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CURRENT FOLLOWER APPROACH BASED PI AND FUZZY LOGIC CONTROLLERS FOR BLDC MOTOR DRIVE SYSTEM FED FROM CUK CONVERTER

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ABSTRACT
This paper presents two controllers for implementing the current multiplier approach over a wide range of speed control of a Brushless DC (BLDC) Motor drive system as a cost effective low-power solution. A CUK converter at the front end feeds the DC bus of the Voltage Source Inverter (VSI), where, closed loop duty ratio control of the converter results in variable DC bus voltage, enabling close matching of the reference speed setting. Two alternate controller configurations viz. PI controller and fuzzy controller are introduced for generating gate trigger signals for the power MOSFET switch of the converter. Comparison of performance covering a over a wide range of operating speed of the entire system using PI/FUZZY controllers is carried out by simulation in MATLAB/Simulink platform.

Keywords: BLDC motor, CUK converter, PI controller, FUZZY controller, current follower approach.

1. INTRODUCTION
BLDC motor has gained popularity due to higher reliability, simplicity in control and lesser maintenance. As far as space and weight are concerned, BLDC motors are the best choice in many applications. The construction and control architecture are also well suited for safe operation in critical applications. Brushless DC motors follow an inside out construction where the rotating element carries permanent magnets. Here, instead of a mechanical commutator, electronically switched commutation is employed in the stator supply through power electronic based switching circuits and Hall sensors for detecting the rotor position. This also facilitates introduction of various control techniques through feedback controllers for frequency and voltage variations.
BLDC motors possess several merits over brushed DC motors and induction motors, such as a better speed versus torque characteristics, high dynamic response, high efficiency and reliability, longer operating life, noiseless operation and larger range of speed. Furthermore, the motor posses linear characteristics between current and torque and also voltage and speed. The above features of the BLDC drive system has resulted in growing application of the same in automobile and aerospace industries. Where reduced space and weight along with high torque to inertia ratio are important aspects.

Nomenclature

Van, Vbn, Vcn	: Voltages in each phase a,b,c, Volts
ia, ib, ic	: Currents in each phase a,b,c, Amps
ea, eb, ec	: Back-EMF's in a,b,c, Volts
R	: Stator resistance per phase in Ω
L	: Self inductance of stator, H
M	: Mutual inductance of stator, H
Te	: Electromagnetic Torque developed by motor, N-m
T_L	: Motor load torque, N-m
B	: Viscous friction coefficient of motor, N-m/rad/sec
J	: moment of inertia rotor shaft and load, kg-m^2
ω	: Angular speed of rotor, rad/sec

2. MATHEMATICAL MODEL OF BLDC DRIVE SYSTEM
BLDC motor's equivalent circuit is shown in Figure-1. The back-EMF waveforms are trapezoidal in shape, while current waveforms are rectangular. Stator windings parameters are same in all the phases and the self and mutual inductances remains constant. The three phase voltage equations are written in matrix form as shown below.

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad (1)$$

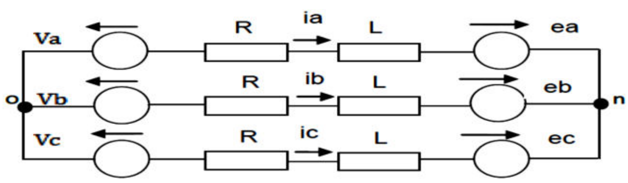

Figure-1. Equivalent circuit of BLDC motor.

The interaction between the current in the stator winding and rotor magnetic field are responsible for the production of electromagnetic torque in BLDC motor and instantaneous torque is given by

$$Te = \frac{ea.ia + eb.ib + ec.ic}{\omega} \quad (2)$$

The torque-balance equation of the rotor yields

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$$\frac{d\omega}{dt} = \frac{Te - TL - B\omega}{J} \quad (3)$$

3. CONTROL OF PMBLDC DRIVE SYSTEM

The associated blocks of the BLDC motor drive system are DC-DC converter DC-AC converter, Hall sensor, digital controller and BLDC motor as shown in Figure-2. The six-step commutation of phase currents are obtained at every 60 degree electrical for the drive system is based on the rotor position feedback.

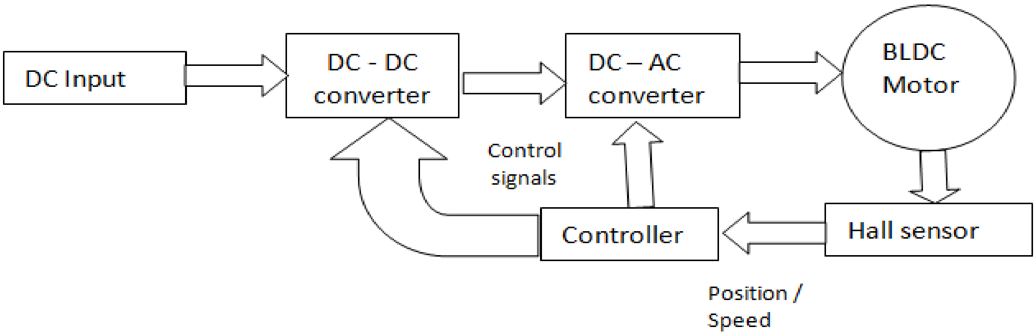

Figure-2. Components of BLDC drive system.

To develop a unidirectional torque, position of rotor and the correct sequence of stator coils switching must be consistent. This is achieved by Hall sensors which sense the instantaneous rotor field magnet position. The Hall sensor circuitry is part of an inherent feedback arrangement for triggering the Voltage Source Inverter in 120 mode of conduction. In a speed control application of the BLDC motor it is necessary to introduce a variable DC link voltage and the same is implemented using a DC-DC CUK converter is employed. This control for the six-pulse inverter is provided at the front end, instead of PWM control of the stator currents is instrumental in reducing the torque ripple to a great extent on the mechanical side.

4. CURRENT FOLLOWER METHOD

As mentioned earlier, implementation of Current Multiplier method is carried out by two alternate controllers as follows:

a) PI controller

b) FUZZY logic controller.

4.1. Current follower method using PI controller

The speed control problem formulated starts with a reference speed setting, which generates a dc voltage through multiplication with $K_{b.}$ The error between this voltage and the DC bus voltage is processed by a PI controller, which is subsequently multiplied with a unit template of supply voltage so as to account for any supply voltage fluctuations.

Further, in this work the speed control is sought to be implemented by controlling the motor currents and thereby the electromagnetic torque. Accordingly a reference current generated block is introduced so as to force the actual dc link current to a desired value in a closed loop manner as shown in figure. Finally, the actuating signal in the form of a PWM control at the IGBT gates is realized by using a 5 kHz saw tooth carrier signal as shown in Figure-3.

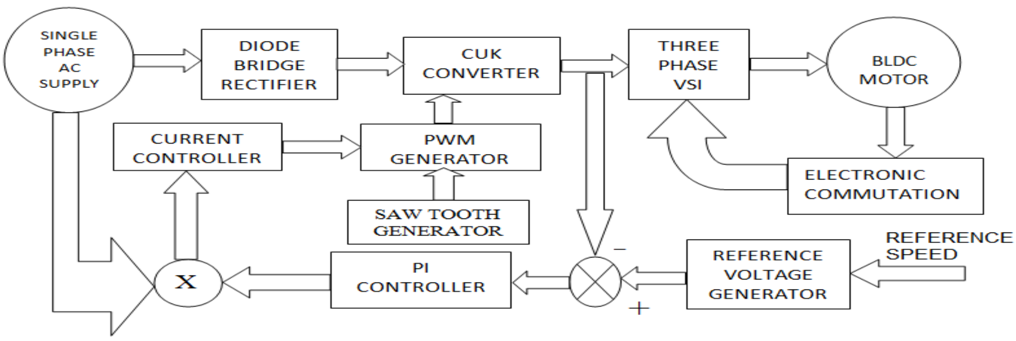

Figure-3. Current follower approach using PI controller.

The MATLAB/SIMULINK model for the BLDC motor system driven by a six-pulse inverter which is fed by CUK converter using PI controller for current follower approach is shown in Figure-4 and the detailed schematic of PI controller is shown in Figure-5.

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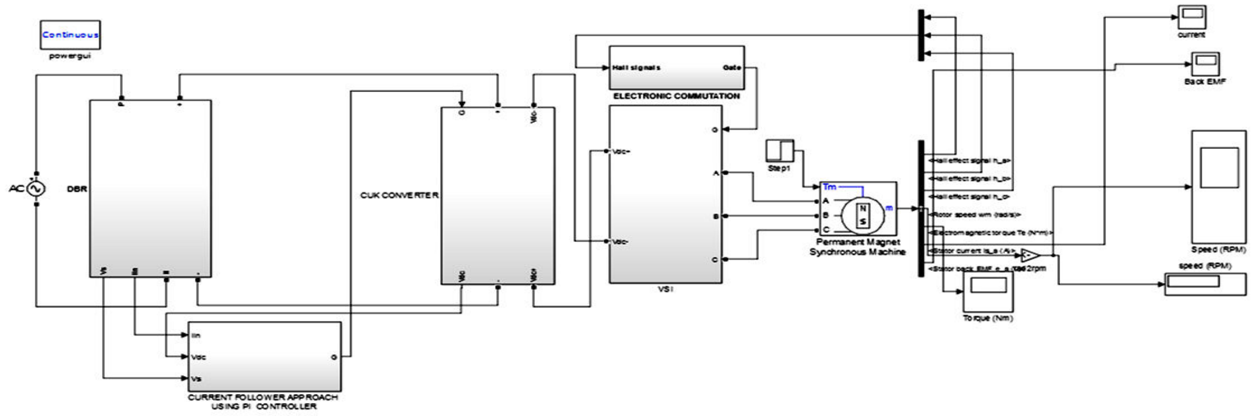

Figure-4. MATLAB /Simulink model for current follower approach using PI controller.

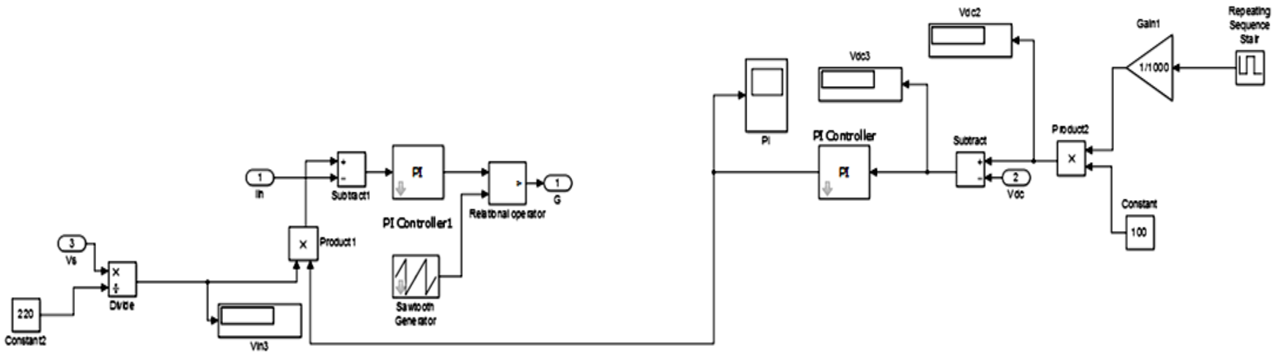

Figure-5. Schematic of PI controller.

4.2. Current follower method using FUZZY controller

In this controller, the PWM generation using a high frequency of 5 kHz saw tooth waveform is compared with a processed voltage signal which is obtained by considering the speed error and passing it through calculation blocks as shown in Figure-6. The corresponding membership functions for the fuzzy controllers are shown in Figure-6. The schematic indicates the linguistic variables after fuzzification of the error signals. The crisp variables at the output of the controller are obtained by employing rule based membership functions.

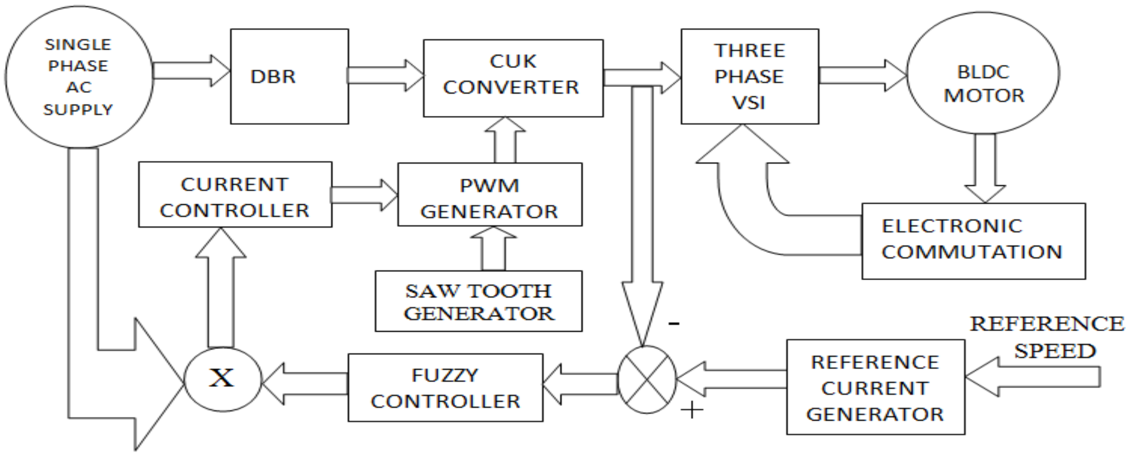

Figure-6. Current follower approach using fuzzy controller.

The MATLAB/SIMULINK model of the BLDC motor driven by a six-pulse inverter which is fed by CUK converter using FUZZY controller for the current follower approach is shown in Figure-7.

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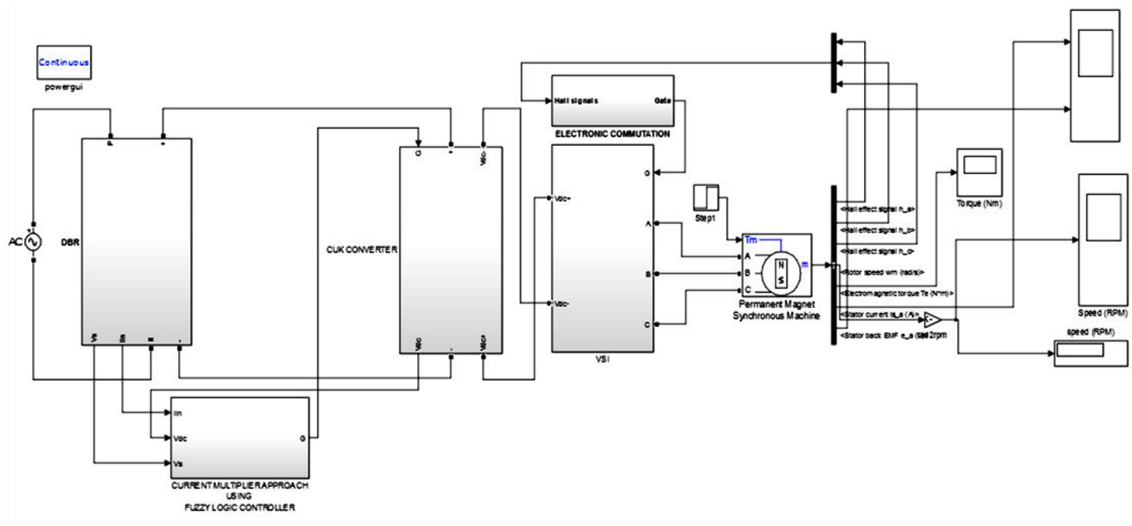

Figure-7. MATLAB /Simulink model for current follower approach using PI controller.

The detailed flow diagram starting from detection of speed error upto PWM generation using a pair of FUZZY controllers depicted in Figure-8.

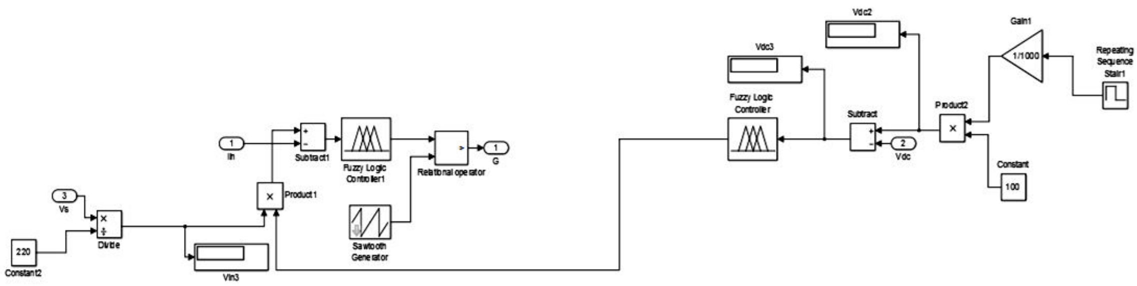

Figure-8. Schematic of FUZZY controller.

5. SIMULATION RESULTS

The proposed strategy is implemented by carrying out simulations for CUK converters using PI controller and FUZZY controller and the results obtained for a constant load torque of 5 N-m. A BLDCM with a nameplate data shown in Table-1 is dealt.

The performance of speed regulation of the overall system for PI controller covering the range of reference speeds and its corresponding variations of the back EMF covering the above runs are also shown in Figures 9, 10, 11, 12.

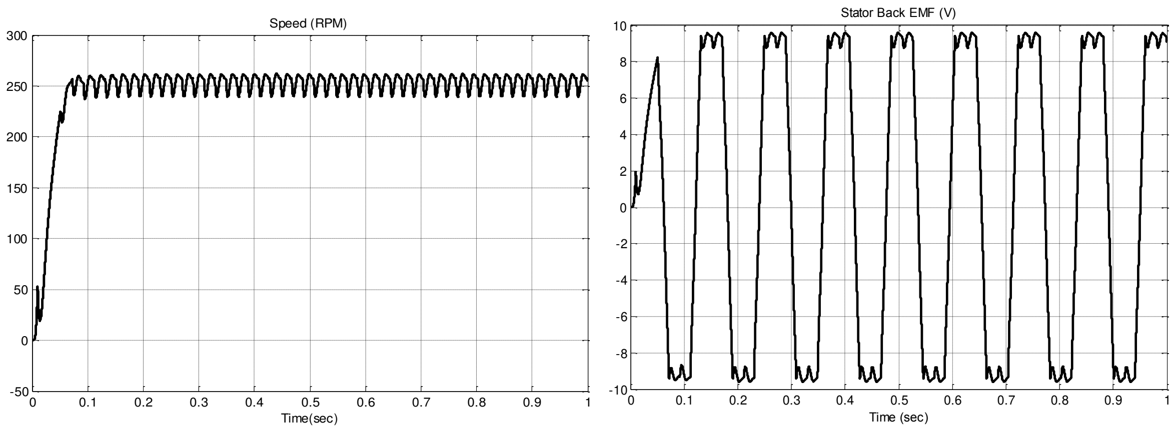

Figure-9. Rotor speed of 250 RPM and its corresponding back EMF waveform using PI controller.

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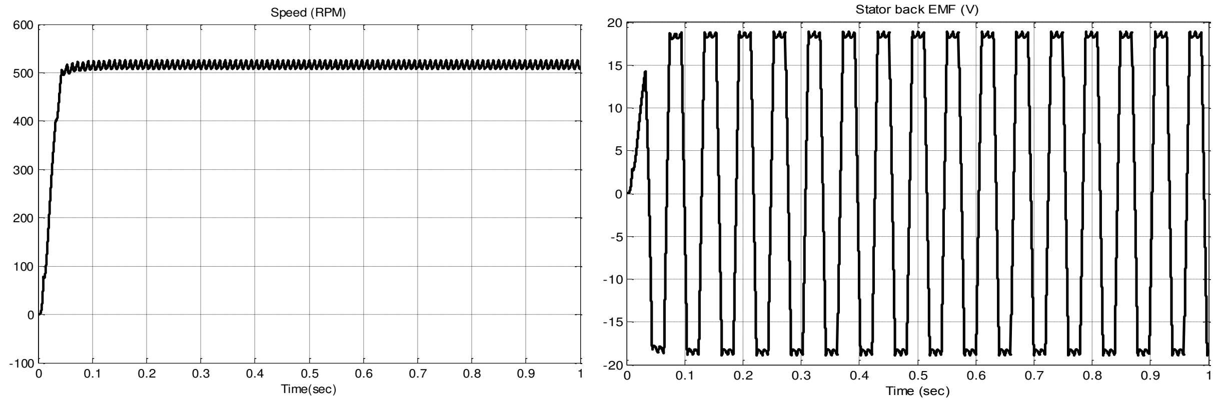

Figure-10. Rotor speed of 500 RPM and its corresponding back EMF waveform using PI controller.

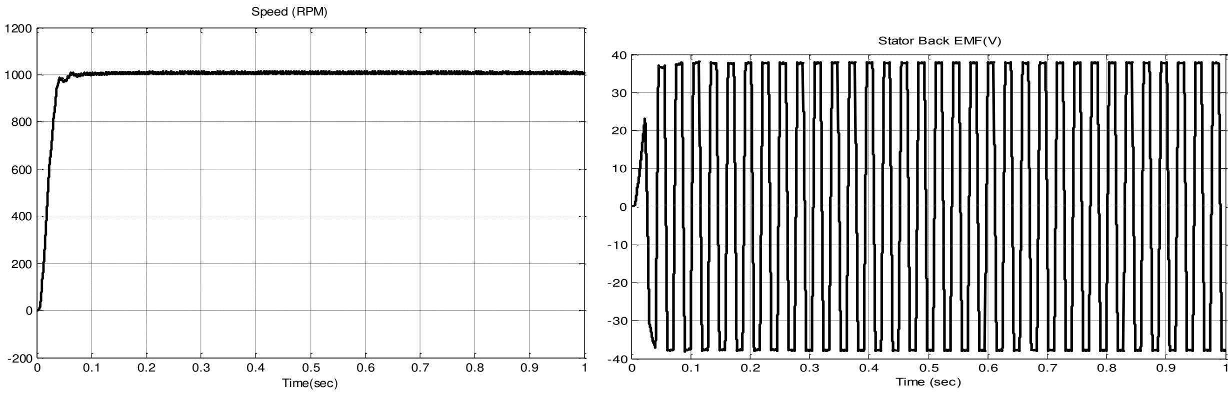

Figure-11. Rotor speed of 1000 RPM and its corresponding back EMF waveform using PI controller.

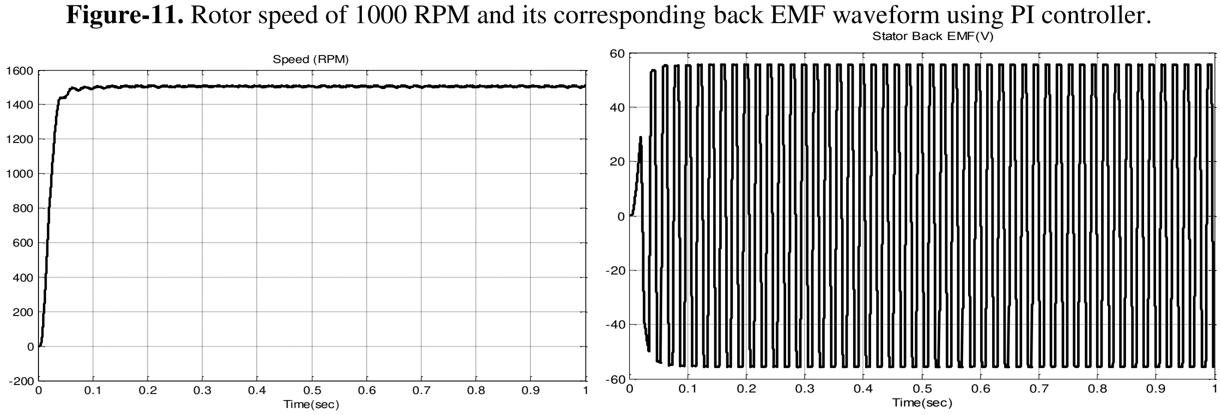

Figure-12. Rotor speed of 1500 RPM and its corresponding back EMF waveform using PI controller.

The performance of speed regulation of the overall system for FUZZY Logic controller covering the range of reference speeds and its corresponding variations of the back EMF covering the above runs are also shown in Figures 13, 14, 15, 16

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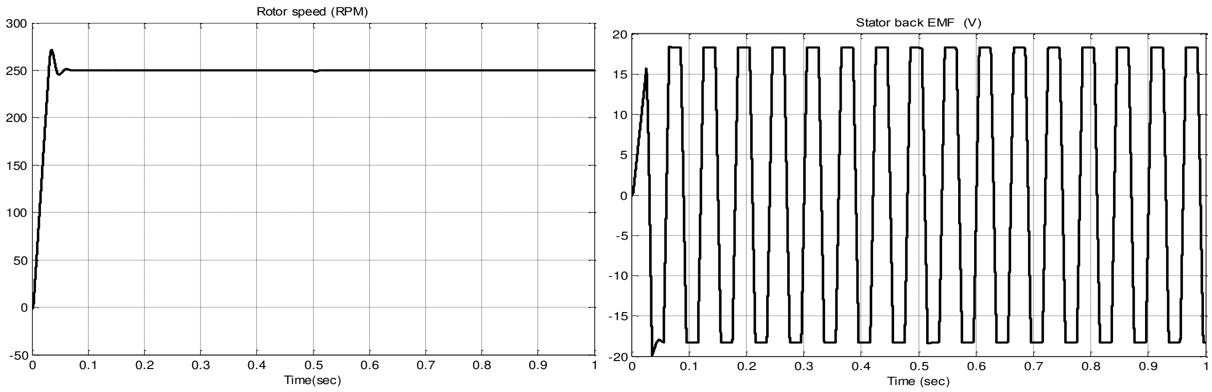

Figure-13. Rotor speed of 250 RPM and its corresponding back EMF waveform using FUZZY logic controller.

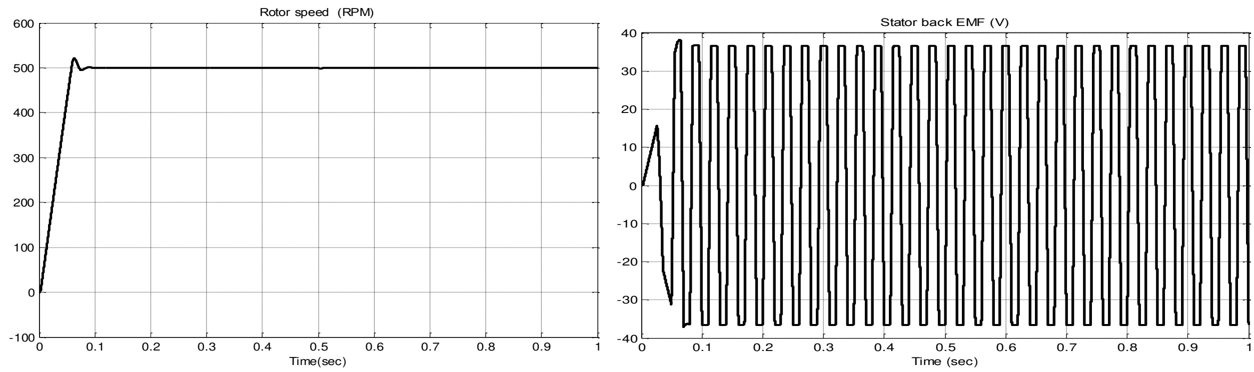

Figure-14. Rotor speed of 500 RPM and its corresponding back EMF waveform using FUZZY logic controller.

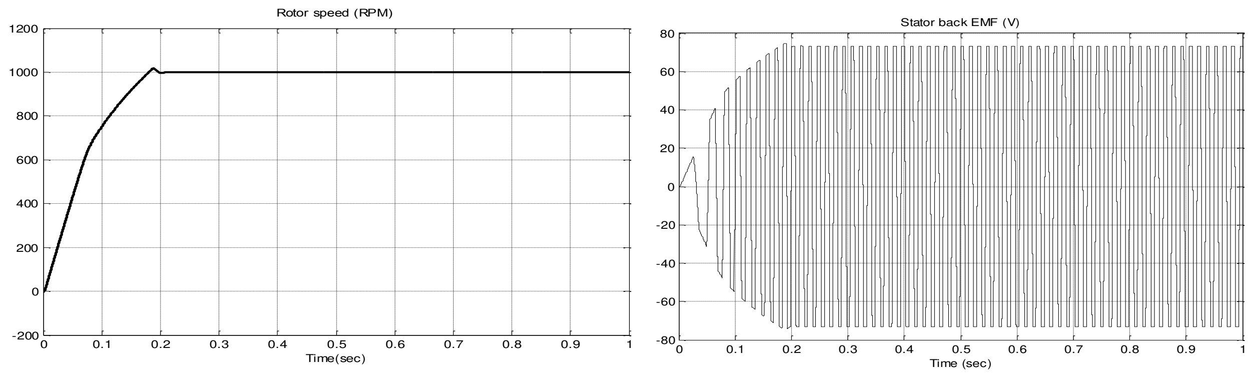

Figure-15. Rotor speed of 1000 RPM and its corresponding back EMF waveform using FUZZY logic controller.

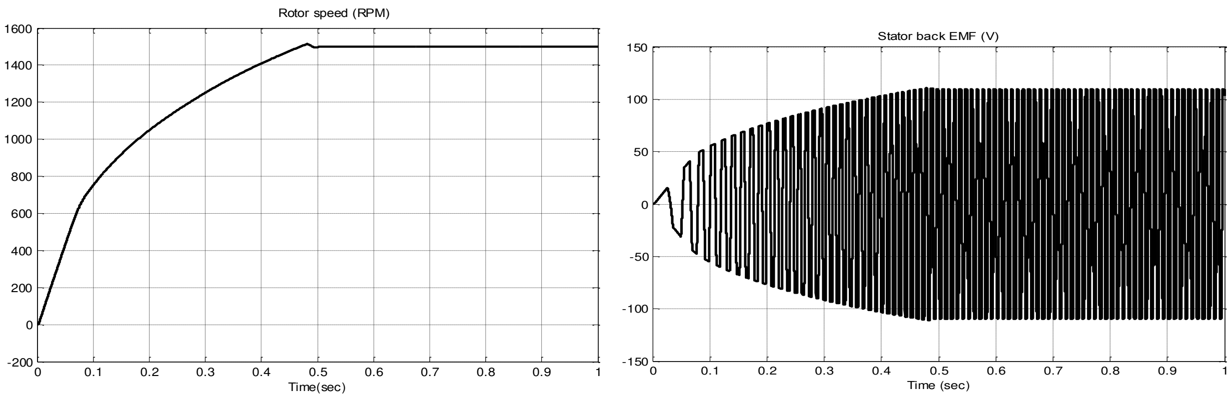

Figure-16. Rotor speed of 1500 RPM and its corresponding back EMF waveform using FUZZY logic controller.

Figure-17 shows the simulated waveforms for the variation of speed following the reference speed for every step change in the BLDCM drive system incorporating the controllers viz PI controller and FUZZY controller. It is observed that smoothness is obtained in actual speed following the reference speed, Back emf and current waveforms using FUZZY controller is far superior than PI controller in the BLDC motor drive system over the time period 2 seconds.

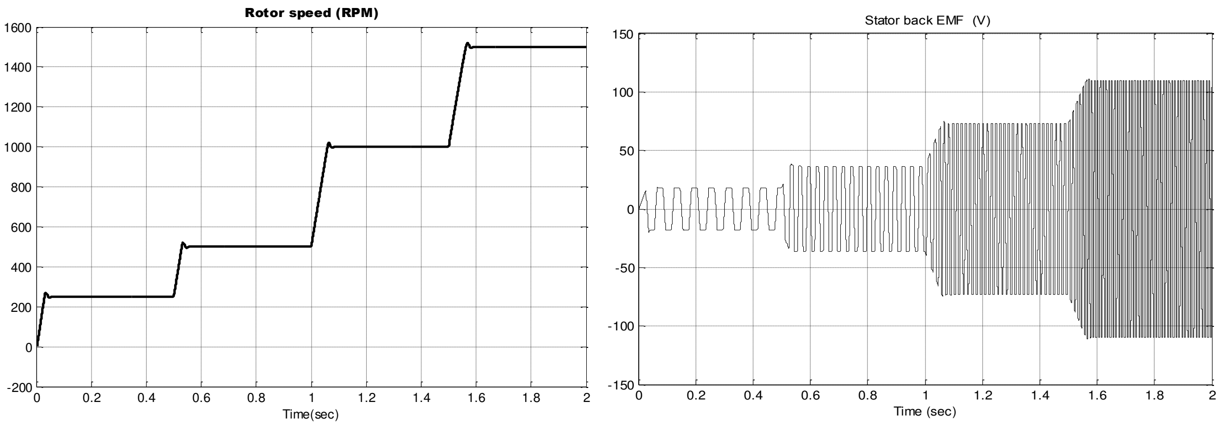

Figure-17. Variation of Rotor speed for each step change and its corresponding Back EMF waveform using FUZZY logic controller

6. CONCLUSIONS

In this paper, simulation of a BLDC motor drive system is carried out by considering the current follower approach and introducing two different controllers viz. PI controller and FUZZY controller. The work covers the mathematical model of the motor and the developing equations of the current follower and implementing the closed loop control system for speed control over a wide range of operations. The simulation results for each controller are obtained separately for comparison. The results obtained show that the FUZZY Logic Controller implemented has smooth waveforms in comparison with the PI controller.

Appendix

Table-1. BLDC motor parameters.

Motor Rating	3 HP
Voltage	380 v
Rated Speed	3000rpm
Phase resistance	0.2 Ω
Phase inductance	8.5mH
Number of pole pairs	4
Back EMF	Trapezoidal

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