TRACK VOLTAGE APPROACH USING CONVENTIONAL PI AND FUZZY LOGIC CONTROLLER FOR PERFORMANCE COMPARISON OF BLDC MOTOR DRIVE SYSTEM FED BY CUK CONVERTER

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ABSTRACT

This research paper deals with speed control of a BrushLess DC motor (BLDC) drive system as a cost-effective solution for low-power applications. The speed of the BLDC motor is controlled by varying the dc-bus voltage of a Voltage Source Inverter (VSI), where a DC-DC converter using CUK configuration is employed. The DC link voltage is controlled in closed loop using voltage follower approach, where the output of CUK converter is controlled by using a reference voltage proportional to desired speed through variable duty ratio control of the power MOSFET switch. Here, two alternate controllers viz. PI and Fuzzy Logic controllers are utilized for generating trigger signals for gate triggering of the power MOSFET switch and the performance are compared. The performance of the entire proposed drive system is simulated for both controllers in MATLAB/SIMULINK environment covering operation over a wide range of reference speed.

Keywords: BLDC motor, CUK Converter, Fuzzy Logic controller, PI Controller, Track Voltage Approach.

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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 [1] are the best choice in many applications. The construction and control architecture are also well suited for safe operation in critical applications. 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 higher range of speed. In automobile industry, high demand for efficient permanent magnet motors motivated the development of BLDC motor drives and their controllers. Similarly, in aerospace applications, where space and weight are important. Quick speed response due to the higher ratio of developed torque to inertia of the BLDC motor is an added advantage.

As far as the construction of the brushless DC motor is concerned, it follows an inside out construction where the rotating element carries permanent magnets [2]. Here instead of mechanical commutator, electronically switched commutation is employed through Hall sensors and power electronic based switching circuits [7], [9] in the stator supply. This also facilitates introduction of various control techniques through feedback controllers for frequency and voltage variations. The motor possesses linear characteristics between current and torque and also voltage and speed.

NOMENCLATURE
Van, Vbn, Vcn : Phase voltages in a,b,c Volts
ia, ib, ic : Phase currents in a,b,c, Amps
ea, eb, ec : back-EMF’s in a,b,c, Volts
R : Stator resistance per phase in Ω
L : Stator self inductance, H
M : Stator mutual inductance, H
Te : Electromagnetic Torque, N-m
TL : Motor’s Load torque, N-m
B : Motor’s coefficient of viscous friction, N-m/rad/sec
J : moment of inertia of rotor shaft and load, kg-m²
ω : Angular speed of rotor, rad/sec.

2. MODELLING OF BLDC DRIVE SYSTEM
The circuit equivalent of the BLDC motor is shown in Fig. 1. The back-EMF waveforms are trapezoidal in nature, while current waveforms are rectangular in shape. Assuming stator windings parameters being same in all the phases and the self and mutual inductances remains constant. The corresponding voltage equations for all the three phases can be written as shown in (1) in matrix form.

![Fig. 1. BLDC motor equivalent Circuit.](attachment://bldc_circuit.png)
The electromagnetic torque produced in BLDC motor is due to interaction of stator winding current and rotor magnetic field and instantaneous torque is as shown in (2)

\[ Te = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega} \]  

(2)

The torque-balance equation of the rotor is shown in equation (3).

\[ \frac{d\omega}{dt} = \frac{Te - TL - B\omega}{J} \]  

(3)

3. CONTROL OF BLDC DRIVE SYSTEM

The entire BLDC motor drive system consisting of DC-DC converter, DC-AC converter (Inverter), Hall sensor, controller and BLDC motor as shown in Fig. 2. Rotor position feedback is required at each 60 degrees electrical for phase current commutation of six-steps in the entire drive system.

![Fig. 2. BLDC drive system Components.](image)

The position of the rotor and switching sequence of the stator coils must be consistent for production of the unidirectional torque. This is achieved by Hall sensors which sense the instantaneous rotor field magnets 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 [3], [4], it is necessary to introduce a variable DC link voltage and the same is implemented using a DC-DC CUK converter [8], [9]. is employed. This control is provided for the six-pulse inverter 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. VOLTAGE FOLLOWER METHOD

As mentioned earlier, implementation of voltage follower method is done by two alternate controllers as follows.

- PI controller.
- FUZZY logic controller.

**Voltage Follower Approach using PI controller**

The reference voltage generated is compared with the voltage generated from the dc link capacitor and obtained error will be fed to the PI controller. The PI controller output signal
will be compared with the saw tooth carrier waveforms for generating the PWM pulses for gate triggering of the 6-pulse inverter is shown in Fig. 3.

**Fig. 3.** Voltage follower approach using PI controller

The BLDC motor MATLAB/SIMULINK model driven by a three phase six-pulse inverter which is fed by CUK converter [6]. using PI controller is shown in Fig. 4. The BLDC motor parameters shown in TABLE I is dealt.

**Fig. 4.** Schematic of BLDC Motor Drive system incorporating Voltage Follower Approach using PI controller

The schematic shown in Fig. 5, consists of PI controller and saw tooth generator. In the voltage follower method, reference voltage is generated corresponding to reference speed. The comparison is made between the reference voltage with the actual dc link voltage. The error signal generated is processed by the PI controller, for comparison with a 20 kHz saw tooth carrier signal, so as to generate PWM signals for the IGBT gates of the VSI as shown in Fig. 5.

**Fig. 5.** Schematic of PI controller

**Voltage Follower Approach using FUZZY controller**

The comparison is made between the reference voltage with the voltage generated from the dc link capacitor and obtained error will be fed to the FUZZY controller. The output signal of the FUZZY controller will be compared with the saw tooth carrier waveforms for generating the PWM pulses for gate triggering of the 6-pulse inverter is shown in Fig. 6.
Fig. 6. Schematic of BLDC Motor Drive system incorporating Voltage Follower Approach using FUZZY controller

The BLDC motor MATLAB/SIMULINK model driven by a three phase six-pulse inverter which is fed by CUK converter [6]. using FUZZY controller is shown in Fig. 7.

Fig. 7. Voltage follower approach using fuzzy controller

The schematic shown in Fig. 8. consist of FUZZY controller [5]. and saw tooth generator. In the voltage follower method, reference voltage is generated corresponding to reference speed. The comparison is made between the reference voltage with actual dc link voltage and an error signal is processed by the FUZZY controller, for comparison with a 20 kHz Saw tooth carrier signal, so as to generate PWM signals for the IGBT gates of the VSI.

Fig. 8. Schematic of FUZZY controller

5. SIMULATION RESULTS

Fig. 9. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 2000 RPM to 1500 RPM and its corresponding Backemf and current waveforms using PI controller.
Fig. 9. Rotor speed, Back EMF and Stator Current waveforms using PI controller

Fig. 10. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 1500 RPM to 1000 RPM and its corresponding Backemf and current waveforms using PI controller.

Fig. 11. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 1000 RPM to 500 RPM and its corresponding Backemf and current waveforms using PI controller.

Fig. 12. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 2000 RPM to 1500 RPM and its corresponding Backemf and current waveforms using FUZZY controller.
Fig. 12. Rotor speed, Back EMF and Stator Current waveforms using FUZZY controller

Fig. 13. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 1500 RPM to 1000 RPM and its corresponding Backemf and current waveforms using FUZZY controller.

Fig. 14. Shows the speed variation of the entire BLDCM drive system for a step change of reference speed from 1000 RPM to 500 RPM system and its corresponding Backemf and current waveforms using FUZZY controller.

Fig. 15. Shows the speed variation of the entire BLDCM drive system simulated waveform for the step change of reference speed for both the controllers viz PI controller and FUZZY controller. It can be observed that smoothness is obtained in actual speed following the reference speed, Backemf and current waveforms using FUZZY controller is far superior than PI controller in the BLDC motor drive system over the time period 2 seconds.
6. CONCLUSION

In this research paper, the entire drive system is simulated over duration of certain time period. Comparison is made on both controller viz. PI controller and FUZZY controller. This is done by analyzing various parameters in simulated waveforms of the entire drive system. Finally, these simulated results shows that the FUZZY controller has better performance and smoothness in waveforms in all aspects as compared to PI controller.

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**TABLE 1** BLDC motor Specifications

<table>
<thead>
<tr>
<th>Motor Rating</th>
<th>5 Horse Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>400 Volts</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>3000 Revolution Per Minute</td>
</tr>
<tr>
<td>Phase resistance</td>
<td>1.875 ohms</td>
</tr>
<tr>
<td>Phase Inductance</td>
<td>8.5 milli Henry</td>
</tr>
<tr>
<td>Number of pole pairs</td>
<td>2</td>
</tr>
<tr>
<td>Back EMF</td>
<td>Trapezoidal</td>
</tr>
</tbody>
</table>
REFERENCES


