [24] appears to be second for IMC method and its value for area- 1 and area- 2 are 0.5492 and 0.4918 respectively. In comparison third priority for Guha, 2016 [26] for PID tuned BSA optimization technique. The IAE value for area- 1 is 0.6994 and for area- 2 is 0.6006 respectively. The IAE value of proposed EHO-PID for area- 1, area- 2 and power deviation are 0.2359, 0.1898 and 0.08043 respectively. The worst performing controllers are based on BFOA tuned PID [34] controller with IAE value for area- 1, area- 2 and power deviation are 6.585, 6.581 and 0.4139 respectively. The other controllers in Ragini [40] presents the IAE values for area- 1 and area- 2 are 1.247 and 1.246 respectively.

Based on ISE

Sahu,2016 [41] proposed TLBO-PID controller with ISE value for area- 1 is 0.2934 may be considered with second priority in section of a controller as compared to controllers in literature. The ISE value of the proposed EHO-PID for area-1, area- 2 and tie-line are 0.09785,0.02268 and 0.003525 respectively are better as compared to PID controller in literature. The worst performing controller in terms of ISE value for area- 1 is 3.288 and is proposed on Ikhe, 2013 [28]. The ISE value of the PID controller in literature are tabulated in table 4.

Table 3 Comparative analysis of Performance indices

Author /technique	Change in frequency in area 1			Change in frequency in area 2			Power deviation in tie line		
	ITAE	IAE	ISE	ITAE	IAE	ISE	ITAE	IAE	ISE
Proposed EHO	0.3486	0.2359	0.09785	0.3953	0.1898	0.02268	0.1683	0.08043	0.003525
Alomoush PSO, 2010 [21]	6.446	2.498	1.942	8.099	2.465	1.483	3.464	1.049	0.2534
Ranjan & pati [22]	1.679	0.9852	0.8401	1.233	0.6263	0.3167	0.5094	0.2622	0.04881
Yesil BB-BC 2, 2014 [23]	4.06	1.513	0.8202	5.239	1.513	0.538	2.224	0.6428	0.08763
Yesil BFOA, 2014 [23]	6.202	2.415	1.98	8.084	2.415	1.472	3.428	1.026	0.237
Tan, 2009 [24]	0.8623	0.5492	0.3502	1.044	0.4918	0.1526	0.4494	0.2099	0.02185
Sahu TLBO, 2016 [25]	1.847	0.8079	0.2934	1.926	0.7079	1.1757	0.7961	0.2968	0.0292
Sahu & tulsichandra	3.548	1.172	0.404	3.354	0.9826	0.2493	1.316	0.3991	0.04113
Nikmanesh NSGA-II, 2016 [8]	2.733	1.334	0.9013	3.355	1.267	0.5899	1.457	0.543	0.09427
Guha BSA, 2016 [26]	1.096	0.6994	0.5725	1.263	0.6006	0.2486	0.535	0.2547	0.03564
Ali GA, 2013 [27]	26.38	4.119	2.189	18.37	2.496	0.653	7.811	1.061	0.1193
Ali BFOA, 2013 [27]	6.202	2.415	1.98	8.084	2.415	1.472	3.428	1.026	0.237
Ali conv., 2013 [27]	7.722	2.307	1.518	9.521	2.307	1.063	4.045	0.9804	0.1662
Khodabakshian SQP [15]	2.567	1.122	0.4818	3.29	1.102	0.3356	1.41	0.47	0.05714
Lakshmi PSO, 2015 [34]	1.637	0.9112	0.6097	1.938	0.8039	0.3389	0.8424	0.3569	0.05152
Lakshmi BFOA, 2015[34]	65.12	6.585	2.94	70.07	6.581	2.468	29.78	2.797	0.4139
Kouba ZN, 2014 [35]	6.635	1.661	0.5938	5.812	1.288	0.3058	1.188	0.3604	0.03527
Kouba PSO, 2014 [35]	18.92	2.613	0.6424	20.94	2.612	0.503	8.903	1.11	0.08823
Ikhe, 2013 [28]	18.39	4.29	3.288	20.75	4.291	2.712	9.243	1.824	0.4354
Pain PSO,2014 [36]	4.662	2.2	2.313	6.385	2.2	1.5	2.715	0.9354	0.2526
Farhani GA, 2012 [29]	5.412	1.898	1.022	6.894	1.898	0.7643	2.922	0.8064	0.1272
Farhani LCOA, 2012 [29]	3.946	1.471	0.7031	5.093	1.471	0.4832	2.164	0.6253	0.08169
Farhani PS, 2012 [29]	4.529	1.583	0.7363	5.757	1.583	0.548	2.445	0.6727	0.08831
Farhani SA, 2012 [29]	4.419	1.56	0.7158	5.625	1.55	0.5272	2.378	0.6585	0.08591
Ikhe, 2012 [30]	5.691	1.851	1.197	7.135	1.851	0.7865	3.031	0.7867	0.1192
Lokanath PSO, 2014 [37]	11.29	2.607	1.127	12.35	2.503	0.958	5.122	1.051	0.1661
Sharma ZN [31]	2.583	1.15	0.8432	2.745	0.9947	0.464	1.02	0.3887	0.05814
Sharma PSO [31]	1.379	0.7802	0.579	1.497	0.6519	0.2748	0.5701	0.2594	0.03438
Salim BFOA [38]	3.643	1.815	1.902	3.688	1.548	1.287	1.663	0.6717	0.1812
Jain ZN, 2014 [32]	18.79	3.565	1.684	21.57	3.565	1.343	9.168	1.515	0.2319
Jain Simplex, 2014 [32]	2.041	1.125	0.9412	2.308	0.995	0.5203	0.9637	0.4213	0.07984
Saifi PSO,2015 [33]	5.187	2.103	1.547	6.309	2.03	1.141	2.67	0.861	0.1916
Salma BAT [39]	1.386	0.8436	0.7085	1.828	0.7975	0.3729	0.7747	0.3386	0.05103
Ragini PSO [40]	2.501	1.247	0.7957	3.471	1.246	0.4895	1.478	0.53	0.08319
Ragini BTSA [40]	2.991	1.218	0.5133	3.941	1.218	0.3534	1.673	0.5175	0.06109

V. CONCLUSION

In this article, two-area non-reheat thermal power system is considered for solving the load frequency problem in power system. The gain of the PID controller are employed by multiple runs of Elephant Herding Optimization algorithm. The performance of proposed PID controller is compared with the PID controller in literature. Furthermore, it also shows that the proposed PID controller for two- area non-reheat power system is robust and is not affected the performance by changing the system parameter within the range of +25% to -25% of their nominal values of the parameters. The proposed PID controller show it is superior as compared to other controller in literature because it damping out the oscillation of the response of the change in frequency and power tie-line of the power system. In this paper, the comparative analysis of proposed controller in terms of performance indices with the controllers in literature. Overall, the proposed PID controller is better in respect of settling time, undershoot, ITAE, IAE and ISE analysis as compared to the controller in literature.

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