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BLDC Motor Speed Control with Digital Adaptive ANFIS and Reduced Harmonic Content

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Brushless DC motors are gradually replacing DC motors in a number of applications, such as aircraft machinery, cars, and home appliances. Brushless DC motor is commutated electronically unlike the DC motor. Brushless DC motor is controlled using three phase power inverters. Depending on the rotor's position and the control algorithm, this inverter supplies power to the stator windings. The motor is electronically commutated, and a sensor approach can be used to accomplish the control strategy algorithm needed for commutation. A speed feedback loop can also be used to manage the motor and bring it to the required level of performance. The motor must be controlled with an appropriate speed controller in order to achieve the needed level of performance in a variety of applications that call for the motor to be operated at constant load conditions, constant speed throughout a range of loading conditions, and variable set speed settings. For this purpose, conventional controllers are used; however, because of the nonlinearity in the drive characteristics of Brushless DC motors, these controllers are particularly challenging to operate under various conditions. Artificial intelligence-based controllers, such as the Particle Swarm Optimisation (PSO) algorithm optimised online ANFIS controller and the Adaptive Neuro-Fuzzy Inference Systems (ANFIS) controller, are proposed as a solution to this issue. The controllers are made to monitor changes in speed references and maintain output speed stability in the face of load fluctuations.

Keywords: BLDC, speed load, ANFIS, PSO.

1. Introduction

Recent developments in modelling of complex physical and technical processes lead to a growing interest in modelling of large-scale dynamical systems. The modelling and performance of the system under considerations are the prime concern of control engineers [1]. No physical system can be accurately modelled for fuzzy control design purposes. There are differences between the actual plant and the mathematical model developed for controller design. The system processes are described by complex models and are non-linear in nature and the information about the stability of a system can be obtained by employing suitable linearized models. It is also preferable to have techniques for creating controllers for higher order systems accessible because of these reasons. Appropriate reduced order models can assist minimise the computational burden associated with designing controllers for higher order linear systems. This research presents a flexible particle swarm optimisation (PSO) based adaptive Neuro Fuzzy interference system (ANFIS) controller parameter assurance technique for direct brushless DC engine speed management. The principal components of the suggested method consist of its simple implementation, consistent convergence characteristic, and high computing efficiency [2][15][16].

MATLAB is used to implement the PSO method, while Simulink is used to represent the brushless DC motor. Comparing with other controller method, the proposed method was more efficient in improving the step response characteristics such as, reducing the steady-state error; rise time, settling time and overshoot in speed control of a linear brushless DC motor [3]. The need of this work is to have a dynamics response of speed with the fuzzy logic controller to control the speed of motor for keeping the motor speed to be constant when the load varies [4][18]. In this study, a fuzzy controller is introduced to maintain a steady motor speed even under load variations [9][17]. However, in the end, an optimisation method is created to achieve the objectives and constraints at various set points, and a PSO is used to optimise its parameters [24]. This algorithm reduced the torque ripple in the steady state by optimising the ANFIS controller's transient state parameters, turn-on and turn-off degrees for each phase, and overall controller parameters. The purpose of this work is to use artificial intelligence techniques to create an appropriate controller for brushless DC motor speed control [8][26]. Furthermore, the controllers are effectively compared using integral performance indices and measured values of time domain parameters. The controllers are made to monitor changes in speed references and maintain output speed stability during load variations. The current work's goals and scope are [6][20]:

- To design and implement a ANFIS Controller for Brushless DC Motor and the various characteristics curves are drawn and analysed.
- Performance Analysis of BLDC motor using Soft Computing techniques using Particle Swarm Optimization Algorithm.
- The Controllers are taken into task as PID controller, Fuzzy controller, Fuzzy-PID and Neuro- Fuzzy.
- The speed control of the BLDC motors is controlled by ANFIS controllers and the characteristics parameters are considered into account as Speed, Torque, Voltage and Current.

There are multiple sections to the paper. The pertinent study conducted by several different researchers is reviewed in the section II that follows. A description of the suggested system's framework is given in part III. Section IV provides a description of the experimental outcome and remarks. Section V provides a conclusion to the suggested task.

2. LITERATURE SURVEY

The current study focuses on BLDC analysis and optimization strategies for various controller-based DC motor speed control.

Setia et al, [5] (2021) suggested a novel approach to power system LFO damping that relies on the best possible coordination of a wide-area measurement-based fractional-order proportional-integral-derivative (WMFOPID) controller acting as a supplementary controller for synchronous generator PSSs and LPFs. In comparison to earlier controllers, the results further demonstrate the optimal WMFOPID controller's strong robustness against various power system uncertainties. Reddy, et al [19] (2022) the speed of a two-mass wind turbine system is controlled using the suggested analytical fractional order PID controller design approach. Because of its inherent benefits, the complicated nonlinear wind turbine system is typically described as a two-mass system. On the other side, high overshoot and wind turbulence are elements that stress wind turbines, and they can be reduced with the right speed management plan. The utilized methodology facilitates the development of fractional order PID parameters in accordance with the intended phase margin and unity gain crossover frequency.

Mohd et al [7] (2023) Proposed a novel approach based on the MP-SEDA-based technique with adjustable CF is put forth for fine-tuning the AVR system's FOPID controller. Liu, et al, [27] (2023) proposed a fractional-order basic system describes a generic type industrial temperature control process for which a fuzzy fractional-order PID controller. The Mittag-Leffler functions that are used to present fractional-order membership functions have fat-tailed distributions. Compared to original membership functions, they can offer an additional optimisation dimension. The detailed design methods and fuzzy rules of the suggested fuzzy logic controller are provided. Online adjustments to the controller parameters are possible based on model uncertainties and disturbances resulting from changes in the surrounding environment. In addition, the suggested control method's superiority is illustrated by the display of investigated temperature control system instances.

Athira, et al, [21] (2023) suggested optimising the fractional order proportional-integral-derivative (FOPID) controller for an automated voltage regulator (AVR) system using a fractional filter. Numerous parameters for the proposed controller can be adjusted. An automated voltage regulator system's best PID controller is to be designed through comparison analysis utilising a variety of optimisation techniques. This study looks at three techniques: the Salp Swarm Algorithm (SSA), Ant Lion Optimisation (ALO), and Particle Swarm Optimisation (PSO) [22]. The performance indexes that are being employed are the overshoot, rising time, and settling time. Each of the suggested optimisation strategies improved the AVR system's transient responsiveness in a unique way, and preliminary findings were encouraging. The superiority of the proposed controller is further supported by comparison with the best-tuned FOPID controllers for the AVR system. M,et al [10] (2023) an enhanced transient responsiveness is achieved with the suggested AVR controller, all while maintaining system stability. Furthermore, because of the additional fractional order operators present, the FOPID offers more design flexibility. The response and optimization procedure of the FOPID reveal two new design flexibilities when compared to the integer-order PID. A thorough statistical analysis of the MPA is given, along with findings produced from 30 runs, and they are compared with prominent approaches found in the literature. When compared to the other approaches under investigation, the suggested FOPID-MPA method offers the best objective function minimization with fewer variances among runs. The statistical parameters are given together with the results of the ANOVA and Tukey tests, which turned out to be the best results that the suggested FOPID-MPA approach could produce.

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3. METHODOLOGY

A speed control is necessary to drive a BLDC motor at the desired speed. The BLDC motor's speed cannot be determined without first adjusting the input direct current voltage. The armature's input voltage is adjusted via the pulse width modulation method if the motor begins to operate slower than its rated speed. A high voltage causes the speed to rise. The flux is decreased by pushing the outgoing current flow ahead when the BLDC motor begins to run faster than its rated speed. Consequently, it is imperative and necessary to use the motor's speed-regulating device. The speed control system of the motor under consideration is depicted in diagram form in Figure 1. The motor's speed regulating process is crucial for getting it to operate at the correct pace. In essence, the input dc voltage or the input current are governed and controlled to regulate the BLDC motor speed. More speed will be produced by the machine at higher voltages. In order to regulate the functioning of BLDC motors, many typical control methods are used. Typically, the voltage of these motors is controlled by a power transistor module, which primarily serves as a linear voltage regulator. The designed controllers must be able to commutate the motor, determine the location of the rotor using the back-EMF, and control the motor's speed using pulse width modulation voltage [11][23].

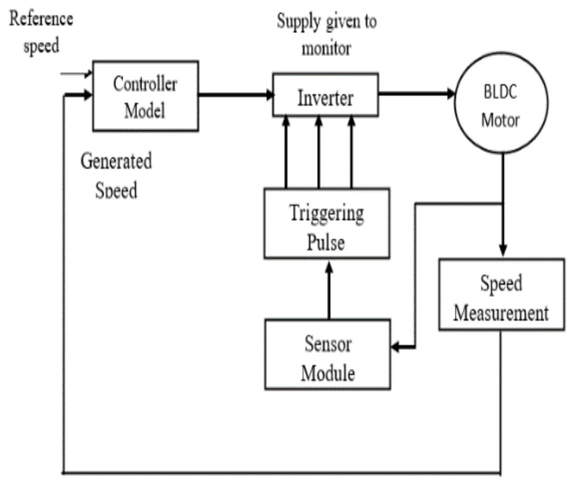


Figure 1 Speed control mechanism of BLDC motor

The development of a new intelligent machine learning controller model for efficient BLDC motor operation is the main goal of this research thesis. Initially, there were several traditional speed controllers and other machine learning models available, but depending on the application, each had its own set of constraints. Therefore, it is constantly necessary to advance and conduct better speed control of BLDC motor utilizing the most recent technology in order to enable the motor to be utilized in a variety of applications.

The main focus of this work is the ANFIS regulator scheme for brushless DC engine speed regulation. Additionally, methods for improving the input enrollment capability's predecessor portion, the input scaling factor, the fluffy surmising framework's succeeding components' coefficients using PSO, and the outcome scaling factor are discussed. Limiting the target capability is one way to improve a framework's time space details and execution files under various working conditions.

Parameters such as overshoot, undershoot, settling time, recovery time, steady state error, root mean squared error, integral of absolute error, and integral of time multiplied absolute error and integral of squared error are measured and compared for the above controllers under different operating conditions of the Brushless DC motor [12]. The optimal controller is recommended and verified based on the simulation findings. Additionally, an effort has been made to provide experimental evidence for the optimal controller's conclusions drawn from the simulation study. Figure 2 shows the BLDC motor's corresponding circuit.

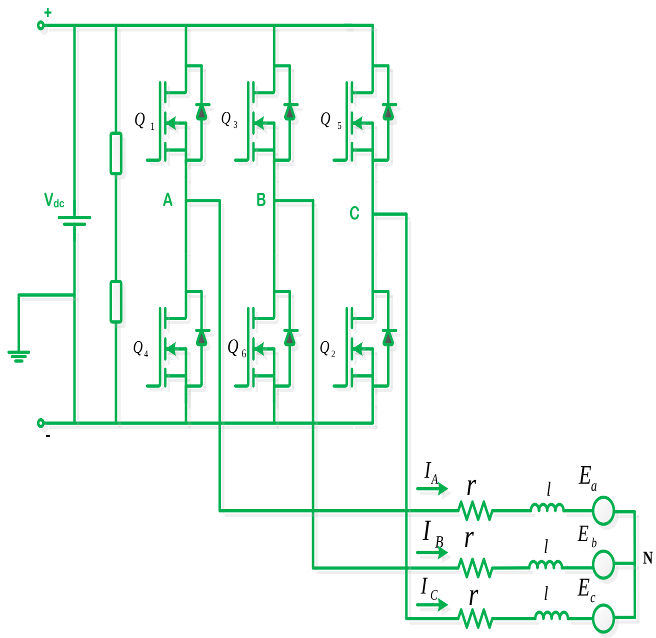


Figure 2: The equivalent circuit of BLDC motor

The internal circle synchronises the PWM inverter gating signal with the loop position by using a loop sensor and an exchanging rationale circuit. The external circle indicates the engine's actual speed; speed error is caused by the difference between the engine's actual speed and the reference speed. The regulator subsequently takes care of the speed error by adjusting the dc transport voltage, exchange rationale, PWM inverter, and engine speed through a controlling signal.

The primary purpose of the synchronous machine, also called the BLDC motor, is to transform electrical energy into mechanical energy by producing magnetic fields between the rotor and stator. PV serves as the power source for both the BLDC and the battery charge. As a result of the PV panel's electricity feeding the BLDC and charging the battery, Relay J1 turns on and

Relays J2 switch off. When operating at a light load, the PV generates more energy than the BLDC needs. As a result, when an EV is running, the battery is charged.

The simulation is completed utilizing the MATLAB tool kit, and the differential conditions for the BLDC engine's terminal voltages are shown in (1).

$$V_a = R_a I_a + L_a \frac{di_a}{dt} + M_{ac} \frac{di_b}{dt} + M_{ac} \frac{di_c}{dt} + e_a \quad (1)$$

$$V_b = R_b I_b + L_b \frac{di_b}{dt} + M_{ac} \frac{di_a}{dt} + M_{ac} \frac{di_c}{dt} + e_b \quad (2)$$

$$V_c = R_c I_c + L_c \frac{di_c}{dt} + M_{ac} \frac{di_b}{dt} + M_{ac} \frac{di_a}{dt} + e_c \quad (3)$$

The resistance in each phase is denoted by R_{a-b} in the preceding equations, the inductance of each phase is indicated by L_{a-b}, and the inductances are indicated by M_{ac}, and M_{bC} . Similar to this, the phase voltages are $V_a, V_b,$ and V_C while the stator currents in each phase are $i_{a1}, i_{b1},$ and i_{C1}. The motor's schematic diagram and circuit diagram are shown in Figure 3.

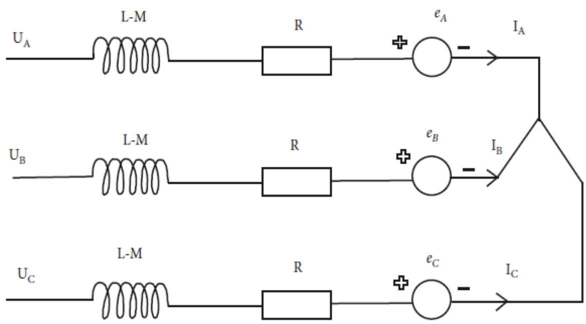


Figure 3: Representation of the BLDC motor.

The computation of the BLDC motor's other characteristics, including torque and EMF, is shown in equation (4). These characteristics are trapezoidal.

$$e_a = f_a(\theta)Ke\omega \quad (4)$$

$$e_b = f_b(\theta)Ke\omega \quad (5)$$

$$e_c = f_c(\theta)Ke\omega \quad (6)$$

Figure 4 depicts the BLDC motor control structure and demonstrates how the gate signal is determined using the back EMF. The accompanying condition gives the electromagnetic force of the engine.

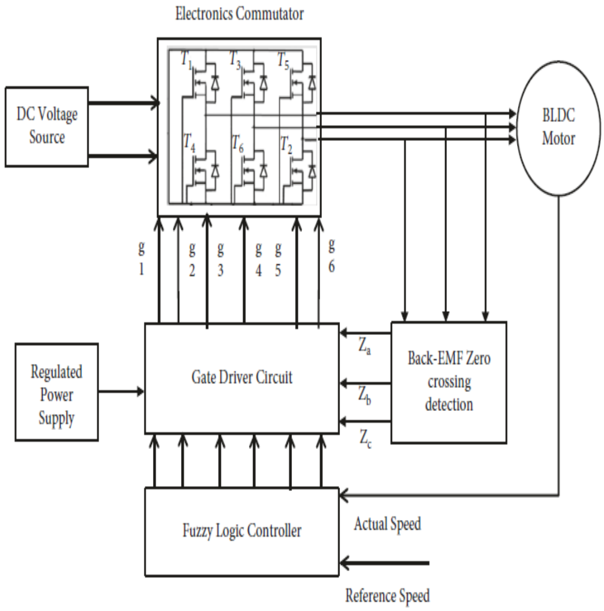


Figure 4: Block diagram of the BLDC motor.

Figure 4 displays the block diagram for the suggested BLDC motor drive. The line voltage is fed into step-down transformer. The reduced line voltage is given to the rectifier where the input AC is converted to DC. Then the output signal is given to the two switch buck boost converter. The proposed design uses a single inductor-capacitor as the converter model and combines a buck converter and boost converter—which is understood as the cascaded connection of a buck converter followed by a boost converter—to create the two active power switches needed for operation.

$$T_e = \frac{1}{\omega_r}(e_a i_a + e_b i_b + e_c i_c) \qquad (7)$$

The motor's rotational speed is indicated by the variable ω_r in the equation above. The formula (8).

$$\frac{d}{dt}\omega_r = \left(\frac{T_e - T_L - B\omega_r}{J}\right) \qquad (8)$$

The following shows the relationship between the mechanical (ω_r) and electrical (ω_e) speeds.

$$\omega_e = \left(\frac{p}{2}\right)\omega_r \qquad (9)$$

The motor's ultimate output power is stated as follows:

$$p = T_e * \omega \qquad (10)$$

The precise speed (radians each second) of the engine is shown by t ω in the above equation, where p stands for total output power. The primary physical factors that guarantee the best control response of BLDCM are resistance, inductance, and back EMF. It is essential to use a

ANFIS controller to adjust the motor's gain characteristics in order to reduce these disruptions. The motor's gain settings are optimised through the use of a ANFIS controller, resulting in ideal response.

The acronym for the Adaptive Neural Fuzzy Inference System is ANFIS. The simulation toolbox function ANFIS creates a Fuzzy Inference System (FIS) utilising input or output data sets. The membership function parameters of the FIS are then adjusted using a least squares sort of technique or a back propagation process. This makes it possible to research fuzzy systems using simulated data. Figure 5 depicts the ANFIS architecture's structure. Fuzzy set rule is applied in the fuzzy set model [13][25]. The primary goal of this approach is to lessen the interpretably. The following is the device's fuzzy rule.

Rule 1:

Input: If x $=A_1$,y $=B_1$,

Output: $Z_1 = p_1x + q_1y + r_1$,

Rule 2:

Input: If x $=A_2$and y $=B_2$,

Output:$Z_2 = p_2x + q_2y + r_2$,

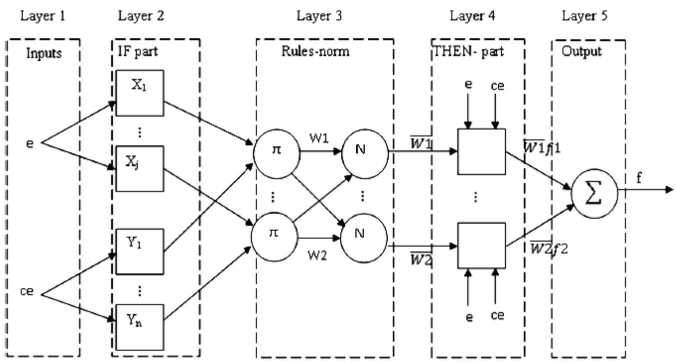


Fig. 5: ANFIS Architecture

First layer : The input layer, which is the first layer, describes the speed error and variance ratio of the designated controller's input parameters, which are denoted by the numbers x0 and x1, respectively. The other layer, where i= 0 to n, receives the input values x0 from this input layer right away.

Second layer : The fuzzy layer, which is the second layer, checks the member function values. This represents the fuzzy pairs of the pertinent input values and obtained the input parameters from the first layer, corresponding to a member function. It also computes the MF variables, which are the inputs for the third layer and tell us how the input parameters x0depend on the fuzzy set in what order.

Third layer : The third layer, referred to as the standard layer, consists of individual layer that perform the pre-capability correlation of the fuzzy conditions. This examines the enactment level of each layer because the number of layers and the number of fuzzy recommendations can be equal. The standardized loads are calculated by each third-layer layer.

Fourth layer : The derived values "y" from the inference of conditions make up the defuzzification layer. The fuzzy singletons mentioning another set of parameters for the neural fuzzy network weigh the links between layers 1-3 and 1-4.

Fifth layer : This final layer is referred to as the output layer. This takes the average of all the incoming layer four inputs and turns the fuzzy classification results into values that are clear.

The shape learning and portioning algorithms form the foundation of the ANFIS controller, which is composed of several regulations. The hybrid parameter of this algorithm may be automatically updated. automatically update the ANFIS controller's parameters and structure. Ultimately, the optimal ZSI pulse is calculated in relation to the fitness function by applying the suggested PSO algorithm. The system can be stabilized by reducing the speed and torque error through the use of optimum pulses.

PSO is a population-based strategy that probes the optimum spot in the search space using a population of individuals [14]. In PSO, the individual is referred to as a particle, which goes around the search space at a variable velocity. Every particle advances stochastically in the direction of its best prior location, as well as the better prior location of the swarm as a whole. If the swarm is N-dimensional, also the search space is M-dimensional, i^{th} particle position is given as Xi (xi1, xi2,..., xiM). This particle's velocities are represented by Vi (vi1, vi2,... viM). Pi (pi1, pi2, piM) is the best prior position of this particle, while Pg is the best previous position determined by the entire swarm (pg1, pg2,... pgM). The particles have been exploited as per the following equations:

$$v_{im}^{k+1} = w^k * v_{im}^k + c_1 * rand() * (p_{im} - x_{im}^k)/\Delta t + c_2 * rand() * (p_{gm} - x_{im}^k)/\Delta$$

$$x_{im}^{k+1} = x_{im}^k + v_{im}^k * \Delta t \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$\omega^k = \omega_{max} - k * (\omega_{max} - \omega_{min}) / k_{max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

c1 and c2 denote acceleration coefficients; signifies inertia weight; w_{max} and w_{min} are the min as well as the max value of w, respectively; k and k_{max} represent current and maximum iterative time, respectively; normally t unit time.

4. RESULTS AND DISCUSSION

The outcomes section examines the presentation of the developed technique. To show how effective the designed technique is, a performance evaluation is necessary. The shape learning and portioning algorithms form the foundation of the ANFIS controller, which is composed of several regulations. The hybrid parameter of this algorithm may be automatically updated. automatically update the ANFIS controller's parameters and structure.

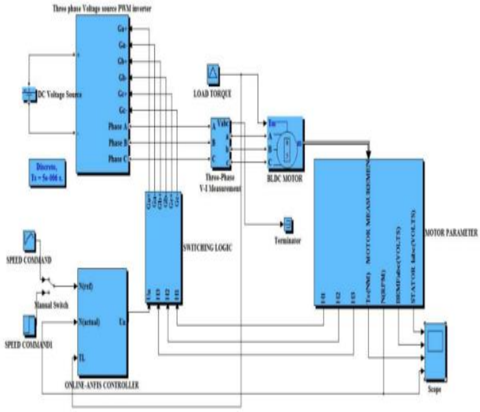


Figure 6: Simulink model of PSO algorithm optimized online ANFIS based speed controller for Brushless DC motor

based speed controller for Brushless DC motor

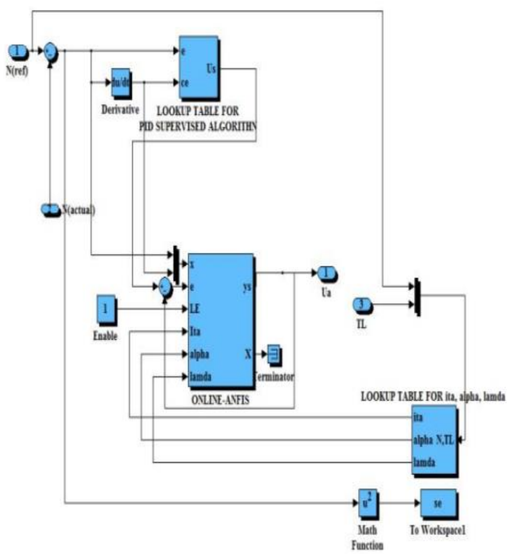
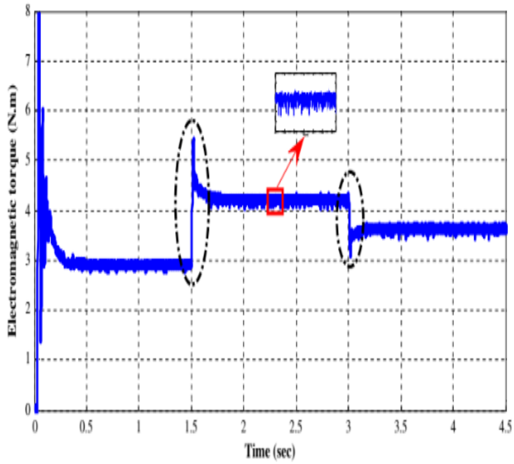
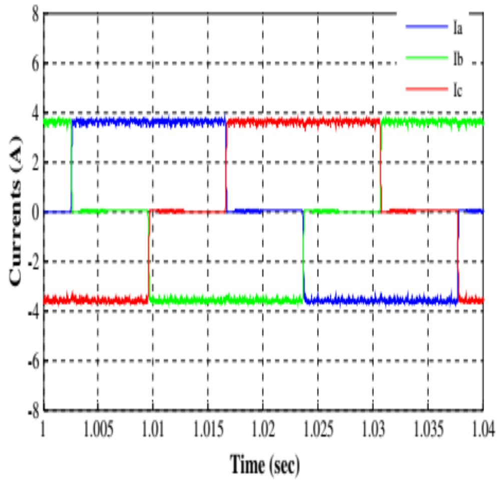


Figure 7: Simulink model of PSO algorithm optimized online ANFIS controller with lookup table

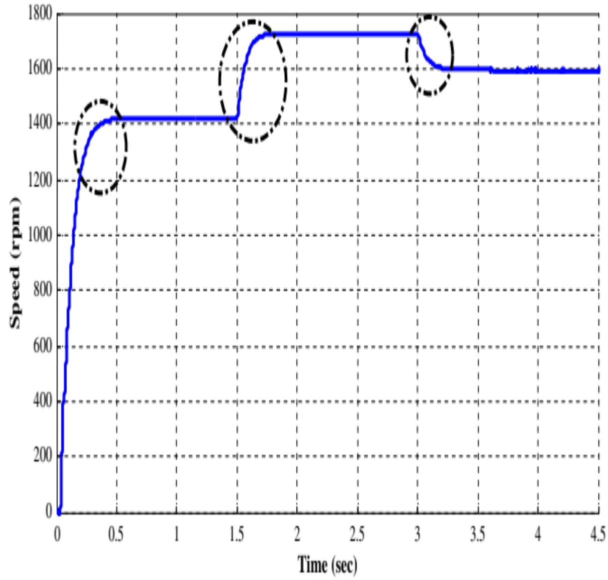
In this instance, torque variation has also been evaluated in addition to voltage. Torque has significantly decreased, as seen in Figure 8. When oscillations are less evident and the voltage is almost stable, every increase in torque has the potential to decrease speed. Examining these conditions, we may deduce that the torque is optimized by the PI controller by tuning it to a nominal value.



(a)



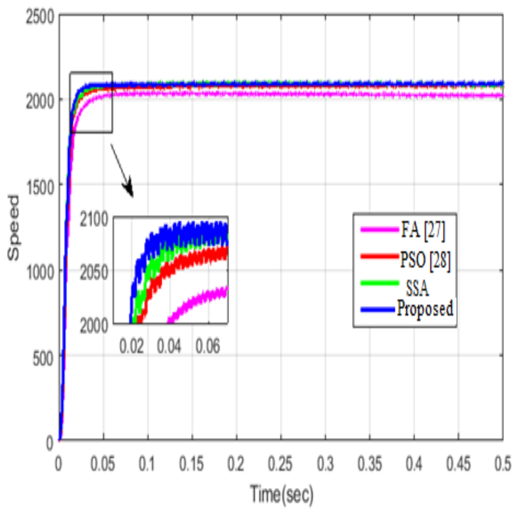
(b)



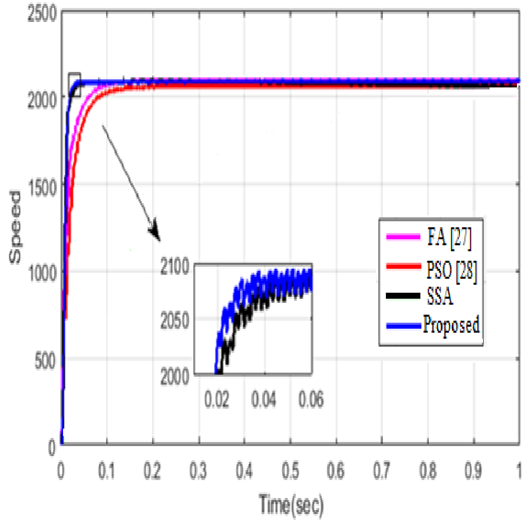
(c)

Figure 8: a) Torque, b) phase current, and c) speed analysis

With the suggested controller, Figure 8 shows the torque, phase current, and speed of the BLDC motor. Analysis of the torque, phase current, and speed performance of the BLDC motor is possible. Different load conditions may affect the BLDC motor, which adds speed and torque functionality to the PV-connected system. The findings of the proposed technique can be analysed using a range of parameters, such as ZSI duty ratios, phase currents, rotor speed, electromagnetic torque, mean DC-link voltage values, and PV power. The best outcomes are achievable when the recommended ANFIS controller with PSO algorithm is used.



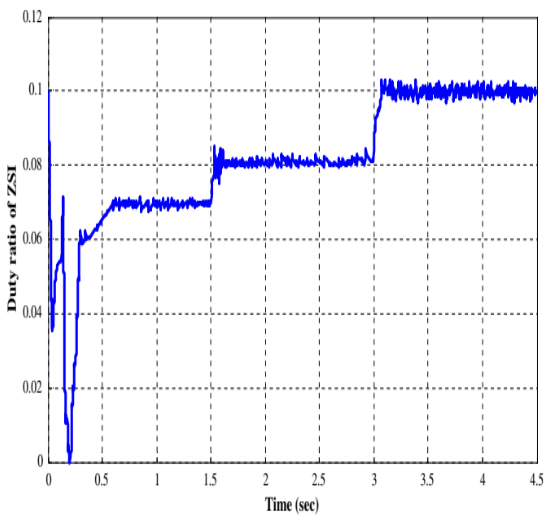
(a)



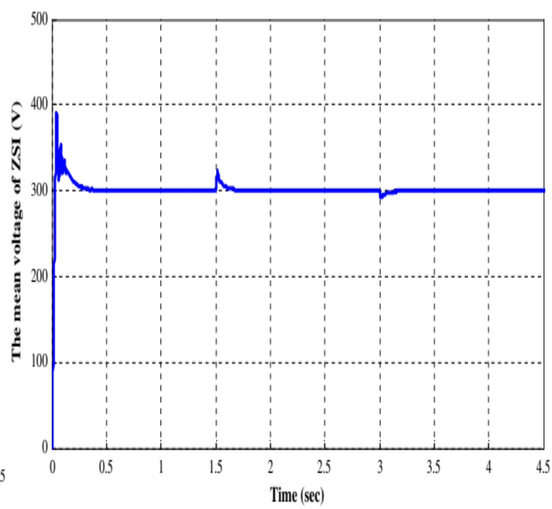
(b)

Figure 9: Comparison plot speed at different condition

Using the existing algorithms for comparison analysis, the effectiveness of well-known techniques for torque management and speed control at reference speed may be assessed. The developed strategy's torque and speed characteristics can be used to assess the method's delivery. The suggested ANFIS-PSO algorithm's main duty is to control ZSI pulses, which produce the ideal pulses for controlling the system's torque and speed. The BLDC motor's speed and torque characteristics are contrasted with those of the existing methods. The speed characteristics are shown in Figure 9.



(a)



(b)

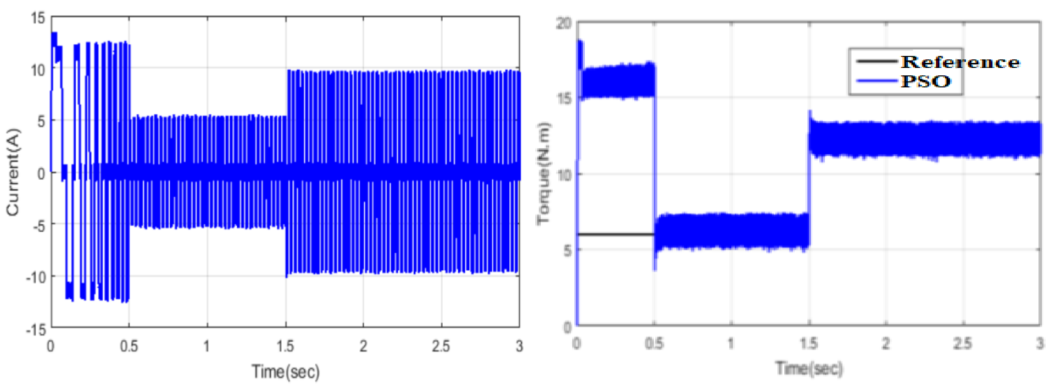
Figure 10: (a) Mean voltage and (b) Duty ratio

The torque, phase current, speed, and recommended controller for a BLDC motor are displayed in Figure 10. Similar to this, figure 10 shows how mean voltage and duty ratio are used to analyse the ZSI. A BLDC motor's torque, phase current, and speed analysis can reveal details about how it operates. The various load scenarios that impact the BLDC motor introduce the torque and speed operations in the PV-connected system. Phase currents, rotor speed, electromagnetic torque, DC-link voltage mean values, PV power, and ZSI duty ratios are a few of the characteristics that can be used to evaluate the results of the suggested approach. The proposed ANFIS controller with PSO algorithm yields the best results. The BLDC motor's maximum power and oscillations with the PV system are improved when the suggested controller is used. The ripple and inaccuracy caused by torque and speed changes in BLDC motors are totally avoided with the help of the recommended technique. Additionally, the recommended strategy was tested under a range of PV system irradiance conditions.

Table 1: comparison analysis of ANFIS gain parameters

controller	**Bat based Controller [7]**	**GA based Controller [8]**	**PSO based ANFIS Controller [proposed]**
Proportional	3.567	4.85	6.246
Integral	4.786	8.275	5.123
Derivative	5.124	6.382	5.6447
λ	0.22	0.48	0.245
μ	0.54	0.67	0.377

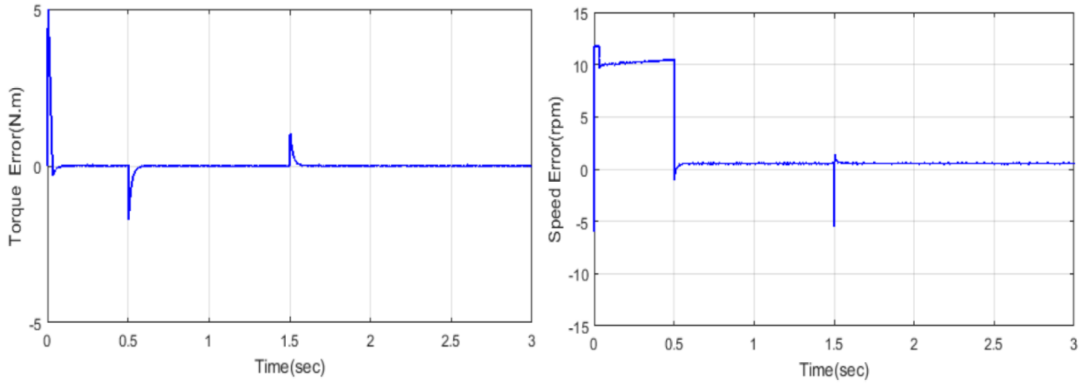
Table 1 presents the comparison study between the proposed optimization algorithm and the previously proposed approach. The suggested technique for various modes of operations and the current bat and GA methods may be compared with the speed comparison analysis. When compared to current methodologies, the suggested method yields the best results in the initial case study.



a) b)

Figure 11 Dynamic parameters of (a) current, (b) torque for 750-rpm

The 750-rpm reference speed was used to evaluate the ripple minimization performance, and Figure 11 is estimated parameters were used. The motor's torque was 15 N-m at first; after 0.75 seconds, it achieved the reference torque. After 1.5 seconds, it was steady. The brushless direct current motor's input parameters served as the basis for these. The motor's electromotive force and speed were the main factors controlling the input current.



a) b)

Figure 12 Error values of (a) torque and (b) speed for 500 rpm

The error values of the torque and the speed are illustrated in Figure 12. These were estimated from the variations in the previous speed to the instant values of the proposed system.

Table 2: Analysis of speed fluctuations using the PSO algorithm under torque ripple reduction

Speed in rpm	Torque ripple in percentage		
	BAT [7]	**GA [8]**	**PSO (proposed)**
500	15.25	18. 1	10.35
700	14.75	13.98	11.5
1000	15.8	17.7	13.01

The investigation of torque ripple reduction under the speed fluctuations is presented in detail in Table 2. The minimal fitness value, average computation time, time domain specifications, and performance indices are all improved by the PSO algorithm optimised ANFIS controller as compared to the other controllers under consideration. Using a DSP processor, the online ANFIS controller optimised by the bat method has been experimentally demonstrated to work in real time. It is evident from the simulation and experimental setup findings that the load variations and set speed variations uncertainty may be eliminated by the Bat optimised online ANFIS controller. The controller is perfect for use in process industries because of its unparalleled performance.

5. CONCLUSION

The speed control of the BLDC motors is controlled by ANFIS controller and the characteristics parameters are taken into account are: Speed, Torque, Voltage and Current. The Characteristics curves are analyzed and suitable Optimization Algorithm are suggested for a particular Motor. The systematic methods utilising artificial intelligence techniques for the design of ANFIS controllers to improve brushless DC motor performance have been provided in this paper. MATLAB/Simulink software is used to develop and validate the suggested controllers. Testing and analysis have been done on the controllers' efficacy under various Brushless DC motor operating circumstances. For the purpose of controlling the speed of a brushless DC motor, various intelligent controllers such as the Coactive Neuro Fuzzy Inference System (CANFIS), recurrent fuzzy neural network, etc., can be used. Their performances can then be compared to those of other well-known controllers. For a variety of suggested controllers, stability analyses and reports can be generated. Based on the stability study, the suitability and efficacy of the controllers under various risky operating situations of the drive may be readily analysed.

References

1. Kroičs, Kaspars, and Arvīds Būmanis. "BLDC Motor Speed Control with Digital Adaptive PID-Fuzzy Controller and Reduced Harmonic Content." Energies 17, no. 6 (2024): 1311.
2. Mukti, I.Z., Khan, E.R., & Biswas, K.K. (2024). 1.8-V Low Power, High-Resolution, High-Speed Comparator with Low Offset Voltage Implemented in 45nm CMOS Technology. Journal of VLSI Circuits and Systems, 6(1), 19-24.
3. Saravanan, P., R. Gandhi Raj, Pudi Sekhar, and P. Vijayarajan. "Speed control of brushless DC electric motor (BLDC) motor using hybrid Takagi Sugeno fuzzy logic and enhanced gravitational search algorithm with PSO." Electric Power Components and Systems 52, no. 9 (2024): 1692-1705.
4. Mumtaj Begum, H. (2022). Scientometric Analysis of the Research Paper Output on Artificial Intelligence: A Study. Indian Journal of Information Sources and Services, 12(1), 52–58.
5. Ma'arif, Alfian, and Naufal Rahmat Setiawan. "Control of DC motor using integral state feedback and comparison with PID: simulation and arduino implementation." Journal of Robotics and Control (JRC) 2, no. 5 (2021): 456-461.
6. Jayasree, V., & Baby, M. D. (2019). Scientometrics: Tools, Techniques and Software for Analysis. Indian Journal of Information Sources and Services, 9(2), 116–121.
7. Baba, Mariem Ahmed, Mohamed Naoui, and Mohamed Cherkaoui. "Modeling and Simulation of a BLDC Motor Speed Control in Electric Vehicles." In International Conference on Digital Technologies and Applications, pp. 883-895. Cham: Springer Nature Switzerland, 2023.
8. Trivedi, J., Devi, M. S., & Solanki, B. (2023). Step Towards Intelligent Transportation System with Vehicle Classification and Recognition Using Speeded-up Robust Features. Archives for Technical Sciences, 1(28), 39-56.
9. Valenza, F., & Cheminod, M. (2020). An Optimized Firewall Anomaly Resolution. Journal of Internet Services and Information Security, 10(1), 22-37.
10. Alqarni, Zuhair. "Higher Order Sliding Mode Control for Speed Control of BLDC Motor." In 2023 IEEE 13th Annual Computing and Communication Workshop and Conference (CCWC), pp. 0212-0217. IEEE, 2023.
11. Rajesh, M., Nagaraja, S.R., & Suja, P. (2024). Multi – Robot Exploration Supported by Enhanced Localization with Reduction of Localization Error Using Particle Swarm Optimization. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 15(1), 202-215.
12. Pandeeswari, S., and S. Jaganathan. "Dual Stage Speed Control of BLDC Motor Using Hybrid QPSO-CSO Technique." Electric Power Components and Systems 52, no. 1 (2024): 67-81.

13. Yağız, E., Ozyilmaz, G., & Ozyilmaz, A. T. (2022). Optimization of graphite-mineral oil ratio with response surface methodology in glucose oxidase-based carbon paste electrode design. Natural and Engineering Sciences, 7(1), 22-33.
14. Naqvi, Syed Shehryar Ali, Harun Jamil, Naeem Iqbal, Salabat Khan, Dong-In Lee, Youn Cheol Park, and Do Hyeun Kim. "Multi-objective optimization of PI controller for BLDC motor speed control and energy saving in Electric Vehicles: a constrained swarm-based approach." Energy Reports 12 (2024): 402-417.
15. Zengeni, T. G., & Bates, M. P. (2022). Advancing Portable Telephone Battery Chargers with Contactless Electrical Energy Transmission Systems. National Journal of Antennas and Propagation, 4(1), 27-32.
16. Sayed, Khairy, Hebatallah H. El-Zohri, Adel Ahmed, and Mohamed Khamies. "Application of Tilt Integral Derivative for Efficient Speed Control and Operation of BLDC Motor Drive for Electric Vehicles." Fractal and Fractional 8, no. 1 (2024): 61.
17. Katiyar, H. (2014). Optimal Power Allocation for Regenerative Relay over α-μ Fading Channel. International Journal of Communication and Computer Technologies (IJCCTS), 2(2), 128-134.
18. Poudel, Yam Krishna, and Pratap Bhandari. "Control of the BLDC Motor Using Ant Colony Optimization Algorithm for Tuning PID Parameters." Archives of Advanced Engineering Science 2, no. 2 (2024): 108-113.
19. Poornesh, Kavuri, R. Mahalakshmi, and Gunavardhan Reddy. "Speed control of BLDC motor using fuzzy logic algorithm for low cost electric vehicle." In 2022 International Conference on Innovations in Science and Technology for Sustainable Development (ICISTSD), pp. 313-318. IEEE, 2022.
20. Bekri, M. E., Diouri, O., & Chiadmi, D. (2023). Dynamic Inertia Weight Particle Swarm Optimization for Anomaly Detection: A Case of Precision Irrigation. Journal of Internet Services and Information Security, 13, 157-176.
21. Jain, Vinay Kumar, and PAPIHA BHARTI. "A REVIEW ON THE CLOSED-LOOP STRATEGY FOR SPEED CONTROL OF BLDC MOTORS." I-Manager's Journal on Digital Signal Processing 11, no. 2 (2023).
22. Nikitina, V., Raúl, A.S., Miguel, A.T.R., Walter, A.C., Anibal, M.B., Maria, D.R.H., & Jacqueline, C.P. (2023). Enhancing Security in Mobile Ad Hoc Networks: Enhanced Particle Swarm Optimization-driven Intrusion Detection and Secure Routing Algorithm. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 14(3), 77-88.
23. Genc, Naci, and Zhansaya Seidakhanovna Kalimbetova. "Cuckoo Optimization Algorithm Based Fuzzy Logic Speed Controller for BLDC Motor." Electric Power Components and Systems 52, no. 11 (2024): 2065-2077.
24. Gökhan, N. U. R., BARIŞ, B. N., Levent, B., SAZAKLIOĞLU, B. S., & Elvan, A. K. (2023). BUSER Transcutaneous Electric Nerve Stimulator Device Design. Natural and Engineering Sciences, 8(1), 18-30.
25. Subbarao, Mopidevi, Kiransai Dasari, SSSR Sarathbabu Duvvuri, K. R. K. V. Prasad, B. K. Narendra, and VB Murali Krishna. "Design, control and performance comparison of PI and ANFIS controllers for BLDC motor driven electric vehicles." Measurement: Sensors 31 (2024): 101001.
26. Jelena, T., & Srđan, K. (2023). Smart Mining: Joint Model for Parametrization of Coal Excavation Process Based on Artificial Neural Networks. Archives for Technical Sciences, 2(29), 11-22.
27. Kroičs, Kaspars, and Arvīds Būmanis. "BLDC Motor Speed Control with Digital Adaptive PID-Fuzzy Controller and Reduced Harmonic Content." Energies 17, no. 6 (2024): 1311.