An Optimal LFC in Two-Area Power Systems Using a Meta-heuristic Optimization Algorithm

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Article Info

ABSTRACT

In this study, an optimal meta-heuristic optimization algorithm for load frequency control (LFC) is utilized in two-area power systems. This meta-heuristic algorithm is called harmony search (HS), it is used to tune PI controller parameters (K_p, K_i) automatically. The developed controller (HS-PI) with LFC loop is very important to minimize the system frequency and keep the system power is maintained at scheduled values under sudden loads changes. Integral absolute error (IAE) is used as an objective function to enhance the overall system performance in terms of settling time, maximum deviation, and peak time. The two-area power systems and developed controller are modelled using MATLAB software (Simulink/Code). As a result, the developed control algorithm (HS-PI) is more robustness and efficient as compared to PSO-PI control algorithm under same operation conditions.

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1. INTRODUCTION

In parallel power systems operations, load frequency control is in reality one of the most important parts which used to minimize area frequency deviation and keep stable tie-line power [1]. The main matter is how to keep the balance between the active and reactive powers which are transported from the generators to utilizers during a wild grid. The balance between both the active and reactive powers at the two ends of the power system effects directly the frequency and the voltage magnitude at the load side. The objectives of load frequency control (LFC) are to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zeros [2]. The frequency is highly dependent on the active power while the voltage is highly dependent on the reactive power.

In last decades, a lot of researchers are applied several strategies to give a solution for the load frequency control (LFC) problems [3],[4]. The performance of LFC depends on the feedback controller design in order to maintain the tie line power flow and the system frequency at their scheduled values [5]. The area control error (ACE) is very important part with the LFC loop which is considered as the control output [6]. The output error of ACE in each power system area demonstrates the relative error feedback in the frequency with respect to the flow of tie-line power. To design a proper controller to minimize the ACE value to be zero, PI controller has been used in different fields due to its simplicity. But, the big obstacle of PI controller is tuning its parameters (K_p, K_i). The methods are used to tune (K_p, K_i) parameters are the Ziegler Nichol's method [7] and trial-and-error approach [8],[9], but these are not efficient with systems have

different load changes in term of multiple interconnected power systems. For this reason and according to the literature survey, Soft-computing techniques such as such as differential evolution [10], practical swarm optimizations [11]-[15], ant colony optimization [16], and genetic algorithms [17],[18] have been widely applied for PI controller tuning in parallel-interconnected power systems.

This research presents an optimal load frequency control (LFC) using PI controller based on harmony search optimization (HS) technique for parallel two-area power system. The two-area power system and LFC loop including the proposed HS-PI controller are modelled using Matlab environment. The integral absolute error (IAE) function is used to determine its minimum value for a step load change. For a good dynamic performance, the robustness of the proposed HS-PI control algorithm is compared with the PI controller based particle swarm optimization (PSO) named PSO-PI controller in terms of time settling, maximum deviation, and peak time.

2. LFC SIMULINK MODEL WITH PROPOSED CONTROLLER

The overall power system of two-area power systems including the LFC model and the PI controller is investigated as shown in Figure 1. Each power system has primary and secondary loops respectively and feedback controller. OUT_1 and OUT_2 are the control outputs of the proposed PI controllers respectively; DPL_1 and DPL_2 are the disturbance load changes; DW_1 and DW_2 are represented the frequency changes in each power system. The nominal parameters of the overall power system are given in [19]. An area control error (ACE) is used for each area to reduce its own value to be zero [20], which is defined as:

$$ACE_1 = B_1\Delta\omega_1 + \Delta P_{12} \tag{1}$$

$$ACE_2 = B_2\Delta\omega_2 - \Delta P_{12} \tag{2}$$

where ΔP_{12} represents the change in the tie line power plant, B_1 and B_2 are the bias frequencies for each area, $\Delta\omega_1$ and $\Delta\omega_2$ represent the frequency deviation for each area.
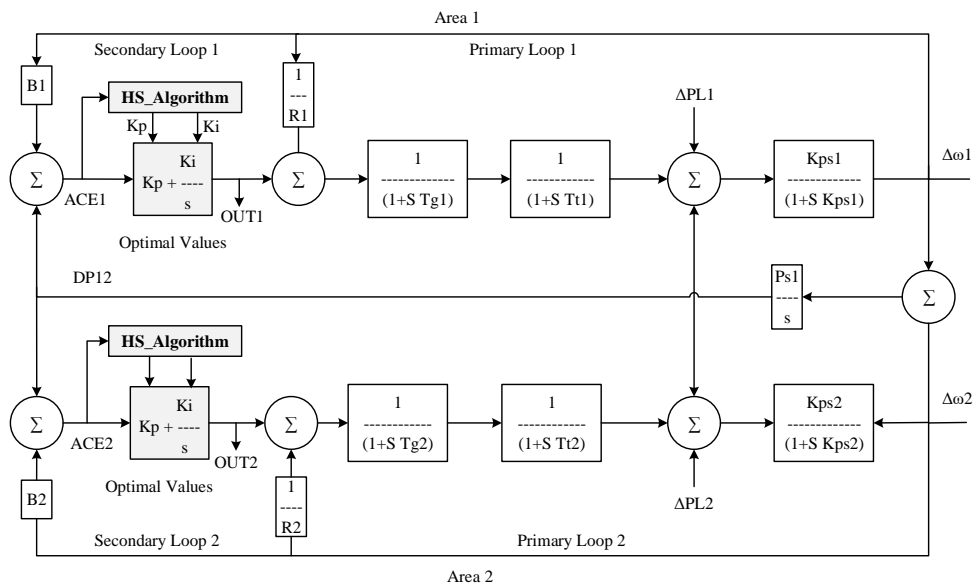

Figure 1. LFC Simulink model with proposed controller

PI controller is one of the popular feedback controller used with the load frequency control for providing an excellent control performance and higher stability. The transfer function of the PI consists of two basic parameters; Proportional (P) and Integral (I). According to [21] and [22], the typical transfer function of the classical PI controller in terms of Laplace domain is described below:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} \tag{3}$$

where, $U(s)$ and $E(s)$ are the control signal and the error signal which is the difference between the input and the feedback correspondingly. K_p is the proportional gain and K_i is the integration gain. Moreover, the output value of the proposed PID controller is given below which generates the proper control signal to keep the system parameters within the nominal values;

$$out(t) = K_p e(t) + K_i \int_0^t e(t)dt \tag{4}$$

where $out(t)$ and $e(t)$ are the control and tracking error signal which is in the form of time domain.
For area1:

$$out_1(t) = K_{p1} ACE_1(t) + K_{i1} \int_0^t ACE_1(t)dt \tag{5}$$

For area2:

$$out_2(t) = K_{p2} ACE_2(t) + K_{i2} \int_0^t ACE_2(t)dt \tag{6}$$

3. HS ALGORITHM CONCEPT

Harmony search (HS) is a well-known meta-heuristic optimization algorithm inspired by the modern natural phenomena, which was proposed by [23]. The basic process of this algorithm is to produce music tunes through pitching the musical instruments in order to search for a harmony. For the harmony improvisation, musicians try various musical combinations stored in their memory to get an excellent quality. Meanwhile, it is similar to the optimization process by creating a new solution using an objective function in order to improve the quality of the generated solutions. In brief, the optimization process of the harmony search algorithm is shown in Figure 2 which can be concluded in five steps [24],[25]: (1) the HS algorithm parameters are initialized such as the harmony memory size (HMS) which is used to specify the solution vectors number, harmony memory considering rate (HMCR, its range between [0,1]) which is used for the solution vector improvement in the harmony memory as well as the pitch adjusting rate (PAR, its range between [0,1]), and the maximum number of improvisation (MaxI) is used to check the stopping criteria; (2) the harmony memory (HM) is initialized by generating a random set of solutions vectors which are identical to the harmony memory size (HMS); (3) A new solution (harmony) is produced in the improvisation process; (4) the harmony memory is updated to check the new generated solution either it is better or worse than the previous one; (5) the stopping criteria process is tested in this step to check whether the maximum iterations number is satisfied or not. If yes, the HS process will stop and the best selected solution ($latest\ k_p, k_i$) is returned back. Otherwise, the procedures in steps 3 and 4 are repeated respectively.
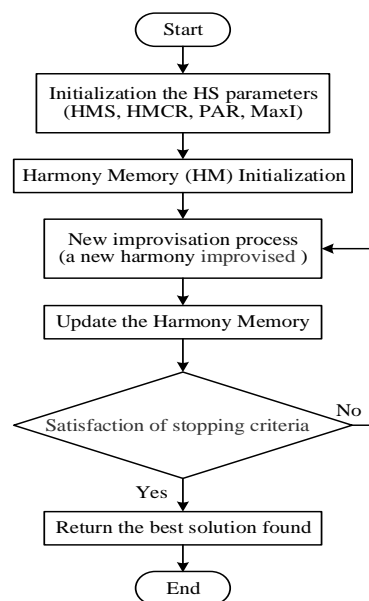

Figure 2. Harmony search algorithm flowchart

4. HS IMPLEMENTATION TO OBTAIN OPTIMAL PI PARAMETERS

In any optimization algorithm, the input vector formula to find the optimal solutions can be defined as;

$$Min. \, or \, Max. = Z(k), k_n \in \mathbf{K_n}; \; (n = 1,2, \ldots \ldots M) \tag{7}$$

where $Z(k)$ is the input vector to the optimization algorithm, k_n is the decision parameter, $\mathbf{K_n}$ is the lower and upper values of each decision parameter ($L_{k_n} < \mathbf{K_n} < U_{k_n}$), and M is the total number of decision parameters. Based on equation (7), two decision parameters (k_p,k_i) of the input vector $Z(k)$ are used in this research to provide the optimal solutions from the HS optimization algorithm as shown in Figure 2. In addition, an objective function is required to evaluate the performance of the input vector $Z(k)$. Therefore, the integral absolute error (IAE) shown below is applied as an optimization problem at the Simulink time.

$$IAE \, (min.) = \int_0^T |e| \, dt + \int_0^{simulink \, time} |ACE1 + ACE2| dt \tag{8}$$

A more explanation of the optimization process for the harmony search algorithm based PI controller is presented as follows:

Control flow of Harmony Search Algorithm based PI Controller: pseudo code

Start program:

    Definition of *input vector formula* $= Z(k), k_n \in \mathbf{K_n}; \; (n = 1,2, \ldots \ldots M)$;

    Definition of HMS, HMCR, PAR, and MaxI;

    Definition the upper and lower boundaries of the decision parameters (k_p,k_i);

    Harmony memory (HM) initialization;

    for $i \leq MaxI$, if satisfied ***do***

        for $j \leq number \, of$ decision parameters, if satisfied ***do***

            if HMCR $> r_1$, if satisfied ***do***

            Choose a decision parameter from the HM;

            $k' = [k_p^1 \quad \ldots \quad k_p^{HMS} \, or \, k_i^1 \quad \ldots \quad k_i^{HMS}]$;

            if PAR $> r_2$, if satisfied ***do***

              Adjust the decision parameter by;

              $k'_{new} = (k'_{selected} + rand)$;

            end

          else

            Choose a new random decision parameter by;

            $k' = rand * [(upper - lower) + lower]$;

          end

        end for j

if the fitness value $f(k')$ of the new solution vector $<$

        the worst fitness value stored in the HM, ***do***

     Accept the new solution vector and replaced by the old one,

     then added it to the HM;

      end

    end for i

    Return back the best solution found (*latest* k_p,k_i);

End Program

discussion).

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5. RESULTS AND DISCUSSION

The objective of this study is to test the proposed HS-PI control algorithm for LFC in two-area power system and compared it with the results obtained by PSO-PI. MATLAB program has been used to model the overall system shown in Figure 1. To check the effectiveness and robustness of the proposed control algorithm, the step load disturbance DPL_1 is selected to be 0.2 pu while DPL_2 is 0.3 pu for both area1 and area 2 respectively. Table 1 shows the optimal values (K_p ,K_i) of the optimization process obtained by both algorithms using the objective function (IAE). Tables 2, 3, and 4 give the transient response

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specifications for ACE_{ij}, $\Delta\omega_{ij}$, and ΔP_{ij} in terms of settling time, maximum deviation, and peak time. It is noted that the HS-PI controller produces good dynamic performances as compared to PSO-PI. Figures 3 and 4 represent the simulation results for ACE1 and ACE2 respectively for both algorithms, it is very clear that the dynamic characteristics for HS-PI are able to make the steady state error to be zero faster than PSO-PI and the overshoot is minimized as well. Figure 5 shows the ΔP_{12} result, the settling time, maximum deviation and peak time are reduced which make the system relatively more stable. Figures 6 and 7 demonstrate the responses for $\Delta\omega 1$ and $\Delta\omega 2$. It is shown that the response of the maximum overshoot and settling time is much better than that one's obtained by PSO-PI.

Table 1. Optimal values of PI tuning using HS and PSO

	PI Parameters	HS_IAE	PSO_IAE
Area1	Kp1	0.434	2.6290
	Ki1	1.504	2.8910
Area2	Kp2	1.092	3.8849
	Ki2	1.144	4.2106
	Min_IAE	**0.0166**	**0.032**
	Elapsed Time (sec)	22.676	29.112

Table 2. ACE_{ij} parameters using HS and PSO based on IAE

		Settling Time (sec)	Max.deviation (p.u)	Peak Time (sec)
HS_IAE	ACE1	6.45	0.0289	1.445
	ACE2	7.65	0.126	1.98
PSO_IAE	ACE1	8.75	0.0806	2.05
	ACE2	9.98	0.224	3.01

Table 3. ΔP_{ij} parameters using HS and PSO based on IAE

		Settling Time (sec)	Max.deviation (p.u)	Peak Time (sec)
HS_IAE	DP12	17.1	0.00589	2.51
PSO_IAE	DP12	19.19	0.01561	3.11

Table 4. $\Delta\omega_{ij}$ parameters using HS and PSO based on IAE

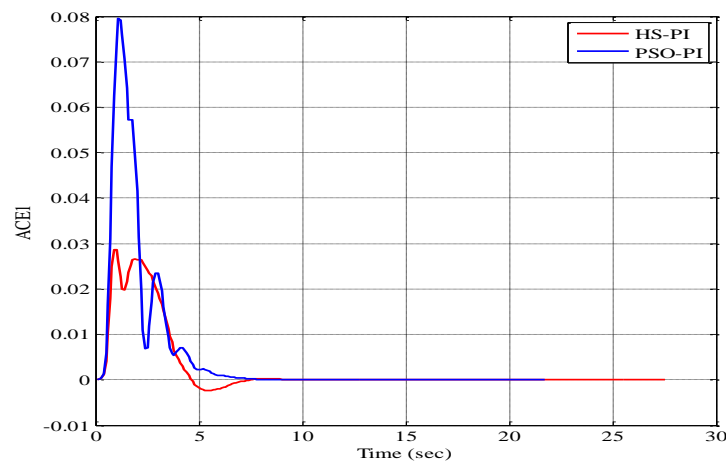|		Settling Time (sec)	Max.deviation (p.u)	Peak Time (sec)
HS_IAE	Dw1	11.089	-0.00162	0.998
	Dw2	6.023	-0.00489	1.231
PSO_IAE	Dw1	14.118	-0.00386	1.529
	Dw2	8.245	-.010012	2.325

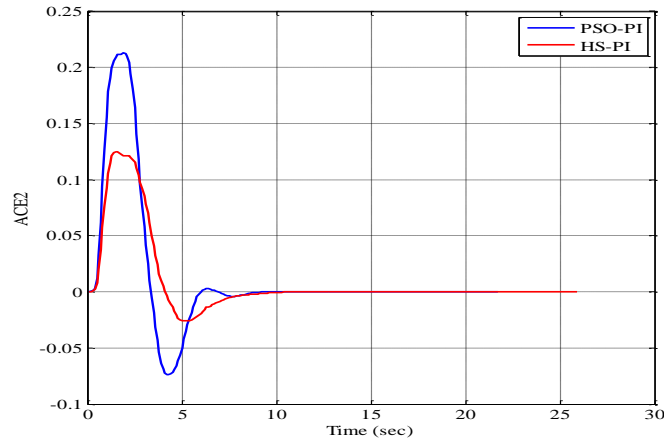Figure 3. ACE1 using HS and PSO algorithms
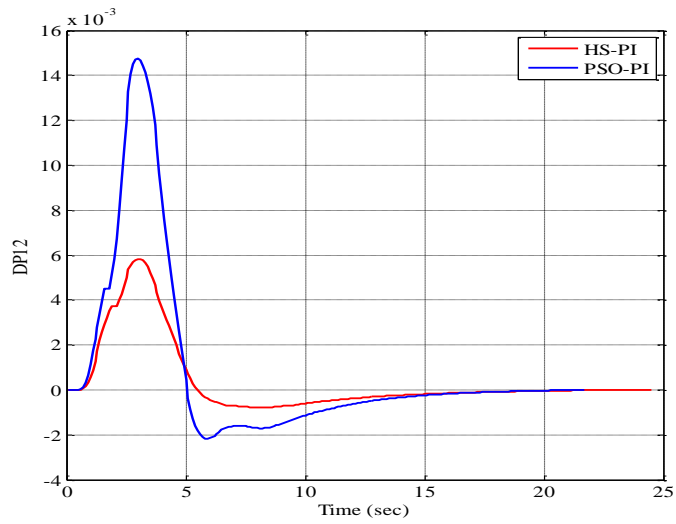
Figure 4. ACE2 using HS and PSO algorithms

Figure 5. ΔP_{12} using HS and PSO algorithms
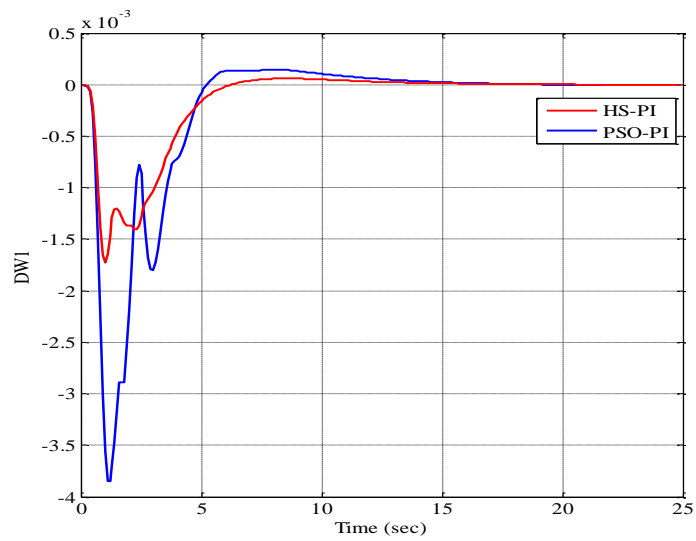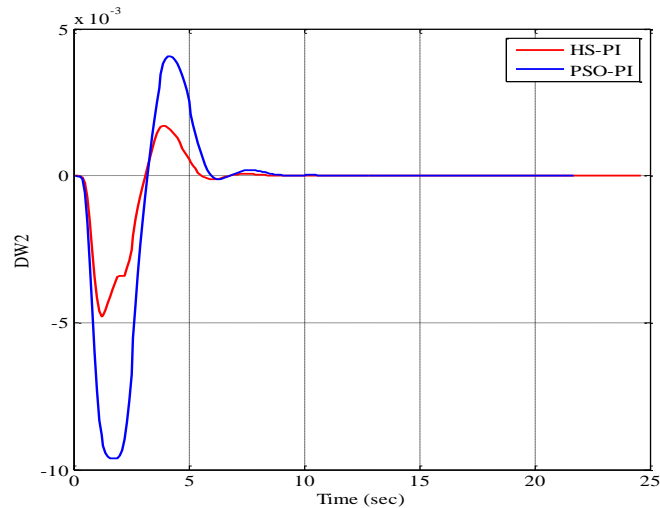

Figure 6. $\Delta\omega1$ using HS and PSO algorithms

Figure 7. Δω2 using HS and PSO algorithms

        To demonstrate the effectiveness of the proposed controller using the harmony search optimization algorithm based PI controller. A statistical analysis is done as shown in Figure 8 to display the convergence characteristics of HS-PI as compared to the convergence characteristics obtained by using PSO algorithm based PI (PSO-PI). In both optimization algorithms, same parameters are used like number of iterations, population size, dimension of problem, and the objective function in equation (8). Based on Figure 8, it is clear that the convergence of the proposed HS-PI is faster than PSO-PI. In other words, the obtained response of the overall system is better and robustness under sudden loads changes. In addition, the iteration number for both HS-PI and PSO-PI runs over 80 as described in Figure 8. It is shown that the value of IAE is 0.016 using the HS-PI controller as compared to 0.032 by using the PSO-PI under different loads.
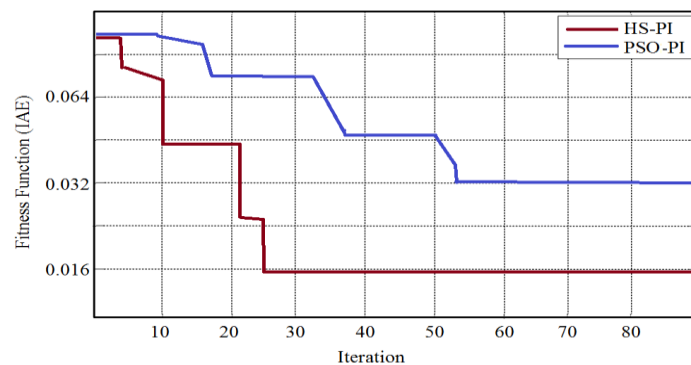

Figure 8. Fitness function based on HS-PI and PSO-PI

6.   CONCLUSION
        In this research, an optimal Harmony-PI controller (HS-PI) has been suggested for LFC in two-area power system in order to increase the system stability and reduce its steady state error under sudden load change. The PI parameters are optimized using harmony search optimization algorithm. The two-area power system including LFC loop and the control algorithm are modelled using Matlab environment. To show the proposed controller performance, the results have been compared with that ones obtained by the PI controller using particle swarm optimization named PSO-PI under same operation conditions. Based on this comparison, the IAE value using HS-PI has been eliminated to 0.01666 as compared to 0.032 of PSO-PI. Further, the robustness of the proposed controller is more stable than PSO-PI controller for the same power system. In addition, it is observed that the dynamic performance of the proposed controller has been improved in terms of settling time, maximum deviation, peak time, and execution time of control algorithm as compared to PSO-PI.

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