DTC Scheme for a Four-Switch Inverter-Fed PMBLDC Motor Emulating the Six-Switch Inverter Operation

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ABSTRACT

The paper deals with the direct torque control (DTC) of brushless DC (BLDC) motor drives fed by four-switch three phase inverters (FSTPI) rather than six-switch inverters (SSTPI) in conventional drives. For any three phase inverter require six switches, but these switches are reduced to four. This reduction of power switches from six to four improves the reliability of the inverter, size of the inverter is reduced and cost of the inverter is also reduces. The FSTPI could be regarded as a reconfigured topology of the SSTPI in case of a switch/leg failure which represents a crucial reliability benefit for many applications especially in electric and hybrid propulsion systems. The DTC of FSTPI-fed BLDC motor drives is treated considering two strategies, such as: 1) DTC-1: a strategy inspired from the one intended to SSTPI-fed BLDC motor drives; 2) DTC-2: a strategy that considers a dedicated vector selection subtable in order to independently control the torques developed by the phases connected to the FSTPI legs during their simultaneous conduction. The operational principle of the four-switch BLDC motor drive and the developed control scheme are theoretically analyzed and the performance is demonstrated by simulation.

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I. INTRODUCTION

Using of Permanent Magnet in electrical machines have so many benefits and advantages then electromagnetic excitation machines these are zero excitation losses result in high efficiency, simple construction, less maintenance requirement , low cost and high torque or high output power per unit volume . Due to high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless dc motor (BLDCM), good choice for high performance applications. Due to the absence of brushes and commutator there is no problem of mechanical wear of the moving parts [1], [2]. As well, better heat dissipation property and ability to operate at high speeds [3] make them superior to the conventional dc machine. However, the BLDC motor constitutes a more difficult problem than its brushed counterpart in terms of modeling and control system design due to its multi-input nature and coupled nonlinear dynamics. Due to the simplicity in their control, Permanent-magnet brushless dc motors are more accepted used in high-performance applications. In many applications, the production of ripple-free torque is of primary concern.

Electrical motors are the part of industry and every year worldwide nearly five billion motors built. This cause the reason for need of low-cost brushless dc motors drives industrial applications [4]. Use of digital control concept is one method because cost of digital control is decreasing day by day. There are two different methods of implementing digital controller one is current mode control and second one is conduction angle control [5]. A zero-voltage- and zero-current-switching full-bridge (FB) converter with secondary resonance is another method in this primary side of the converter have FB insulated-gate bipolar transistors, which are driven by phase-shift control and secondary side is composed of a resonant tank and a half-wave rectifier [6]. Without an auxiliary circuit, zero-voltage switching and zero-current switching are achieved in the entire operating range. In this without using additional inductor, the leakage inductance of the transformer is utilized as the resonant inductor. It has many advantages, including high efficiency, minimum and number of devices this topology is attractive for high-voltage and high-power applications.

For closed loop speed control operation, in current control loop, three phase stator current information is required. The current sensors and the associated accessories increase the complexity of the system, cost and size of the motor drives and decrease the reliability of the system and also more number of power electronics switches means more switching losses and costly. Therefore to overcome this problem a new drive system is proposed which uses four switches and two current sensor, less switches and less current sensors means less switching losses and low cost.

This paper deals with an application of closed speed control of a PMBLDCM Drive using FSTIP. The performance of the proposed drive is very better with less torque ripple, smooth speed control, less voltage stress and low Current THD. Another advantage of this method is that due to two sources reliability of the system increases.

II. PMBLDC Motor Drive Strategies

Fig. 1 shows the general BLDC drive system fed by inverter. Fig. 2 shows the trapezoidal back EMF and corresponding currents for operation of BLDC drive system. For getting constant output power, current is fed through the motor at flat portion of the back EMF as shown in fig. 2. Using digital control each phase of motor is energized according to those sequences. Therefore the position of rotor is important for driving the motor. Here for sensing position of rotor hall sensors are used. The desired current profile is achieved by proper switching of voltage source inverter.

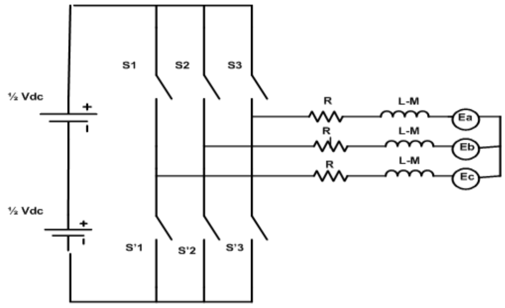

Fig. 1 BLDC Motor Drive System

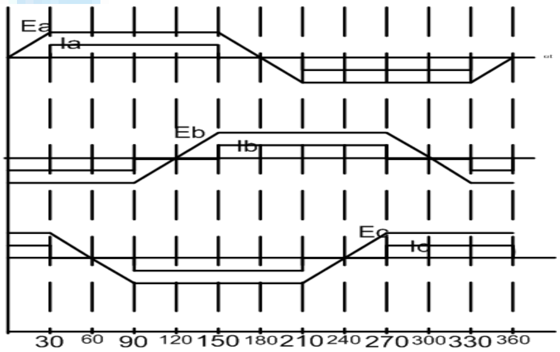

Fig.2 BLDC Motor back emf and the motor phase currents

Fig. 3 shows the closed loop speed control of conventional SSTPI fed BLDC drive system using hysteresis current control scheme, in this we required three hysteresis current controller and we have to sense stator currents for this three current sensors are required. This method has following drawbacks, current sensors are bulky, heavy, expensive, and torque fluctuations is due to differences in current sensor sensitivities.

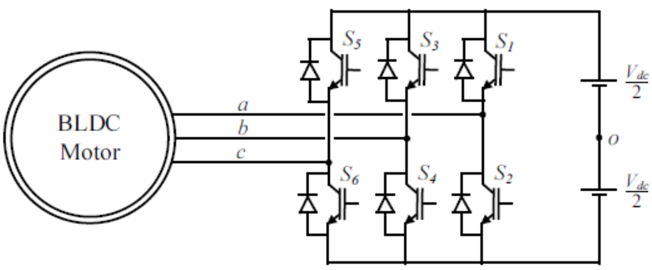

Fig. 3. SSTPI fed BLDC motor drive connections

Fig.4 shows the proposed schematic diagram of closed loop speed control of FSTPI fed PMBLDCM drive with split DC source. The advantage of this schematic is, in this two current sensors and four power electronic switches are used means low cost and less switching losses and the performance of the drive is improved i.e., reduced torque ripple, less voltage stress and fast dynamic performance of PMBLDCM drive.

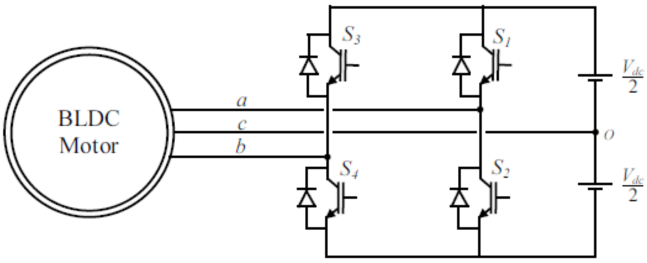

Fig. 4. FSTPI fed BLDC motor drive connections.

III. Proposed FSTPI BLDC Motor Drive

Fig. 5 shows the schematic diagram of FSTPI fed PMBLDC drive. Here actual motor speed is compared with the reference speed of the motor which gives speed error and it is fed to the Proportional integral controller, which gives the ref. torque signal, this ref. torque signal is compared with the actual motor torque, which gives the reference magnitude of currents, which is compared with the stator current, this error signal is fed to hysteresis controller to produce gate pulses to the two leg inverter to control the output voltage.

The main parts of the proposed drive are the two leg inverter , PMBLDCM drive, outer speed control loop and inner torque control loop and hysteresis controller which are modeled by mathematical equations and combing of thse equations represents the complete model of two leg inverter fed PMBLDC drive with two input DC source for closed loop speed control.

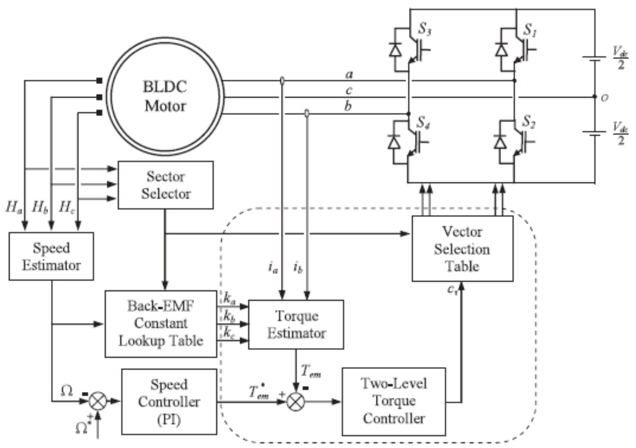

Fig. 5. Implementation scheme of a DTC strategy of FSTPI-fed BLDC motor drives inspired from the one considering the case where the BLDC motor is fed by a SSTPI-inverter.

A. Speed controller

Speed of the motor is compared with actual speed of the motor and is feed to PI controller ,which gives reference torque signal. The output of the PI controller at kth instant is reference torqueTr (n) is given as,

$$Tr(n) = T(n-1) + Kpsc[\omega e(n) - \omega e(n-1)] + Kisc\ \omega e(n) \quad (1)$$

Where Kpsc and Kisc are the proportional and integral gains of the speed controller.

B. Reference current signal (Iref)

Reference current signal is generated when it is multiplied with torque constant Kte , is given as

$$Iref=Kte*Tr \quad (2)$$

C. Hysteresis controller

Hysteresis current is generated by comparing Iref current with the actual motor phase current, this current is feed to hysteresis controller to generate gate pulse for DC source switch and for two leg inverter switches

D. Two leg inverter

Two leg inverter consist of four power electronic switches SW1, SW2, SW1' and SW2'. Two phases are taken from the inverter legs, where as the third phase output is taken from the midpoint of the two capacitors. Van, Vbn and Vcn are the terminal voltages of BLDCM which can be expressed as the function of the ststes of the power electronics switches as

$$V_{an} = \frac{V_{dc}}{3}(4SW1 - 2SW2 - 1) \quad (3)$$
$$V_{bn} = \frac{V_{dc}}{3}(-2SW1 + 4SW2 - 1) \quad (4)$$
$$V_{cn} = \frac{V_{dc}}{3}(-2SW1 - 2SW2 + 2) \quad (5)$$

Above equations s can be written in matrix form as

$$\begin{bmatrix} V_{an} \\ v_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3}\begin{bmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{bmatrix}\begin{bmatrix} SW1 \\ SW2 \end{bmatrix} + \frac{V_{dc}}{3}\begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix} \quad (6)$$

Table I shows the modes of operation of two leg inverter fed BLDCM and output voltgae

Table I: Modes of operation switching states and output phase voltage

Switching sequence		Output phase voltages		
SW1	SW2	V_{an}	V_{bn}	V_{cn}
0	0	$-\frac{V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$\frac{2V_{dc}}{3}$
0	1	$-V_{dc}$	V_{dc}	0
1	0	V_{dc}	$-V_{dc}$	0
1	1	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$-\frac{2V_{dc}}{3}$

E. PMBLDCM drive

The PMBLDCM motor is modelled by using set of differential equations given as

$$\frac{di_p}{dt} = (v_p - i_p R_a - E_p)/(L_s + M) \quad (7)$$

Where p =a,b,c phases

$$\frac{d\omega_r}{dt} = \left(\frac{P}{2}\right)(T_m - T_l)/J \quad (8)$$

Otor back emf is expressed as a function of position (θ) as

$$E_p = k_b f_p(\theta)\omega_r \quad (9)$$

$f_p(\theta)$ represents the function of rotor position with the maximum value of ±1 , which is similler to trapezoidal induced emf and is given as

$$f_p(\theta)=1 \quad \text{for } 0<\theta<2\pi/3 \quad (10)$$

$$f_p(\theta)= \left(\frac{6}{\pi}\right)(\pi - \theta) - 1 \quad \text{for } 2\pi/3< \theta<\pi \quad (11)$$

$$f_p(\theta)= -1 \quad \text{for } \pi< \theta<5\pi/3 \quad (12)$$

$$f_p(\theta)= \left(\frac{6}{\pi}\right)(\theta - 2\pi) + 1 \quad \text{for } 5\pi/3< \theta<2\pi \quad (13)$$

Function for phase a and phase b is obtained with a phase difference of 120^0 and 240^0 repectively.

Electromegnetic torque equation given as

$$T_m = K_b(f_a(\theta)i_a + f_b(\theta)i_b + f_c(\theta)i_c) \quad (14)$$

IV. Simulation Results

To evaluate the performance of the proposed PMBLDCM drive system, simulation models have been developed and the simulation is carried out using MATLAB/ SIMULINK. Fig. 6 shows MATLAB/SIMULINK model of closed loop speed control of PMBLDCM drive using FSTPI. The performance of the drive is simulated for constant rated torque (10 Nm) at rated speed.

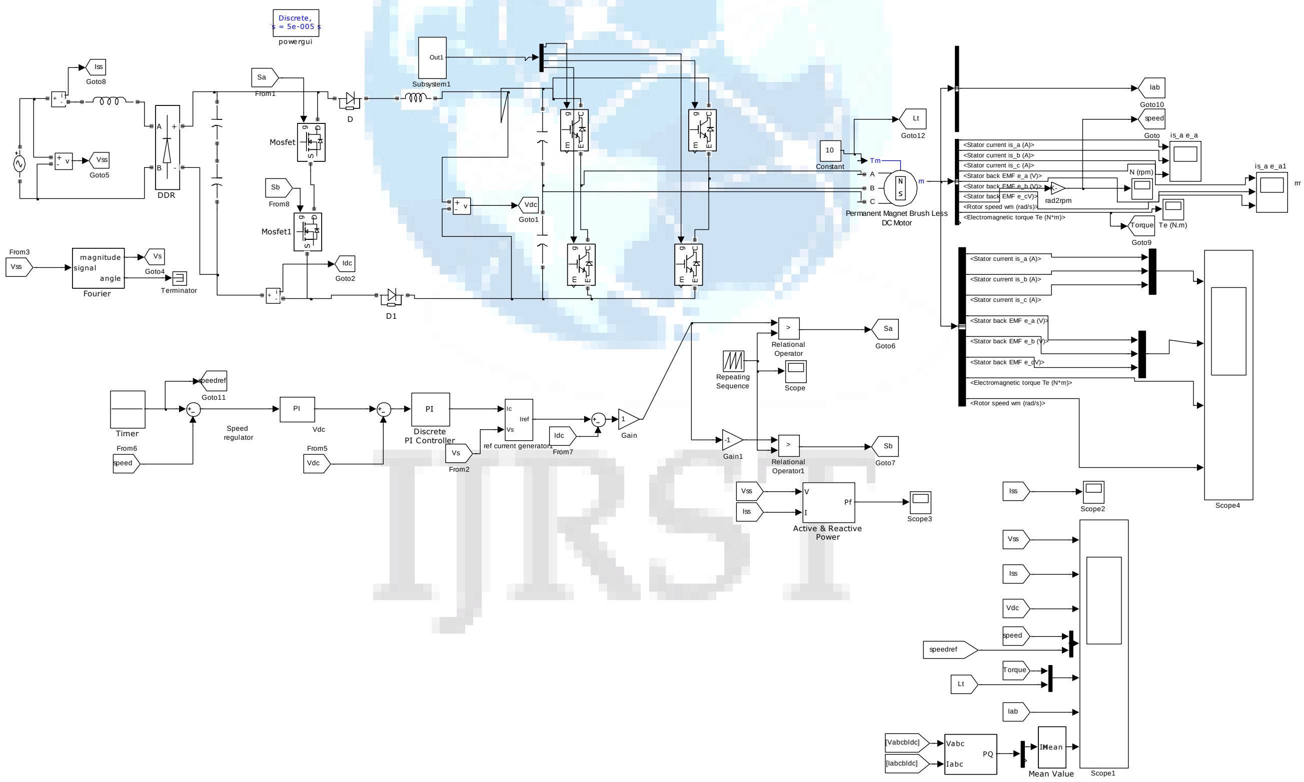

Fig. 6 Proposed Four Switch Three Phase Inverter fed BLDC Motor Drive

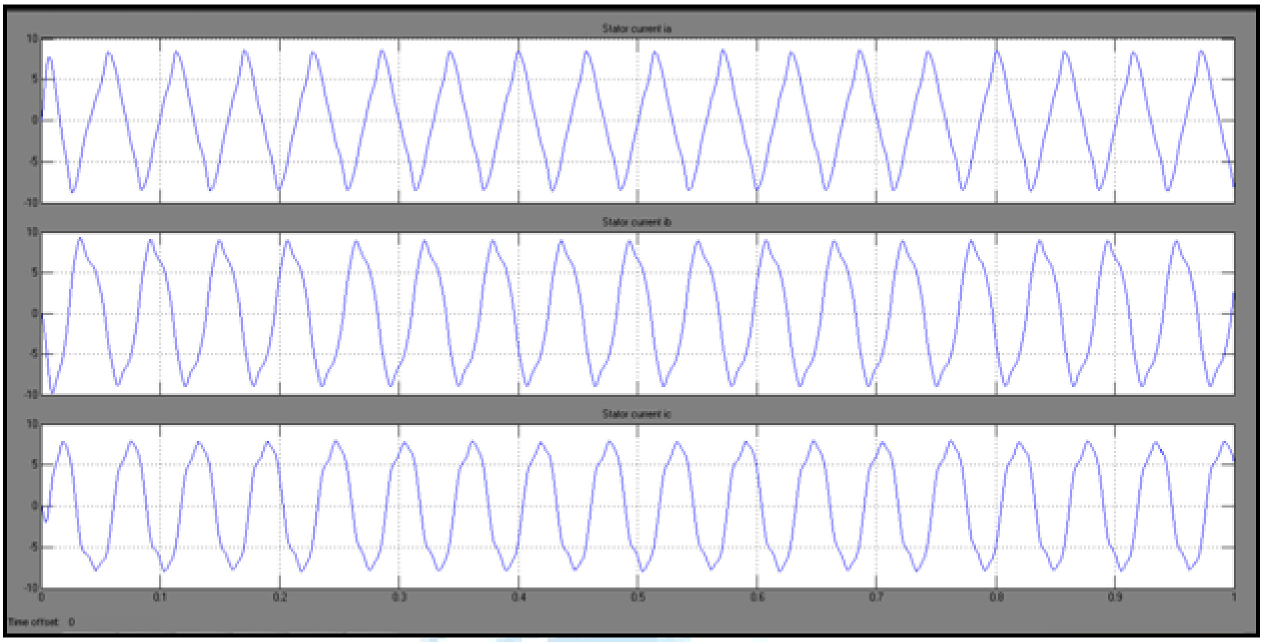

Fig.7.Stator Three Phase Currents

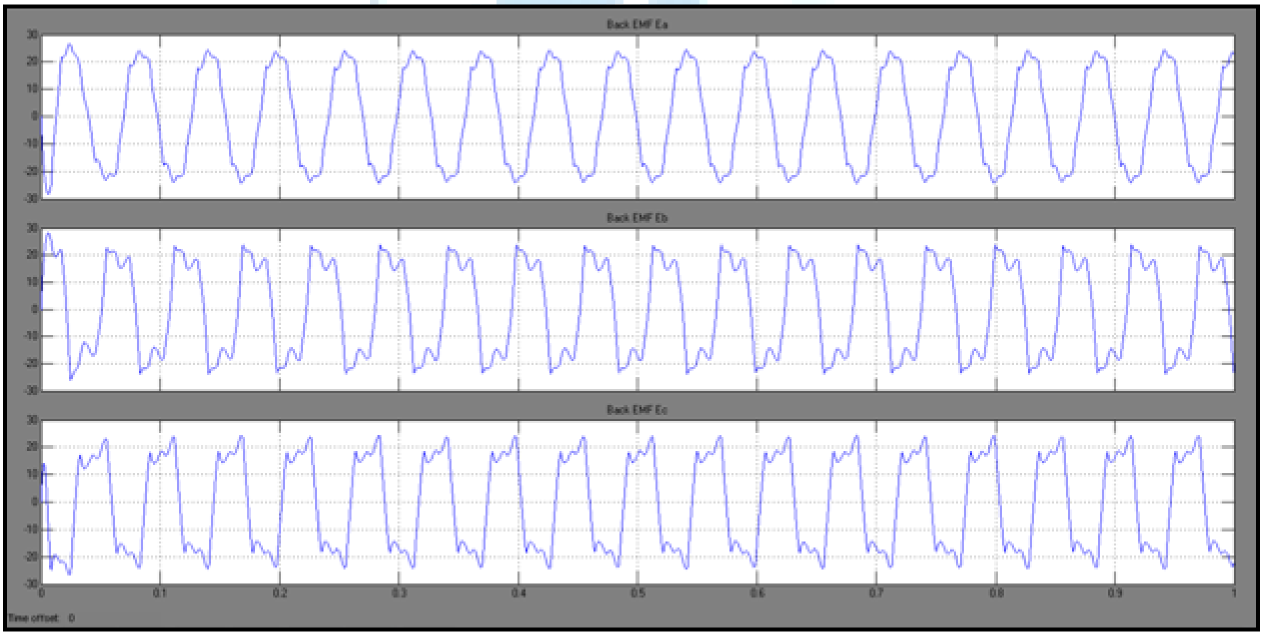

Fig.8.Back emf waveforms of the three phases.

V. CONCLUSION

The usage of BLDCM enhances various performance factors ranging from higher efficiency, higher torque, high power density, low maintenance and less noise than conventional motors. The main drawback is high cost. To reduce the cost and to get better performance of the drive, In this paper a FSTPI fed BLDCM drive is proposed which uses only four switches and two current sensors compared with six switches and three current sensors in case of SSTPIr BLDCM drive. Less number of switches and current sensors means, less switching loss and low cost. In this paper a two leg inverter fed BLDCM drive with split DC source is proposed. This proposed method is a simple, low cost and enhanced performance of dive is obtained i.e., reduced torque ripple, less voltage stress, Low current THD and fast dynamic performance of PMBLDCM drive. In case failure of one dc source, the drive will operate, and stoppage of work can be avoided in industrial applications i.e reliability of the drive increases.

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