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Sensor less Control of BLDC Motor Using Anfis

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Abstract— This study presents a sensor less control strategy for brushless DC (bldc) motors using an adaptive neuro fuzzy inference system (anfis) to generate virtual hall effect signals from the measured three-phase back-emfs. The proposed approach eliminates the need for physical position sensors by producing digital hall equivalent signals that directly interface with conventional commutation logic circuits, providing a seamless drop-in replacement for the hall sensors.

The controller was modelled and simulated in MATLAB/Simulink with a closed-loop PI speed controller (K_p = 0.013, K_i = 16.61). The anfis network was trained on data collected at a reference speed of 3000 rpm from a sensor equipped bldc test bench in Simulink. The trained model was validated under both loaded and unloaded operating conditions. A unit step load torque was applied at t=0.1s to evaluate dynamic performance. The results demonstrate that the anfis based system exhibits a dynamic response comparable to the conventional hall sensor-based control.

Keywords — bldc motor, sensor less control, anfis, virtual hall signals, logic gate circuits

I. Introduction

Bldc motors convert electrical energy into mechanical energy without using carbon brushes. They have become integral in various applications ranging from automotive to medical to HVAC industries, and so on, because of their advantages over traditional brushed DC motors, including higher efficiency, reliability, quieter working and a longer lifespan. Bldc motors operate without brushes, reducing mechanical wear and maintenance requirements [1-3]. Instead, they use electronic commutation to control the motor phases, providing smoother operation and higher performance. The electronic commutation of bldc motors traditionally relies on sensors like hall sensors or optical encoders to determine the rotor's position [4-5]. However, hall sensors can fail under high temperatures or pressurized environments [6]. Developments in sensorless techniques address these issues by estimating position from electrical characteristics, such as back emf zero-crossing detection, flux observers, model-reference adaptive control, extended Kalman filters, and sliding-mode observers. [5, 7-8]

There is a recent development that controls the bldc motor drive by employing a hybrid control strategy for a Z-source inverter. In this approach, fuzzy logic control techniques are utilized. Z-source inverters are used to handle variable input voltages and can be regulated using conventional pulse-width modulation (PWM) techniques [9].

A paper by Goswami et al. presented sensorless control of the motor based on the zero-crossing detection of the indirect back emf approach. The results indicated that the hybrid fuzzy-PI controller exhibits superior performance compared to the fuzzy logic controller, the anti-windup PI controller, and the conventional PI controller [10].

Pradeep et al. proposed a sensor less intelligent speed control technique for bldc motors using an Adaptive Network-based Fuzzy Inference System (ANFIS) optimized by an Artificial Bee Colony (ABC) algorithm. The anfis generates hall signals from the motor's back emf, and the ABC provides inverter pulses, eliminating logic gate circuits. A PI controller regulates the input DC voltage of the inverter, while Optimized Field Oriented Control (OFOC) is implemented for sensorless bldc motor control [11].

Another paper by Hemalatha et al. proposed a hybrid technique involving Back-EMF zero crossing detection and an anfis controller optimized by Particle Swarm Optimization (PSO). The anfis estimates commutation signals from line voltages, with the ZCP detection circuit generating inverter control [12].

Based on the strong motivation from studies employing anfis for sensorless bldc control [11,12], we refine its application for robustness and real-time viability. While Pradeep et al. [11] used anfis for hall signals followed by ABC algorithm for gating pulses, introducing computational overhead and

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latency as standard bldc hardware already includes high-speed logic gates optimized for instantaneous hall-to-commutation conversion. This paper explores a more efficient architecture: anfis-generated virtual hall signals as a direct digital drop-in replacement to these logic gates (via lookup tables), ensuring precise and low-latency commutation without algorithmic overhead.

II. Materials and Methods

A. *System Overview*

The proposed sensorless bldc control system estimates rotor position using anfis controller that processes instantaneous three-phase back emf inputs to generate virtual hall signals (H_a, H_b, H_c). These signals are then fed into the commutation logic circuits to generate gate pulses for the three-phase inverter. A PI controller regulates speed by adjusting the DC input voltage to the inverter. A simplified block diagram of the proposed system is illustrated in Fig. 1.

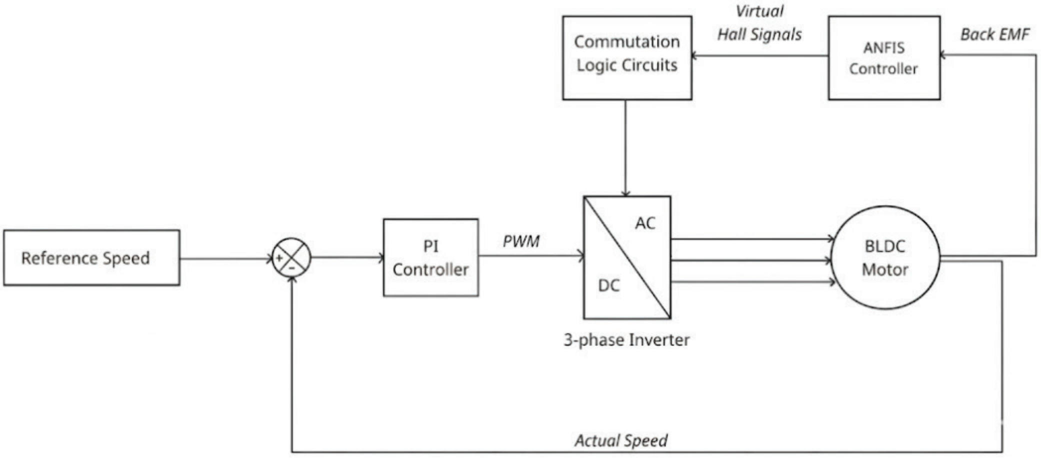

Fig. 1 Block diagram of the proposed methodology

The detailed MATLAB/Simulink implementation of this architecture is depicted in Fig. 2, highlighting anfis controller and commutation logic circuits.

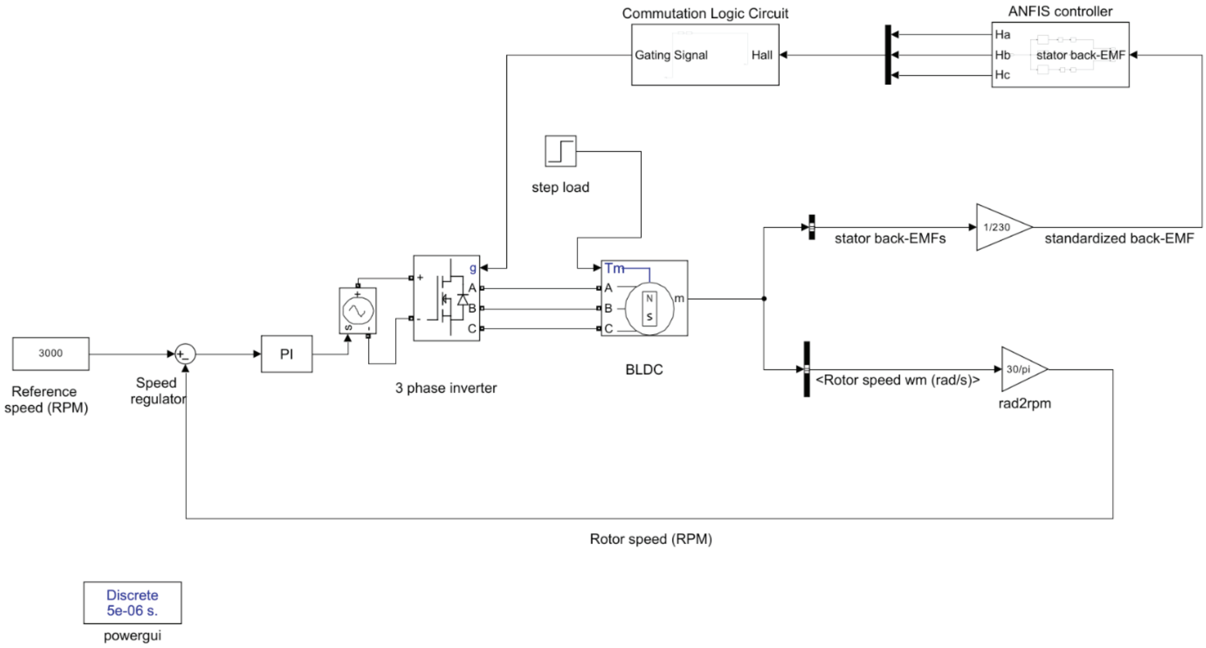

Fig. 2 Simulink model of the proposed methodology

B. *Adaptive Neuro-Fuzzy Inference System (ANFIS) Design*

The anfis controller is designed using a Sugeno type fuzzy inference system due to its efficiency in function approximation. Three independent anfis models were trained to generate each virtual hall signal, taking three back emf signals (E_a, E_b, E_c) as input. Table 1 summarizes the FIS parameters.

Table 1
FIS Specifications

Parameter	**Specification**
Inputs	3 (E_a, E_b, E_c)
Output	1 (virtual hall signal H_x)
Number of Rules	10
Membership Functions (MFs)	10 Gaussian MFs per input
Defuzzification Method	Weighted Average

ANFIS outputs continuous values, which are converted into binary hall equivalent signals using round and saturation blocks to ensure digital compatibility with the commutation logic.

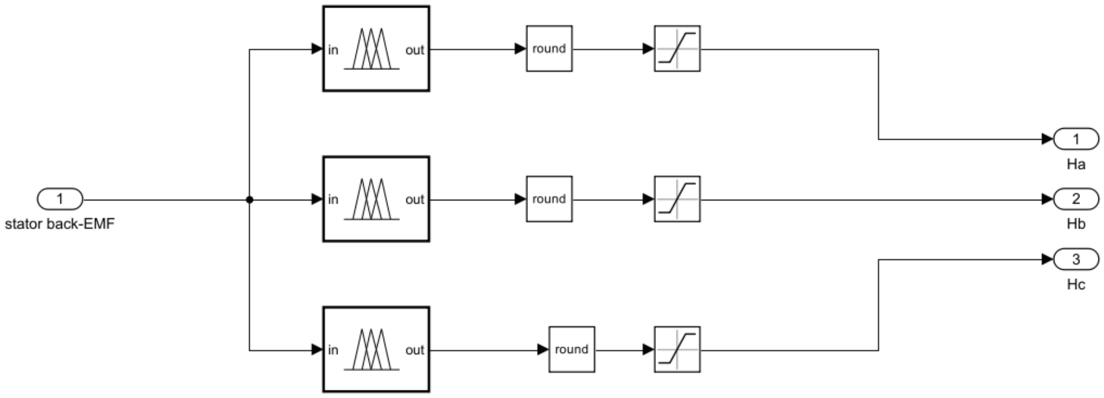

Fig. 3 ANFIS controller for generating hall signals

C. *Commutation Logic Circuits*

The commutation logic circuit converts virtual hall signals generated by the anfis controller into the corresponding gating pulses for the three-phase inverter. It consists of two stages: a decoder circuit and a gate activation circuit.

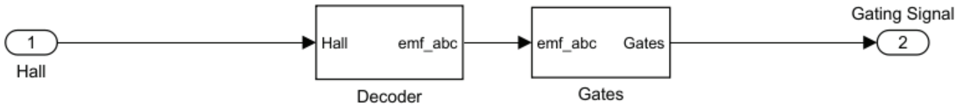

Fig.4 Overall commutation logic circuit.

1) *Decoder Circuit:* The decoder maps the binary hall signal combinations to phase back emf states according to the truth table presented in Table 2. Each unique combination of Hall inputs (H_a, H_b, H_c) corresponds to a specific commutation sector that defines the polarity of the phase emfs.

Table 2
Decoder Truth Table

H_a	H_b	H_c	emf_a	emf_b	emf_c
0	1	1	0	-1	+1
0	1	0	-1	+1	0
0	0	1	+1	0	-1
1	0	0	-1	+1	0
1	1	1	0	-1	+1
1	1	0	+1	0	-1
1	1	1	0	0	0

2) *Gate Activation Circuit:* The gate activation circuit translates the emf sector information into six-step gating signals. The corresponding logic relationships are listed in Table 3.

Table 3
Gates Truth Table

emf_a	emf_b	emf_c	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
+1	-1	0	1	0	0	0	1	0
0	+1	-1	0	1	0	1	0	0
-1	0	+1	0	0	1	0	0	1
-1	+1	0	1	0	0	0	1	0
0	-1	+1	0	1	0	1	0	0
+1	0	-1	0	0	1	0	0	1

A. *ANFIS Training and Dataset Creation*

The ANFIS controller was trained to generate virtual Hall signals (H_a, H_b, H_c) using the corresponding phase back-EMFs (E_a, E_b, E_c) as inputs. The training dataset was obtained from a MATLAB/Simulink model of a hall-sensor-equipped bldc motor operated at a reference speed of 3000 rpm.

During a 5-second simulation, instantaneous values of the three-phase back emf and actual hall signals were recorded, producing approximately 800,000 samples. The recorded back emf data were normalized by dividing by the peak expected value of 230V, scaling them into the standard range of [-1, 1] for stable and efficient anfis training.

The anfis model utilized the hybrid learning algorithm, combining the least squares method and backpropagation, as implemented in the MATLAB ANFIS GUI. Three separates but identically structured anfis networks were trained, each responsible for generating one virtual hall signal.

III. Results

The parameters of the bldc motor used in the study are summarized in Table 4. These values were used for both hall sensor based and anfis based controllers under identical test conditions.

Table 4
Parameters of BLDC Motor

S.N.	Description	Units	Values
1	Input Voltage	V	220
2	Stator Phase Resistance (R_s)	Ω	2.875
3	Stator Phase Inductance (L_s)	H	8.5×10^{-3}
4	Pole Pairs	-	4
5	Moment of Inertia (J)	$Kg.m^2$	0.8×10^{-3}

A. *Under Load*

To access the performance of the proposed anfis based sensorless control system under real operating conditions, simulations were carried out by applying a unit step load torque at t = 0.1seconds. The PI controller parameters were set to $K_p = 0.013$ and $K_i = 16.61$. The bldc motor was tested at two reference speeds: 1500 rpm and 3000 rpm, the latter being the speed used during anfis training. The corresponding speed and electromagnetic torque responses are presented in Fig. 5 and Fig. 6 respectively.

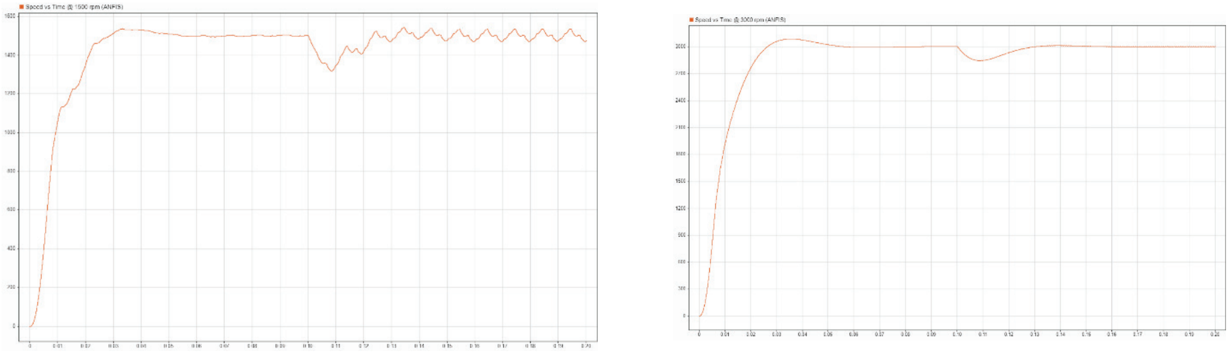

Fig.5 Speed response of the anfis based sensorless bldc motor under step load at (a) 1500 rpm(b) 3000 rpm

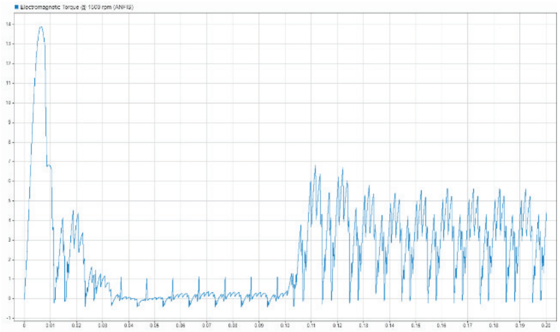

Fig. 6 (a) Torque response of the anfis based sensorless bldc motor under step load at 1500 rpm

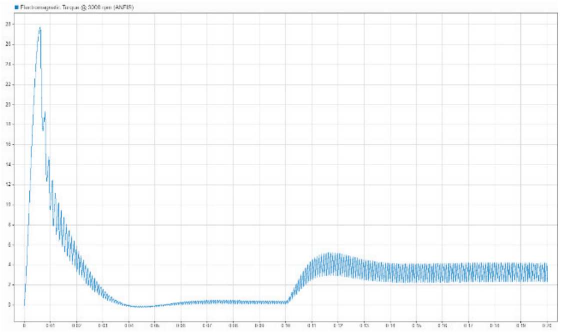

Fig. 6 (b) Torque response of the anfis based sensorless bldc motor under step load at 3000 rpm

As seen in Fig. 5 and Fig. 6, the anfis controller provides stable operation and quick recovery following the load disturbance.

At 3000 rpm, the controller trained at the same operating operation achieves smooth speed tracking and minimal torque ripple. At 1500 rpm, a slightly higher transient dip and longer settling time are observed, reflecting the model's reduced generalization when operating away from the trained reference speed. Despite this, the motor remains stable and well damped, confirming the robustness and adaptability of the proposed control method.

B. *Without Load*

For benchmarking purposes, both the conventional hall sensor system and the proposed anfis based system were evaluated under no-load conditions. The comparative results are presented in Table 5.

Table 5

Comparison of Speed Response without Load

Commutation Method	**Reference Speed (RPM)**	**Rise Time (s)**	**Settling Time (s)**	**Peak (RPM)**
Hall sensor	1500	0.0151	0.0263	1505.7
Hall sensor	2300	0.0153	0.0247	2337.3
Hall sensor	3000	0.0157	0.0429	3085.4
ANFIS	1500	0.0169	0.0389	1535.8
ANFIS	2300	0.0155	0.0395	2371.7
ANFIS	3000	0.0157	0.0429	3085.5

The results show that the anfis controller performs comparably to the traditional sensor-based control, with similar rise and settling times and only a marginal increase in overshoot. This confirms that the anfis generated virtual hall signals can reliably replace physical sensors without degrading control accuracy.

IV. Discussion and conclusion

The proposed anfis based sensorless control approach effectively reproduces the commutation logic of a conventional hall sensor based bldc drive. By combining the adaptive learning of neural networks with the interpretability of fuzzy rules, the controller estimates rotor position directly from the measured back emfs, eliminating the need for physical sensors.

The simulation results indicate that the anfis controller provides reliable speed and torque tracking, particularly at the trained reference speed of 3000 rpm, where its performance closely matches that of the sensor-based system. When tested at 1500 rpm, a slightly longer settling time and increased overshoot were observed, reflecting the model's limited generalization when operating away from its training speed.

A key limitation of this study is the assumption of clean back emf signals in the simulation environment. In practical systems, these signals must be estimated from noisy phase voltages affected by PWM switching and inverter harmonics. Addressing this issue would require dedicated filtering techniques, which remain open areas for future work.

Despite these constraints, the proposed anfis controller demonstrates strong potential for fault-tolerant operation. Its digital output compatibility with commutation logic circuits allows it to serve as a direct replacement in case of hall sensor failure, offering a practical solution for a reliability critical application such as electric vehicles, aerospace actuators, and industrial automation systems.

Future work will focus on real-time hardware implementation and noise-resilient back-emf estimation, aiming to extend the controller's applicability across a wider range of operating speeds and real-world conditions.

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