FUZZY CONTROLLED BIPOLAR-STARTING AND UNIPOLAR-RUNNING CONVERTER FOR EXTENDED TORQUE-SPEED CHARACTERISTICS OF ELECTRIC VEHICLE

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ABSTRACT: In this paper a novel configuration to a low cost converter which make a spindle motor at lofty speed with high starting torque employing the bipolar starting and unipolar running algorithm is proposed. This topology is straightforward and developed with merely eight switches in the converter to drive the spindle motor at elevated speed with high starting torque. These motors are mainly used in electric vehicle (EV) applications because of its high speed and compact size. In order to read and write the enormous data with quick rate, the spin speed of spindle motor should be high with high starting torque. The proposed topology has been controlled with fuzzy controller and its performance is compared with conventional PI controlled drive. The proposed concept can be implemented with MATLAB/SIMULINK software, to verify the speed response with PI and Fuzzy logic controllers.

KEYWORDS: Bipolar and unipolar algorithm, EV Spindle Motor, Unipolar drive, Pi controller and Fuzzy logic controller.

INTRODUCTION

Brushless DC motor has the characteristic of simple structure, large torque, don't need to change phase based on the brush, and has long use time, good speed regulation. For the advantages mentioned above now electric vehicles and micro electric motor cars in the market mostly adopt BLDCM. The traditional BLDC controlling system requires hall sensor signals to drive the motor. When disturbance on the hall sensor exists, the wrong actions on the main circuit prompts the BLDCM action unsteady, the reliability of the whole controlling system is greatly reduced, also the cost of controller is increased. In recent years, some of these developments like Proportional-Integral (PI) controllers have been implemented for the speed control of B LDC motors. Numerous methods were proposed in literature [2]-[10] to accomplish high speed operation. High speed action could be attained by any of the four methods. The primary technique is to intend the electromagnets in such a way that, for a given system voltage the machine has low back emf with high speed [4]. But the shortcoming is that a low starting torque can be achieved with minimum back emf. With Parallel winding run to run and winding start the motor at far above the ground speed in this second method motor achieves huge starting torque In this [5], this needs added switching devices and extra complex control logic. And the third concept is to employ an advanced dc bus voltage, where a huge speed with massive starting torque with high speed operation can be reached. But this scheme has a difficulty that the switch voltage rating is to be improved and it requires a current protection to edge the current during low speeds. This also affixes cost and safety exposure to the system.

Apart from the exceeding three methods, the forth method is to employ a converter which can supply high speed with high starting torque. To acquire high speed BLDC motor should be operated in unipolar mode and to obtain high torque BLDC motor wants to be functioned in bipolar mode. In [2], a novel converter is planned which can realize 14 identical rating switches to get high starting torque with high speed. Downside of this circuit is, using frequent switches and gate drives.

A new inverter topology is present which uses only eight switches with bipolar operation to reach high torque during starting and unipolar operation afterward to achieve high speed in this paper. The proposed inverter is controlled by closed loop operation with pi and fuzzy logic controllers. When fuzzy used as the controller it reduces error value and change in error value between two signals but pi reduces only the error values. Compared to the pi controller, fuzzy controller effectively controls the proposed topology. This improves the speed response and the system efficiency.

PROPOSED INVERTER OPERATION

In predictable BLDC motor throughout bipolar procedure, at any time crossways DC bus, two phases approach in series. Simply half of the DC bus voltage is useful to each phase, resulting in accumulation of torque constant on both phases there by attaining high starting torque. But speed will be imperfect. To acquire higher speed, complete DC bus voltage is to be injected to each phase. Where each phase conducts only in single direction which in turn diminishes the starting torque, This can be accomplished in unipolar operation,. To get high motor speed and to get high torque motor should be operate in unipolar and bipolar modes. Based on speed obligation variable of modes between unipolar and bipolar operation is carried out. The proposed inverter consists of four legs. The three phases of BLDC motor is coupled to first three legs and neutral point is joined to the fourth leg as shown in Fig.1. In bipolar operation first three legs are lively and the fourth leg is inactive.

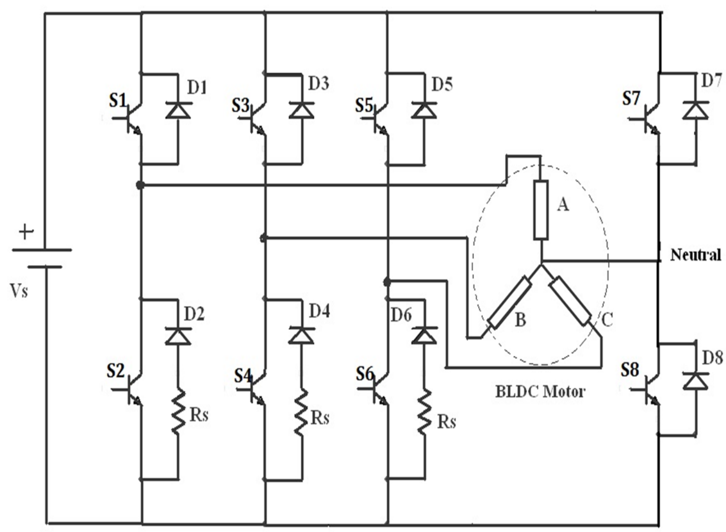

Figure 1. Proposed Inverter Circuit

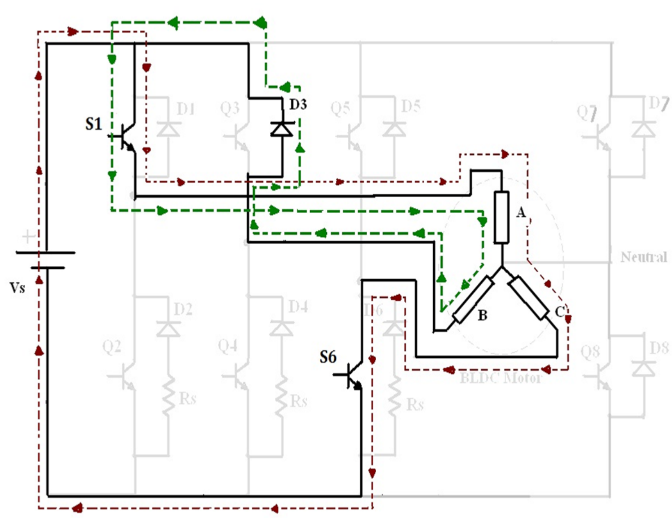

Figure 2. Negative conducting B Phase due to Free-wheeling

Phase-A conducts in optimistic direction in bipolar operation by switching on S4 and S1, and phase B conducts in negative direction by switching on-off S4 and S6, a bypass path is recognized through phase B, diode D3, switch S1 and Phase A as shown in Fig. 2.

Free-wheeling energy in positive conducting phase A floods through resistor R_s, D2, phase A, phase C, and S6, as shown in Fig. 3 by switching on S3,S6 and switching off S1. R_s. In negative conducting phase the free-wheeling energy totally converted into useful torque. Whereas in positive conducting phase the useful freewheeling energy is incompletely converted into useful torque, where as the remaining energy is dissipated in resistor Rs.

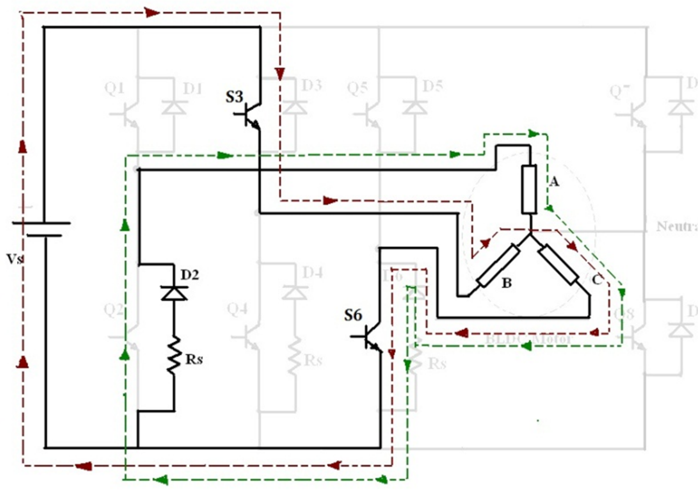

Figure 3. Positive conducting A phase on freewheeling action

In unipolar operation switch S8 is everlastingly closed so that S2, S4 and S6 are bypassed as shown in Fig. 4. Here by switching S1, phase A conducts in optimistic way. Phase B has negative back EMF and phase A is conducting in positive direction in unipolar operation which glides through diode D4 which in turn creates negative torque. This difficulty has been conquer in [2] by using six added switches in sequence along with the bypassing diodes. In proposed converter this setback is defeat by combining a huge value resistor R_s in succession along with the free-wheeling diode. Hence in association with [2] approximately the same presentation is achieved with lesser number of switches and gate drives with slightest convolution in control. So the drive is to be functioned in unipolar mode during running and bipolar mode throughout starting to get high speed and high starting torque.

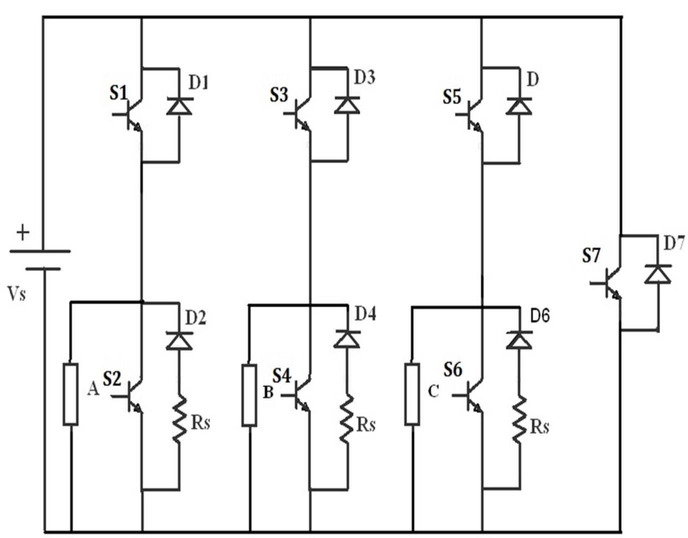

Figure 4. Proposed Inverter Circuit in Unipolar mode

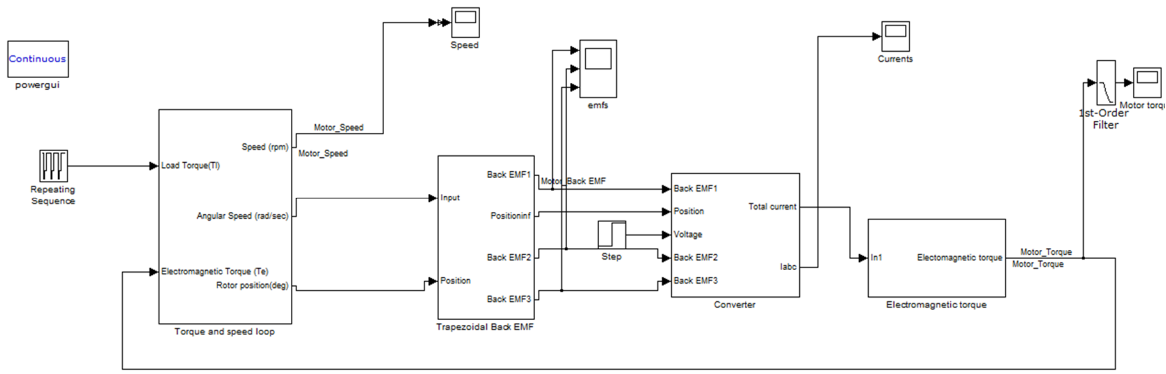

Figure 7. MatLab/Simulink representation of BLDC Motor

As the comparable inverter is being used for both unipolar and bipolar modes of operation, the current restriction is mandatory as the whole dc voltage is applied across only one winding in unipolar mode. In Fig. 5 and Fig. 6 the speed torque individuality of BLDC motor based on mathematical model with proposed converter topology process with current limitation with two diverse speeds are shown

Figure 5. Torque Speed Characteristic with current limitation

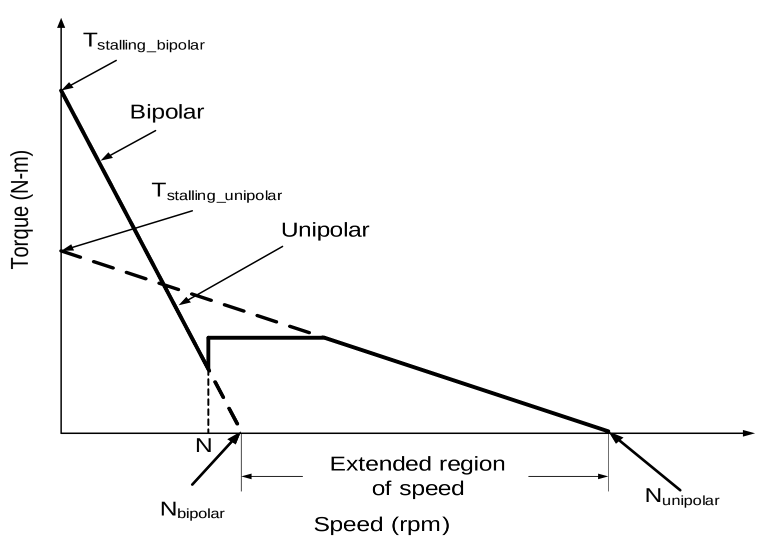

Figure 6. Torque Speed Characteristics with current limitation

SIMULATION RESULTS

Case 1: Open loop controlled BLDC drive with Bipolar and unipolar modes

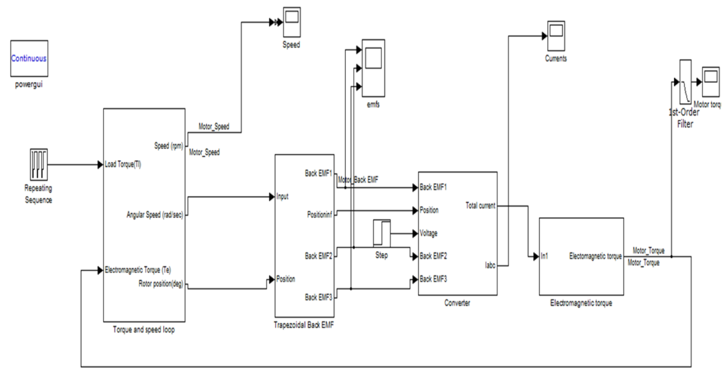

Figure 8. Matlab/Simulink model of BLDC drive with Unipolar and Biploar modes of operation

Figure 8 shows the BLDC drive controlled in open loop condition with Bipolar mode with 0 to 2secs and unipolar mode with 2sec to remaining time.

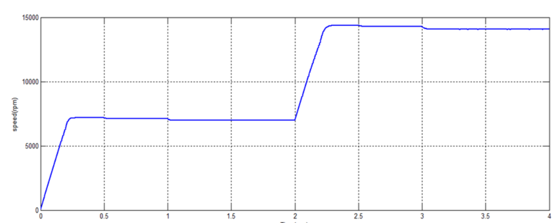

Figure 9. Simulated Output Speed characteristics of bldc motor

Figure 9 shows the BLDC drive speed controlled in open loop condition with Bipolar mode with 0 to 2secs and unipolar mode with 2sec to remaining time.

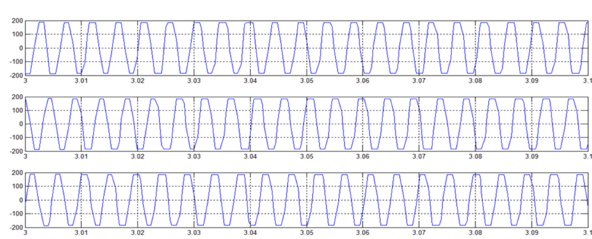

Figure 10. Simulated output Back emfs of bldc motor in Bipolar and unipolar modes of operation

Figure 10 shows the Back emfs of bldc motor with open loop controlled in Bipolar and unipolar modes of operation.

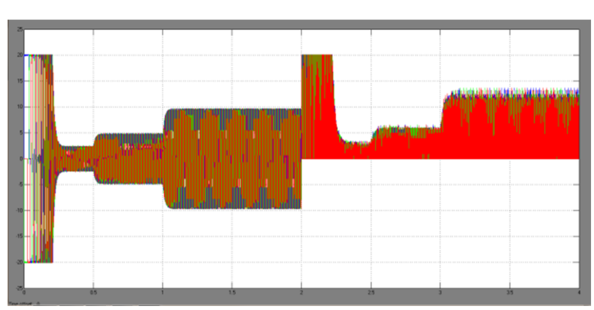

Figure 11. Simulated current wave form of bldc motor in Bipolar and unipolar modes of operation

Figure 11 shows the current of bldc motor with open loop controlled in Bipolar and unipolar modes of operation.

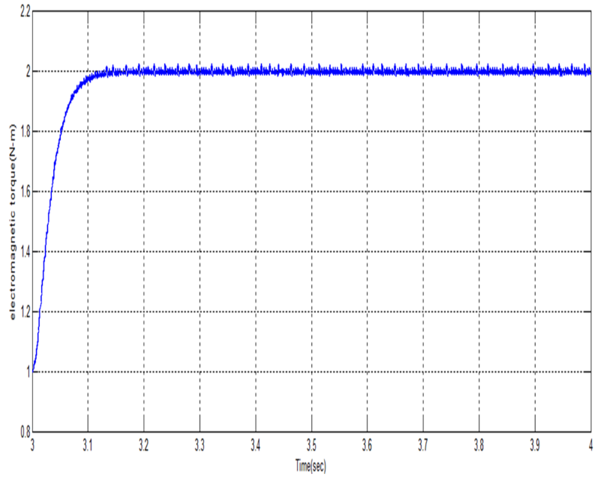

Figure 12. Simulated Electromagnetic torque wave form of BLDC motor in Bipolar and unipolar modes of operation

Figure 12 shows the Electromagnetic torque of bldc motor with open loop controlled in Bipolar and unipolar modes of operation.

Case 2: PI based Closed loop controlled BLDC with Bipolar mode.

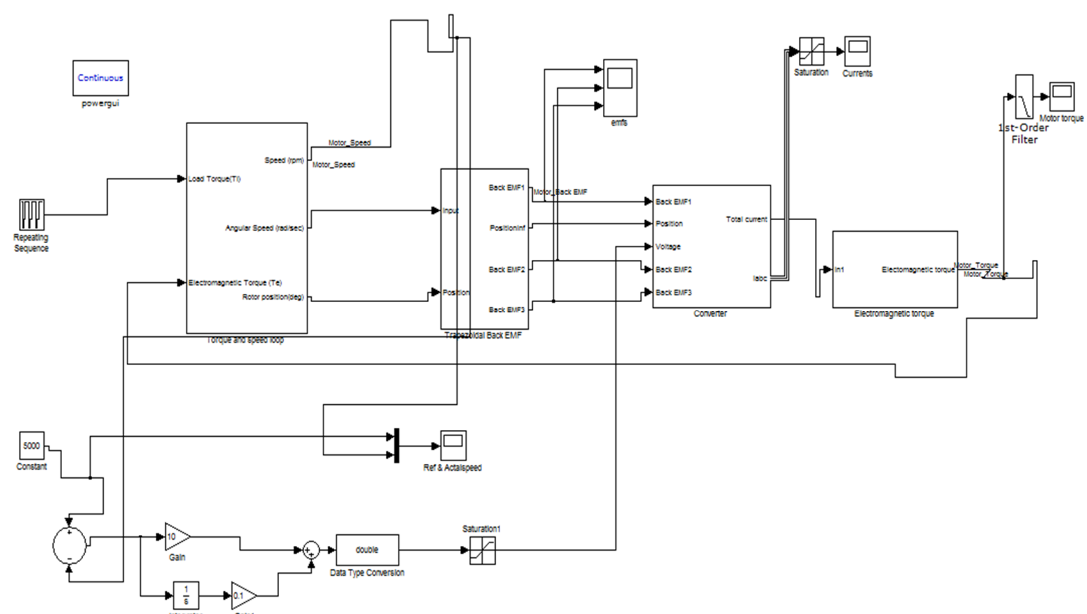

Figure 13. Simulated model of PI controlled BLDC drive in Bipolar mode

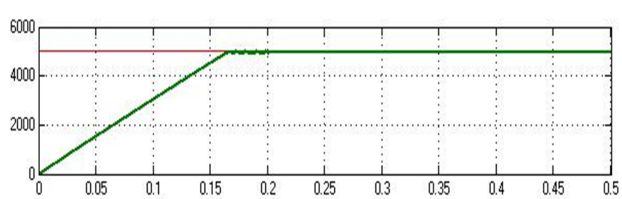

Figure 14. Simulated Speed wave form of PI controlled BLDC drive in Bipolar mode

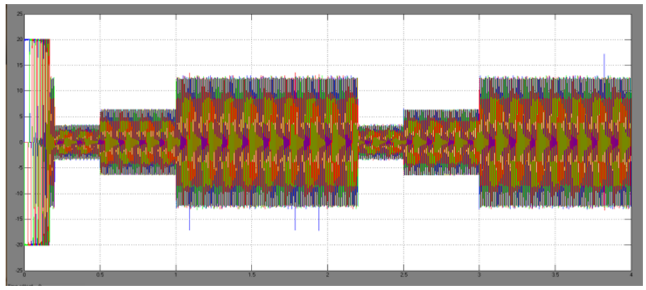

Figure 15. Simulated Current wave form of PI controlled BLDC drive in Bipolar mode

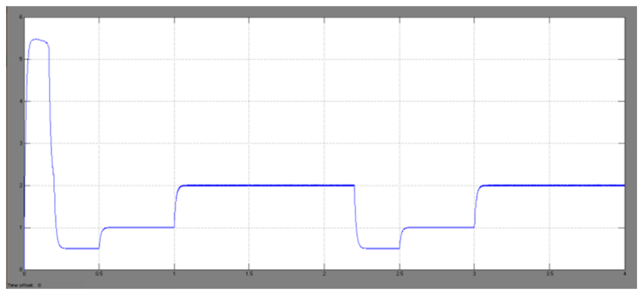

Figure 16. Simulated torque wave form of PI controlled BLDC drive in Bipolar mode

Case 3: PI based Closed loop controlled BLDC with Unipolar mode.

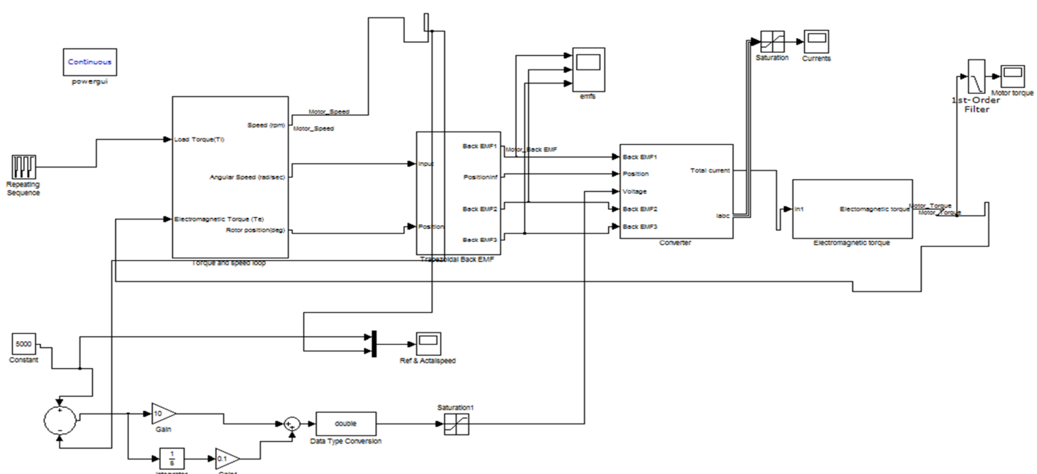

Figure 17. Simulated model of PI controlled BLDC drive in Unipolar mode

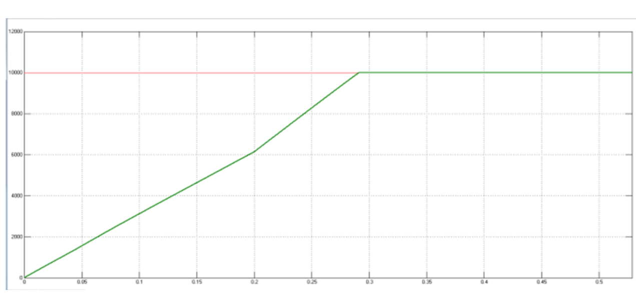

Figure 18. Simulated Speed wave form of PI controlled BLDC drive in Unipolar mode

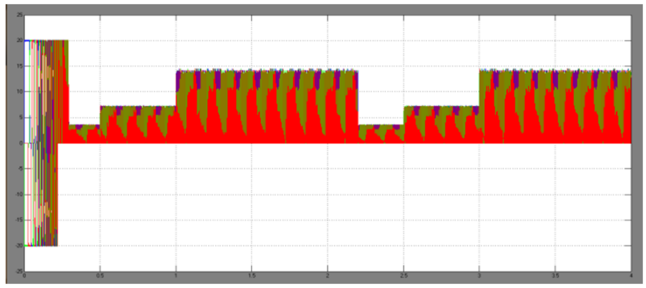

Figure 19. Simulated Current wave form of PI controlled BLDC drive in Unipolar mode

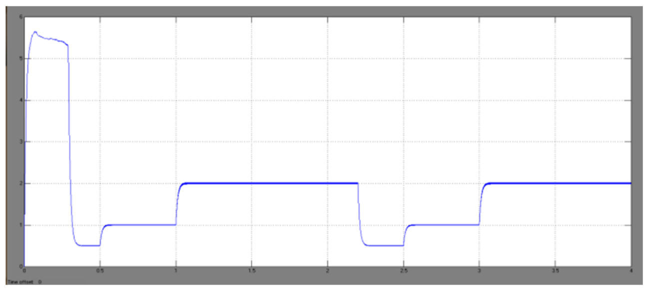

Figure 20. Simulated torque wave form of PI controlled BLDC drive in Unipolar mode

Case 4: FUZZY based Closed loop controlled BLDC with Bipolar mode.

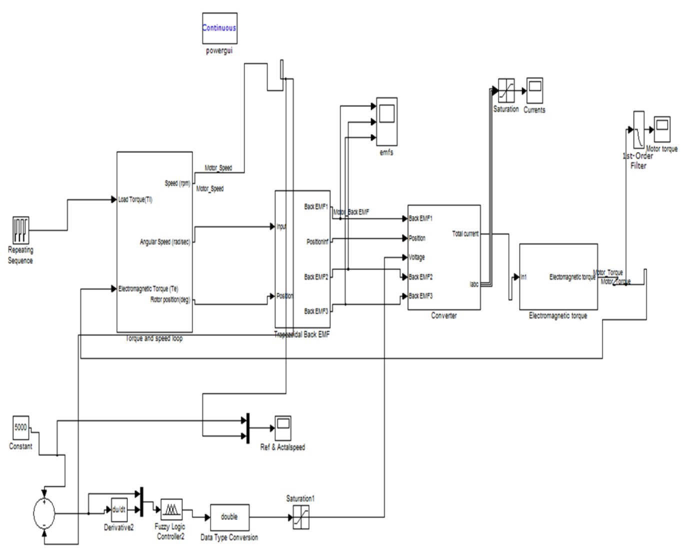

Figure 21. Simulated model of FUZZY controlled BLDC drive in Bipolar mode

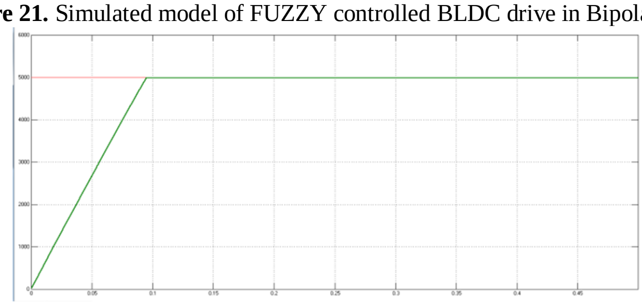

Figure 22. Simulated Speed wave form of FUZZY controlled BLDC drive in Bipolar mode

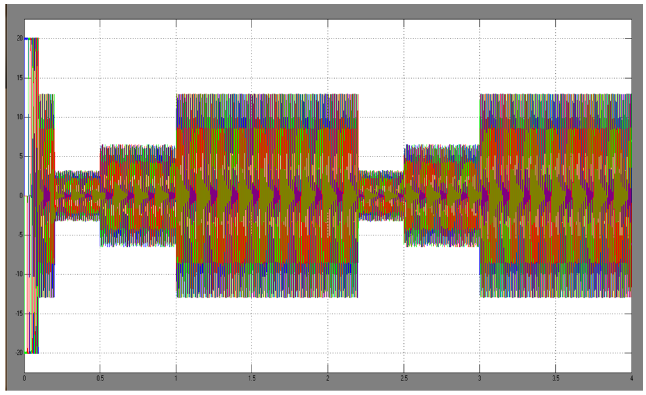

Figure 23. Simulated Current wave form of FUZZY controlled BLDC drive in Bipolar mode

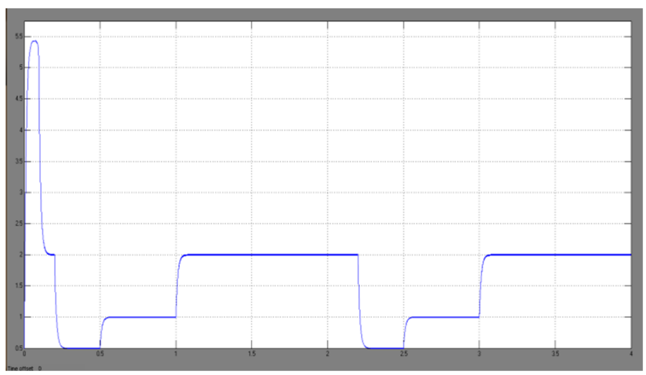

Figure 24. Simulated torque wave form of FUZZY controlled BLDC drive in Bipolar mode

Case 5: FUZZY based Closed loop controlled BLDC with Unipolar mode.

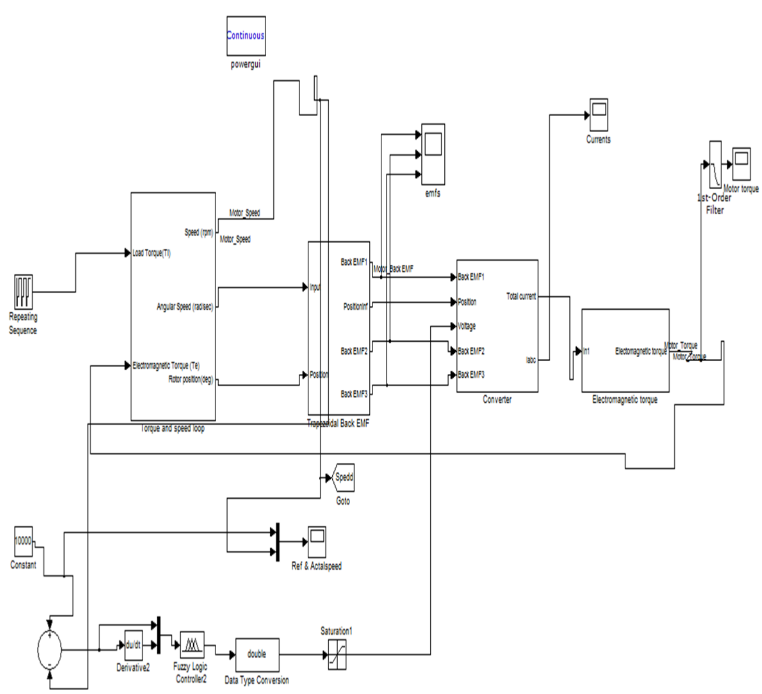

Figure 25. Simulated model of FUZZY controlled BLDC drive in Unipolar mode

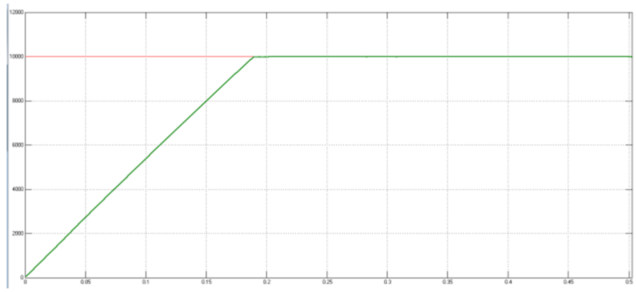

Figure 26. Simulated Speed wave form of FUZZY controlled BLDC drive in Unipolar mode

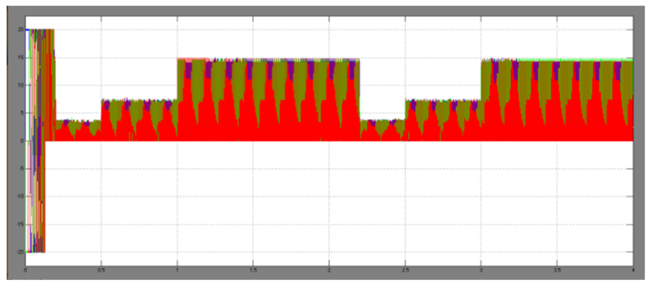

Figure 27. Simulated Current wave form of FUZZY controlled BLDC drive in Unipolar mode

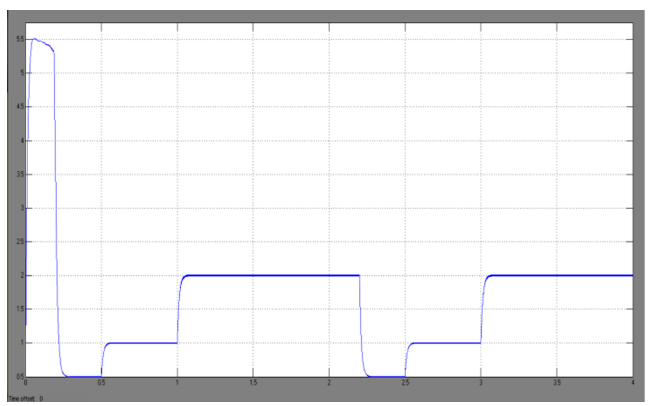

Figure 28. Simulated torque wave form of FUZZY controlled BLDC drive in Unipolar mode

Table 1. Comparison of Speeds to reach steady state in different modes of operation

Controller	Mode	Steady state time
PI	Bipolar	0.16 sec
Fuzzy	Bipolar	0.095 sec
PI	Unipolar	0.29 sec
Fuzzy	Unipolar	0.19 sec

CONCLUSION

Bipolar-starting and unipolar - running algorithm uses a BLDC motor at elevated speeds with high starting torque is presented in this. The proposed cost effectual inverter topology uses merely eight switches. The speed torque distinctiveness of spindle motor can be extensive to acquire high speeds with this little cost topology. This topology is top matched for short power drives, because a lofty power drive would need a elevated powered resistor Rs. The proposed BLDC motor is tested under PI and Fuzzy controllers in closed loop with Bi polar and unipolar modes of operations. In Bipolar mode of operation the current of motor will be in both positive and negative axes, but in unipolar mode of operation currents will be in only positive axes. Simulated results show that the best speed response of BLDC motor in bipolar mode of operation with fuzzy logic controller is 0.095sec and Unipolar mode of operation with fuzzy logic controller at 0.19sec.

APPENDIX

The following four equations in bipolar mode represent the three phase star connected BLDC motor

$$v_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \qquad (1)$$

$$v_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \qquad (2)$$

$$v_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + e_c - e_a \qquad (3)$$

$$T_e = B\omega_m + j\frac{d\omega_m}{dt} + T_L \qquad (4)$$

The symbol i, e and v specifies the phase currents, back EMF and phase to phase voltages correspondingly, in three phases a, b and c. R is the resistance and L is the inductance per phase values and electrical torque and the load torque are T_e and T_L respectively. Rotor inertia is J; B is a friction constant and ω_m is the rotor speed. The back EMF's and the electrical torque can be represented as

$$e_a = \frac{K_e}{2}\omega_m F(\theta_e) \qquad (5)$$

$$e_b = \frac{K_e}{2}\omega_m F(\theta_e - \frac{2\pi}{3}) \qquad (6)$$

$$e_c = \frac{K_e}{2}\omega_m F(\theta_e - \frac{4\pi}{3}) \qquad (7)$$

$$T_e = \frac{K_t}{2}\left[F(\theta_e)i_a + F(\theta_e - \frac{2\pi}{3})i_b + F(\theta_e - \frac{4\pi}{3})i_c\right] \qquad (8)$$

Where the back EMF and torque constants are K_e and K_t.

The function F(θ_e) provides the trapezoidal waveform of the back emf. solitary period of this waveform can be written as

$$\begin{aligned} F(\theta_e) &= 1 & & 0 \le \theta_e < \frac{2\pi}{3} \\ &= 1 - \frac{6}{\pi}\left(\theta_e - \frac{2\pi}{3}\right) & & \frac{2\pi}{3} \le \theta_e < \pi \\ &= -1 & & \pi \le \theta_e < \frac{5\pi}{3} \qquad (9) \\ &= -1 + \frac{6\pi}{3}\left(\theta_e - \frac{5\pi}{3}\right) & & \frac{5\pi}{3} \le \theta_e < 2\pi \end{aligned}$$

As phase currents are balanced,

$$i_a + i_b + i_c = 0 \qquad (10)$$

By eliminating one phase current variable i_c the two independent voltage equations can be written as

$$v_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \qquad (11)$$

$$v_{bc} = R(i_a + 2i_b) + L\frac{d}{dt}(i_a + 2i_b) + e_b - e_c \qquad (12)$$

For implementation in Matlab/Simulink, (11), (12) and (4) must be written in state space form.
In unipolar mode of operation, the BLDC motor can be represented by the subsequent equations.

$$v_{an} = Ri_a + L\frac{d}{dt}i_a + e_a \qquad (13)$$

$$v_{bn} = Ri_b + L\frac{d}{dt}i_b + e_b \qquad (14)$$

$$v_{cn} = Ri_c + L\frac{d}{dt}i_c + e_c \qquad (15)$$

$$T_e = B\omega_m + j\frac{d\omega_m}{dt} + T_L \qquad (16)$$

For implementation in Matlab/Simulink, (13)-(16) are also written in state space form.

REFERENCES

R. Civilian, and D. Stupak, "*Disk drive employing multi mode spindle drive system*," US patent 5471353, (Oct 3, 1995).

G.H. Jang and M.G. Kim, *"A Bipolar-Starting and Unipolar-Running Method to Drive an EV Spindle Motor at High Speed with Large Starting Torque*," *IEEE Transactions on Magnetics*, Vol. 41, no.2, pp. 750-755, (Feb. 2005).

E.Grochowski and R.F. Hyot,"*Future trends in Electric vechile*",IEEE Tran. On Magnetics,vol.32,no.3,pp1850-1854,(May 1996)

J.D.Ede, D.Howe and ,Z.Q.Zhu,"*Optimal split ratio control for high speed permanent magnet brushless DC motors*", in Proc.5th Int,Conf..Electrical Machines and Sytems',vol.2,(Aug 2001),pp 909-912

S.X.Chen, M.A.Jabbar, Z.J.Lie and O.D. Zhang,"*New Challenge: Electromagnetic design of BLDC motors for high speed fluid film bearing spindles used in hard disk drives*",IEEE Trans. Magnetics ,vol32,no.5, pp3854-3856,(Sep. 1996).

T.Kenzo and S. Nagamori, *Permanent Magnets and Brushless DC Motors*, Tokyo,Japan,Sogo Electronics,(1984).

J.R.Hendershot and Miller,"*Design of Brushless Permanent Magnet Motors*, Oxford Univ. Press,(1994)

S.W.Cameron."Method *and apparatus for starting a sensorless polyphase dc motors in dual coil mode and switching to single coil mode at speed"*, U.S.Patent 5455885,, (Nov.28,1995)

T.Gopalaratnam and H.A.Toliyat, "*A new topology for unipolar brushless dc motor drives*",. IEEE Trans Power Electronics, vol.18,No.6, pp 1397 1404,(Nov.2003)

Bhim Singh and Sanjeev Singh, "*State of art on permanent magnet brushless Dc motor Drives*", Journal of Power Electronics", vol.9 no.1 pp 1-17 (Jan.2009)

Maxon Precision Motors Inc., http://www.maxonmotor.com.