DS Journal of Digital Science and Technology
Volume 1 Issue 2, 11-17, Oct - Dec 2022
ISSN: 2583-5416/ https://doi.org/10.59232/DST-V1I2P102

Original Article

Modified Field-Oriented Control-Based Sensorless Speed Control for BLDC Motor via Elephant Herding Optimization

R.Surendiran[1]

[1] *School of Information Science, Annai College of Arts and Science, Kumbakonam, India.*
ORCID :0000-0003-1596-7874

surendiranmca@gmail.com

Received: 29 October 2022; Revised: 12 November 2022; Accepted: 20 November 2022; Published: 06 December 2022;

Abstract - Brushless DC (BLDC) motors are becoming increasingly popular and are replacing brush motors in a variety of applications due to their improved mechanical and electrical features and simple design. Speed encoders can be used to measure speed in the past, but they are quite costly and make noise when placed on the motor shaft. To overcome this issue, this research presents the sensorless speed control method, which is developed by sensing the speed and back-emf. In this paper, an intelligent Adaptive Network-based Fuzzy Inference System (ANFIS) and Elephant Herding Optimization (EHO) based Modified Field oriented control (MFOC) is proposed to regulate the BLDC motor speed. The main objective of the proposed technique is to control the BLDC motor system without a Hall sensor and speed encoder. Here, the proposed ANFIS controller is employed to create Hall signals. The pulses for the three-phase inverter are generated using an EHO-based MFOC technique, eliminating the need for logic gate circuits. MATLAB/Simulink is used to evaluate the proposed approach. The proposed approach has high efficiency and low time domain specifications, according to the findings of the experiments.

Keywords - BLDC motors; Sensorless speed control; ANFIS; Hall signals; Elephant Herding Optimization.

1. Introduction

The recent fast spread of engine drives in the automotive sector with product hybrid technology has created a high need for efficient variable velocity electric motor drives with long-term stability and good transient performance in adjustable-rate drives [1]. Brushless DC (BLDC) motors are an excellent choice for these types of drives. A BLDC engine resembles a DC electric motor; however, it uses an electronically regulated commutation mechanism rather than a mechanical commutation. When the engine drive is used in variable acceleration applications, the travel speed suffers greatly due to uncertain load characteristics and unexpected variable changes [2]. The magnetic field created by the rotor and stator both revolve at the same frequency, making the BLDC motor a form of synchronous motor

The BLDC engine drive can be used with or without sensors. The sensorless controlled BLDC motor is popular because it reduces both the cost and the time of the trip. Speed sensors and external positions should be eliminated to make the system cost-effective and more efficient. Sensorless control refers to methods for sensing rotor position that does not use sensors and instead depend on measuring the EMF generated by the rotor [4]. Because the BEMF is nearly nil at stationary and near-zero speed and cannot be correctly recognised, additional mechanisms are necessary to control BLDC motors at near-zero speed, increasing the cost. Most BLDC motors include three Hall sensors incorporated in the stator. When the rotor poles pass near a sensor, it emits Low and

High signals. The precise commutation sequence to the stator winding may be obtained by combining the responses of these sensor devices [2,5].

This paper proposes Elephant herding optimization (EHO) and the Adaptive Network Fuzzy Inference System (ANFIS) based sensorless speed control technique. A BLDCM speed controller uses pulse-width modulation (PWM) instead of traditional Hall sensors and encoders. The paper's organization is the existing related works as described in section 2. BLDC motor's mathematical model is explained in section 3. The proposed ANFIS-HHO-based speed control approach is presented in Section 4, while the results of the motor performance are discussed in Section 5. Finally, section 6 provides the conclusion.

2. Related works

Numerous existing approaches for dealing with speed control of BLDC motor techniques have been presented by many researchers and have certain limitations highlighted in this section.

Muthamizhan et al. (2021) [6] offer a sensorless control method for a PMBLDC motor that employs a Z-source Inverter (ZSI) and FLC hybrid control. The proposed motor drive is resistant to harmonics in current /voltage amounts, and it integrates advantages from the qualities of direct torque control and field-oriented supplied by each approach. As functioning in steady-state mode via DTC, the fusion controller assists in correct speed changes and reduces speed ripple compared to FOC within transient conditions. Shrutika et al. (2021) [1] present a back EMF (BEMF) observer-based sensorless control technique for motors using terminal current and dc bus voltage sensors that are not affected by rotor speed.

Sun (2022) [7] offers numerous DC motors, the method of pulsing high-frequency voltage injection is used to achieve saturated convex polarity, and the motor rotor pole position data is extracted from the cross-axis current response to acquire the real position of the rotor. Only at zero and low speeds can this approach identify the location and speed of the motor rotor. Attar et al. (2021) [8] present the BEMF integration method based on the sensorless BLDC motor control. As the name implies, this system relies on incorporating the electrical BEMF signal to obtain immediate details about the rotor position. It controls a BLDC motor without using velocity and position sensors, instead of relying on incorporating the non-fed stages' BEMF signal.

Vanchinathan et al. (2021) [9] propose an adaptive Fractional Order Proportional Integral Derivative (FOPID) controller based on the Artificial Bee Colony (ABC) algorithm for optimizing the performance of a BLDC motor. It is also worth noting that Hall Effect sensors have several drawbacks, including hardware failures, low reliability, the requirement for unique mechanical mounting solutions, and electrical interference. PID controllers are typically utilised for optimal tuning to enhance time-domain features like settling time, steady-state error and peak time. However, it has several abnormalities, such as a maximum settling time and variability in steady-state errors owing to changes in set speed and load.

2.1. Design of BLDC Motor

This approach to simulating BLDC motors is based on a few assumptions, like ignoring induced currents in the rotor caused by stator harmonic fields and stray and iron losses. The motor is said to have three stages. The stator winding connected circuit equations are stated in terms of motor electrical constants.

The phase currents of the stator are limited to be balanced.

$i_{as} + i_{bs} + i_{cs} = 0,$

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = R_r \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \mathrm{P} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_{as} \\ e_{bs} \\ e_{cs} \end{bmatrix} \tag{1}$$

The instantaneous EMFs are represented as

$$\left.\begin{aligned} e_{as} &= f_{as}(\theta_r)\lambda_p\omega_r \\ e_{bs} &= f_{bs}(\theta_r)\lambda_p\omega_r \\ e_{cs} &= f_{cs}(\theta_r)\lambda_p\omega_r \end{aligned}\right\} \tag{2}$$

The electromechanical torque is denoted by

$$J\frac{d\omega_r}{dt} + B\omega_r = T_e - T_l \tag{3}$$

where B, J, T_l and ω_r are the frictional coefficient, the moment of inertia, load torque and the motor's angular velocity, respectively.

3. Proposed Sensorless Speed Control by EHO

This proposed work provides the implementation of Modified Field Oriented Control (MFOC) of BLDC motor without using Hall sensors. Sensorless control of a BLDC motor based on determining the BEMF's zero-crossing instant (by terminal voltages) and then determining the right commutation moment. A PI controller senses the motor's speed control and compares it to the reference speed for control action, which controls the velocity with appropriate proportional and integral gain values. An ANFIS controller converts the produced BEMF in the BLDC motor's stator to hall signals. The motor will run without Hall effect sensors in this state, and closed-loop speed control will be activated. The obtained reference current is compared with the actual measured stator current, and the current error is sent to the input of the EHO-based FOC block to generate gate pulses. The proposed block diagram is exposed in figure 1. The position obtained by Hall Effect sensors is based on the angular position of the rotor evolution between 0 and 360, as shown below in table 1, using this switching logic of Hall Effect sensors, where the switching sequence for shaft rotation is clockwise. The three-phase voltages are derived using the following calculations.

$$V_{as} = \frac{v_d}{2}(S1 - S2) \tag{4}$$

$$V_{bs} = \frac{v_d}{2}(S3 - S4) \tag{5}$$

$$V_{cs} = \frac{v_d}{2}(S5 - S6) \tag{6}$$

Where $v_d \rightarrow$ applied DC voltage

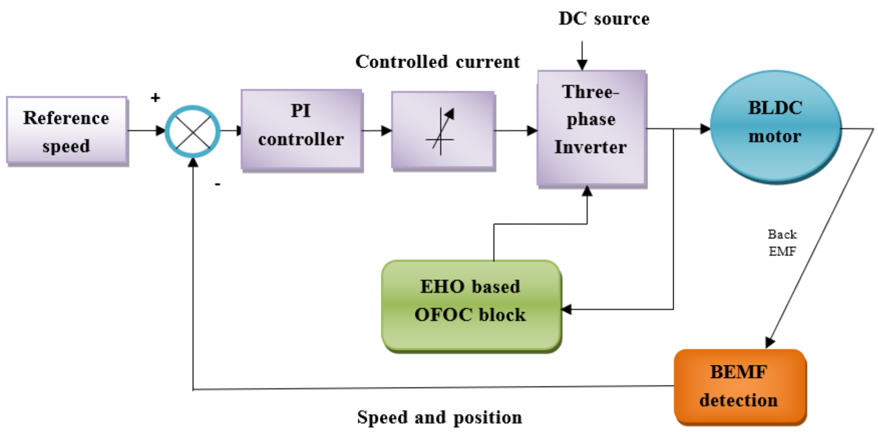


Fig. 1 Proposed sensorless speed control using EHO

Table 1. Hall effect sensor signals for inverter operation mode

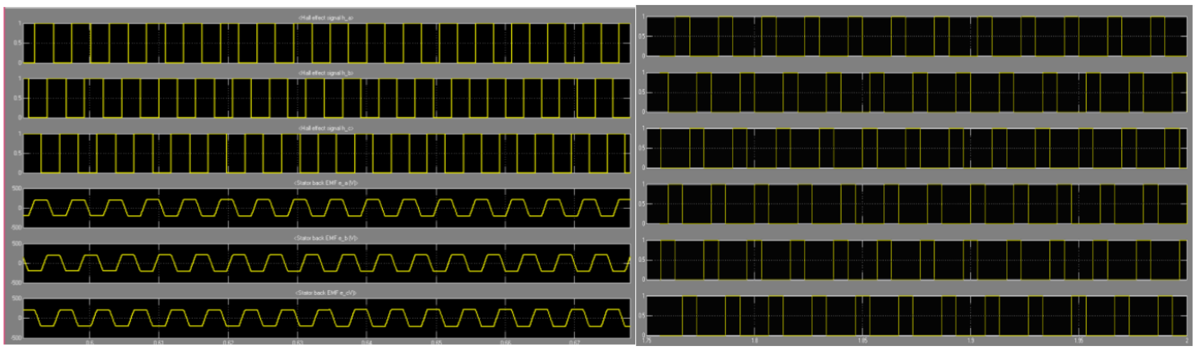
Sequence number	Angle (°)	Hall sensors			Switch closed		Phase current		
		H_1	H_2	H_3			i_a	i_b	i_c
1	0-60	1	0	1	S_1	S_4	+	-	off
2	60-120	1	0	0	S_1	S_6	+	off	-
3	120-180	1	1	0	S_3	S_6	off	+	-
4	180-240	0	1	0	S_3	S_2	-	+	off
5	240-300	0	1	1	S_5	S_2	-	off	+
6	300-360	0	0	1	S_5	S_4	off	-	+

In the first running stage, electrical commutation is often performed by utilising a standard PWM signal to power a transistor power stage. The flux predictor computes the rotor flux by removing from the supplied phase voltage those voltage drops that are not connected to the BEMF. The calculated BEMF is then utilised to calculate the rotor flux. It is fine-tuned using EHO optimization techniques subsequently to decrease steady-state error and improve transient responsiveness using the ANFIS controller.

4. Results and discussions

To validate the efficacy of the presented method, the framework is modelled and tested in this part using MATLAB/SIMULINK. The proposed system output results are compared with the standard Fuzzy logic Controller (FLC) [6] and Artificial Bee Colony (ABC) [9] algorithm. For the controllers under consideration of, the speed response like recovery time, settling time, peak overshoot, rising time, undershoot, and steady-state error is determined and compared. BLDC motor drive system's specifications are: Rated current – 50 Amps, rated speed – 2000 rpm/min, rated voltage – 470V and rated power – 1.1 HP, flux linkage established by magnets – 0.175, moment of inertia - 0.0008, pole pairs – 4, voltage constant - 0.1466, torque constant - 1.4 Nm, stator phase resistance – 3 Ω, and stator phase inductance - 0.001. The work described here is based on the speed management of an inverter-fed sensorless BLDC motor under various operating situations (varying set speed, varying load and constant load).

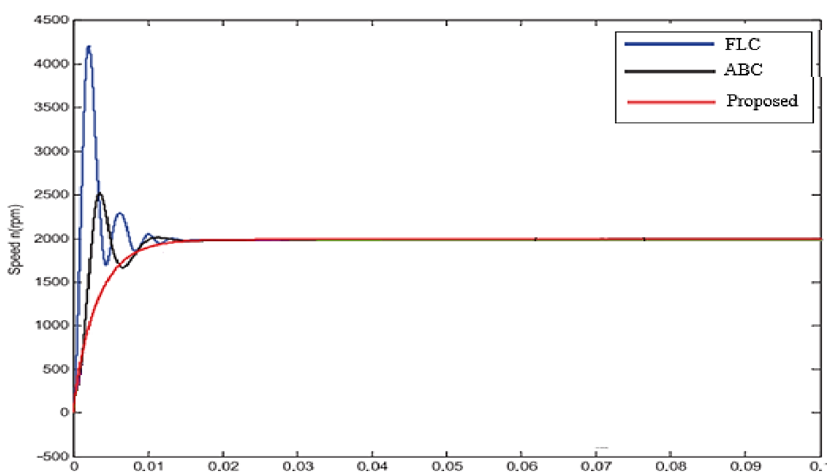
Primarily, the simulation is run for a reference speed is 2000 r/min. Figure 2 (a) shows the waveform of Hall Effect signals of the ANFIS controller and stator current. Figure 2 (b) shows the gate pulses of the EHO-based pulse generator. It shows that the pulses are generated in a sequence the same as the switching ON of the switches. A three-phase inverter is indeed modelled and switched at a frequency of 10k Hz. Hall sensor data determine the rotor position, and the inverter switches are switched on and off in response, allowing for a continuous revolution.



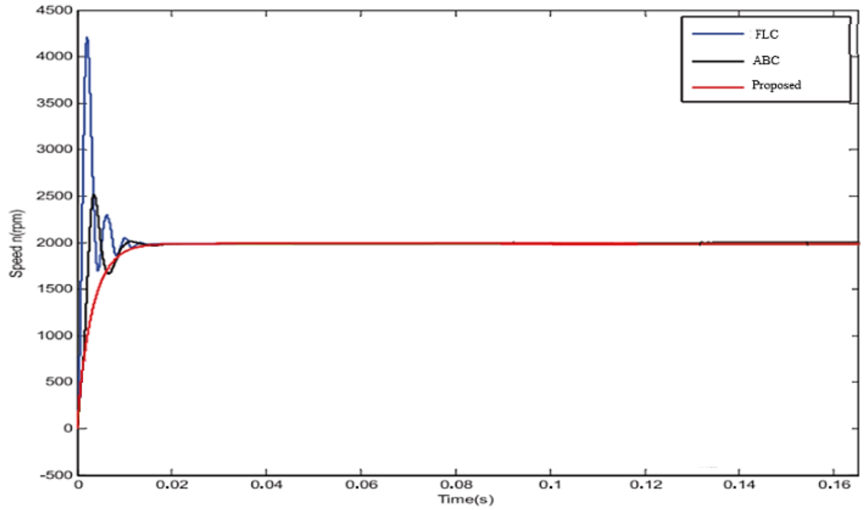
(a) **(b)**

Fig. 2 (a) ANFIS controller's hall effect signals and stator current (b) EHO-based gate pulses to inverter

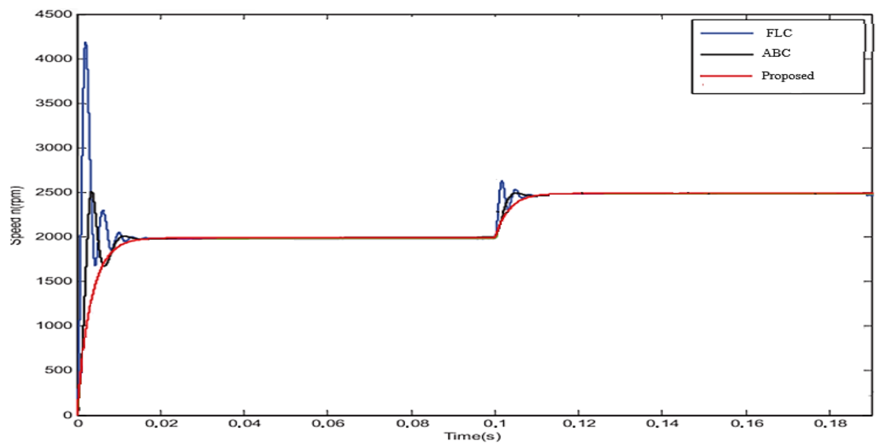
The goal rotation speed of 2000 rpm is still entered into the system, and the load is changed from no load to 3 Nm at 0.1 s. Figure 3 (a) depicts the response of speed curves for various load circumstances. From figure 3 (b), the least peak undershoots, overshoots, and the least peak time of the proposed controller are 0.1005 s, 0.01 and 0.4r/min, respectively. Furthermore, the proposed recovery time is 0.01 s, which is the shortest. As a result, the suggested controller outperforms the other control methods studied. As can be seen from figure 3 (c), For FLC and ABC methods, oscillation occurs when the set speed abruptly changes at 0.1 s. the less recovery time of the EHO method is 0.012 s and the less steady-state error is 0.35 %, shows the EHO method outperforms than the existing methods. As a result of the aforementioned simulations, it is clear that all of the control systems are capable of tracking the given speed appropriately. The performance of FLC and ABC under abrupt load fluctuations, on the other hand, is unsatisfactory. Furthermore, whereas the others do not produce oscillations in the speed response curves, ABC and FLC do. According to the simulation results summary, the suggested EHO has superior control performance regarding a steady-state error, recovery time and settling time.



(a)



(b)



(c)

Fig. 3 Comparison of speed responses with (a) no load, (b) varying load, and (c) set speed vary conditions

Table 2. Performance of BLDC motor under the variable load condition

Controllers	Control parameters			
	Peak overshoot (s)	Peak undershoot (r/s)	Recovery time (s)	Steady-State error (s)
FLC [6]	0.105	3.29	0.025	0.6
ABC [9]	0.10128	1.0	0.025	0.65
Proposed	0.1005	0.4	0.01	0.35

Furthermore, the time domain specifications such as steady-state error, overshoot, recovery time, undershoot and settling time are assessed and compared between FLC, ABC and proposed methods. The simulation findings show that the EHO-based technique clearly outperforms competing controllers under all BLDC motor operation circumstances investigated.

5. Conclusion

In this research, the Modified field-oriented control-based sensorless speed control method is proposed. The main objective of the proposed technique is controlling the BLDC motor system without a hall sensor and speed encoder. Here, the proposed ANFIS controller is employed to create Hall signals. The EHO-based MFOC approach provides the pulses needed for the three-phase inverter, eliminating the need for logic gate circuits. The proposed scheme is simulated using MATLAB/Simulink. The proposed method is compared with the existing FLC and ABC control methods in terms of speed and recovery time, peak overshoot, peak undershoot, and steady-state error of BLDC motors under various load conditions. The proposed approach performs well, according to the findings of the experiments.

References

[1] C. Shrutika et al., "Back-EMF Estimation-Based Sensorless Control of Brushless DC Motor," *2021 1st International Conference on Power Electronics and Energy, IEEE,* pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Tzuen-Lih Chern et al., "Sensorless Speed Control of BLDC Motor Using Six Step Square Wave and Rotor Position Detection," *2010 5th IEEE Conference on Industrial Electronics and Applications, IEEE,* pp. 1358-1362, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[3] J. Srinivas Rao, G. Ravi Kumar, and O. Chandra Sekhar, "Sensorless Speed Control of Brushless DC Motor Using Fuzzy Controller," *2016 International Conference on Electrical, Electronics, and Optimization Techniques, IEEE,* pp. 4082-4085, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[4] A. Kiruthika, A. Albert Rajan, and P. Rajalakshmi, "Mathematical Modelling and Speed Control of a Sensored Brushless DC Motor Using Intelligent Controller," *2013 IEEE International Conference on Emerging Trends in Computing, Communication and Nanotechnology, IEEE,* pp. 211-216, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[5] Wei Chen, and Changliang Xia, "Sensorless Control of Brushless DC Motor Based on Fuzzy Logic," *2006 6th World Congress on Intelligent Control and Automation, IEEE,* vol. 2, pp. 6298-6302. 2006. [CrossRef] [Google Scholar] [Publisher Link]

[6] T Muthamizhan, P Saravanan, and Ramaprasad Maharana "Sensorless Control of Z Source Inverter fed BLDC Motor Drive by FOC-DTC Hybrid Control Strategy Using Fuzzy Logic Controller," *2021 7th International Conference on Electrical Energy Systems, IEEE,* pp. 358-363, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Lihui Sun, "Low Speed Sensorless Control Method of Brushless DC Motor Based on Pulse High Frequency Voltage Injection," *Alexandria Engineering Journal*, vol. 61, no. 8, pp. 6457-6463, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] A. Attar, J. Bouchnaif, and K. Grari, "Control of Brushless DC Motors Using Sensorless Back-EMF Integration Method," *Materials Today: Proceedings*, vol. 45, pp. 7438-7443, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] K. Vanchinathan, and N. Selvaganesan, "Adaptive Fractional Order PID Controller Tuning for Brushless DC Motor Using Artificial Bee Colony Algorithm," *Results in Control and Optimization*, vol. 4, p. 100032, 2021. [CrossRef] [Google Scholar] [Publisher Link]