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# Tuning of PID Controller for Load Frequency Control Problem via Harmony Search Algorithm

**M. Omar*, M. A. Ebrahim, A. M. abdelGhany, F. Bendary**
Faculty of Engineering at Shoubra, University of Benha, Shoubra, Cairo 108, Egypt
*Corresponding author, e-mail: engmahmoudomar_10@yahoo.com

***Abstract***

*In this paper, a new artificial intelligence technique, Harmony Search (HS), will be used for the optimization of a classical order PID for a two-area load frequency control (LFC) model using the participation factor concept. The HS has four main variants, these variants had been used for the optimization of classical order PID controllers in case of centralized control scheme, the results had been compared to select and recommend the best HS variant. Then, this best HS variant had been used for the tuning of PID controllers in case of decentralized scheme.*

***Keywords***: *load frequency control, harmony search, fitness function*



## 1. Introduction

The problem of 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:

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

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

c) 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 variants is illustrated in Section 2. Section 3 will focus on the modelling of the proposed LFC model. In Section 4, a brief discussion of classical order PID will be introduced. This section contains also the fitness function and design criteria to be used in the optimization process. Simulation and results obtained after the application of PID Controller had been introduced in section 5. The main conclusions are driven in section 6.

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## 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 this section, a brief review of HS algorithm and its variants is given. The analogy between improvisation and optimization is likely as follows [2]:

1) Each musician corresponds to each decision variable.
2) Musical instrument’s pitch range corresponds to the decision variable’s value range.
3) Musical harmony at a certain time corresponds to the solution vector at certain iteration.
4) Audience’s aesthetics corresponds to the objective function to be minimized or maximized.

In this section, a brief review of HS algorithm and its variants is given.

### 2.1. The Basic Harmony Search Algorithm

Before the discussion of the HS algorithm, this section will identify the main parameters of the algorithm as follows:

HM: harmony memory, it is the solution matrix, each row in the HM represents a solution vector.

HMS: harmony memory size, it represents the number of available solution vectors in the harmony memory (number of rows).

HMCR: harmony memory consideration rate, it is a number which determines the probability of selecting a solution from the existing HM solutions.

PAR: pitch adjustment rate, it is a number which determines the probability of adjusting the selected solution within a certain range.

BW: band width, the available range of adjusting the selected solution.

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 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 [8]. The steps of the solution are illustrated in the flow chart given in Figure 1 as follows:

Step 1: initialize the HS parameters.

Step 2: generate random vectors (X1,…., XHMS) as many as HMS then store them in HM in matrix form, and evaluate the fitness function corresponding to each solution vector:

$$HM = \left( \begin{array}{cccc|} X_1^1 & \cdots & X_n^1 & F(x^1) \\ & \vdots & & \\ X_1^{HMS} & & X_n^{HMS} & F(x^{HMS}) \end{array} \right)$$

Step 3: Improvise a new harmony from the HM with probability HMCR (0 ≤ HMCR≤ 1), pick the stored value from HM, after that, and with probability of PAR (0 ≤ PAR≤ 1), adjust the selected solution with the band width value according to the following relation:

$$Xi' = Xi' + rand * BW \quad (1)$$

Step 4: If Xi' is better than the worst vector X worst in HM, replace Xworst with Xi'.

Step 5: Repeat from Step 2 to Step 4 until termination criterion (e.g. maximum iterations) is satisfied.

### 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 [4]. 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 shown below:

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

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

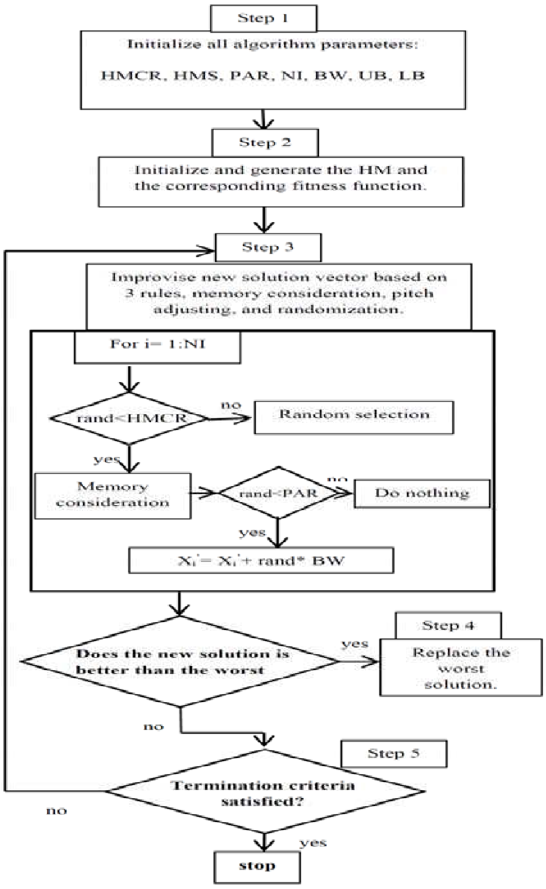


Figure 1. Optimization procedure of the Harmony Search algorithm

In Equation (2), PAR (i) is the pitch adjustment rate in generation i, PARmin is the minimum adjustment rate, PARmax is the maximum adjustment rate. In Equation (3), BW (i) is the distance bandwidth in generation i, BWmin and BWmax are the minimum and maximum bandwidths, respectively.

### 2.3. Global Best Harmony Search (GHS)

Inspired by the particle swarm optimization [5], a GHS algorithm that modifies the pitch adjustment rule has been proposed [6]. Unlike the basic HS algorithm, the GHS algorithm generates a new harmony vector XB = {xB(1), xB(2),…., xB(n) } in the HM. The pitch adjustment rule is given as below [11]:

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

Where k is a random integer between 1 and n. In addition, the GHS algorithm employs the dynamic updating procedure for the PAR parameter, Equation (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 XB to produce a new vector Xnew. However, the modified pitch adjustment rule may break the building structures in XB, so that Xnew may become worse than Xb 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 XB, 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 xnew(j),is assigned to the corresponding decision variable xB (j) in XB, while in the GHS algorithm, xnew(j) is determined randomly by selecting amongst any one of the decision variables of XB [9].

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.

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

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.These four types of HS are the most popular and commonly used in the different optimization problems, also, there are other types not listed here, had been worked out by researchers, all these types deal with the parameters setting and formulation.

## 3. Modeling of System under Study

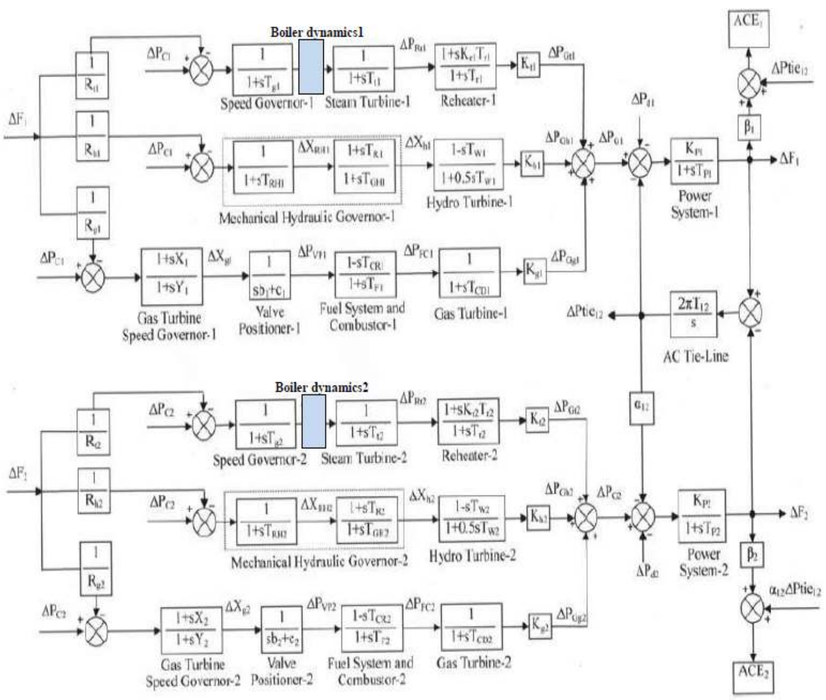


Figure 2..Two area power system model

The system investigation is carried out on an interconnected combined power system as shown in Figure 2 [10]. The model is about 2 area symmetrical model as shown in the figure; every area consists of three types of plants, thermal with reheat, hydro and gas plant. The sharing factors are 0.6, 0.3 and 0.1 respectively. The physical meaning of the variance of the sharing factors is that, the steam plant in general has greater rating rather than the other two types, so it must work as base unit with greater sharing factor for operational and economic criteria. In contrast, the gas plant usually operates as peaking unit due to the high running cost for this type of generation stations. In this paper we proposed to insert the boiler dynamics model to the thermal plants to make the model more realistic. The Boiler dynamics model is shown in Figure 3 [11].

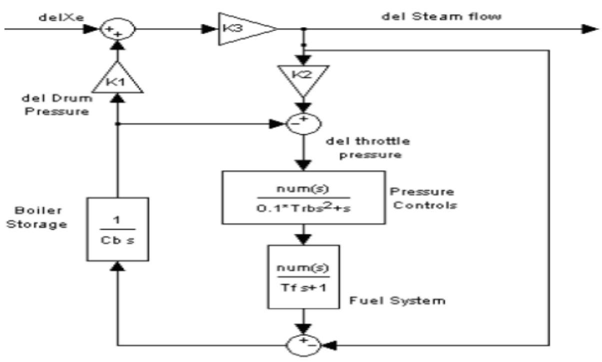


Figure 3. Boiler Dynamics model

## 4. Classical Order PID

In this section, a brief discussion of both the classical order PID controllers will be introduced.Also, the objective function and design criteria used in this research work will illustrated. The PID control is a widely used approach for designing a simple feedback control system [12]. It has the simple construction given in Equation (7).

$$k(s) = k_p + k_i / s + k_d s \quad (7)$$

Where kp, ki and kd are proportional, integral and derivative gains respectively. 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 [13]. The input to the controller is the area control error (ACE), and the output is u(s) as shown in Equation (8).

$$u(s) = -k(s) * ACE \quad (8)$$

These gains have been minimized subjected to the following inequalities:

$$k_i^{\min} \le k_i \le k_i^{\max}$$
$$k_d^{\min} \le k_d \le k_d^{\max}$$
$$k_p^{\min} \le k_p \le k_p^{\max}$$

Where max and min refers to the permissible upper and lower values for each gain. In addition, the controller has been optimized according to the following fitness function:

$$J = \int_0^\infty t\left\{\left|\Delta f_i\right| + \left|\Delta p_{tie\,ij}\right|\right\} \quad i = 1,2,3,...,\ i \neq j \tag{9}$$

## 5. Simulation and Results

In this paper the research work has been organized as follows:

a) The classical PID controller had been tuned with the four mentioned HS variants in case of centralized control (a controller for each area) (2 controllers) scheme and the best HS variant had been selected to complete the research work with this one.

b) With the best HS variant, PID controllers had been tuned for each plant in each area (6 controllers) to achiev the concept of decentralized control scheme. Then, a comparison between the centralized and decentralized schemes had been done to select and recommend the best one for the control applications.

### 5.1. Centralized PID Tuning via all HS Variants

In this section, 2 PID controllers (one for each area) had been tuned with the previously mentioned fitness function for the four types of HS algorithm via MATLAB software. The resulted values of controller gains had been listed in Table 1. The response of the system in case of applying the proposed technique PID controllers had been compared with another PID tuned via BFO algotithm as given in [10] for the same model excluding the boiler dynamics.

Table 1. Values of PID gains for centralized control

| Type | Area 1 | | | Area2 | | |
|---|---|---|---|---|---|---|
| | kp | ki | kd | kp | ki | kd |
| HS | 7.851 | 5.205 | 3.525 | 8.524 | 7.165 | 7.525 |
| IHS | 9.7 | 7.254 | 4.2469 | 7.2884 | 8.2969 | 8.5175 |
| GHS | 9.701 | 5.179 | 5.989 | 10 | 6.8601 | 9.8969 |
| SGHS | 9.57 | 4.247 | 7.3062 | 6.8944 | 3.8359 | 2.22 |
| BFO | 5.067 | 4.269 | 3.5851 | 1.8619 | 0.8629 | 1.5942 |

The system had been tested for 1% load increment in area 1. Maximum overshoot (%Mp), peak time (tp) and settling time (ts) had been recorded in Table 2.

Table 2. System performance evaluation for all variants

| Type | $\Delta f_1$ | | | $\Delta f_2$ | | |
|---|---|---|---|---|---|---|
| | % $M_p$ | $t_p$ | $t_s$ | % $M_p$ | $t_p$ | $t_s$ |
| HS | 1.19 | 0.34 | 8 | 0.715 | 0.73 | 5.6 |
| IHS | 1 | 0.31 | 7 | 0.59 | 0.68 | 5 |
| GHS | 0.93 | 0.25 | 7.5 | 0.47 | 0.6 | 5.2 |
| SGHS | 0.85 | 0.24 | 7 | 0.52 | 0.83 | 5 |
| BFO | 1.16 | 0.344 | 16 | 0.917 | 1.02 | 16.8 |

The frequency deviation and tie line power responses are shown in Figure 4-6.

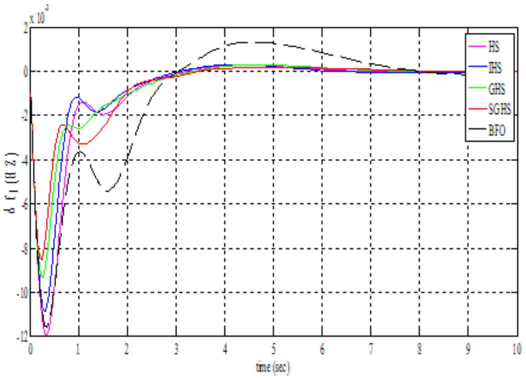


Figure 4. Frequency deviation response in area 1 for all variants

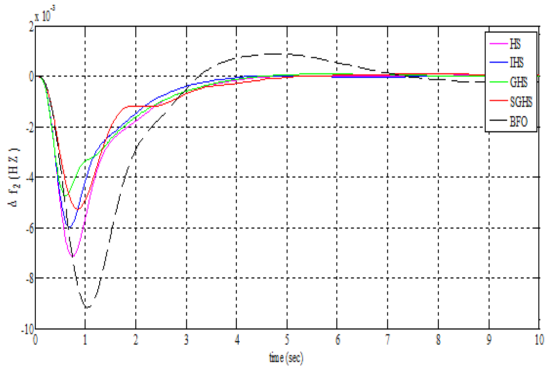


Figure 5. Frequency deviation response in area 2 for all variants

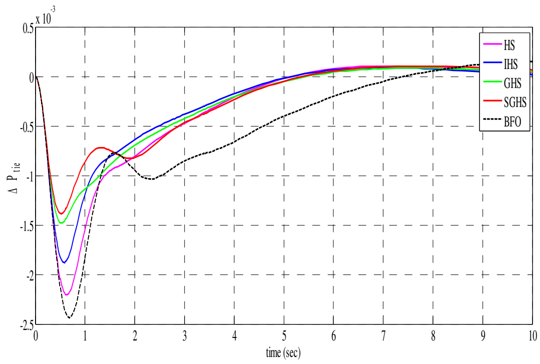


Figure 6. Tie line power deviation response for all variants

From the previous figures and results listed in Table 1, it is shown that all HS variants based PID controllers have better effect than BFO based PID in spite of existing of the bolier dynamics. It is also clear that the SGHS based PID is the most effective one among all HS types, so this type will be recommended for the next stage (Decentralized Control).

### 5.2. Decentralized PID Tuning via SGHS Variant

In this section, 6 PID controllers (one for each plant) had been tuned with the same fitness function to achieve the concept of decentralized control. In this case, the controllers had been tuned with the best HS variant resulted above (SGHS). Results from centralized and decentralized control schemes had been compared to evaluate and recommend the best and most applicable scheme in the control applications. The values of controllers' gains had been listed in Table 3.

Table 3. Values of PID gains for decentralized control

| PID no | Area 1 | | | Area 2 | | |
|---|---|---|---|---|---|---|
| | kp | ki | kd | kp | ki | kd |
| 1 | 9.1929 | 10.455 | 8.909 | | | |
| 2 | 7.7127 | 3.5816 | 8.9901 | | | |
| 3 | 9.3063 | 1.7918 | 5.4315 | | | |
| 4 | | | | 7.8116 | 9.9093 | 10.751 |
| 5 | | | | 9.8312 | 7.0195 | 5.7648 |
| 6 | | | | 5.8749 | 1 | 10 |

The system had been tested for the same load disturbance value 1% in area 1. Maximum overshoot (%Mp), peak time (tp) and settling time (ts) had been recorded in Table 4 for both centralized and decentralized SGHS based controllers.

Table 4. System performance evaluation for centralized and decentralized schemes

| Type | $\Delta f_1$ | | | $\Delta f_2$ | | |
|---|---|---|---|---|---|---|
| | % $M_p$ | $t_p$ | $t_s$ | % $M_p$ | $t_p$ | $t_s$ |
| Centralized | 0.85 | 0.24 | 7 | 0.52 | 0.83 | 5 |
| Decentralized | 0.783 | 0.2 | 6.85 | 0.326 | 0.55 | 8 |

The frequency deviation and tie line power responses are shown in Figure 7-9.

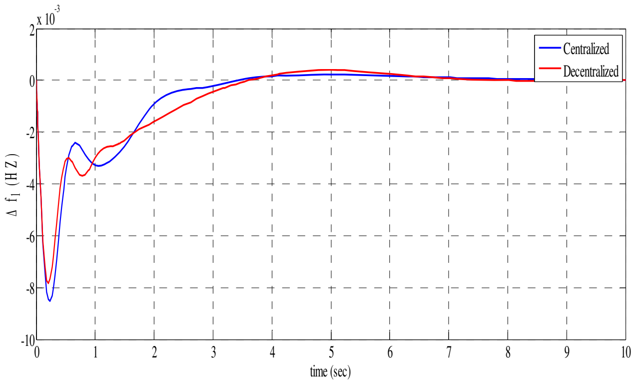


Figure 7. Frequency deviation response in area 1

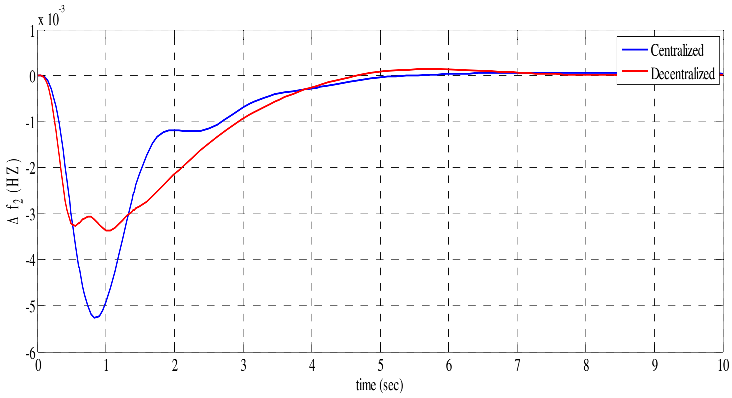


Figure 8. Frequency deviation response in area 2

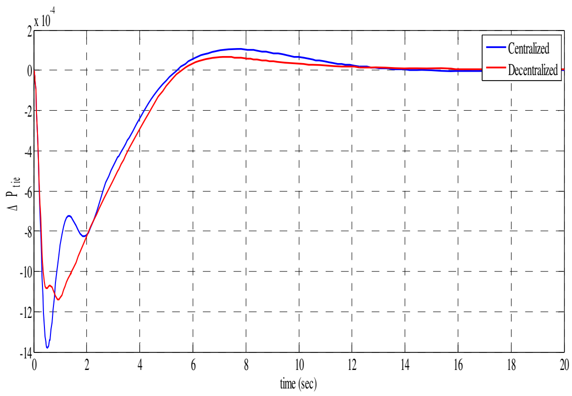


Figure 9. Tie line power deviation response

From the previous figures and results listed in Table 4, it is shown that the decentralized control scheme is better than the centralized one. From the practical side, the decentralized control is more applicable and widely used because it is not logic in realistic model to give the same control signal to all the plants in the same area (centralized scheme) and force all the plants in this area to respond with the same value and profile.

## 6. Conclusion

In this paper a new artificial intelligence optimization technique (HS) had been applied for the tuning of classical PID order controller in case of centralized and decentralized control schemes. The results had proven the effectiveness of this optimization technique in tuning this type of controllers for this model. It also proved the wellness of decentralized control scheme in comparison with the centralized one.

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