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DESIGN AND DEVELOPMENT OF ANFIS WITH FOPID CONTROL SCHEME FOR BRUSHLESS DC MOTOR SPEED CONTROL

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Abstract –
BLDC motors are ideal for low and medium power applications because to their high torque/inertia ratio, good dependability, huge energy density, broad speed control range, and low maintenance needs. It is a three-phase synchronous motor with rotor permanent magnets and stator three phase windings. Because there are no mechanical brushes or commutator assemblies, it is also known as a remotely switched motor. Instead, electronic commutation is employed depending on the position of the rotor measured by the Hall-effect position sensor. Modern speed control solutions for drives with different speeds have evolved significantly from their traditional equivalents. Closed loop control strategies were established for industrial drive applications, and PI, PID, FOPID, and FUZZY controllers were utilised in conjunction with power electronic converters.
A Hybrid Fuzzy-FOPID controller is employed in the current system to regulate the BLDC motor. The DC inverter voltage is controlled by a fuzzy logic controller, and the BLDC motor set point is controlled by a FOPID controller via the inverter gate circuit. A modified harmony search (HS) metaheuristic Algorithm is designed for modifying FOPID controller settings. The motor is tested in three distinct working circumstances to confirm the functionality of the present controller: no-load function, varying load execution, and varying speed operation. The hybrid fuzzy-FOPID controller that was installed greatly enhances motor speed and torque responsiveness in a number of operating circumstances. In the current system, Hybrid Fuzzy-FOPID has the drawback of having a slightly greater steady-state error, ripples throughout the speed profile, and restricted starting torque in all three operating circumstances. To overcome the drawbacks of the present system, we must employ a BLDC motor with a hybrid ANFIS-FOPID controller. The proposed work was created and implemented in MATLAB/SIMULINK.

Keywords – Speed control, Brushless DC (BLDC) motor, Fuzzy control, ANFIS, FOPID, Harmony Search (HS).

1. INTRODUCTION

Permanent Magnet Brushless DC (PMBLDC) Motor is a high power density motor with low electrical power consumption. The PMBLDC motor offers several significant benefits over traditional brushed DC motors and induction motors. It features improved torque-to-speed characteristics, a faster dynamic response, and is more efficient [1]. Another significant point to mention is that it includes an electronic commutation mechanism rather than brushing commutation, which ensures a longer life

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term. This motor likewise features a trapezoidal back EMF and a rotor made entirely of permanent magnet materials. The motor utilised in electrical cars, namely in the gear change mechanism and speed control technique, is a BLDC motor. The BLDC motor has a permanent magnet on the rotor side, a larger frequency fluctuation, an initial high torque characteristic, and the lack of brushes, all of which boost the application of the BLDC motor [2]. Because of these advantageous characteristics, BLDC motors are preferred over ac and dc motors. The direct torque control (DTC) is one of the key control systems for sinusoidal AC motors that has been adopted for the BLDC because it has a quick torque response and is simple to apply [3]. BLDC motors have numerous advantages over brushed DC motors and induction motors, including improved speed-to-torque features, high dynamic performance, high efficacy and reliability, inexpensive drives, extremely long life (no brush erosion), simple operation, higher speed ranges, and reduced electromagnetic interference (EMI). Furthermore, because BLDC motors have less inertia, starting and stopping the motor is easier, and the supplied torque to motor size ratio is greater [4]-[8]. Because of this, BLDC motors have been used in a broad range of commercial and home applications, including refrigerators, washing machines, PCs, military and automotive industries, and aerospace.

Because of its inherent advantages of simple construction and stable operation, the proportional integral and derivative (PID)-based control method is widely employed in industry [9]. Even under the current environment, more than 95% of closed loop economic controllers are PI or PID based, although this controller is not recommended for BLDC motors due to their nonlinear behaviour. Researchers developed numerous artificial intelligence-based strategies to account for the nonlinear parameter change of BLDC motors [10].

To ensure the successful functioning of the PMBLDC motor, several different types of control strategies have been created. The technique of four quadrant current control is suggested. This motor is controlled by a traditional PI controller. PI controllers are the most often used motor drive control systems. In addition, fuzzy logic controllers and anti-wind up fuzzy controllers are suggested for PMBLDC motors [11]. A comparison between fuzzy controller and conventional PI controller demonstrates that the fuzzy controller provides quick dynamic response when compared to the traditional PI controller mechanism. In recent decades, ANN has surpassed all other control systems in popularity. An intelligent controller is created in this study to control the BLDC motor speed. The controller was created with the help of a control specialist and plant characteristics. The suggested intelligent controller does not require precise system modelling knowledge [12]-[14]. In terms of robustness and disturbance rejection, the performance of the devised intelligent controller is also compared to that of the conventional controller. The suggested intelligent controller has a high level of resilience and anti-interference capability. An adaptive neuro-fuzzy inference system (ANFIS) responds quickly and reliably. In terms of implementation, it is more or less the same for all control applications, i.e. a controller created for one application may be used for another by just modifying the rule base and the fuzzy sets. Industrial demands may be readily met by building specialised ANFIS with fewer regulations and minimal hardware. It may be used to tackle problems with system control that have uncertain dynamics.

2. BLDC Operation

Three phase stator windings and pairs of permanent magnet poles in the rotor are used in BLDC motors. The stator winding distribution is designed so that the produced reverse electromotive force (back-emf) has a trapezoidal form. As a result of these properties, each phase may be represented as a resistance, an inductance, and a trapezoidal back-emf. The design is quite similar to that of a permanent magnet synchronous motor. The key distinction is the wave form of the back-emfs. Despite being classified as a direct current motor, the BLDC runs on three-phase alternating currents. The interplay of stator and rotor electromagnetic fields drives the rotor by appropriately managing the current direction in each winding. To correctly operate the motor, the rotor position must constantly be known, which can be directly observed or inferred. Brushless DC motors are made up of two basic components: the stator and the rotor. The rotor is made of a permanent magnet material such as NdFeB. The rear emf of this motor is trapezoidal in form. As illustrated in (1), the mathematical model of a PMBLDC motor may be stated in state space form.

$$\dot{x} = Ax + Bu + Ce \quad (1)$$

$$x = [i_{as} \quad i_{bs} \quad i_{cs}]^t \quad (2)$$

$$u = [v_{as} \quad v_{bs} \quad v_{cs}]^t \quad (3)$$

$$e = [e_a \quad e_b \quad e_c]^t \quad (4)$$

$$A = \begin{bmatrix} -\frac{R_s}{L-M} & 0 & 0 \\ 0 & -\frac{R_s}{L-M} & 0 \\ 0 & 0 & -\frac{R_s}{L-M} \end{bmatrix} \quad B = \begin{bmatrix} \frac{1}{L-M} & 0 & 0 \\ 0 & \frac{1}{L-M} & 0 \\ 0 & 0 & \frac{1}{L-M} \end{bmatrix}$$

$$C = \begin{bmatrix} -\frac{1}{L-M} & 0 & 0 \\ 0 & -\frac{1}{L-M} & 0 \\ 0 & 0 & -\frac{1}{L-M} \end{bmatrix}$$

$$T_e = [e_a i_{as} + e_b i_{bs} + e_c i_{cs}]/\omega_m$$

In this equation, vas, vbs, and vcs are the stator phase voltages, wm is the rotor speed in radian per second, Rs is the stator per phase resistance, ias, ibs, and ics are the stator phase currents, L is self-inductance per phase, M is mutual inductance between phases, and ea, eb, and ec are three phase The moments of inertia J, the friction co-efficient B, the produced electromagnetic torque Te, and the load torque Tl are all connected. In the BLDC motor drive shown in Fig. 1, the motor is driven at each time by energising two phases of the motor based on rotor position information gathered from three 120 apart hall-effect sensors, each of which gives a 1 or 0 signal when it is close to the north and south poles of the motor's rotor, respectively. Gate signals are created based on hall-effect sensors to turn MOSFET switches S1-S6 ON or OFF. Table 1 shows the gate switching signals and phase current status as a function of rotor position.

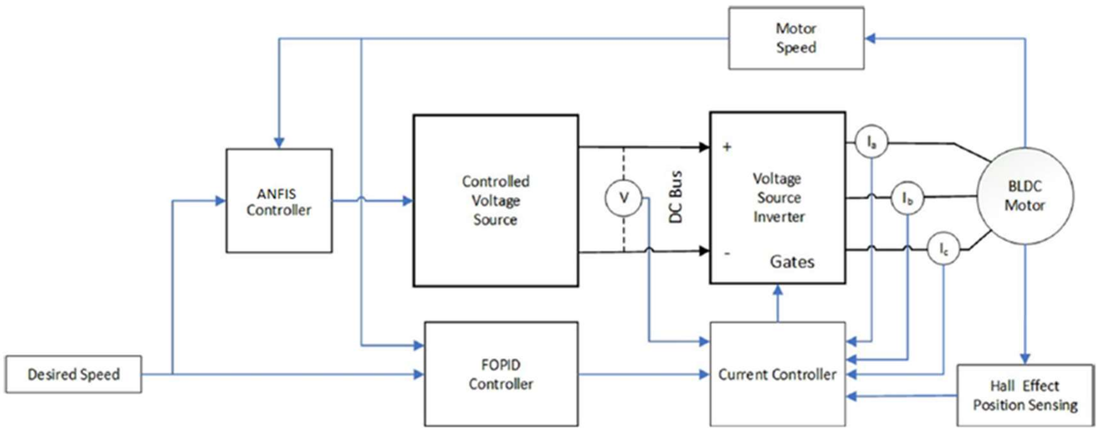


Fig.1: Schematic diagram of BLDC motor.

Rotor angle (rad)	Closed switches		Phase current		
			A	B	C
$0-\pi/3$	S6	S1	+	–	OFF
$\pi/3-2\pi/3$	S2	S1	+	OFF	–
$2\pi/3-\pi$	S2	S3	OFF	+	–
$\pi-4\pi/3$	S4	S3	–	+	OFF
$4\pi/3-5\pi/6$	S4	S5	–	OFF	+
$5\pi/6-2\pi$	S6	S5	OFF	–	+

Table-1: switching gate signals

Because of its nonlinear coupled dynamics and multi-input nature, BLDC motors are challenging to regulate. FOPID is capable of controlling motor speed with good results. However, fluctuations in load and speed diminish its performance. Using ANFIS to manage the inverter DC bus voltage can therefore improve system performance and adjust the control system to changes in operating conditions. The proposed technique for BLDC motor speed management in this paper employs a ANFIS controller to manipulate DC inverter voltage and a FOPID controller to regulate BLDC motor reference current via the inverter gate circuit. Both controllers will work in tandem to reduce the measured speed's departure from the reference speed while also lowering torque ripples.

A. FOPID:

The complicated operations of today's industries may be too much for the traditional PID tuning methods to handle. With the use of non-integer order calculus, the fractional order PID controller was developed as an extension of the classical PID controller for improved control. In the fractional calculus, integration and differentiation are performed at a fractional or complex order. The capacity to inherit the character of the processes is the primary benefit of the fractional derivative. Fractional order process models and controllers are commonplace in the control loop. However, controllers are typically implemented as fractional orders since integer order models are more common for the processes being regulated. In contrast, if the plant model is acquired in the form of a partial model, it is transformed into an integer order system by estimating the fractional components with one of many proposed approximations.

B. Fuzzy logic controller:

To develop a fuzzy logic controller, an accurate model of a complicated system is not required; instead, an understanding of the system's general behaviour is needed. The use of a fuzzy logic controller makes it easier to explain system performance in terms of language variables. The fuzzy logic controller lays the path for the development of a resilient nonlinear system with a high degree of automation. The three key phases in the design of a fuzzy logic controller are fuzzification, inference mechanism, and defuzzification. The inaccuracy is standardised to a per-unit with regard to the reference speed in this research. As shown in Fig. 2, the fractional order-PID (FO-PID) control is used to build the controller law. This makes it easier for the fuzzy controller to detect any reference speed. The controller will try to minimise the error to zero by altering the duty cycle. The Fuzzy controller takes error 'e' and variation in error 'ce' as input variables and outputs control signal 'ctrl'. Fig. 3 depicts the different membership rules.

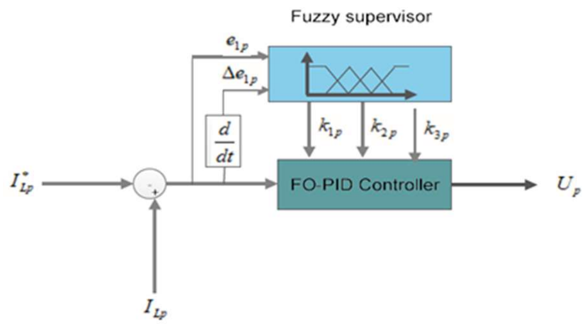


Fig.2: Fuzzy-FOPID Controller.

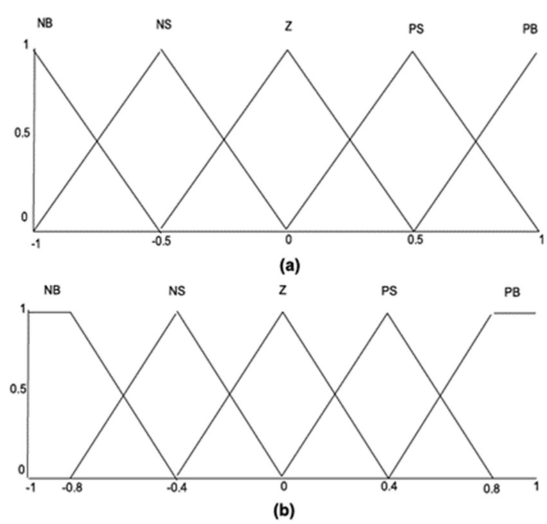


Fig.3: Membership function rules.

Harmony Search Method (HSA) is a recently proposed population-based musically inspired meta-heuristic algorithm. HSA replicates music improvisation behaviour by depicting the action of experimenting with different pitch combinations to achieve the greatest harmony. This is done in HSA during the selection phase, when the values of New Harmony can be chosen from Harmony Memory

(HM), which represents the location where HSA stores the solution set. They can also be picked from HM with a minor alteration or at random from the permitted range of values.

C. Adaptive Neuro Fuzzy Inference System:

An adaptive network is made up of adaptable nodes connected by directed connections. Adaptability nodes indicate that each of these nodes' outputs is dependent on the parameter associated with this node, and the training process describes how these parameters should be modified to minimise a specified error measure.

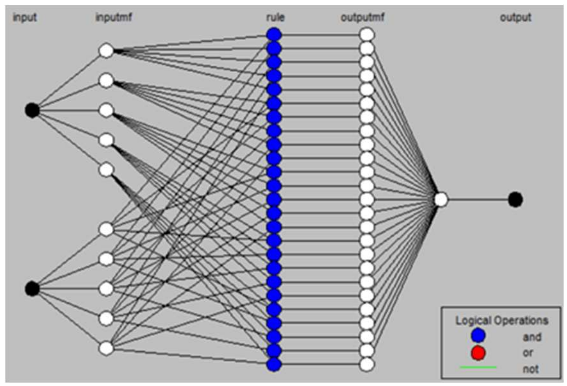


Fig.4: ANFIS layer.

3. SIMULATION RESULTS

The suggested controller and fuzzy PID controller are used to measure and evaluate the torque and speed of the brushless motor. The BLDC motor's characteristics are provided in Table I, and its performance is calculated using MATLAB/Simulink simulation.

Parameter	Value
Poles	2
Torque constant	1.3 N.m/A
Voltage constant	136.13 V/KRPM
Stator resistance	10.91 ohms
Stator inductance	30.01 mH
Rotor inertia	$2.8 * 10{-}4 kg.m2$
Rotor friction	0.001 $N.m/rad/s$

A. EXISTING SYSTEM:

1) No load operation:

Figures 5 & 6 illustrate the speed and torque responses with conventional and suggested controllers. Table II compares the performance of the conventional and suggested controllers, revealing that the proposed ANFIS controller outperforms the other controllers.

Controller	Peak value (N.m)	Settling time (s)
Existing system	9.5	0.018
Proposed system	9	0.018

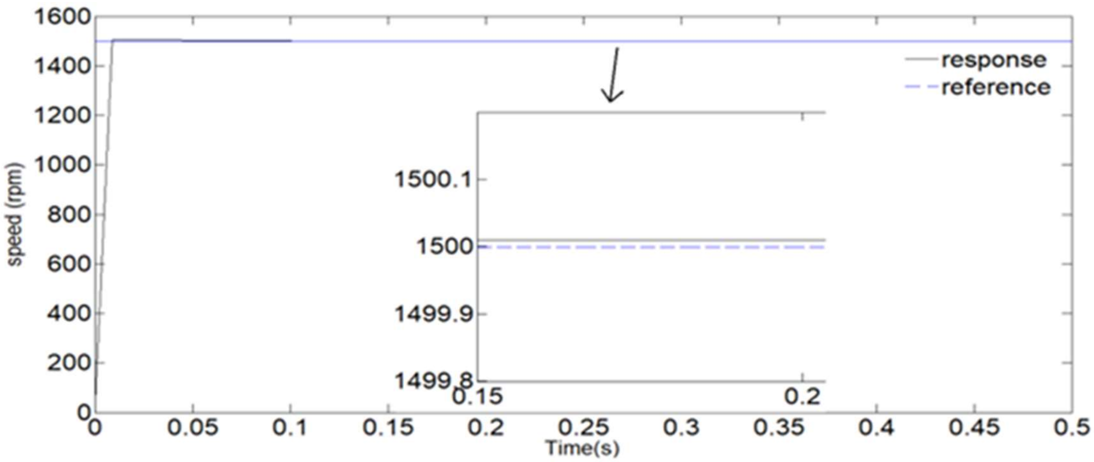
The suggested controller reduces beginning torque by limiting starting current and settling time.

2) Varying load operation:

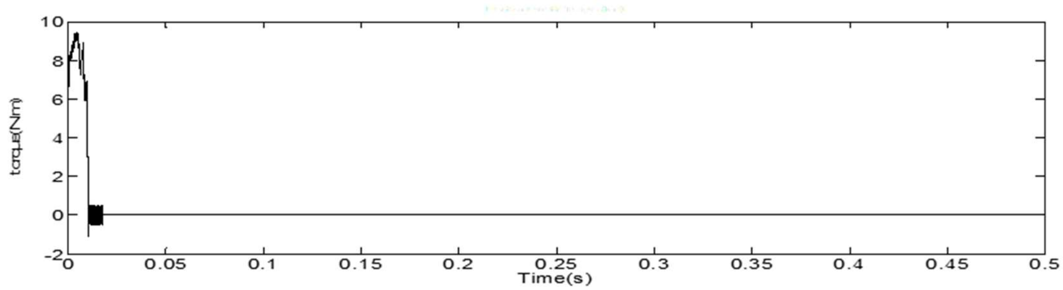
Figures 7 & 8 illustrate the speed and torque responses with conventional and suggested controllers. The suggested controller offers speed response with a short settling time and low steady-state error, as well as torque response with minimal torque ripples and a low beginning torque.

3) Varying speed operation:

Figures 9 & 10 illustrate the speed and torque responses with conventional and suggested controllers. The suggested controller provides a rapid settling time and minimal steady-state error and torque ripples over the whole speed profile. However, there is a significant difference in torque response with speed change.

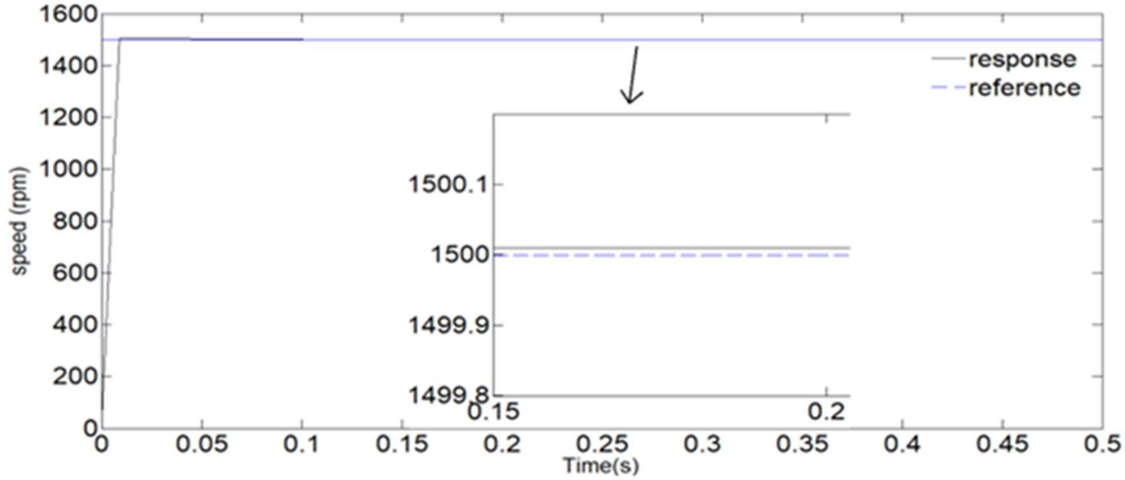


(a)

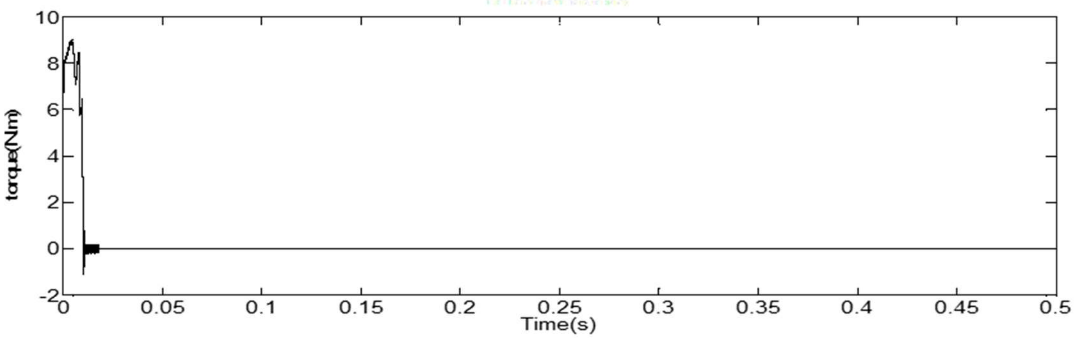


(b)

Fig.5: Existing system, (a) speed, (b) torque response.

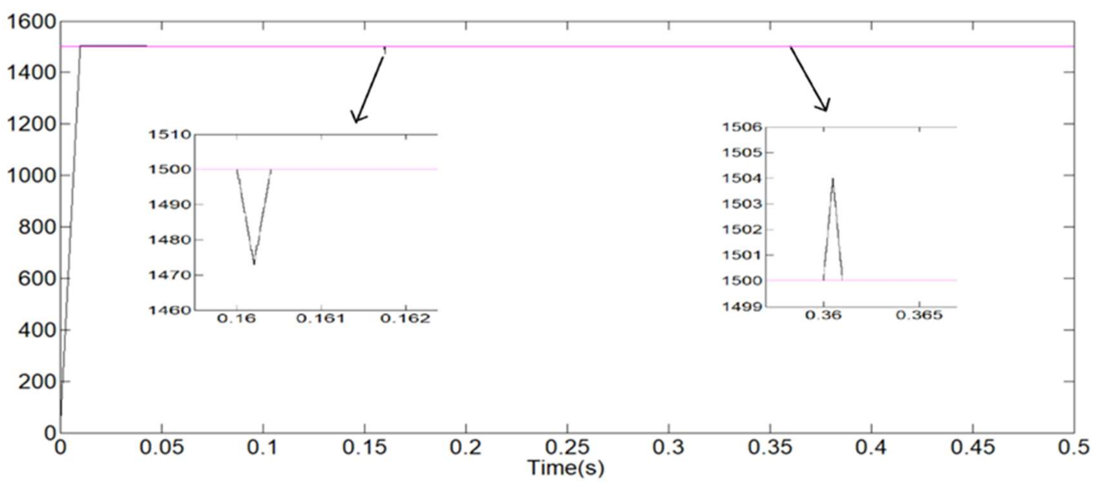


(a)

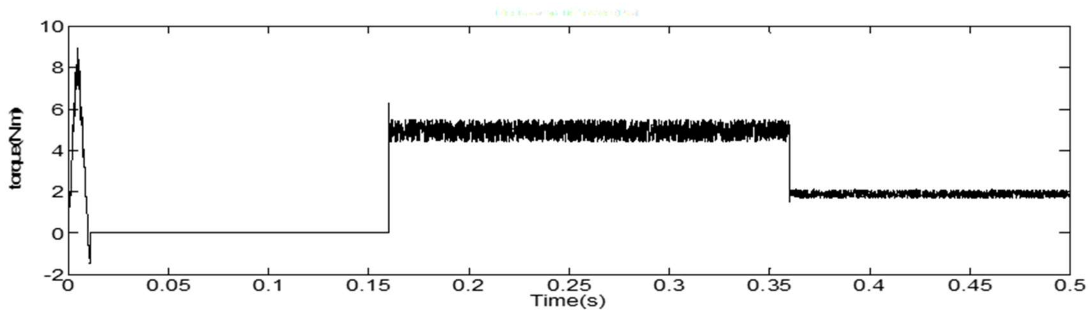


(b)

Fig.6: proposed system, (a) speed, (b) torque response.

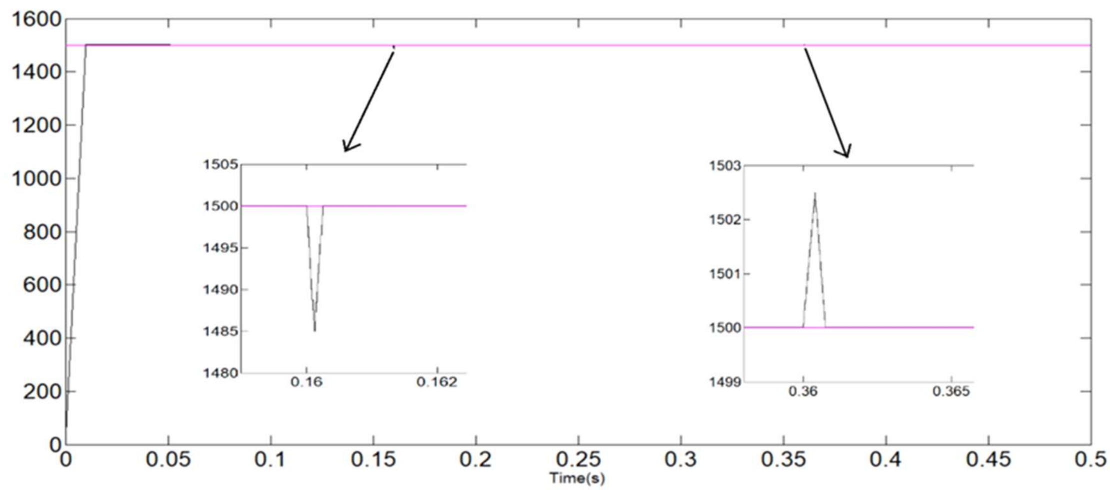


(a)

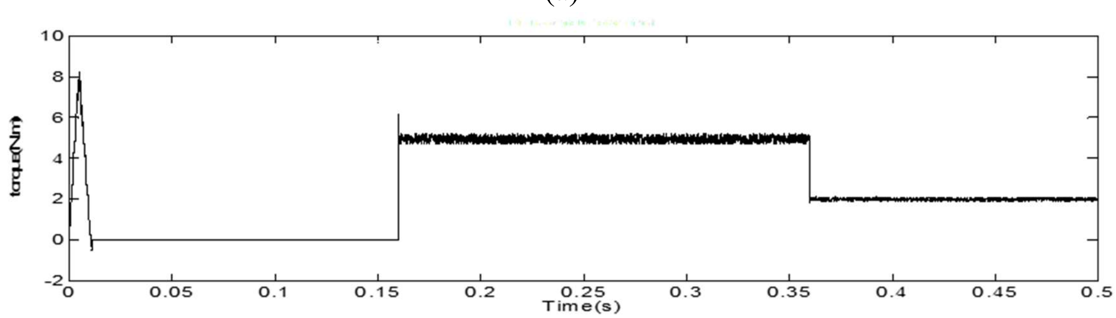


(b)

Fig.7: Existing system, (a) speed, (b) torque response.

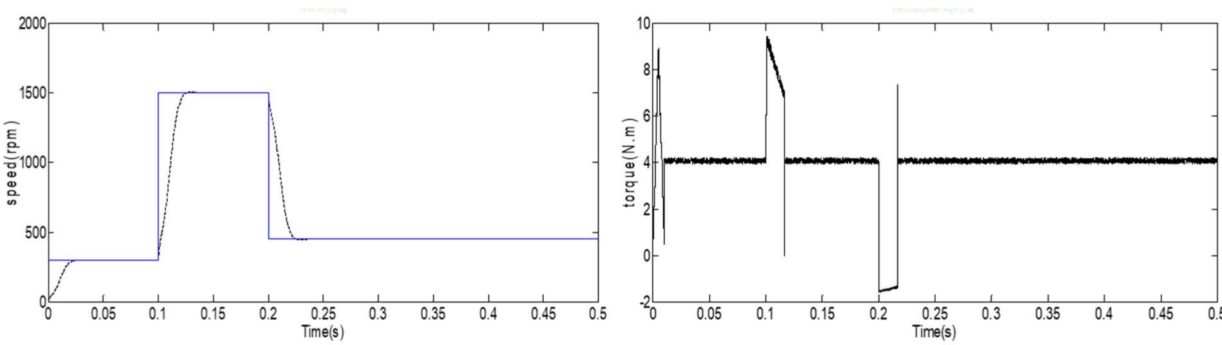


(a)



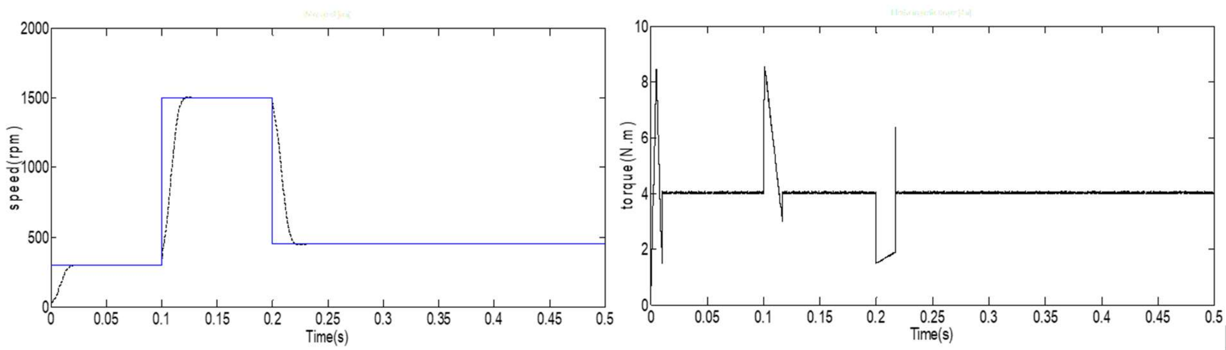
(b)

Fig.8: Proposed system, (a) speed, (b) torque response.



(a) (b)

Fig.9: Existing system, (a) speed, (b) torque response.



(a) (b)

Fig.10: Proposed system, (a) speed, (b) torque response.

CONCLUSION

According to this paper, the performance of ANFIS-based BLDC drives outperforms traditional fuzzy controlled BLDC drives. It may be justified by doing a comparison study between ANFIS and fuzzy-based BLDC simulink design. When compared to Fuzzy-based BLDC, ANFIS-based BLDC takes less time to attain a steady state value. These are investigated using speed torque responses. The dynamic response shows that torque ripple is greatly decreased, and no chattering is detected as a result of the control signal with the suggested rotor position controller.

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