Research article

Speed Orientation of combined Induction Motor Renewable Energy System via Firefly Approach

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This article introduces the layout of a traditional (PI) Proportional Integral controller via (FA) Firefly Approach to adjust the speed of the commonly used motor; (IM) Induction Motor; supplied by (WT) Wind Turbine as a one of renewable energy resources. WT acts as a main mover to a joined (DC) Direct Current source. DC/AC inverter is utilized to obtain a 3 phase system from the product of DC generator. The developed layout process of the speed controller is formed as a time domain optimization task. FA is involved to seek optimum elements of the controller by reducing the suggested objective time function. The attitude of the decided FA has been valued with the attitude of the traditional (ZN) Zeigler Nichols and (PSO) Particle Swarm Optimization to confirm the supreme adequacy of the developed FA in setting the PI controller. Moreover, the attitude of the suggested controller has been valued for the variation of load torque and speed WT. Imitation results prove the better achievement of the tuned PI elements relied on FA compared with tuned PI elements based on PSO and traditional one along a vast scope of working cases.

1. INTRODUCTION

IM was the aim of distinct studies due to its low cost, robustness, efficiency and reliability. However, its control introduced difficulties due to its highly coupled structure and high non-linearity.[1,2] Several intelligent techniques were utilized for speed orientation of IM like Neural Network (NN).[3,4] The NN technique had its merits and demerits. The achievement of this process was enhanced by NN but the major process of this approach was the electing value of layers and neurons in every layer. Another technique like Fuzzy Control (FC) for designing speed orientation of IM was presented in[5,6] but it needed more fine setting and imitation before being operational. Sliding mode was suggested to control the speed of IM in[7] but this technique had many cons as uncertain convergence time, and singularity.

Global optimization approaches had caught the attention in controller parameter optimization.[8] Genetic Algorithm was discussed in[9] for optimum layout of IM speed orientation. This approach needed a so large processing period that could be various minutes relying on the capacity of the working system. Another technique as Tabu Search was illustrated in[10] to layout a vigorous controller for IM but, it seemed an efficient for the layout process, the competence was minimized by the application of largely objective function, and high value of tuned parameters. Simulated Annealing was presented in[11] for optimum setting of controller but this approach might fail by getting trapped in one of the local optimum. Swarming strategies in fish schooling were utilized in the PSO and introduced in[12] for optimum layout of speed orientation of IM.[13] However, PSO pained from the fractional optimism, which caused it to be less accurate at the regulation of its speed and the direction.[14] Furthermore, this approach suffered from delayed congregation in reduplicate seeking phase, soft native seeking capability and approach could result in potential trap native lower resolutions. Bacteria foraging scheme was addressed in[15,16] to deal with this issue but it had a poor convergence performance. Archimedes approach was presented in[17] to find a solution for this case, but this approach could stick in local solutions and had a weak exploitation. Dragonfly approach was discussed in[18] to handle the case of speed orientation of IM but this approach required large computational time. To resolve these demerits, this article shows a novel evolutionary approach called FA to layout a might speed orientation for IM. FA is addressed newly[19] that is inspired by the mating attitude of insects. FA has introduced good execution in handling optimization processes in distinct areas like speed orientation for DC motor,[20] load frequency control,[21,22] and reduction of power loss.[23]

This article suggests FA for optimum styling of the PI parameters for speed orientation of IM provided by WT that has an easy frame and sturdy achievement in a vast domain of working cases. The layout task of the developed approach is formed as an optimization style and FA is used to request the optimum elements of the controller. Through reducing the suggested objective time function, in which the variations among the datum and real speed is included; speed orientation of the motor under study is enhanced. Emulation outcomes establish the efficacy of the developed controller in supplying perfect speed orientation for a vast do-

Symbols

$R_{1s}, L_{1\mathrm{ls}}$	Elements of stator impedance,
R'_{2r},$L'_{2\mathrm{lr}}$	Elements of rotor impedance,
L_m	Magnetizing inductor,
L_{1S},L'_{2r}	Net stator and rotor inductances,
$V_{1\mathrm{qs}}, i_{1\mathrm{qs}}$	Volt and current of q axis stator,
$V'_{2\mathrm{qr}}$,$I'_{2\mathrm{qr}}$	Volt and current of q axis rotor,
$V_{1\mathrm{ds}}, i_{1\mathrm{ds}}$	Volt and current of d axis stator,
$V'_{2\mathrm{dr}}$,$I'_{2\mathrm{dr}}$	Volt and current of d axis rotor,
$\phi_{1\mathrm{qs}}, \phi_{1\mathrm{ds}}$	Fluxes of q and d axis for stator,
$\phi'_{2\mathrm{qr}}, \phi'_{2\mathrm{dr}}$	Fluxes of q and d axis for rotor,
ω_{mr}	Angular velocity of the rotor,
θ_{mr}	Rotor angular site,
P	Value of pole pairs,
ω_{2r}	Electrical angular velocity (ω_{mr}. P) ,
θ_{2r}	Electrical rotor angular site (θ_{mr}.P),
T_e	Electromagnetic torque,
T_L	Shaft mechanical torque,
J_c	Coefficient of combined rotor and load inertia,
B	Coefficient of combined rotor and load viscous friction,
R	The radius of WT rotor,
V_ω	The wind speed,
ω_t	The mechanical angular rotor speed of the WT,
P_t	Wind power (hp),
ρ	Air density (kg/m^3),
V	Wind speed (m/s),
R_A	The space of turbine blades (m2),
C_{PP}	Coefficient of P_t,
i_a, V_a	The current and volt at armature,
i_{fi}, V_{fi}	The current and volt at field,
R_{ar}, L_{ar}	Elements of armature impedance,
R_{fi}, L_{fi}	Elements of field impedance,
R_{Lo}, L_{Lo}	Elements of load impedance,
R_{to}	=R_{ar} + R_{Lo},
L_{to}	=L_{ar} + L_{Lo},
M_{af}	The mutual inductance among rotor and stator,
ω_r	The angular input speed.

main of speed turbine and torque of load. In addition, the obtained results prove the supremacy of the developed FA approach in setting controller parameters compared with PSO and classical approach.

2. *STUDIED SYSTEM*

The studied system contains WT as a main mover to a joined DC source. The product DC volt is switched to 3 phases source via a DC/AC inverter. The 3 phases product

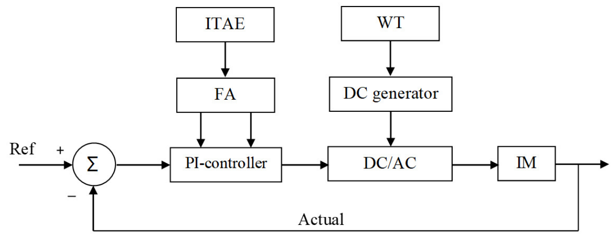


Fig. 1. The schematic diagram of the tested system.

volt of the DC/AC inverter is fed to the 3 phases IM. The suggested approach relied on FA is utilized to adjust the actual speed of the motor. The graphical outline is given in Figure 1.

2.1. IM PATTERN

The electrified portion of the motor is introduced by a 4th paradigm and the mechanistic side by a 2th paradigm. Each electrified parameters and variable are pointed to the stationary side of IM. This is shown by the main mark (′) in the motor equalization addressed in the following relations. Each stator and rotor variables are in the arbitrary 2-axis reference frames.[24,25]

$$V_{1qs}=R_{1s}.i_{1qs}+\tfrac{d}{dt}.\phi_{1qs}+\omega.\phi_{1ds},\quad V_{1ds}=R_{1s}.i_{1ds}+\tfrac{d}{dt}.\phi_{1ds}-\omega.\phi_{1qs} \tag{1}$$

$$V'_{2qr}=R'_{2r}.i'_{2qr}+\tfrac{d}{dt}.\phi'_{2qr}+(\omega-\omega_{2r}).\phi'_{2dr},\quad V'_{2dr}=R'_{2r}.i'_{2dr}+\tfrac{d}{dt}.\phi'_{2dr}-(\omega-\omega_{2r}).\phi'_{2qr} \tag{2}$$

$$T_e=1.50.P.(\phi_{1ds}i_{1qs}-\phi_{1qs}i_{1ds}) \tag{3}$$

$$\phi_{1qs}=L_{1s}.i_{1qs}+L_m.i'_{2qr},\phi_{1ds}=L_{1s}.i_{1ds}+L_m.i'_{2dr} \tag{4}$$

$$\phi'_{2qr}=L'_{2r}.i'_{2qr}+L_m.i_{1qs},\phi'_{2dr}=L'_{2r}.i'_{2dr}+L_m.i_{1ds} \tag{5}$$

$$L_{1s}=L_{1ls}+L_m,L'_{2r}=L'_{2lr}+L_m \tag{6}$$

$$\frac{d}{dt}.\omega_{mr}=\frac{1}{J_c}(T_e-B.\omega_{mr}-T_L) \tag{7}$$

$$\frac{d}{dt}.\theta_{mr}=\omega_{mr} \tag{8}$$

2.2. WT MODELLING

The WT is expressed by no dimensional shapes of the power point (C_{pp}) as a function of together the tip speed rate λ and the blade pitch angularity β. To use the obtainable wind energy, the account of λ would be kept at its best amount. Thus, the power point related to that amount shall be upper.

The apex speed rate (λ) can be introduced as the ratio of the angular rotor speed of the WT to the linear wind speed at the tip of the blades.[26] It may be written as below:

$$\lambda=\omega_t.\frac{R}{V_\omega} \tag{9}$$

Equalization 9, the relation between λ and β may be expressed in the following relation[27]:

$$\frac{1}{\lambda_i}=\frac{1}{\lambda+.08\beta}-\frac{.035}{\beta^3+1} \tag{10}$$

A universal equalization is applied to found$C_{pp}(\lambda,\beta)$. This equation, based on the modelling turbine characteristics of,[26,27] is:

$$C_{pp}(\lambda,\beta)=C(\frac{C_2}{\lambda_i}-C_3.\beta-C_4).e\hat{(}-\frac{C_5}{\lambda_i})+C_6\lambda \tag{11}$$

where β is the pitch angularity and the parameters C_1 to C_6 are:

C_1 = .5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5=21, C_6 = 68/10000.

The upper amount of C_{pp} parameter ($C_{pp\max}$= .48) is reached for (β = 0) degree and for λ = 8.10. This private rate of λ is determined as the normal amount (λ_nom). WT is destined to contain low cut-in and cut-out speed (2-3m/sec: 7-9m/sec). The power product model of WT may be characterized by (12):

$$P_t=\frac{1}{2}.\rho.\Pi.C_{pp}xV(\lambda,\beta)^3.R_A^2 \tag{12}$$

2.3. DC SOURCE

The developed system may be emulated with a suitable expression. The DC generator can be modelled in terms of equations as follows.[24,25] The following equalizations may be emulated via Simulink in the gross system.

$$V_{fi}=R_{fi}.i_{fi}+L_{fi}.\frac{di_{fi}(t)}{dt} \tag{13}$$

$$i_f.\omega_r.M_{af}=R_{to}.i_a+L_{to}.\frac{di_a(t)}{dt} \tag{14}$$

$$V_a=R_{Lo}.i_a+L_{Lo}.\frac{di_a(t)}{dt} \tag{15}$$

3. OPTIMIZATION MATTER

The aim of an optimization process is to reduce the objective time domain function deduced for the tested framework. Integral of Time Absolute Error (ITAE) is applied as a performance index. Hence, the objective equation J_t is written as:

$$J_t=\int_0^\infty t\,|e(t)|dt \tag{16}$$

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

According on this time domain objective equation, optimization process may be expressed as: Reduce J_t as follow:

$$K_{po}^{lower}\le K_{Po}\le K_{po}^{upper},K_{io}^{lower}\le K_{io}\le K_{io}^{upper} \tag{17}$$

This article condenses on optimum setting of PI parameters for speed orientation of IM via FA. The target of this optimization is to seek for the best parameters that lowers the distinction among actual speed and reference one.

4. FIREFLY ALGORITHM

FA is inspired by the mating attitude of fireflies.[19,20] These fireflies may be insects that are able to output innate lighting to pull a prey or mate. This lighting seems to be in a singular style and outputs a surprising sight in the equatorial zones over summer. The concentration (L) of lighting reduces as the space (r) grows and thence generality insects may transmit over distinct hundred meters. In the application of the approach, the glistering lighting is formed like a path that it obtains related to the optimized time domain function. Several principles are applied to expand the constructing of FA.

1. A firefly shall be catched by different insects negligent of their type.
2. Attraction is comparative to their shine and reduces as the interval between them grows.
3. The amount of the objective function defines the brightness of a firefly.[21,22]

The suggested approach relies on duo significant operators: the change of the lighting consistency and the form of the pull.

- Lighting Strength and Appeal

The appeal β of an insect is explained by its lighting strength$L$ that is comparable to the rate of topical time domain mission. As the lighting strength lowers with the range from its reason, the attraction varies with the range r_{fij}among insect fi and insect fj. Also, lighting is achieved by the waist. When the waist is defined, the lighting strength of one insect may be defined by the equalization below.

$$L(r) = L_o.e^{-\gamma r^2} \qquad (18)$$

where γ is the imbibition parameter, and L_o is its first shine, its shine namely at $r = 0$. The pull of an insect is calculated by equalization 15 where β_o is the pull at $r = 0$,

$$\beta = \beta_o.\,e^{-\gamma.r^m}, (m \geq 1) \qquad (19)$$

- Space

The space among every duo insects fi and fj at x_{fi} and x_{fj} respectively, the cartesian space is found by equalization (16) where $x_{\text{fi,fk}}$ is the fk$^{\text{th}}$ element of the locative match x_{fi} of the i^{th} insect and d is the numeral of dimensions.

$$r_{fij} = \sqrt{\sum_{k=1}^{d}(x_{fi,k} - x_{fj,k})^2} \qquad (20)$$

- Modify Location

Placement can be modified when insect i is catched to one more charming insect$j$ that is defined by the equalization below:

$$x_{fi} = x_{fi} + \beta_o.\,e^{-\gamma.r_{fij}^2}.\,(x_{fj} - x_{fi}) + \alpha \in \qquad (21)$$

Where the 2nd item is related to the pull whilst the 3rd item is random amount with α being the randomization item and $\in$ being the vector of stray values taken from the distribution of gaussian. The value γ describes the inequality of the attraction and its amount changes from 0.1 to 10 deciding the congregation rate of the developed approach. It is precious pointing out that the developed approach reaches the universal optimization by insects' uninterrupted modifying location based on the shine and pull.

- Congregation of Approach

For each great numeral of n insects, if $n >> m$, where m is the numeral of native optimum of an optimization process, the congregation of the approach may be achieved. Here, the primary position of n insects is uniformly divided in the whole seeking area, and as the generations of the technique keep insects gather into the whole topical optimal. By comparing the best resolutions between full these primes, the universal optimum is obtained. The steps of the developed approach are displayed in Figure 2.

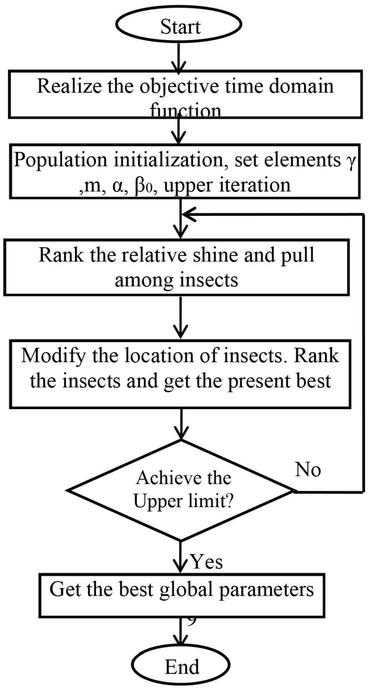


Fig. 2. FA chart.

Appendix in-cludes the values of the developed approach.

5. EMULATION AND RESULTS

The supremacy of the developed FA over PSO and traditional ZN in finding PI elements is discussed for speed orientation of IM in this part. The developed FA and PSO are coded by MATLAB. Table 1. displays the elements of every PI controller and the time response for each approach. The amounts of percentage overshoot and settling time with the FA are lower than the traditional approach and PSO. This confirms that oscillations are reduced highly by applying the developed FA.[23]

5.1. VARIATION IN WT SPEED

The responses of the frame for change of the speed of WT are given here. Figure3 displays the change of the speed of WT as an input perturbation while the load torque is fixed at whole load torque (11.80N.m). Figure 4 gives the product power of the WT. The product power is changing for the variation in WT speed. Figure 5 shows a comparison among the FA, PSO and traditional approach on the speed reaction of IM. Figure 5a discusses the zoom for change in speed. It is obvious, the dynamic and steady procedure of IM as a function of settling time and overshoot has been improved.

Also, the developed approach is more active in enhancing speed adjustment of the motor under study compared with PSO and ZN based techniques.

Table 1. The characteristics for each controller.

	K_{Po}	K_{io}	Time of Settling	% Over shoot
FA	0.1544	0.6221	0.76	12.20
PSO	0.1876	0.7423	0.81	12.60
ZN	0.0135	0.7848	2.74	48.80

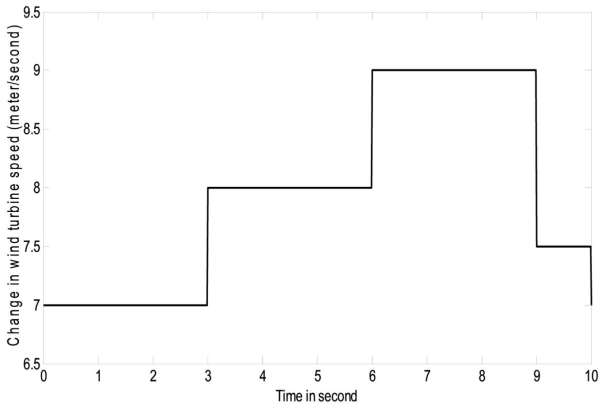


Fig. 3. The variation of speed WT.

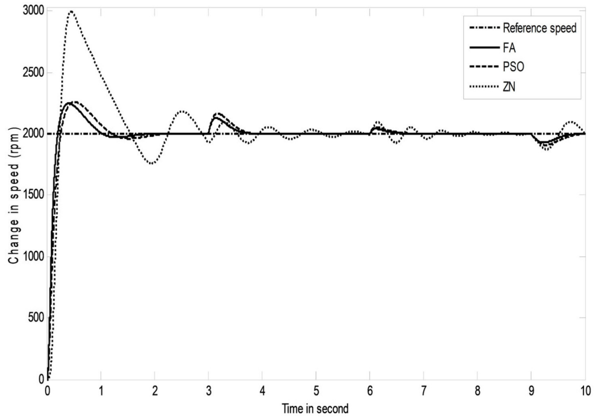


Fig. 5. The variation of motor speed for distinct approaches.

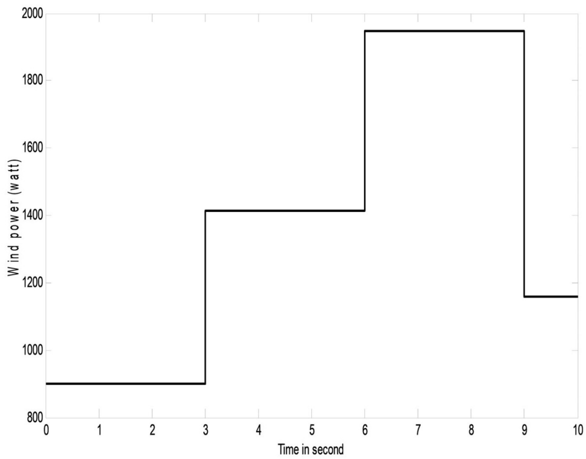
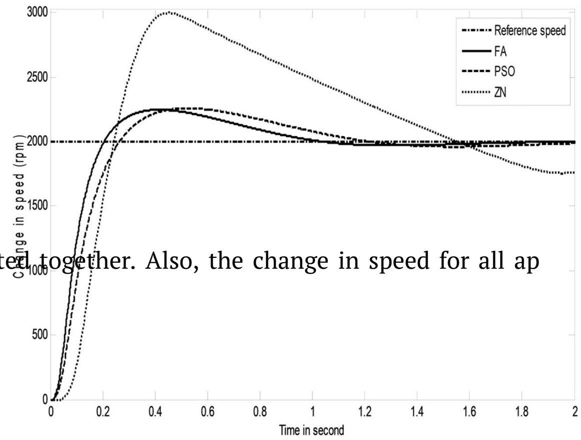


Fig. 4. The product power of WT.



lemented together. Also, the change in speed for all ap

Fig. 5a. Zoom of motor speed for change of WT speed.

5.2. VARIATION IN LOAD TORQUE

The responses of the system for change of the load torque are illustrated in this portion. Figure 6. gives the change of the load torque as an input perturbation while the speed of WT is fixed at 8m/s. Also, the response of the motor for various approaches are given in Figure 7. Figure. 7a introduces the zoom for change in speed based on change in load torque.It is obvious from this Fig., the developed FA outlives PSO in tuning the speed of IM and minimizing settling time successfully. Thus compared with the traditional technique and PSO based approach, PI based FA promotes highly the frame execution.

5.3. VARIATION IN WT SPEED AND LOAD TORQUE

In this state, changes of speed WT and load torque are implemented together. Also the change in speed for all approaches is given in Figure 8. From this figure it is obvious that the developed FA is more dynamic in enhancing speed response of the motor than other approaches. Moreover, it has a lower settling time and the reaction of speed is directed speedily with the required speed. Also, the sublimity of the developed FA than PSO for speed orientation is given in Figure 8a. Thus, the nobleness of the developed FA than PSO and ZN is proven.

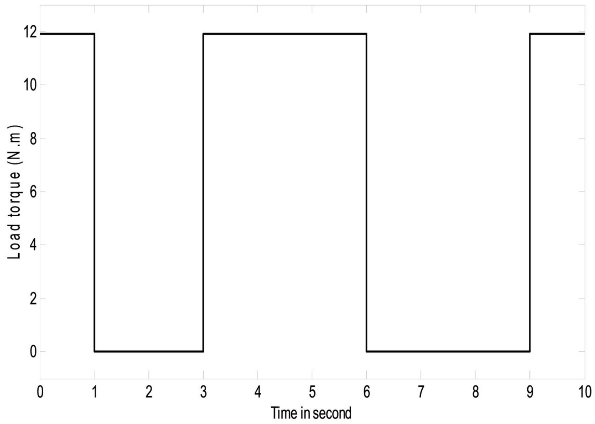


Fig. 6. The variation of load torque.

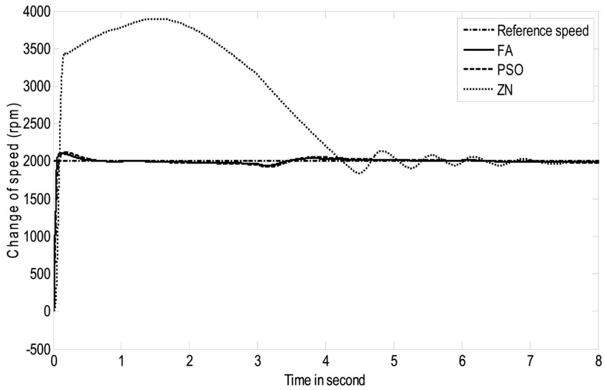


Fig. 7. Speed response of IM for distinct controllers.

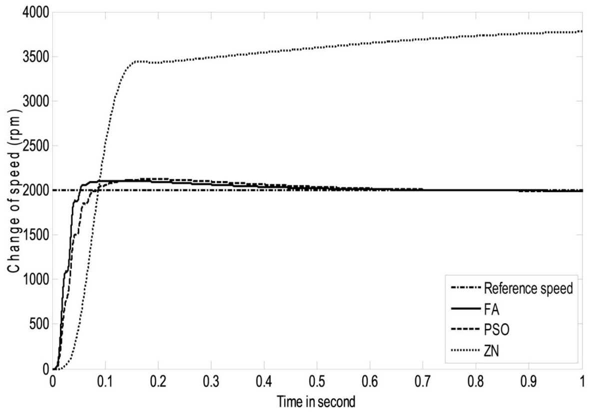


Fig. 7a. Zoom for speed response based on change in load torque.

5.4. STRENGTH AND VARIOUS INDICES:

To prove the strength of the developed approach, several working indices: (IAE) Integral of Absolute Error, (ISE) Integral of Square Error, and (ITSE) Integral of Time compound Square Error are being utilized as:

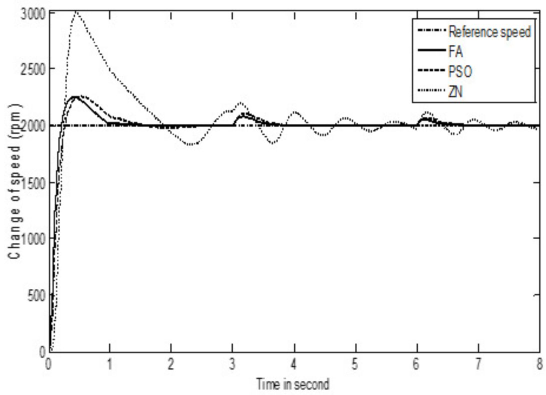


Fig. 8. The variation of motor speed for distinct approaches.

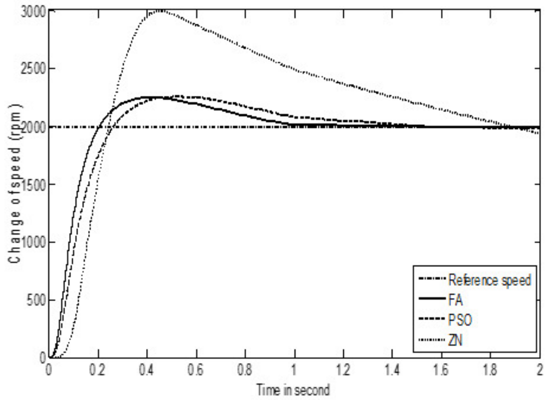


Fig. 8a. Zoom of motor speed for distinct approaches.

$$IAE = \int_0^{t_{em}} (|e|).\, dt \tag{22}$$

$$ISE = \int_0^{t_{em}} e^2 dt \tag{23}$$

$$ITSE = \int_0^{t_{em}} te^2 dt \tag{24}$$

where t_{em} is the time of emulation and equalizes to ten sec. Numeral results of achievement strength for whole approaches are recorded in Table (2) for high variation of torque of load, and elements of WT frame. It may be shown that the amounts of these frame achievements with the developed approach are lower compared with those of PSO and ZN. This confirms that the settling time, over shoot, and speed variations are highly reduced by placing the developed FA based tuned PI. Finally, values of these indices are lower than those given by ICA in.[28]

6. CONCLUSION

This article suggests a novel optimization approach marked as FA for optimum styling of PI parameters for speed setting of IM. The layout process of the suggested approach is affirmed as an optimization process and FA is carried out to

Table 2. Distinct indices for each approach.

	Equation 22	Equation 23	Equation 24
FA	23.87	121.69	463.8
PSO	28.63	153.17	504.21
ZN	49.84	451.10	1475.0
ICA[28]	24.94	126.38	472.40

seek optimum elements. By lowering the designed function, in which the divergence among the datum speed and current one is included; speed setting of IM is promoted. Emulation outcomes assure that the developed FA in regulation of PI elements is potent in its working and obtains a premium attitude for the divergence in speed WT and torque of load compared with PSO setting PI elements and traditional approach. Moreover, its structure is simplest and it is plain to apply and adjust.

CONFLICTS OF INTEREST

Author presented in this manuscript does not have any conflicts of interest.

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APPENDIX

The optimization parameters are as shown below:

a) PSO parameters: C_1=C_2=2.0, ω=0.9.

b) The parameters of FA: γ=1.0; β_0=0.1; α=0.1; maximum number of generations=100; number of fireflies=50.

c) DC generator values: R_{fi}= 33.70 ohm, L_{fi}= 1.70 H, R_{ar}= .0125 ohm, $\mathrm{L_{ar}}$= .08 H, R_{Lo}= 0.313 ohm, L_{Lo}= 1.62 H, M_{af}= 0.8 H.

d) Motor values: f =60 Hz, rated volt=220 V, P =2, L_{ls}= 2mH, R_{1s}= 0.435 ohm, R_{2r} =0.408 ohm, L_{lr}=2 mH, B=0.001, J_c=0.356, T_L=11.80N.m, L_m=0.06934 H.