Harmony Search based PID for Multi Area Load Frequency Control Including Boiler Dynamics and Nonlinearities

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Abstract: - This paper proposes a new Artificial Intelligence technique known as Harmony Search (HS) for optimal tuning of PID controllers for Load Frequency Control (LFC). The system proposed here is a three area with reheat thermal system containing nonlinearities represented by Generation Rate Constraint (GRC), Dead Band and Boiler Dynamics. The proposed system has been chosen especially to mimic typical system behaviour in actual operation. Four different generations (versions) of HS have been used for tuning the PID controllers. The closed loop response of the system using the optimized PID gains has been compared with another one tuned by Genetic Algorithm (GA). Simulation results significantly verify that the sample controller can favourable performance and contribute efficiently enhancing the system dynamic behaviour.

Key-Words: - Harmony search, Load Frequency Control**,** PID controller, Objective Function

1 Introduction

LFC is considered as one of the main and most important topics in the power system. The main purpose of LFC is to maintain the system frequency of each area and the inter-area tie line power within tolerable limits. This important function is authorized to LFC due to the fact that a reliable power system should maintain voltage and frequency at scheduled range while providing an acceptable level of power quality [1].Usually LFC is classified to three levels:

•Primary control: is done by governors of the generators, which provide immediate action to sudden change of load.

•Secondary control: keeps frequency at its nominal value by adjusting the output of selected generators (controller is needed).

•Tertiary control: is an economic dispatch that is used to operate the system as economically as possible [2]. Several control techniques had been applied to LFC problem during the past years, which has greatly improved the response of power system to a large extent. A robust LFC using LMI control technique for single area power system has been designed in [3]. The disadvantage of this method represents in the complexity of controller design and implementation, which in turn makes the process very complex especially for large scale interconnected power systems. In [4] LFC with fuzzy logic controller (FLC) including nonlinearities and boiler dynamics is introduced which has greatly improved the performance of the controller. In [5] another technique had been suggested for tuning the parameters of a PID controller for LFC in a single area power system by using particle swarm optimization (PSO). Ant Colony Optimization (ACO) [2] also used in this field for the purpose of tuning of a PID parameters for single area with reheat thermal model including nonlinearities. Bacteria Foraging Optimization (BFO) technique has been applied to a two area system with different step load changes in [6].

The paper is organized as follows: a brief description for HS technique is illustrated in Section 2. Section 3 will focus on the modelling of three area power system including nonlinearities and boiler dynamics and will discuss the control scheme. In Section 4, simulation and results obtained from the application of HS tuned PID controllers on the system. The main conclusions are driven in section 5.

2 Harmony Search Algorithm

HS was proposed by Zong Woo Geem in 2001[7]. It is well known that HS is a phenomenon-mimicking algorithm inspired by the improvisation process of musicians. In the HS algorithm, each musician (decision variable) plays a note for finding a best harmony (global optimum) all together. In this section, a brief review of HS algorithm and its variants is given.

2.1 The Basic Harmony Search Algorithm

In the basic HS algorithm each solution is called a harmony and represented by an n-dimension real vector. An initial population of harmony vectors is randomly generated and stored in a harmony memory (HM). Then a new candidate harmony is generated from all of the solutions in the HM by using a memory consideration rule, a pitch adjustment rule and a random re-initialization.

Finally, the HM is updated by comparing the new candidate harmony and the worst harmony vector in the HM. The worst harmony vector is replaced by the new candidate vector if it is better than the worst harmony vector in the HM. The above process is repeated until a certain termination criterion is met. The basic HS algorithm consists of three basic phases, namely, initialization, improvisation of a harmony vector and updating the HM as described below in Fig. 1 [7]. HS tries to find a vector X which optimizes a certain objective function through the following governing equations and steps:

Step 1: generate random vectors (X^1,…., X^{HMS}) as many as HMS (Harmony Memory Size), then store them in harmony memory (HM) in matrix

$$HM = \begin{pmatrix} X_1^1 & . & . & . & X_n^1 \\ . & & & & \\ X_1^{HMS} & & & & X_n^{HMS} \end{pmatrix}$$

Step 2: with probability HMCR (Harmony Memory Considering Rate ($0 \le HMCR \le 1$), pick the stored value from HM:

$$X'_i = X_i^{\mathrm{int}(u(0,1)*HMS)+1} \qquad (1)$$

Step 3: perform additional work if the value in step 2 came from HM. with probability PAR (pitch adjusting rate; ($0 \le PAR \le 1$), change X_i' by a small amount: $X'_i \leftarrow X_i + \delta$ or $X'_i \leftarrow X_i - \delta$ for discrete variable; or $X'_i \leftarrow X_i + fw.u(-1,1)$ for continuous variable.

Step 4: If X_i' is better than the worst vector X^{worst} in HM, replace X^{worst} with X_i'.
Step 5: Repeat from Step 2 to Step 4 until termination criterion (e.g. maximum iterations) is satisfied.

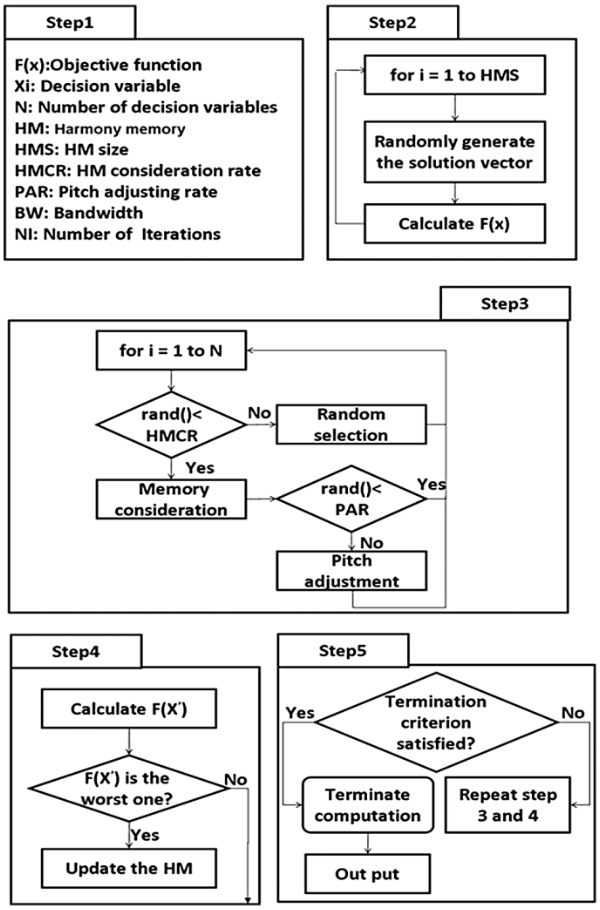

Fig.1. Optimization procedure of the Harmony Search algorithm.

2.2 The Improved Harmony Search (IHS)

The IHS algorithm addresses the shortcomings of the basic HS algorithm which uses fixed values for *PAR* and *BW* parameters [8]. The IHS algorithm applies the same memory consideration, pitch adjustment and random selection as the basic HS algorithm, but dynamically updates values of *PAR* and *BW* as below:

$$PAR(i) = PAR_{min} + \frac{PAR_{max} - PAR_{min}}{NI} * i \tag{2}$$

$$BW(i) = BW_{max} * e^{\left(\frac{\ln\frac{BW_{min}}{BW_{max}}}{NI} * i\right)} \tag{3}$$

In Eq. (2), *PAR (i)* is the pitch adjustment rate in generation *i*, PAR_{min} is the minimum adjustment rate, PAR_{max} is the maximum adjustment rate. In Eq. (3), *BW (i)* is the distance bandwidth in generation i, BW_{min} and BW_{max} are the minimum and maximum bandwidths, respectively.

2.3 Global Best Harmony Search (GHS)

Inspired by the particle swarm optimization [9], a GHS algorithm that modifies the pitch adjustment rule has been proposed [10]. Unlike the basic HS algorithm, the GHS algorithm generates a new harmony vector XB = {$x_B(1)$, $x_B(2)$,…., $x_B(n)$ } in the HM. The pitch adjustment rule is given as below [11]:

$$\mathrm{X_{new}}(\mathrm{j}) = \mathrm{X_B}(\mathrm{k}) \quad \mathrm{j} = 1,2, \ldots \mathrm{n} \tag{4}$$

where *k* is a random integer between 1 and *n*. In addition, the GHS algorithm employs the dynamic updating procedure for the *PAR* parameter, Eq. (4). It is claimed that the modified pitch adjustment allows the GHS algorithm to work more efficiently on both continuous and discrete problems. The advantage of this algorithm is that it selects the global best solution every generation as it is without any adjustment to the values of the variables.

2.4 Self Adaptive GHS (SGHS)

An extension of the GHS algorithm, a self-adaptive GHS (SGHS) algorithm is presented in this section. Unlike the GHS algorithm, the SGHS algorithm employs a new improvisation scheme and an adaptive parameter tuning method. The GHS algorithm takes advantage of the best harmony vector X_B to produce a new vector X_{new}. However, the modified pitch adjustment rule may break the building structures in X_B, so that X_{new} may become worse than X_b with a high probability when solving problems with a global optimum having different numerical values for different dimensions. Therefore, to better inherit good information from X_B, a modified pitch adjusting rule is presented below:

$$x_{new}(j) = x_B(j) \quad j = 1,2, \ldots n \tag{5}$$

It should be noted that, according to the modified pitch adjustment rule $x_{new}(j)$,is assigned to the corresponding decision variable $x_B(j)$ in X_B, while in the GHS algorithm, $x_{new}(j)$ is determined randomly by selecting amongst any one of the decision variables of X_B.

In addition, in the memory consideration phase, the equation in GHS is replaced by Eq. (6) in order to avoid getting trapped in a locally optimal solution.

$$x_{new}(j) = x_a(j) \pm r * BW \tag{6}$$

In the SGHS algorithm, four control parameters HMS, HMCR, PAR and BW are closely related to the problem being solved and the phase of the search process that may be either exploration or exploitation. In this paper, HMS is kept as a user specified value so as to deal with different problems with different dimensions. The other three parameters are either learnt or dynamically adapted with respect to the favourable evolution of the search process [7].

3 Thermal Power System

In this section a detailed discussion about the model under study will be introduced.

3.1 System Model

The system investigation is carried out on a three area interconnected reheat thermal power system as shown in Fig. 2 [12-13].It contains nonlinearities represented in GRC and dead band (backlash).The first one as its name implies (GRC) respects for the turbine illustrates the limitation on the generation rate of change in the output generated power due to the limitation of thermal and mechanical movements [14], for thermal stations it is taken to be 0.1 p.u Mw per minute [15]. The second nonlinearity is defined as the total magnitude of a sustained speed change; within which there is no resulting change in valve position. All types of governors have a dead band in response, which is important for power system frequency control in the presence of disturbances, here it is taken to be 0.0005 [14]. The system is simulated in presence of boiler dynamics which has a significant effect on the dynamic behaviour of the system.

3.2 Boiler Dynamics

The model of boiler dynamics is represented in Fig. 3 [16]. Boiler is a device meant for producing steam under pressure. The model is basically for a drum type boiler. An oil/gas fired boiler system has been employed in this study, since such boilers respond to load demand changes more quickly than coal-fired units [17]. Drum type boiler is otherwise known as recirculation boiler which relies on natural or forced circulation of drum liquid to absorb energy from the hot furnace walls, called water walls for generating steam. The boiler receives feed water which has been preheated in the economizer and provides saturated steam outflow. The changes in generations are initiated by turbine control valves and the boiler controls respond with necessary

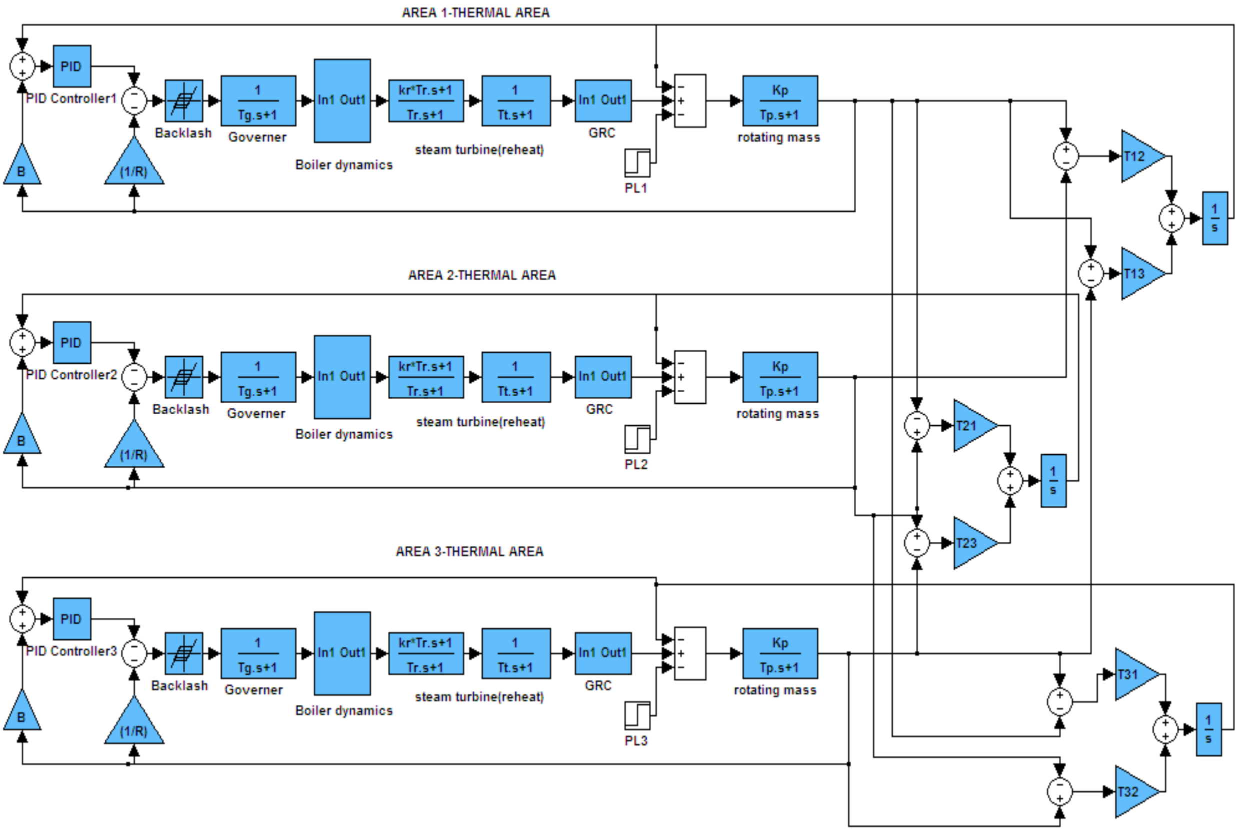

Fig. 2 Three area power system model.

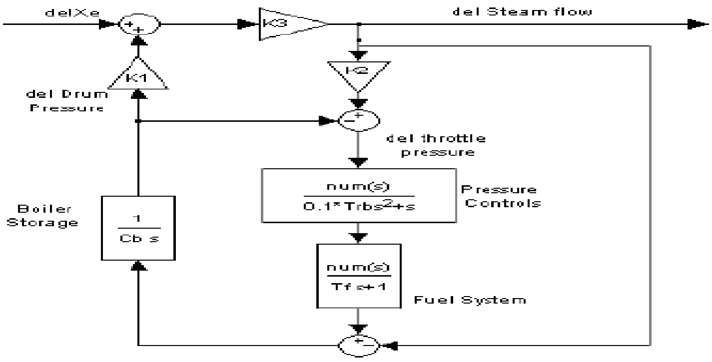

Fig. 3 Boiler dynamics model.

control action, changes in steam flow and changes in throttle pressure, the combustion rate and hence the boiler output.

3.3 Control Scheme

The controller type used here is a PID controller with the transfer function given in Eq. (6):

$$K(s) = K_p + K_i / s + K_d s \qquad (6)$$

Where k_p, k_i, k_d are proportional, integral and differential gains respectively. The input to the controller is the area control error (ACE), and the output is u(s) as shown in Eq. (7).

$$u(s) = -K(s) * ACE \qquad (7)$$

The function of each part of a PID controller can be described as follows, the proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady-state error, and finally the derivative part dampens the dynamic response and improves the system stability [2]. In this work the integrated time absolute error for the frequencies and tie line powers is used as the objective function for tuning the PID controllers as given in Eq. (8).

$$J = \int_0^{\infty} t\left\{ \left|\Delta f_i\right| + \left|\Delta p_{tie\,ij}\right| \right\} \quad i = 1,2,3,...,\ i \neq j \qquad (8)$$

4 Simulation and Results

In this section the values of PID controller gains, given in Table 1, tuned by the HS and its variants have been used to test the performance of the system for load increment of 1% in area 1. The response of the system has been compared with GA tuned PID, to demonstrate the robustness and effectiveness of the proposed algorithm. The response of frequency deviations and tie line powers is shown in Fig (4, 5, 6, 7, 8, and 9).The settling time, percentage overshoot and percentage undershoot for frequency deviations and tie line powers have been recorded and tabulated in Table 2. From these results it is found that overshoot and settling time for SGHS base PID for Δf1 (for example) have been reduced than HS based PID by 22% and 16% respectively, also reduced than GA based PID by 279% and 25%. Finally we can conclude that SGHS is the best and more efficient type among the four stated types.

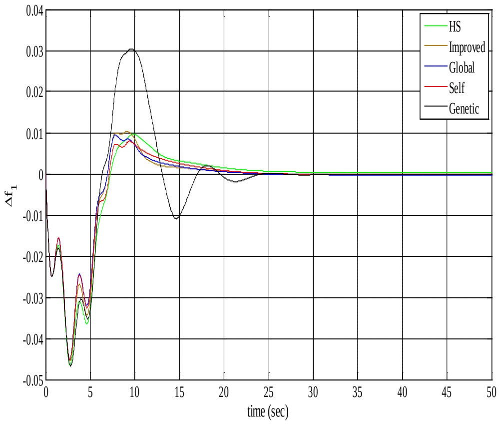

Fig. 4.Frequency response in area 1.

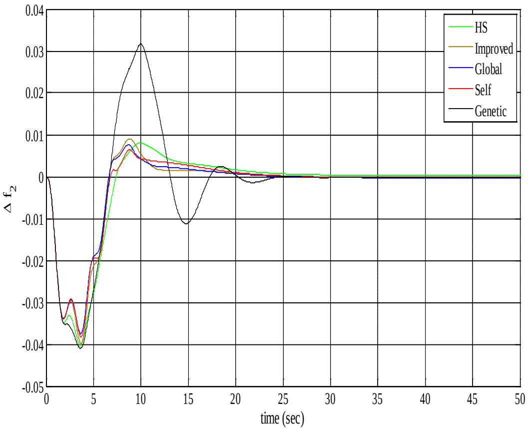

Fig. 5.Frequency response in area 2.

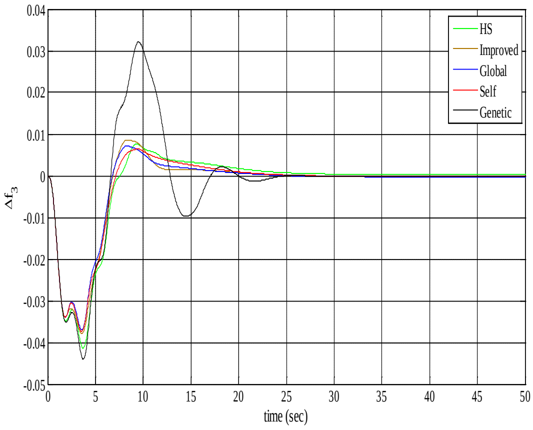

Fig. 6.Frequency response in area 3.

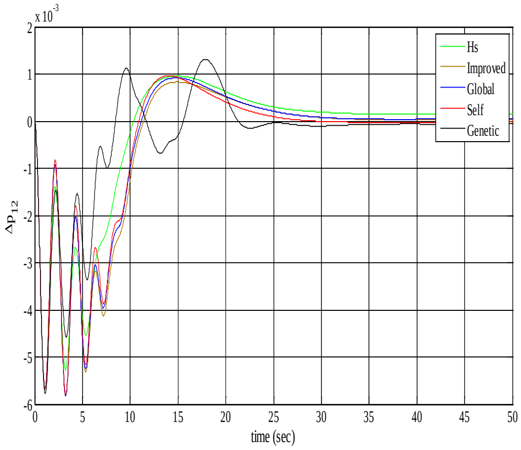

Fig. 7.Tie line power deviation Δptie12.

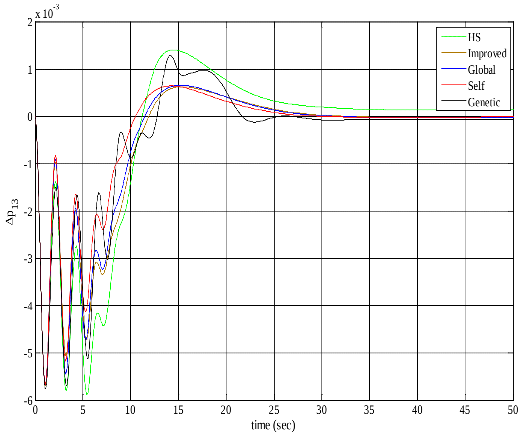

Fig. 8.Tie line power deviation Δptie13.

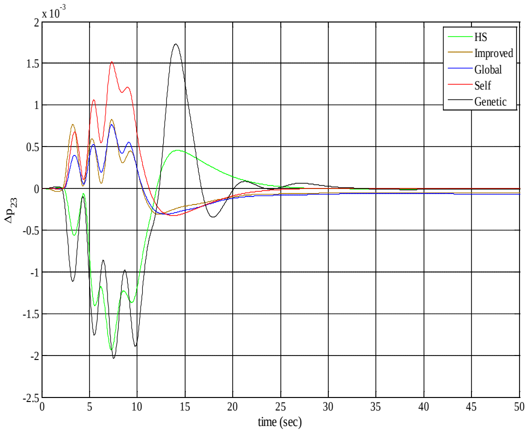

Fig. 9.Tie line power deviation Δptie23.

Table 1.Values of PID gains.

Type	% overshoot			% undershoot			Settling time (seconds)		
	Δf_1	Δf_2	Δf_3	Δf_1	Δf_2	Δf_3	Δf_1	Δf_2	Δf_3
HS	0.967	0.8	0.76	4.46	4	4.1	28	28	28
Improved	1	0.9	0.85	4.5	3.9	3.7	25	26	26
Global	0.94	0.75	0.72	4.5	3.8	3.7	24.5	25	25
Self	0.79	0.63	0.64	4.5	3.8	3.7	24	24	24
GA	3	3.1	3.2	4.68	4.1	4.4	30	30	30

Table 2.System Performance.

Type	Area 1			Area 2			Area 3		
	K_p	K_i	K_d	K_p	K_i	K_d	K_p	K_i	K_d
HS	15.7468	5	10.8487	20	5	8.9577	11.0435	10.3773	5
Improved	19.8291	5.0373	6.314	19.634	15.8483	10.0647	19.7984	13.1129	17.1162
Global	19.5649	5.4701	6.131	16.3497	12.5308	7.4084	19.5913	9.6538	8.8064
Self	16.794	5.4672	5.0174	18.5253	14.3411	7.7244	19.8241	5.7857	7.5958
GA	8.43	17.4864	19.3019	10.9832	5.3665	14.6309	11.6005	18.4158	13.3748

5 Conclusions

In this paper a PID controller which is tuned via HS algorithm has been strongly proposed for LFC problem. The results declared that HS and its variants based PID is capable to guarantee robust stability and robust performance in presence of nonlinearities and boiler dynamics. The effect of boiler dynamics is to increase the settling time and oscillations of the system and makes the system more realistic. The proposed controllers succeeded in damping all oscillations, minimizing settling time and reducing overshoot. From the above results and figures it is clear also that the fourth generation HS type which is called SGHS algorithm is the best among all HS family which differ from all other types by adjusting the *PAR* value during the solution process.

Appendices

(a) System data: [12]

T_{ti}=0.3s, T_{gi}=0.02s, K_{ri}=0.333, T_{ri}=10s

T_{pi}=20 s, T_{12}= T_{13}= T_{23}=0.444, i = 1, 2& 3

R_i=2.4 Hz/ pu MW, K_{pi}=120 Hz/pu MW

B_i =0.425 pu MW/Hz

(b) Boiler data: [12]

K_1= 0.85, K_2= 0.095, K_3= 0.92, C_b= 200

T_f= 10, Trb= 69

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