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Optimal design of PID controller for load frequency control using Harmony search algorithm

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Abstract

This paper deals with soft computing technique, used for tuning PID controller. Controller tuned with a harmony search algorithm is used for controlling the frequency and Tie-line power responses of a non reheat two area power system. Step load perturbation has been given in both areas simultaneously. The dynamic results obtained by the proposed controller are compared with PID controller of recent published paper. The performance of the controllers is simulated using MATLAB/Simulation software. The results of tuned PID are compared with conventional controller on the basis of settling-time, peak over-shoot and peak under-shoot. Proposed PID gives better results than the conventional controller. The comparative results also tabulated as a comparative performance.

Keywords: *Load frequency control (LFC), Automatic control error (ACE), Proportional Intergal Derivative controller (PID), Harmony search algorithm (HSA).*

1. Introduction

Power system operator has a responsibility that adequate power must deliver to consumer. Reliability and economically must maintain. For this control, strategy is needed [1]. It means that there should balance between real and reactive power. As reactive power depends on the voltage and real power on the generation, it means frequency [2]. The analysis for controlling frequency and voltage can be taken separately. In this paper, automatic frequency control is taken. As the load is changed; the frequency is changed to meet the requirement of the connected load [3]. The load is varied with fast rate and slow rate we are considering the fast variation; slow variation is not considered. In larger inerter-connected power system tie line power should be maintained in a tolerable limit with respect to load change [4]. It becomes necessary to regulate the input to the turbine by opening of valve the input can be steam or hydro for hydro alternator. For this, an efficient control strategy is required. The controlling of electric power of the generator by this method is automatic generation control (AGC) [5, 6]. In this paper, a step disturbance is considered, and it is seen that the frequency steady state error and tie line steady state error following the step disturbance should be zero [7].

In the ALFC, there are two loops primary loops and secondary loop, primary loop is fast, and it is called uncontrolled loop. The secondary loop is slow, which is called controlled loop. Secondary control loop is done to make the automatic control error to zero. The conventional control strategy for LFC problems is to be taken the integral of the control error as the control signal, an integral controller provides zero steady-state error. However, it exhibits poor dynamic behavior, to improve the dynamic behavior many control techniques are used such as linear feedback, optimal control, and variable structure control have been proposed [8]. Many algorithms for controlling the conventional controller gains are proposed. The algorithms are PSO, genetic algorithm, ZN algorithm [9].

In this paper, the harmony search algorithm is used for tuning the free coefficients of PID controller. Harmony search algorithm uses a Meta heuristic approach to solve many optimiza-

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tion problems this algorithm was inspired by the method used to improve the tuning or pitches of the music to obtain better harmony [10]. Harmony search algorithm works on the mimicking the improvisation of music players. As the most structural optimization methods are based on mathematical algorithms that require strongly built gradient information [11]. The harmony search algorithm does not require initial values and uses a random search instead of a gradient search; so that the derivative information is unnecessary. This algorithm is conceptual using the musical improvisation process of searching for a perfect state of harmony (i.e harmony memory) to automatically adjust parameter values. This algorithm does not require to fixe initial condition. This algorithm is used by engineers to solve the optimization problem [12].

Boroujeni et al [13], proposed work for two are power system. Author Tuned the PI by HSA for quenching the deviation in frequency and Tie-line power due to different loading conditions. Compare the result of tuned PI by tuned IP. Show effectiveness of both controllers in industries. Sambariya and Nath, 2015, have proposed the application of particle swarm optimization (PSO) in optimal tuning of PID parameters for two-area load frequency power system in [14]. The new NARMA L2 controller is presented in [15]. The fuzzy logic based controller for multi-area system is presented in [16]. The application of adaptive nero fuzzy logic controller is presented in [17].

Abedinia et al [18], proposed work to solve the LFC problem. By implementing a new multi-stage fuzzy (MSF) controller based on multi-objective Harmony search algorithm (MOHSA). Membership Function of fuzzy is designed automatically by the proposed MOHSA method. Compare results with other controllers used for LFC. Sanpala and Vakula [19], in proposed work two interconnected are with identical parameters are considered for study. The presented work better utilized the harmony search algorithm to design the optimal parameters of Fuzzy-PID.

Sambariya and Prasad [20], have designed a Fuzzy logic power system stabilizer, whose parameters are tuned by Harmony search algorithm. The Parameters of the PD controller are considered as the normalized factors of FPSS and Tuned using harmony search algorithm.

In this paper, conventional PID controllers are compared with HSA-PID controller. It is found that tuned PID controller is better than the conventional controller. The settling time, overshoot time, steady-state error is reduced by using a proposed controller as compared to the convention controller. By MATLAB software the frequency response, tie line power, governor power disturbance response is compared of both the area.

The paper is organized in 5 sections. The problem formulation with system description, process and objective function is presented in section 2.. The harmony search algorithm used to tune the parameters of PID controller is presented in section 3.. The system responses with proposed PID controller in terms of frequency and tie-line power are compared to that of the controllers available in literature and mentioned in section 4.. The paper is concluded in section 5. and followed with appendix, nomenclature and references.

2. Problem formulation

2.1. System description

The system under consideration is a two-area power system. It consists of governor, non-reheat turbine and load-inertia. The models of the components are solved for obtaining state vector matrix by state space modeling method. Defining the state variables in terms of differential variables of the system. The state variables as $x_1, ..., x_9$ are defined by differential variables as in Eqn. 1. The block diagram representation of the system is shown in Fig. 1. The u_1, u_2 and

$d_1 = \Delta p_{d1}, d_2 = \Delta p_{d2}$ are representing the control and disturbance variables.

$$\begin{aligned} x_1 &= \Delta f_1 \\ x_2 &= \Delta p_{t1} \\ x_3 &= \Delta p_{g1} \\ x_4 &= \Delta f_2 \\ x_5 &= \Delta p_{t2} \\ x_6 &= \Delta p_{g2} \\ x_7 &= \Delta p_{tie12} \\ x_8 &= \int ACE_1 dt \\ x_9 &= \int ACE_2 dt \end{aligned} \tag{1}$$

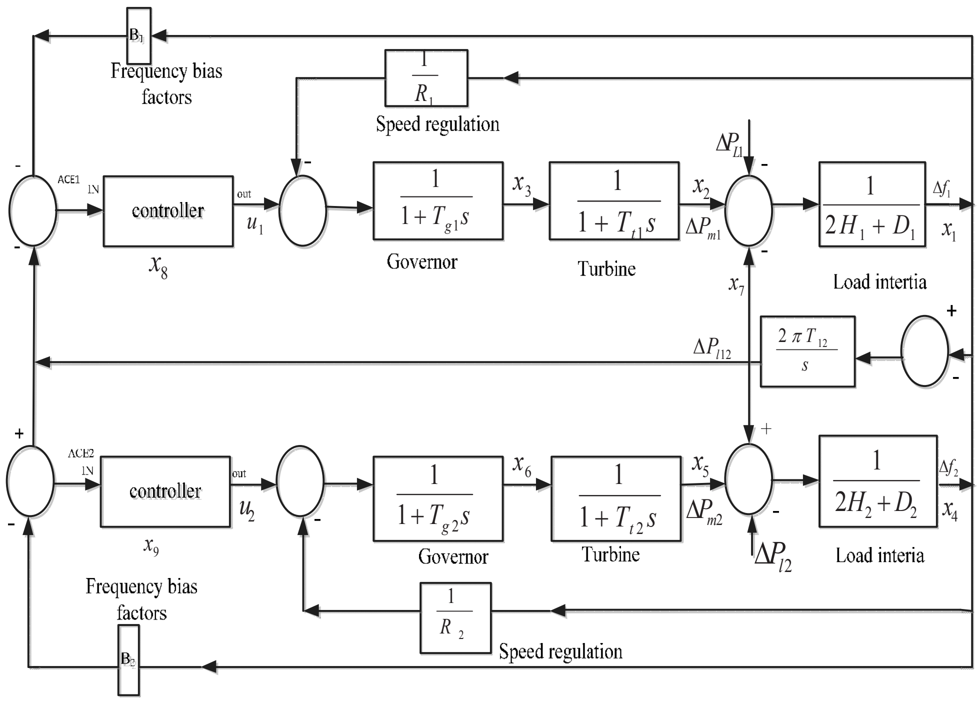

Figure 1. Block Diagram of two-area interconnected system

State space equations for two area are given as following:

$$\dot{x}_1 = \frac{-D_1}{2H_1}x_1 + \frac{1}{2H_1}x_2 + \frac{-1}{2H_1}x_7 + \frac{(-d_1)}{2H_1} \tag{2}$$

$$\dot{x}_2 = \frac{-1}{T_{t1}}x_2 + \frac{1}{T_{t1}}x_3 \tag{3}$$

$$\dot{x}_3 = \frac{-1}{R_1 T_{g1}}x_1 - \frac{1}{T_{g1}}x_3 + \frac{-1}{T_{g1}}u_1 \tag{4}$$

$$\dot{x}_4 = \frac{-D_2}{2H_2}x_4 + \frac{1}{2H_2}x_5 + \frac{1}{2H_2}x_7 - \frac{d_2}{2H_2} \tag{5}$$

$$\dot{x}_5 = \frac{-1}{T_{t2}}x_2 + \frac{1}{T_{t2}}x_6 \tag{6}$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \\ \dot{x}_6 \\ \dot{x}_7 \\ \dot{x}_8 \\ \dot{x}_9 \end{bmatrix} = \begin{bmatrix} \frac{-D_1}{2H_1} & \frac{1}{2H_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1 T_{g1}} & 0 & \frac{-}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-D_2}{2H_2} & \frac{1}{2H_2} & 0 & \frac{1}{2H_2} & 0 & 0 \\ 0 & \frac{-1}{T_{t2}} & 0 & 0 & 0 & \frac{1}{T_{t2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{R_2 T_{g2}} & 0 & \frac{-1}{T_{g2}} & 0 & 0 & 0 \\ 2\pi T_o & 0 & 0 & -2\pi T_o & 0 & 0 & 0 & 0 & 0 \\ -B_1 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -B_2 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \end{bmatrix} \tag{12}$$

$$\dot{x}_6 = \frac{-1}{R_2 T_{g2}} x_4 - \frac{1}{T_{g2}} x_6 + \frac{1}{T_{g2}} u_2 \tag{7}$$

$$\dot{x}_7 = 2\pi T_0 x_1 - 2\pi T_0 x_4 \tag{8}$$

$$\dot{x}_8 = (-B_1)x_1 - x_7 \tag{9}$$

$$\dot{x}_9 = (-B_4)x_4 + x_7 \tag{10}$$

The Eqns. 2 - 10 can be organized as a vector matrix as following in Eqn. 11.

$$\dot{x} = Ax + Bu + Cd \tag{11}$$

where x is state vector, u is control vector and d is the disturbance vector. The complete matrix representation is shown in following Eqn. 12.

The two systems interconnected are shown in Fig. 1. The Governor, turbine and load inertia block are represented with their time constant. The both areas are interconnected using tie-line. The relevant data of the system is presented in the Appendix.

2.2. Process

Study of load frequency control is considered for two interconnected area power system. Step Disturbance of 0.01 p.u is given to both areas. The u_1, u_2 are two controlled signal given to governor for controlling dynamic response deviations. Harmony Search algorithm is used for tuning the parameters of PID controller. The designed controller is used control the frequency and tie - line power deviations in the interconnected area are controlled. The main impact of HSA-PID is to control the transient response of the system. The tuning scheme of PID parameters is shown in Fig. 2.

2.3. Objective function

The area control error of both of the areas is sensed and the difference (i.e. error of ACE) is considered as the signal to be minimized under optimization. The parameters of both PID controllers are optimized under optimization using HS algorithm subjected to the upper and lower bounds of the parameters as shown in Eqn. 13.

$$\begin{array}{c} K_{pj}^{\min} \leq K_{pj} \leq K_{pj}^{\max} \\ K_{ij}^{\min} \leq K_{ij} \leq K_{ij}^{\max} \\ K_{dj}^{\min} \leq K_{dj} \leq K_{dj}^{\max} \end{array} \tag{13}$$

where, j stands for the PID controller connected an area i.e $j = 1, 2$. These parameters of the PIDs are optimized using the objective function as shown in Eqn. 14. It shows the minimization of integral square error (ISE) of the area control error for the simulation time T_{sim}.

$$ISE = \int_0^{T_{sim}} ACE_1(t) - ACE_2(t)\, dt \tag{14}$$

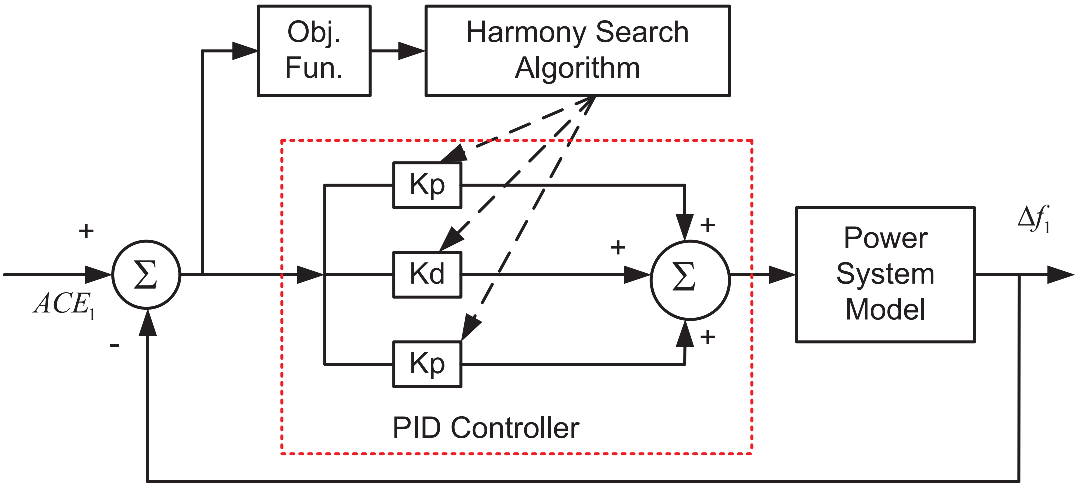

Figure 2. The scheme of optimization of PID parameters using harmony search algorithm

3. Harmony search algorithm

The harmony search algorithm (HSA) was developed by Geem.et.al in 2001 [21]. The HSA is made efficient by using improvisation technique used in music making. The musician selects the pitches of the instrument for getting better state of harmony. A musician improvisation is same as the search process in optimization. Every music pitch is equal to the appreciation of beauty of quantity [22].

The per-formation and efficiency of most of the Meta heuristic algorithm depends on the extent of balance between diversification and intensification during the search process. The exploitation is the ability of an algorithm to exploit the search space in the neighborhood of the current good solution using the information already collected [12]. The pitch adjustment technique helps in finding the best solution in the harmony memory [23].

The harmony search algorithm depends on the points such as Harmony memory size (HMS), Harmony memory consideration rate (HMCR), when a musician is improving, he or she has three possible choice:(1) playing any famous exactly from his or her memory,(2) playing something similar to the for a mentioned tune(thus adjusting the pitch slightly),(3) composition new or random notes [24, 25].

3.1. Steps of HS algorithm

Each row of harmony memory (HM), consists of N decision variables and the fitness score ω ([$x^1, x^2, ..., \omega$]). The HM is initialized with HMS randomly generated solution vectors [24].

3.1.1. Initialization

Let in an optimization problem, the objective function is represented by Minimization of $F(x)$, which is subjected to $x_i \in X_i$, $i = 1, 2, 3N$. Where, x is the set of design variables (x_i), ($x_i^L \leq x_i \leq x_i^U$), and N is the count of design variables.

- Define the variable limits as lower (x_i^L) and upper (x_i^U) or $x_i^L \leq x_i \leq x_i^U$.
- Deciding the value of harmony memory size (HMS), from the range $10 \leq HMS \leq 100$.
- Decide value of HMCR (harmony memory consideration rate) within the range $0.0 \leq HMCR \leq$

1.0.

$$x'_i \leftarrow \left\{ \begin{array}{ll} x'_i \quad l\{x_i^1, x_i^2, ..., x_i^{HMS} & : prob.\ HMCR \\ x'_i \in X_i & : prob.\ (1 - HMCR) \end{array} \right\} \tag{15}$$

- Decide the value of PAR (pitch adjustment rate) from the range $0.0 \leq PAR \leq 1.0$.

$$x_j^i = x_j^L + rand(0,1) \times (x_j^U - x_j^L) \tag{16}$$

$$x'_i \leftarrow \left\{ \begin{array}{ll} yes & with\ probability\ PAR \\ no & with\ probability\ (1 - PAR) \end{array} \right\} \tag{17}$$

- Compute the step size (b_i) as $b_i = \frac{x_i^U - x_i^L}{N}$.
- Specify the maximum limit of iteration number.

3.1.2. HM Initiation

The HM matrix as in Eqn. 18 is filled with randomly generated possible solution vectors for HMS and is sorted by the values of the objective function $f(x)$.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & ... & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & ... & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & ... & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & ... & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \Rightarrow \begin{bmatrix} f(x^1) \\ f(x^2) \\ \vdots \\ f(x^{HMS-1}) \\ f(x^{HMS}) \end{bmatrix} \tag{18}$$

3.1.3. Improvisation

A New Harmony vector $x' = (x'_1, x'_2, ..., x'_n)$ is generated based on three criteria: random selection, memory consideration, and pitch adjustment.

- *Random Selection*: To decide the value of x'_1 for the New Harmony $x' = (x'_1, x'_2, ..., x'_n)$, the HS algorithm randomly selects a value from range with a probability of $1 - HMCR$.
- *Memory Consideration*: To decide the value of x'_1, the HS algorithm randomly selects a value from the HM with a probability of $HMCR$, where $j = 1, 2, ..., HMS$. It can be represented as in Eqn. 18.
- *Pitch Adjustment*: Each element of the New HM vector $x' = (x'_1, x'_2, ..., x'_n)$ is subjected to determine whether it should be pitch-adjusted or not. The selected x'_i is further adjusted by adding an amount to the value with a probability of PAR. The PAR parameter is called the probability of pitch adjustment and is represented by Eqn. 17 [26].

  The $'no'$ with probability $1 - PAR$ represents that the probability of not adding any amount. On the other hand, if the pitch adjustment decision for x'_i is yes, then it is replaced by $x'_i \leftarrow x'_i \pm bw$; where, bw is distance bandwidth in case a continuous variable. The pitch adjustment is performed on every variable of the New HM vector.

3.1.4. Updating HM

Let the HM vector is $x' = (x'_1, x'_2, ..., x'_n)$, which is resolved by minimization of objective function is better than the worst harmony present in the HM. Therefore, the New Harmony is inserted into the HM, while, the worst harmony is removed from the HM.

3.1.5. Stopping criterion

If the maximum count of improvisations is reached and the stopping criterion as maximum number of iterations is satisfied, then the process of computation is terminated. Otherwise, go to steps improvisation and updating HM as above to repeat the process. The HS algorithm is shown in the Fig. 3.

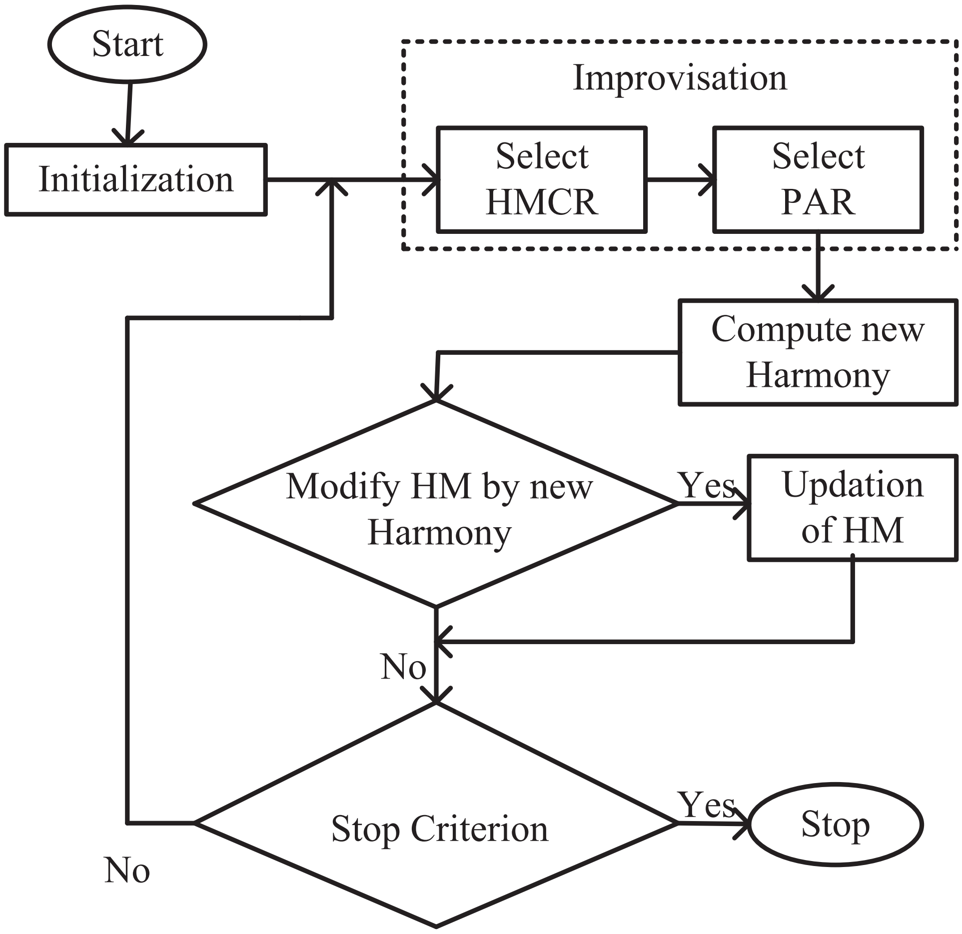

Figure 3. Working of Harmony Search Algorithm

4. Result and discussion

4.1. Optimization of PID parameters

The system shown in Fig. 1 equipped with PID controllers with unknown parameters as $K_{p1,2}, K_{i1,2}, K_{d1,2}$ is simulated to tune these parameters using harmony search algorithm. The problem of optimization is subjected to minimization of ISE based objective function as shown in Eqn. 14 and the parameter bounds as in Eqn. 13. The optimized PID parameters using HS algorithm are shown in Table 1. The plot of the fitness function with iteration counts is shown in Fig. 4. It can be seen that the fitness function gets reduced as the iteration count is increased and around 190 it becomes constant. It is the instant, where the optimal parameters are considered.

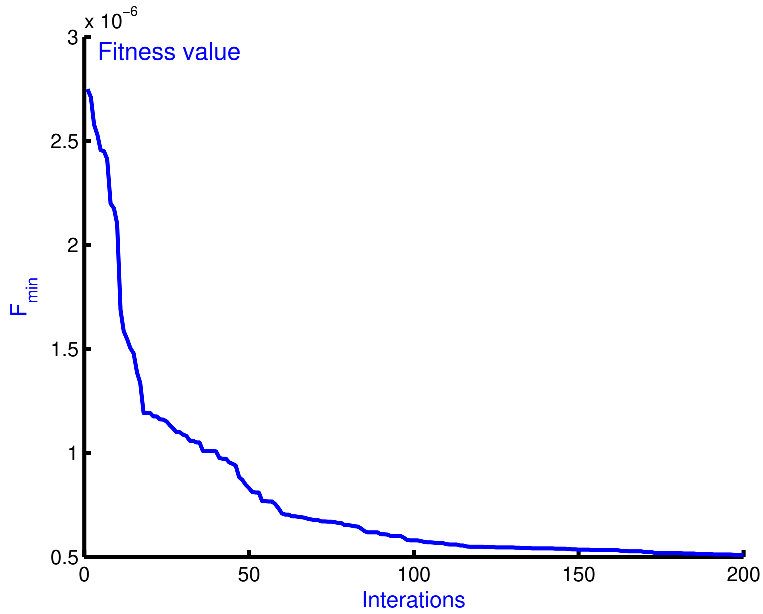

Figure 4. The variation of fitness function with iterations using harmony search algorithm

Table 1. Comparison of parameters of PID controller in literature and proposed HSA-PID controller

Controllers	K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
HSA-PID (Prop.)	1.8677	1.9934	1.9099	1.4324	1.9139	1.8247
PSO-PID [27]	3.0	0.8531	0.35	1.98	0.3919	0.1978
Conv-PID [28]	0.1109	0.2742	0.1110	0.0121	0.2019	0.0030
PSO-PID [5]	22.8070	2.0734	17.4628	22.8070	2.0734	17.4628
BFOA-PID [29]	0.1317	0.4873	0.2506	0.1317	0.4873	0.2506
PSO-PID [30]	0.790	1.4252	0.4652	0.790	1.4252	0.4652

4.2. Performance comparison

In this presented work, a two area interconnected system with non-reheat turbine is considered for load frequency control (LFC) problem. A step load of 0.01 p.u are given in both areas, which show robustness of the system. Generally, literature survey on LFC show that authors considered in general 1% step load perturbation in an area is given for an optimal results. In proposed work, disturbance is given in both area. It has been used for PID tuning. The HSA-PID results are compared with recent published papers by considering their PID parameters. Frequency responses of area-1 and area-2 are shown in Fig. 5 - Fig. 6. The tie - line power response is shown in Fig. 7. It is seen that proposed controller results are far better than the conventional controller. The tie-line power response of an interconnected area obtained by the proposed controller is compared with PID controller. Comparison of frequency responses on the basis of settling - time, over - shoot and under-shoot as given in the tabular form in Table 2 - Table 3 and the tie

-line comparison is given in Table 4. It is found that HSA tuned PID is better than controllers in [5, 27–30].

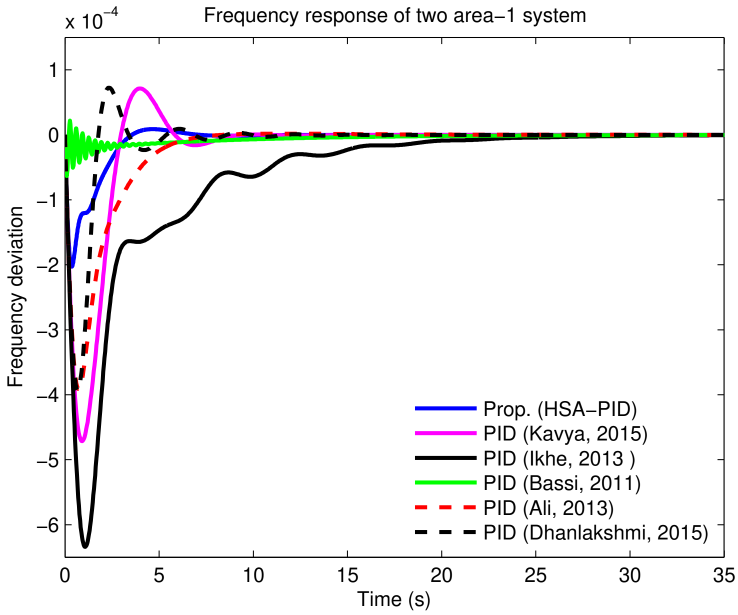

Figure 5. Frequency response of area-1 obtained by HSA-PID and compared with controllers in [5, 27–30]

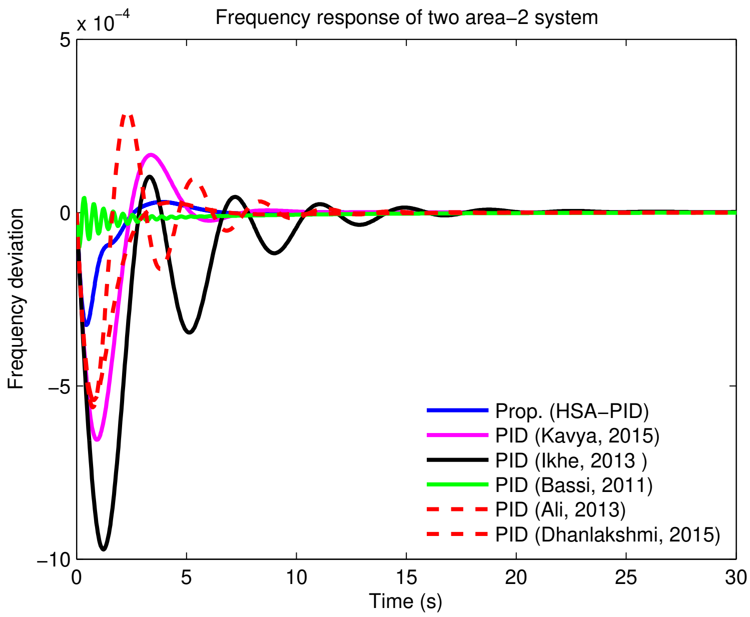

Figure 6. Frequency response of area-2 obtained by HSA-PID and compared with controllers in [5, 27–30]

Table 2. Comparison of frequency response of area-1 of HSA-PID compared with conventional PID

Controllers	Settling time	Over shoot	Under shoot
HSA-PID	12	0.085×10^{-6}	-2.03×10^{-4}
PSO-PID [27]	14.1	7.34×10^{-4}	-4.71×10^{-4}
Conv-PID [28]	28.35	-	-6.51×10^{-4}
PSO-PID [5]	33.16	2.2×10^{-4}	-6.3×10^{-4}
BFOA-PID [29]	17.28	-	-3.9×10^{-4}
Conv-PID [30]	18.32	7.34×10^{-4}	-3.8×10^{-4}

Table 3. Comparison of frequency response of area-2 of HSA-PID compared with conventional PID

Controllers	Settling time	Over shoot	Under shoot
HSA-PID	12.2	0.31×10^{-4}	-3.24×10^{-4}
PSO-PID [27]	13.0	1.65×10^{-4}	-6.32×10^{-4}
Conv-PID [28]	27.50	1.05×10^{-4}	-9.70×10^{-4}
PSO-PID [5]	27.10	4.4×10^{-4}	-1.7×10^{-4}
BFOA-PID [29]	16.20	2.8×10^{-5}	-5.4×10^{-4}
Conv-PID [30]	28.55	3.00×10^{-4}	-5.5×10^{-4}

Table 4. Comparision of Tie-line power response of area-12 of HSA-PID compared with conventionl PID

Controllers	Settling time	Over shoot	Under shoot
HSA-PID	26.0	1.70×10^{-4}	-
PSO-PID [27]	27.2	4.4×10^{-4}	-4.4×10^{-4}
Conv-PID [28]	43.0	1.043×10^{-4}	-
PSO-PID [5]	-	2.25×10^{-4}	-
BFOA-PID [29]	29	3.87×10^{-5}	-0.98×10^{-4}
Conv-PID [30]	27.0	3.35×10^{-4}	-1.0×10^{-4}

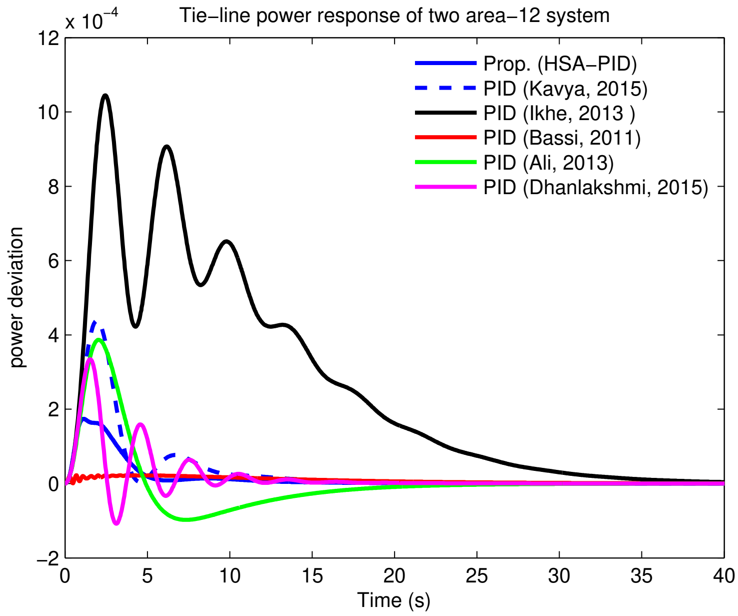

Figure 7. Tie-line power response of area-12 obtained by HSA-PID and compared with controllers in [5, 27–30]

5. Conclusion

This study shows the application of tuned PID controller for Load Frequency Control of a two area having different parameter's values. In this paper, the dynamic responses of the system have been examined by considering a 1% step load perturbation in either or simultaneous areas. The conventional controller and PID tuned with different techniques are found to be slow as compared to PID tuned by the harmony search algorithm. The transients in responses are removed much faster by proposed PID as compared to the classical controller.

Appendix

Data for area-1 of two-area system

$R_1 = 0.005$, $D_1 = 0.60$, $H_1 = 5.0$, $BasePower = 1000MVA$, $T_{g1} = 0.20$, $T_{t1} = 0.50$, $B_1 = 20.1$

Data for area-2 of two-area system

$R_2 = 0.0625$, $D_2 = 0.90$, $H_2 = 4.0$, $BasePower = 1000MVA$, $T_{g2} = 0.30$, $T_{t2} = 0.60$, $B_2 = 16.90$

Nomenclature

R_1, R_2 represents the speed regulation.
D_1, D_2 represents the frequency-sensitive load coefficient.
H_1, H_2 represents inertia constant.
T_{g1}, T_{g2} represents the governor time constant.
T_{t1}, T_{t2} represents the turbine time constant.
B_1, B_2 represents the frequency bias factors.

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