Artificial Intelligence Based Speed Control of DC Motor Using PIDN Controller

K. Murali Krishna Raju[1], B. Keerthi[2], M. ReshmaDaneela[3], K. Siva Kumar[4] and D. Sandeep[5]
Department of Electrical and Electronics Engineering
Chalapathi Institute of Engineering &Technology, Lam, Guntur, Andhra Pradesh, INDIA-522032

Abstract: In this article, proportional integral derivative with filter (PIDN) controller is implemented based on firefly algorithm for speed control of a DC motor, which is one of the power system application. PID parameters KP, KI, KD and N are tuned by using nature-inspired optimization algorithm called as firefly algorithm. Desired response of DC motor is obtained by using tuned parameters of PID. Thereafter comparative analysis has been done with other controllers like proportional (P), integral (I), derivative (D), proportional-integral (PI), proportional-integral-derivative (PID), proportional-integral-derivative with filter (PIDN) in terms of different performance indices (PIs) like integral of square error (ISE), integral of time-weighted absolute error (ITAE), integral of absolute error (IAE), and integral of time-weighted square error (ITSE) and different time domain specifications. Also, studies are carried with random input pattern considering ISE. Comparison of DC Motor responses with P, I, D, PI and PID controller shows better response with PIDN controller in terms of settling time, peak overshoot and peak undershoot. Moreover, PIDN controller with ISE as PI exhibits performance over ITSE, IAE and ITAE. Further, PIDN controller with ISE considering random input pattern also shows that proposed PIDN controller outperforms over PI and PID controllers

Key Words— PIDN controller, D.C Motor, PIDN, Firefly Algorithm, Performance Indices

I. INTRODUCTION

Many distributed real-time applications, such as audio-andvideo-conferencing, collaborative environments and distributed interactive simulation require simultaneous communication between groups of computers with quality of service guarantee; these applications involve a source in sending messages to a selected group of receptors. Classic unicast and broadcast network communication is not optimal; therefore,[1] Deering proposed a technique called IP multicast routing for one-to-multiple and multiple to multiple communication, which entrusts the task of data duplication to the network applications can send one copy of each packet and address it to the group of involved computers. The network takes care of message duplication to the receivers of the group.

Many applications use dc motor to benefit from their simple, wide and precise control characteristics. Such applications include, for example robotic manipulators, steel rolling mills, electric trains, cranes, electric cars, etc [1-2]. Even the Brushless DC (BLDC) motor has been developed with higher efficiency in operation than classic DC motor [3]. The most flexible control is obtained by means of Separately Excited DC Motor (SEDM). The best quality of this motor is that it provides high torque load sustainable property, and it can be used with batteries and solar cells [4]. DC motors are a good field to study advanced control algorithms, due to the fact that its theory can be projected on other types of motors [5].

The speed control of dc motor with power electronic systems is obtained generally by changing its terminal voltage. A PID controller is a good candidate for speed control of dc motors. It is the most common controller used in industry due to its simplicity and ease of implementation [6]. In addition, the PID controller is used for controlling the brushless dc motor by designing two controller types Fuzzy logic and PI controllers [7]. The unknown DC motor parameters could be estimated by experimental data onto armature current and speed response, or by adapting an adaptive model with reference model created based on experimental data [8]. In some cases, the system parameters are changing during operation, and the PID controller cannot adjust its own gains to cope with these changes, which will emanate the need to online retune the PID gains [9]. Parameters tuning of the DC motor can be easily achieved by the use of artificial intelligence techniques.

Speed control of a power apparatus application i.e. D. C Motor is very essential because these motors are widely used in residential and industrial purposes. Different algorithms based PID for speed control of a D. C Motor is reported in literature [10]. Regarding FOPID, based on various metaheuristic optimization algorithm (MOAs), very few works are reported in literature [11-18]. In this respect, various MOAs like Earthquake algorithm, Genetic algorithm, Cuckoo search optimization algorithm, Grey wolf optimization algorithm and Bee colony algorithm based PID are proposed for D. C Motor speed control [11-18].

D.C Motor speed control is obtained by using variousMOAs based PID have been considered in above discussed works. Quick disturbance rejection is achieved by using PIDN as compared with P, I, D, PI and PID. Therefore, there is a scope for implementation of PID using various MOAs for speed control of a D. C Motor. In the present work we implement PID for speed control of a D. C Motor based on firefly algorithm.

The optimum values of the above mentioned controllers can be found by traditional optimization as well as bio-inspired optimization techniques. Algorithms like direct search, gradient search, random search etc., are of traditional optimization techniques having a drawback of sticking at local minima with slow search speed, no guarantee in obtaining global optima and makes large number of iterations in reaching optimum solution [18] -[20]. These are overcome by bio-inspired algorithms like fire fly algorithm (FA) [21] and is utilized for setting of controller parameters at optimum values.

❖ **The main contributions of this chapter are**

a) In this work, we implement PIDN based on firefly algorithm for speed control of a D. C Motor.
b) Optimization of PIDN parameters K_TP, K_I, K_D and N is carried out by using firefly algorithm.
c) We obtain desired response of motor by using optimized parameters of PIDN.
d) Later on comparative analysis is done with firefly based PIDN, PID, PI, P, I and D in the sense of various PIs and time domain specifications.
e) Also, the investigations considering PIDN with various load pattern are carried.

.II. SYSTEM COMPONENTS

A. PIDN controller

To achieve an ideal response, coefficients such as K_P, K_I, K_D and N are optimized. The transfer function equation and diagram of PIDN with input (R) and output (U) are shown in (1) and Fig.1.

$$G_{PIDN}(s) = K_P + \frac{K_I}{s} + K_D s \frac{N}{s+N} \qquad (1)$$

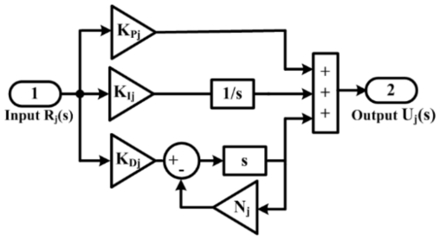


Fig.1 Transfer function diagram of PIDN

B. Various performance index criteria's:

Meta-heuristic algorithms are utilized for the optimization of several secondary controllers considering various performance index criteria's (PIC). PICs are helpful in reducing the errors of the system.

a) $\eta_{ISE} = \int_0^t (\Delta e)^2 dt$

b) $\eta_{IAE} = \int_0^t |\Delta e| dt$

c) $\eta_{ITSE} = \int_0^t (\Delta e)^2 \times t dt$ and

d) $\eta_{ITAE} = \int_0^t |\Delta e| \times t dt$

C. The inputs considered:

The input of a DC motor is current/voltage and its output is torque. By understanding the concept, the investigations on speed control of DC motor with AI techniques are carried by considering two types of input (i) Step input signal and (ii) Random input pattern.

D. DesignModelling of DC Motor under analysis

Armature controlled separately excited D. C Motor is the system under analysis. Fig. 2(a) shows the equivalent circuit of the analysing system. The following is the mathematical modelling of the analysing system. This is the electro mechanical system. While modeling the system we assume that electrical system consists of only armature circuit. Fig. 2 (b) shows the armature equivalent circuit.

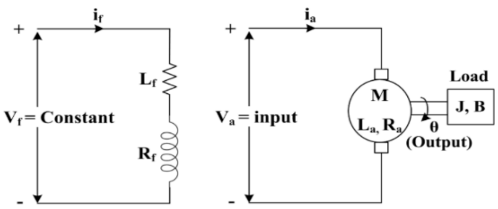


Fig. 2 (a) D. C Motor equivalent circuit

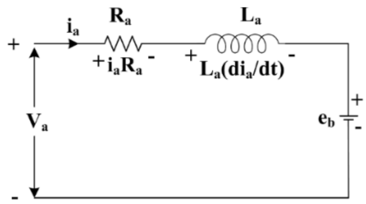


Fig. 2 (b) Armature equivalent circuit

The transfer function of the D. C Motor with input voltage (Va) and angular velocity (w) is in (2) [2].

$$\frac{\omega(s)}{v_a(s)} = \frac{\chi}{(R_a + sL_a)(Is + B) + H\chi} \quad (2)$$

From [2], consideringvalues and (2) is modified as (3).

$$\frac{\omega(s)}{v_a(s)} = \frac{1.23}{0.005s^2 + 0.0252s + 1.523} \quad (3)$$

III. FIREFLY ALGORITHM

Firefly Algorithm inspires the flashing behaviour of fireflies in solving problems. Fireflies are winged beetles or insects that produce light and blinking at night. The light has no infrared or an ultraviolet frequency which is chemically produced from the lower abdomen is called bioluminescence. They use the flash light especially to attract mates. The flash light also used as a protective warning mechanism to remind the fireflies about the potential predators [22, 23].

FA was developed by Yang in 2008. It works on the firefly's brightness. The characteristics of FA are [22, 23].

a) A firefly will be attracted to each other regardless of their sex because they are unisexual.
b) Attractiveness is proportional to their brightness whereas the less bright firefly will be attracted to the brighter firefly. However, the attractiveness decreased when the distance of the two fireflies increased.
c) If the brightness of both fireflies is the same, the fireflies will move randomly

Based on its brightness (objective function) the fireflies with lower brightness mates with fireflies of higher brightness in order to produce new solutions. Therefore, in
FA previous solution is updated by a new solution based on their brightness level and its Flow chart of FA is illustrated in Fig.3. The best solution is considered with good fitness. The tuned values of FA are fireflies number = 30, max_{gen} =100, β = 0.3, α = 0.4 and γ = 0.6. The proposed controller gains such as K_P, K_I, K_D and filter (N) coefficients are optimized by Firefly algorithm technique, subjected to constraints given by (4).

$$K_{Pj\min} \le K_{Pj} \le K_{Pj\max},\ K_{Ij\min} \le K_{Ij} \le K_{Ij\max},$$
$$K_{Dj\min} \le K_{Dj} \le K_{Dj\max} \text{ and } N_{j\min} \le N_j \le N_{j\max} \quad (4)$$

In this section, system under investigation has been discussed and simulation results of FA based P, I, D, PI, PID and the proposed PIDN controllers for speed control of D.C. Motor has been presented.

Also, the simulation results of speed control of a D.C [23] – [25]. Motor using various controllers based on FA are presented. Simulation diagrams for various performance indices are shown in Fig. 4(a) – Fig. 4 (d).

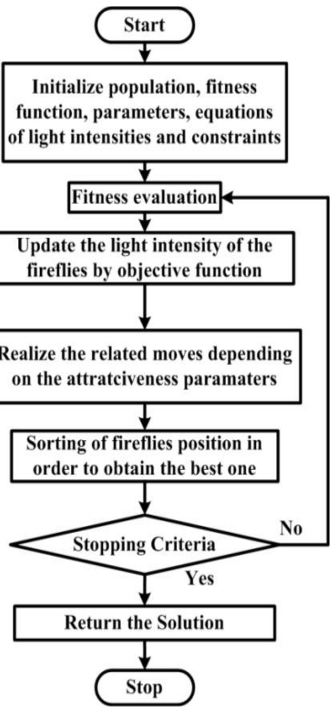


Fig. 3 Flow chart of FA.

V.SIMULATION RESULTS

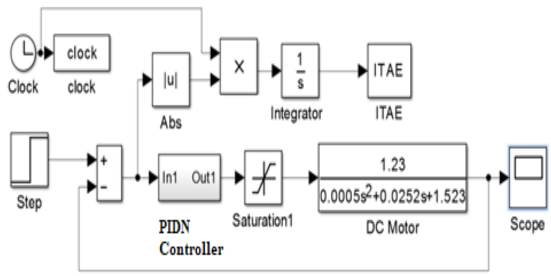


Fig.4 (a)

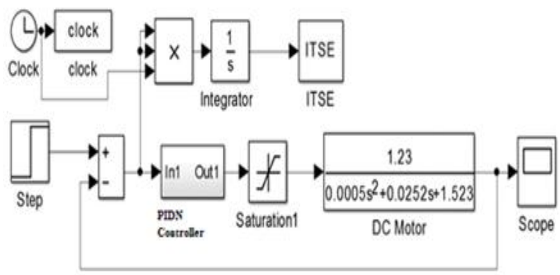


Fig.4 (b)

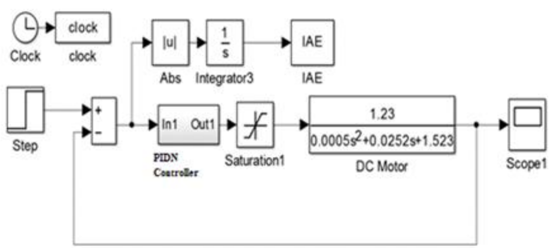


Fig.4 (c)

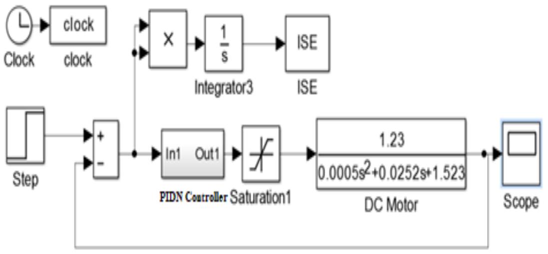


Fig.4 (d)

Fig. 4 Simulink diagrams of speed control of D.C Motor using PIDN considering (a) ITAE, (b) ITSE, (c) IAE and (d) ISE as a performance index

A. P, I, D controller's comparison with ISE considering unit step input

The system in Fig.4 (d) is with DC motor, PIDN controller and ISE as performance index are considered for the study. The PIDN controller gains are optimized by firefly algorithm and are noted in Table.1. The obtained dynamic responses are plotted in Fig.5. The values of settling time, peak overshoot and peak undershoot are noted in Table 2.Careful observations from Fig. 5 suggests that system dynamics are not settled with P, I and D controllers.

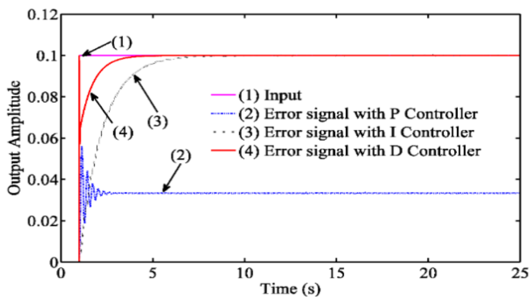


Fig. 5(a)

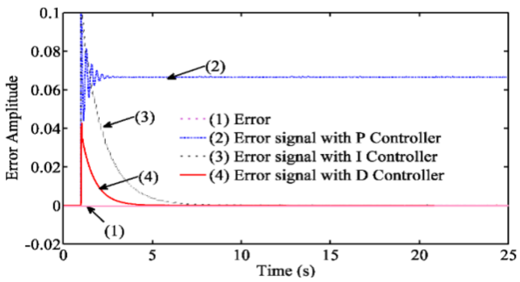


Fig. 5 (b)

Fig.5 DC motor responses (a) output and (b) error

Table 1. Optimum gains of P, I and D controller with ISE considering unit step input	
With P-controller	K_P = 0.6210
With I-controller	K_I = 1.000
With D-controller	K_D = 0.8760

Table 2 **Values of settling time, peak overshoot and peak undershoot P, I and D controllers**

	Peak overshoot	Peak undershoot	Settling time
P controller	1.6	0.7	8
I controller	1.4	0.85	14
D controller	1.2		10

B. PI, PID and the proposed PIDN controller's comparison with ISE considering unit step input

System in Section B is provided with PIDN controller considering ISE and the controller gains are optimized by FA technique. Table 3 lists the controller optimum values and its corresponding dynamics are compared and plotted in Fig. 6 respectively. The performance values of this study are tabulated in Table 4. Critical observations from Fig.8, Fig.9 and the performance values from Table 4 shows that the proposed PIDN controller exhibits better system dynamics over other P, I, D, PI and the PID controllers in terms of settling time, peak overshoot and peak undershoot.

Table 3. Optimum gains of PI, PID and the proposed PIDN controller with ISE considering unit step input	
With PI-controller	K_P = 0.4786; K_I = 0.8741
With PID-controller	K_P = 0.5558; K_I = 0.9816; K_D = 0.4963
With PIDN-controller	K_P = 0.1117; K_I = 0.9633; K_D = 0.9926; N = 35.5768

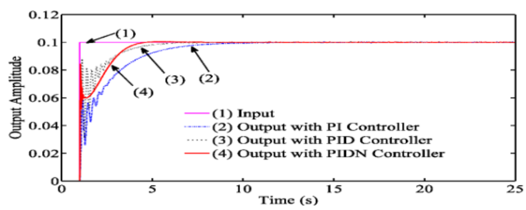


Fig. 6(a)

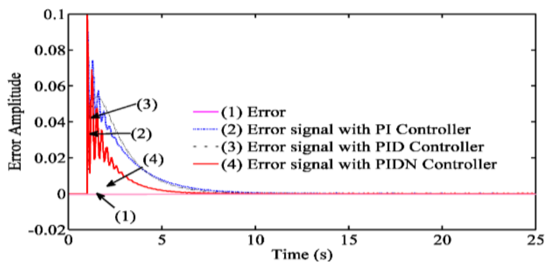


Fig. 6(b)

Fig.6 DC motor responses with PI, PID and PIDN controller (a) Output and (b) Error

Table 4 Values of settling time, peak overshoot and peak undershoot for PI, PID and the proposed PIDN controllers			
	Peak overshoot	Peak undershoot	Settling time
PI controller	0.6	0.1	10
PID controller	0.08	0.03	6
PIDN controller	0.009	0.0005	5

A. Comparison of various performance indices with the proposed PIDN controller

The best controller from section B is considered for the study and is provided with various performance indices. The transfer function diagrams of various performance indices are shown in Fig. 4. Firefly algorithm is utilized for the optimization of controller gains and the controller optimum values are noted in Table 5.From the observations of Fig. 7 (a) and Fig.7(b), it is evident that performance of ISE with PIDN controller outcomes over ITSE, IAE and ITAE. Also, from Fig.7 (c), it is clear that the convergence with ISE is faster than other PICs.

Table 5. Optimum gains the proposed PIDN controller with ISE, IAE, ITSE and ITAE considering unit step input	
With ISE	$K_P = 0.1117$; $K_I = 0.9633$; $K_D = 0.9926$; N = 35.5768
With ITSE	$K_P = 0.4094$; $K_I= 0.6041$; $K_D= 0.2200$; N=57.7746
With IAE	$K_P= 0.0451$; $K_I= 0.6819$; $K_D= 0.6145$; N=35.019
With ITAE	$K_P= 0.3168$; $K_I= 0.7553$; $K_D= 0.7653$; N=16.672

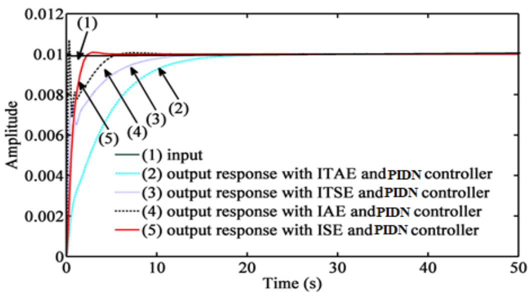


Fig. 7(a)

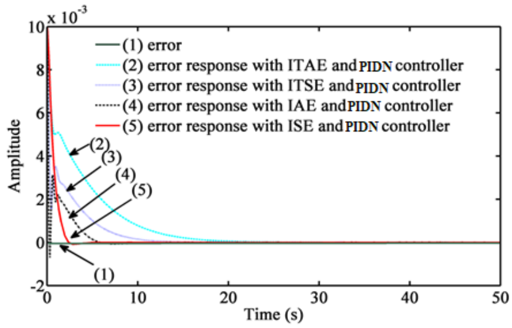
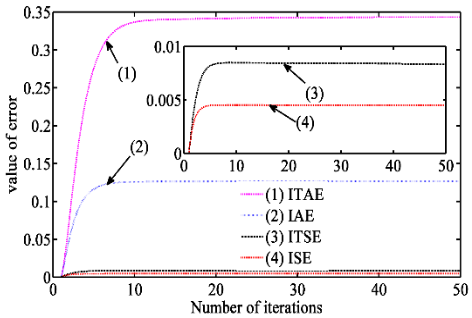


Fig. 7 (b)



Fi.g 7 (c)

Fig.7 DC motor responses with various PICs (a) Output, (b) Error and (c) Convergenve

B. Comparison of various controller considering ISE as PIC and random pattern input

The best performance index from section Cie., ISE is considered for this study. Investigations are carried with random input pattern. Controllers such as PI, PID and the proposed PIDN are considered for the investigations. The suggested controller values are optimized by Firefly algorithm and are noted in Table 6. The corresponding dynamic responses with random input pattern are compared and are plotted in Fig. 8. Observations from Fig.17 and Fig.18, shows that the responses with the proposed PIDN controller exhibits better dynamics over PI and the PID controllers. From this section, it is evident that with random input also, the proposed PIDN controller shows better responses.

Table 6. Optimum gains of PI, PID and the proposed PIDN controller with ISE considering random input pattern	
With PI-controller	$K_P = 0.5577$; $K_I = 0.9814$
With PID-controller	$K_P = 0.5545$; $K_I = 0.9806$; $K_D = 0.4953$
With PIDN-controller	$K_P = 0.557$; $K_I = 0.9820$; $K_D = 0.5010$; N = 35.6010

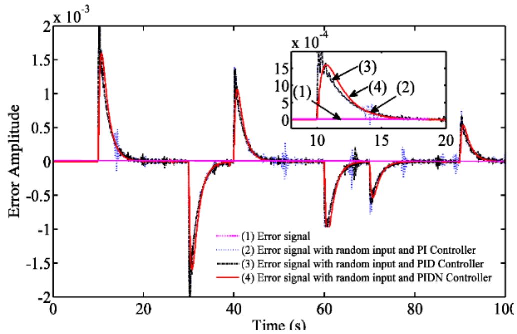


Fig.8 (a)

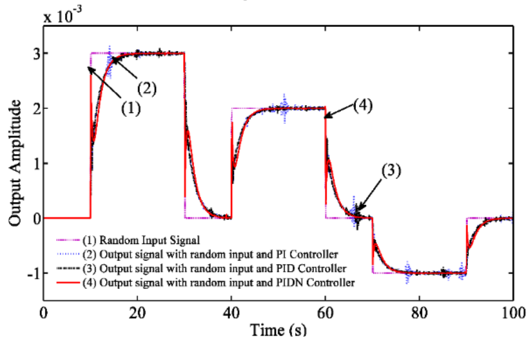


Fig. 8 (b)

Fig. 8 DC motor responses with random input (a) Output and (b) Errror

VI. CONCLUSION

From the simulation results obtained, we observed the following conclusions Controllers such as P, I and D has shown more values of settling time, peak overshot and peak undershoot over PI, PID and PIDN controllers, Output and error responses with ISE outperforms over other performance indices like ITSE, IAE and ITAE, PIDN controller with ISE converges faster than ITSE, IAE and ITAE, D.C Motor output and error responses with the proposed PIDN controller show better responses over other controllers with unit step and random input patterns, The proposed PIDN controller with firefly algorithm shows better responses for random input pattern also, PIDN controller with random input pattern shows better responses over PI and PID controllers.

REFERENCES

[1] George, M. (2008). "Speed control of separately excited DC motor." American journal of applied sciences, 5(3), 227-233.

[2] Pavankumar, S., Krishnaveni, S., Ven, gopal, Y. B., &Babu, Y. K. (2010, November). "A neuro-fuzzy based speed control of separately excited DC motor." In Computational Intelligence and Communication Networks (CICN), 2010 International Conference on pp. 93-98. IEEE.

[3] G. G. Raja Sekhar, &BasavarajaBanakar, " Solar PV fed non-isolated DC-DC converter for BLDC motor drive with speed control" Indonesian Journal of Electrical Engineering and Computer Science (IJEECS), Vol. 13, No. 1, pp. 313-323, January 2019.

[4] Khanke, M. P., & Jain, A. P. S. (2015). "Speed control of Separately Excited DC Motor using various Conventional Controllers". International Journal of Engineering Research and Applications, 5(4), 67-72.

[5] Qadir, A. S. (2013). "Electro-mechanical modeling of SEDM (separately excited DC motor) & performance improvement using different industrial controllers". Lulu. com.

[6] Fahmy, R. A., Badr, R. I., & Rahman, F. A. (2014). "Adaptive PID controller using RLS for SISO stable and unstable systems". Advances in Power Electronics, 2014.

[7] Muhammed A.Ibrahim, et al. "Optimal PID controller of a brushless DC motor using genetic algorithm" International Journal of Power Electronics and Drive System (IJPEDS), Vol. 10, No. 2, pp. 822-830, June 2019.

[8] ByamakeshNayak, ,&SangeetaSahu, "Parameter estimation of DC motor through whale optimization algorithm" International Journal of Power Electronics and Drive System (IJPEDS), Vol. 10, No. 1, pp. 83-92 , March 2019.

[9] Mansour, T., Konno, A., & Uchiyama, M. (2011). "Neural Network Based Tuning Algorithm for MPID Control." In PID Control, Implementation and Tuning. InTech

[10] I. Podlubny, Fractional Differential Equations, Academic Press, New York, 1999.

[11] T. Chiranjeevi, N. Ram Babu, S.K. Pandey et al., Maiden application of flower pollination algorithm based tilt integral derivative controller with filter for control of electric machines, Materials Today: Proceedings, (2021). Doi: https://doi.org/10.1016/j.matpr.2021.05.049.

[12] A.K.Yadav et al., Soft Computing in Condition Monitoring and Diagnostics of Electrical and Mechanical Systems, 1E, Springer Nature, Part of the Advances in Intelligent Systems and Computing, vol. 1096, pages 496, 2020, ISBN 978-981-15-1532-3. Doi: https://doi.org/10.1007/978-981-15-1532-3.

[13] A. Iqbal et al., Meta Heuristic and Evolutionary Computation: Algorithms and Applications, 1E, Springer Nature, Part of the Studies in Computational Intelligence, vol. 916, pages 849, 2020, ISBN 978-981-15-7571-6. Doi: https://doi.org/10.1007/978-981-15-7571-6.

[14] Jafar A. Alzubi, AI and Machine Learning Paradigms for Health Monitoring System: Intelligent Data Analytics, 1E, Springer Nature, Part of the Studies in Big Data, vol. 86, pages 513, 2020, ISBN: 978-981-33-4412-9. Doi: https://doi.org/10.1007/978-981-33-4412-9.

[15] A. Iqbal et al., Renewable Power for Sustainable Growth, 1E, Springer Nature, Part of the Lecture Notes in Electrical Engineering, vol. 723, 805 pages, 2021, ISBN: 978-981-33-4080-0. Doi: https://doi.org/10.1007/978-981-33-4080-0.

[16] N. Fatema et al., Intelligent Data-Analytics for Condition Monitoring: Smart Grid Applications, 1E, Academic Press, 2021, ISBN: 978-0-323-85510-5. Doi: https://doi.org/10.1016/C2020-0-02173-0.

[17] S.Srivastava et al., Applications of Artificial Intelligence Techniques in Engineering- volume 1, 1E, Springer Nature, Part of the Advances in Intelligent Systems and Computing, vol. 698, 643