Improved Harmony Search Algorithm for Speed Control of DC Series Motor PV System

E. S. ALI
Electrical Department, Faculty of Engineering, Jazan University, Jazan, KINGDOM OF SAUDI ARABIA

Abstract:- This article introduces the speed control of the DC motor solar system. The developed design matter of the speed controller is established as an optimization problem. Improved Harmony Search Algorithm (IHSA) is employed to seek for optimum Proportional Integral (PI) parameters of speed controller by diminishing the time domain cost function. The performance of the suggested IHSA based speed control of DC motor has been contrasted with Particle Swarm Optimization (PSO) and the traditional PI controller found by Ziegler Nichols (ZN) under diverse operating cases and disturbances. The results of the suggested IHSA are confirmed via time domain analysis, and diverse performance indices. Simulation results have proven the influence of the developed approach in adjusting the speed of the DC motor over PSO and traditional algorithms.

Key-Words: Improved Harmony Search Algorithm; PV; Speed Control; DC Motor; PI Controller.

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1. Introduction

Series DC motors are used widely in implementations that need high starting torque [l, 2]. Due to the inherent characteristics taken by the DC motor system, like the complexity of the system nonlinearity, unavailability of precise mathematical pattern, the use of traditional PI controllers become an appropriate solution due to small steady-state error and soft costs. However, inspection of the elements of the PI controller is not a simple task, particularly under various operating conditions, and abnormal modes of operation [3, 4].

Solar systems work by transforming light into electrical power. When subject to sunlight the semiconducting material creates electrons in the materials' atoms to be knocked loose. The electrons that are knocked loose then flow via the material to generate an electric current called a DC. This DC is passed through wiring to an inverter that converts the DC to AC so it can be connected to a major electricity distribution board that is either used within the home or fed back into the national network [5-7]. PV is utilized in this article to feed DC motor.

Previously, Artificial Intelligence (AI) mechanisms have been examined in literature to find solutions for speed control of DC motors. Neural Network (NN) is addressed in [8, 9, 10, and 11]. The NN approach has its own merits and demerits. The implementation of the system is enhanced by a NN based controller but, the prime problem of this controller is the large training time, choosing number of layers and number of neurons in every layer. Another AI mechanism like Fuzzy Control (FC) has received great attention in control implementations. In contrast with the traditional mechanisms, FC contrives the control effect of a plant in terms of linguistic basics drawn from the demeanor of a humane operator rather than in terms of an approach synthesized from a pattern of the plant [12, 13]. It can be developed on the basis of linguistic information given from the prior information of the control system and allows better performance results than the traditional controllers. However, a cruel work is unavoidable to get the efficient signals when designing FC. Moreover, it needs more fine tuning before being operational.

Recently, global optimization approaches have attracted the interest in improving speed tracking systems. Tabu Search (TS) is illustrated in [14] to plan a powerful controller for an induction motor. However, it seems to be factual for the design task, the efficiency is decreased by the use of strongly epistatic objective functions and large number of elements to be optimized. Otherwise, it is a time consuming technique. Another heuristic approach as Genetic Algorithm (GA) is discussed in [15] for optimum design of speed control of Switched Reluctance Motor (SRM). Despite this optimization approach needs a very long run time that may be diverse minutes or even hours relying on the dimension of the system under study. Swarming strategies in bird flocking are utilized in the PSO and discussed in [16] for optimum design of speed control of various motors [17, 18, and 19]. However, PSO suffers from partial optimism. In addition, the algorithm suffers from low local search capability and the algorithm may lead to sensible entrapment in local lower solutions. Bacteria

Foraging (BF) approach has been used [20] in speed control of DC motors, but the BF approach relies on random search directions that may lead to delay in arriving at the global solution. Firefly Algorithm (FA) is illustrated in [21] for speed control DC motors connected with the solar system. A novel metaheuristic nature inspired approach, called Improved Harmony Search Algorithm (IHSA), which was evolved by [22-23] to appear a solution for diverse optimization problems. It is imitated by the improvisation of music players [23]. The superiority of its enhanced algorithm is achieved over others in [24, 25, 26, and 27]. Moreover, its effectiveness is proven in diverse engineering tasks [28]. Also, it is clear from the literature survey that the implementation of IHSA to solve the task of speed control of DC motors has not been discussed. This motivates us to adopt IHSA to treat this problem.

This article decides IHSA for speed control of DC series motors provided by PV systems. IHSA is used for finding the PI controller elements to adjust the duty cycle of the DC-DC converter and then control the speed of the DC series motor. The design process of the decided controller is submitted as an optimization process and IHAS is used to search for optimum controller parameters. By reducing the time domain cost function symbolizing the error between reference and actual speed is optimized. The validation of the decided controller is examined under diverse operating conditions in comparison with the PSO based PI and traditional controller via time domain simulation and performance indices. Simulation results illustrate that the decided algorithm achieves good robust execution for tracking speed systems under diverse operating conditions and disturbances.

2. Test System

The system under study contains a solar system that works as a voltage source for a joint DC series motor. The input of the solar system is the surrounding temperature and radiation, while the product is the DC voltage. IHSA is used to adjust the duty cycle of DC-DC converter and thus the voltage and speed of a series DC motor. The graphical block diagram is displayed in Fig. 1.

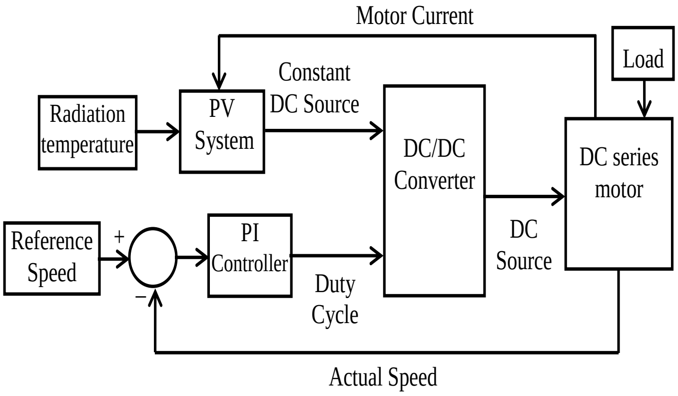

Fig. 1. Block diagram of test system.

2.1 DC Series Motor Model

The constants of DC series motors are given in [29]. The DC series motor can be expressed by the following equations [29-30].

$$\frac{di_a(t)}{dt} = \frac{V_t(t)}{L_a + L_f} - \frac{R_a + R_f}{L_a + L_f} i_a(t) - \frac{M_{af}}{L_a + L_f} i_a(t)\omega_r(t) \quad (1)$$

$$\frac{d\omega_r(t)}{dt} = \frac{M_{af}}{J_m} i_a^2(t) - \frac{f}{J_m}\omega_r(t) - \frac{T_L}{J_m} \quad (2)$$

Where the parameters definition and values are given in [21, 29].

2.2 PV Modelling

The PV cell model is given in Fig. 2. The output voltage and current from the cell is relied on the load operating point. The solar system mathematical modelling is displayed by the following equations [6, 7].

$$I_c = I_{ph} - I_o \left\{ e^{\left[\frac{q_o}{AkT}\left(V_c + I_c R_s\right)\right]} - 1 \right\} \quad (3)$$

$$V_c = \frac{AkT}{q} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - I_c R_s \quad (4)$$

$$I = I_{ph} - I_o \left\{ e^{\left[\frac{q_o}{n_s AKT}\left(V + n_s I R_s\right)\right]} - 1 \right\} \quad (5)$$

$$V = \frac{n_s AkT}{q_o} \ln\left(\frac{I_{ph} + I_o - I}{I_o}\right) - n_s I R_s \quad (6)$$

Where;

$$I_{ph} = \frac{G}{1000}\left[I_{sc} + k_i\left(T - T_r\right)\right] \quad (7)$$

$$I_o = I_{or}\left(\frac{T}{T_r}\right)^3 e^{\left[\frac{q_o E_g}{AK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right]} \quad (8)$$

The product power of the module can be specified simply from the equation below.

$$P = V.I \quad (9)$$

Where the parameters definition and values are given in [21].

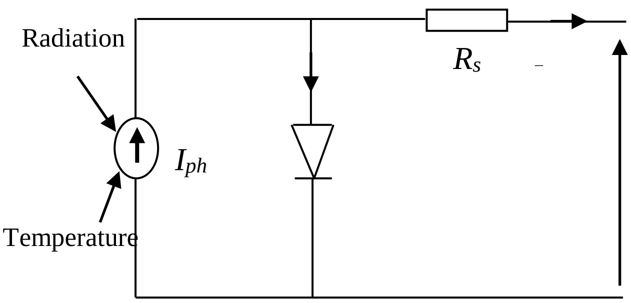

Fig. 2. PV cell equivalent circuit.

2.3 DC-DC Converter

In this article, a hybrid DC-DC converter is utilized. For this converter type, the equations in continuous conduction mode are [31]:

$$V_B = \frac{-K}{1-K} V_{ph} \quad (10)$$

$$I_B = \frac{K-1}{K} I_{ph} \quad (11)$$

The duty cycle of the pulse width modulation is K. V_B, I_B are the product voltage and current of the converter respectively.

3. Cost Function

A performance index can be determined by ITSE [32, 33]. The cost function J is defined as:

$$J = \int_0^\infty t e^2 dt \quad (12)$$

Where $e = w_{reference} - w_{actual}$

This cost function J optimization problem can be written as: reduce J subjected to:

$$K_p^{\min} \le K_P \le K_p^{max},\ K_I^{\min} \le K_I \le K_I^{max} \quad (13)$$

Normal ranges of the optimized elements are [0.001-10] for K_P and K_I .

This article focuses on optimum tuning of PI controllers for speed tracking of DC series motors using IHSA. The target of the optimization is to seek for the optimal parameters setting that reduces the variance between reference speed and actual one.

4. Optimization Algorithms

4.1 Traditional Harmony Search Algorithm

HSA is stimulated by the improvisation of music players [22]. The optimized solution vector is illustrated by the harmony, and the global and local searches are presented by the musician's improvisations [23]. This approach involves Harmony Memory (HM) considering rate and pitch adjustment rate for seeking the optimal solution [24]. It is a simple approach, few in elements and easy in implementation [25]. It has been utilized successfully for distinct optimization processes. The steps of this approach are presented below [26]:

1- Initialization of an optimization task and algorithm parameters. The optimization task is defined as reduce $J(x)$ according to $x_i \in X_i$ $i = 1,...n$.

where $J(x)$ is the cost function, $x_{il} \le X_i \le x_{iu}$, is the set of every solution vector and, x_{il}, and x_{iu} are the lower and upper limits for each parameter, and n is the parameters number.

Here, the harmony memory size (hms), harmony memory considering rate ($hmcr$), pitch adjusting rate (par), distance bandwidth (bw) and upper iterations are defined.

2- Initialization of HM that is filled with random amounts equal to the hms.

3- Improvisation of a novel harmony subject to the memory consideration, par, and random selection. The solution parameter is modified subject to probability of par. The updated rule are written as:

$$x_i = x_i \pm r.bw \quad (14)$$

where r is a regular random number between [0, 1].

4- Modify HM . If a novel harmony is better than any existing harmony, then displace it.

5- Restore steps 3 and 4 till the stopping criterion is finished.

4.2 Improved Harmony Search Algorithm

HSA may fail in applying local search for some applications. IHSA is used to update the par and bw in improvisation step [22] instead of their values in HSA to improve its efficiency and to eliminate its shortage [23]. The modified elements are given below:

$$par(k) = par_{\min} + \left(\frac{par_{\max} - par_{\min}}{K}\right) k \quad (15)$$

$$bw(k) = bw_{\max} \exp\left(\frac{\ln\left(\frac{bw_{\min}}{bw_{\max}}\right)}{K}\right) k \quad (16)$$

Where K is the upper number of improvisations, and k is the current improvisation. IHSA is suggested here to find the optimum values of the PI controller for speed control of the motor.

5. Results and Discussion

In this section, various comparative cases are tested to discuss the efficiency of the decided IHSA controller compared with PSO and ZN under change of load torque, surrounding temperature and radiation changes. The designed values of the PI controller with the decided IHSA, traditional approach and PSO are displayed in Table 1.

Table. 1. Comparison between several approaches.

	K_P	K_I
IHSA	0.0919	2.3357
PSO	0.0941	2.2597
ZN	0.0765	1.5736

5.1 Response under step variation of load torque

Fig. 3 gives the step response of load torque. The speed change under variation of the load torque is displayed in Fig. 4. The real speed hounds the reference speed with small overshoot and settling time. The settling time is 0.03 second approximately. Also, the speed response is quicker with the suggested controller than PSO and ZN for the step variation of load torque. Moreover, the decided controller is powerful in its operation and allows a prime behaviour compared with traditional PI and PI based on PSO.

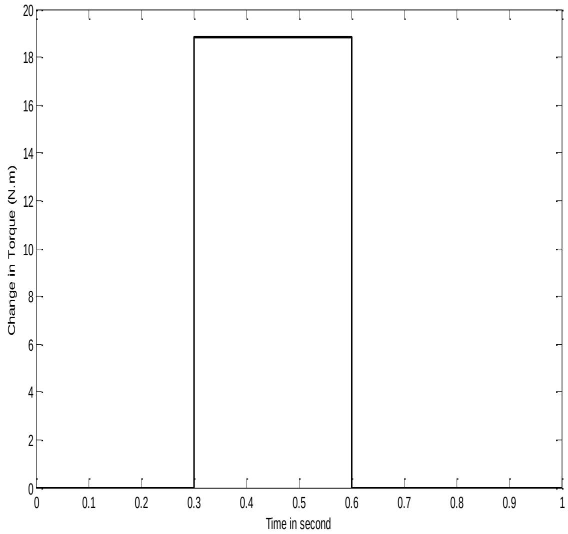

Fig. 3. Step variation of load torque.

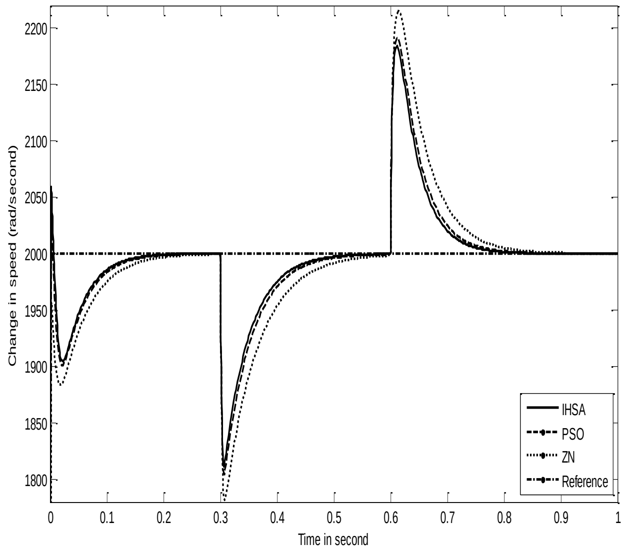

Fig. 4. Change in speed for several algorithms.

5.2 Response under step variation of radiation

In this issue, the system responses under change of solar system radiation are discussed. Fig. 5 gives the change of the solar system radiation as an input perturbation. Moreover, the system response based on several algorithms is displayed in Fig. 6. It is obvious, the suggested IHSA based controller enhances effectively the speed control of the DC motor. Also, the suggested method outperforms PSO in designing speed controllers and minimizing settling time. Thus, PI based IHSA greatly improves the behaviour characteristics of DC motors compared with those based PSO and traditional approach.

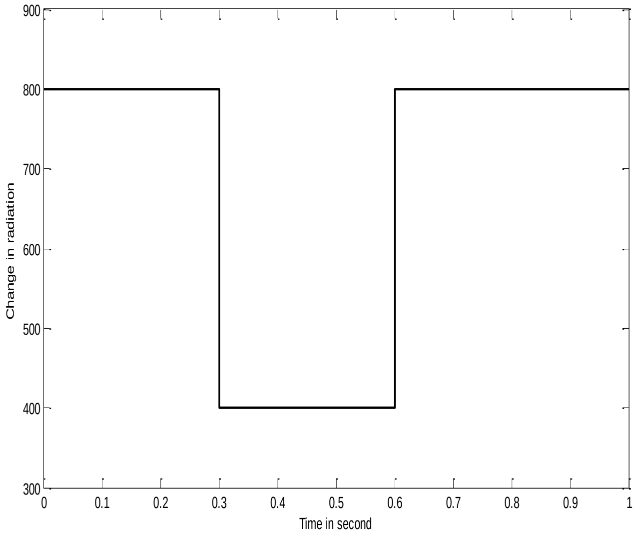

Fig. 5. Step change for solar system radiation.

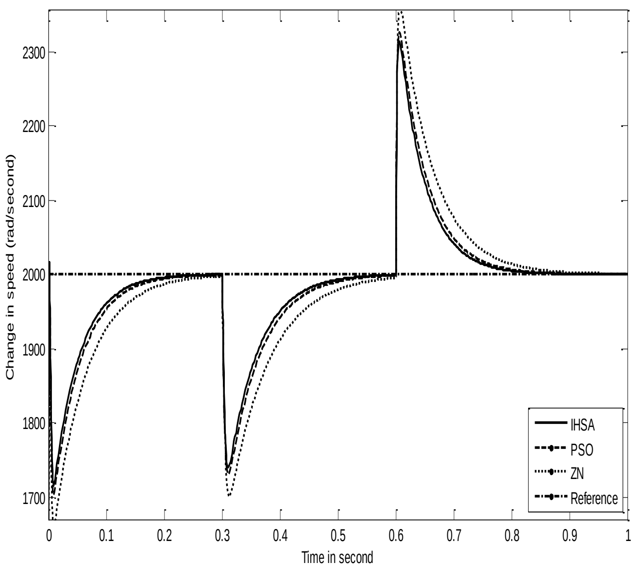

Fig. 6. Variation in speed for several controllers.

5.3 Response under step variation of load torque, temperature and radiation

The effect of applying step variation of load torque, temperature and radiation of the solar system is given in this issue. Fig. 7 explains the change of load torque, temperature, and radiation. A comparison between the real and reference speed is displayed in Fig. 8. It is clear that the steady state and transient operation of the DC motor in terms of settling time and overshoot has been improved. Moreover, the suggested controller using time domain cost function arrives at good robust behaviour in comparison with the traditional technique and PSO.

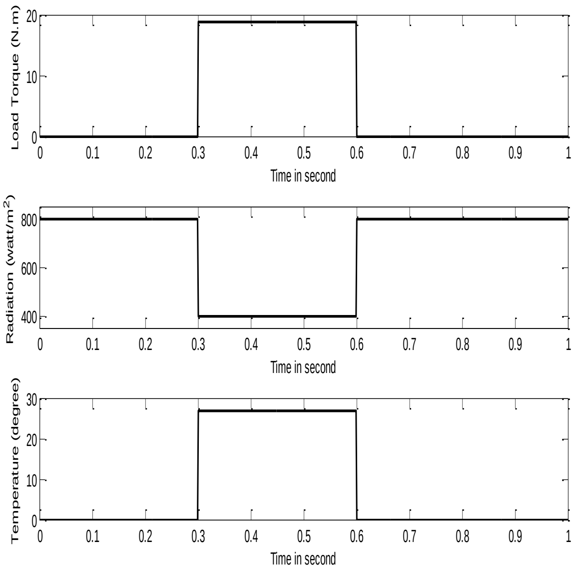

Fig. 7. Step variation of load torque, solar system temperature and radiation.

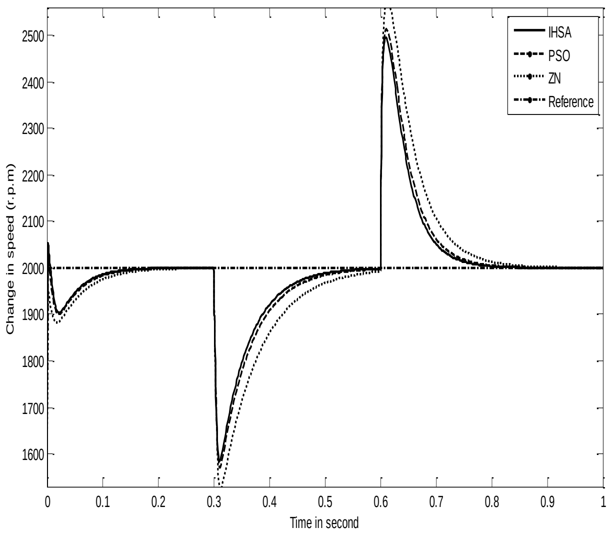

Fig. 8. Variation of speed for various controllers.

5.4 Response under variation of load torque, temperature and radiation

In this issue, the system response under large variations of load torque, temperature and radiation is obtained. Fig. 9, presents the variation of load torque, temperature, and radiation. Also, the effect of the suggested IHSA controller on speed response is displayed in Fig. 10. It is clear that the suggested

IHSA controller is strong in tracking reference speed. Moreover, the suggested controller has a small settling time and system response is quickly driven with the reference speed. Thus, the superiority of the suggested algorithm over the traditional approach and PSO is confirmed.

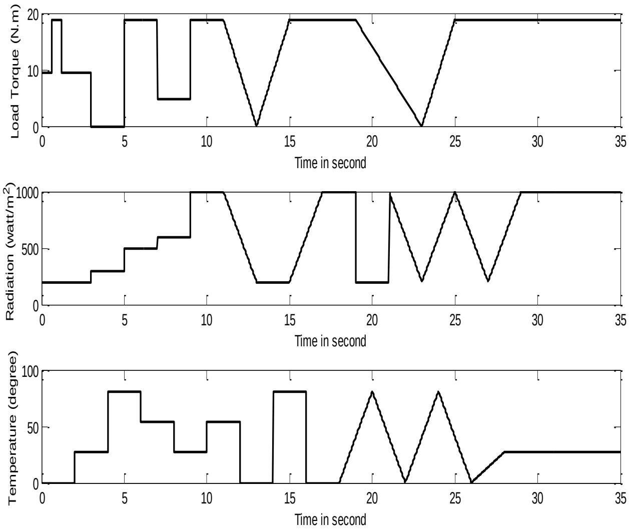

Fig. 9. Variation of load torque, solar system temperature and radiation.

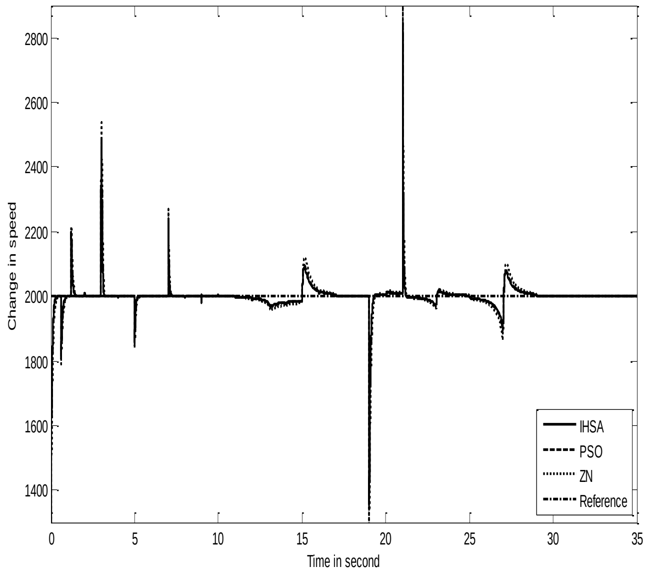

Fig. 10. The variation in speed with various controllers.

5.5 Robustness and performance indices:

To prove the robustness of the suggested controller, several performance indices: the Integral of Absolute amount of the Error (IAE), the Integral of the Time multiplied Absolute amount of the Error (ITAE), the Integral of Square Error (ISE) and the Integral of the Time multiplied of Square Error (ITSE) are being utilized as:

$$IAE = \int_{0}^{t_{sim}} (|e|)dt \quad (17)$$

$$ITAE = \int_{0}^{t_{sim}} t(|e|)dt \quad (18)$$

$$ISE = \int_{0}^{t_{sim}} e^{2}dt \quad (19)$$

$$ITSE = \int_{0}^{t_{sim}} te^{2}dt \quad (20)$$

Where t_{sim} is the simulation time and equalizes to 35 second. It is remarkable that the lower the amount of these indices is, the superior the system response in terms of time domain features. Numerous results of behaviour robustness for total controllers are recorded in Table (2) under considerable change of load torque, and elements of the solar system. It can be observed that the amounts of these system behaviours with the IHSA are smaller compared with those of PSO and ZN. This explains that the settling time, overshoot, and speed variation of total units are largely reduced by applying the developed IHSA based tuned PI. Ultimately; amounts of these indices are lower than those acquired by FA in [21].

Table. 2. Amounts of performance indices.

	Performance indices			
	IAE	ITAE	ISE	ITSE
IHSA	48.6421	710.3912	828.7726	9471
PSO	55.4362	861.4831	1134.31	12462
FA	50.212	758.862	948.898	10617
ZN	71.4856	1075.8	1582.90	18452

6. Conclusions

In this article, a modern method for speed control of a DC motor is developed via IHSA. The design problem of the developed controller is formed as an optimization process and IHSA is used to search for optimum variables of the PI controller. By reducing the time domain cost function, in which the difference between the reference and real speed are involved; speed control of the DC motor is improved. Simulation results confirm that the designed IHSA tuning PI controller is strong in its operation and affords superb behaviour for the change in load torque, temperature, and radiation compared with other techniques. Also, the system behaviour characteristics in terms of several indices reveal that the developed controller proves its efficiency more than PSO and traditional one.

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