SENSORLESS CONTROL OF FOUR SWITCH INVERTER PERMANENT MAGNET BRUSHLESS DC MOTOR

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Abstract : The main purpose of this paper is to develop low cost four-switch brushless dc (BLDC) motor drives for practical industrial applications. Permanent Magnet Brushless DC (PMBLDC) machines are more popular due to its simple structure and low cost. Cost reduction in BLDC motor drives can be achieved by two methods, one is topological approach and second is control approach. In the topological approach, the number of switches, sensors and associated circuitry is minimized.

Normally for the BLDC Motor drive six switches inverter topology is used. By reducing the no of switches the cost reduction can be achieved. Moreover switching and conduction losses can be reduced. The simulation of sensor less control of drive is done in Matlab/Simulink. Control with sensor, the controller is used Fuzzy logic Controller and in sensor less control the method is used terminal voltage sensing.

***IndexTerms* BLDC Motor, VSI Topology,Sensorless Control**

I. INTRODUCTION

Because of the distinct advantages of high efficiency, high power density and minimal maintenance, the Permanent Magnet (PM) Brushless DC machine is becoming increasingly attractive for industrial and electric vehicle (EV) applications. A brushless DC motor (BLDC) is a synchronous electric motor which is powered by direct current electricity (DC) and has an electronically controlled commutation system; instead of a mechanical commutation system with brushes. It has all the good advantage of DC drives and eliminating the drawbacks using electronic commutation. So in this motor current and torque, voltage and rpm are related linearly. Normally from the Hall Effect sensor, the signal for commutation is generated. But using these sensors the size of the BLDC motor will become larger and when space will be a main constraint, BLDC motor fails to meet the same. BLDC Motors are extensively used in domestic and automobile industries. The market is too competitive so cost reduction and higher performance will be the prime importance. Cost reduction in BLDC motor drives can be achieved by two methods one topological approach and second control approach. In the topological approach, the number of switches, sensors and associated circuitry used to compose the power converter is minimized. Normally for the BLDC Motor drive six switches inverter topology is used. By reducing the no of switches the cost reduction can be achieved. Moreover switching and conduction losses can be reduced. So here Four Switch VSI(FSVSI) topology is attempted. By using the Sensor less control the cost of the For extensive system testing and evaluation program, detailed computer modelling and simulation is being developed. Modeling of the PMBLDC machine and the controller are essential for evaluating their performance. Each of the simulators allows setting of the input parameters of the drive as well as the setup of certain load torque and speed profiles in order to evaluate the drives.
The simulation of sensor less control of drive is done in Matlab/Simulink. Control with sensor, the controller is used Fuzzy logic Controller and in sensor less control the method is used terminal voltage sensing.

II. FOUR SWITCH FED BLDC MOTORS

However, these days, the BLDC motor is attracting much interest, due to its high efficiency, high power factor, high torque, simple control, and lower maintenance. With those advantages, we have been investigating the possibility of the reduced converter for BLDC motor drives with advanced control techniques. As a result, we found that one switch leg (two switches) in the conventional six-switch converter, asshown in Fig. 3.1, is redundant to drive the three-phase BLDC motor. It results in the possibility of the four-switch configuration instead of the six switches as shown in Fig.2.1 in order to use the four-switch converter topology for the three-phase BLDC motor drive, a new control scheme should be developed.

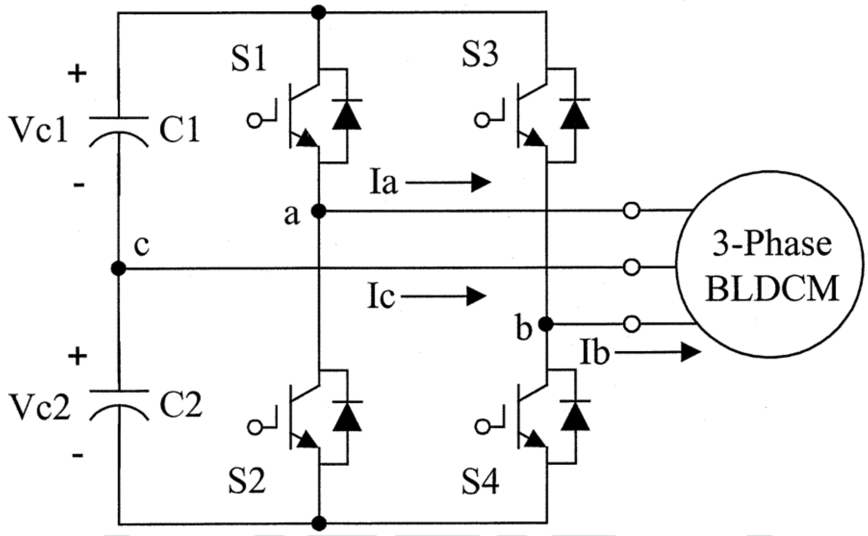

Figure:2.1 Four switch configuration

A brushless DC motor (BLDC) is a synchronous electric motor which is powered by direct current electricity (DC) and has an electronically controlled commutation system; instead of a mechanical commutation system with brushes. It has all the good advantage of DC drives and eliminating the drawbacks using electronic commutation. So in this motor current and torque, voltage and rpm are related linearly. Normally from the Hall Effect sensor, the signal for commutation is generated. But using these sensors the size of the BLDC motor will become larger and when space will be a main constraint, BLDC motor fails to meet the same. BLDC Motors are extensively used in domestic and automobile industries The market is too competitive so cost reduction and higher performance will be the prime importance. Cost reduction in BLDC motor drives can be achieved by two methods one topological approach and second control approach. In the topological approach, the number of switches, sensors and associated circuitry used to compose the power converter is minimized. Normally for the BLDC Motor drive six switches inverter topology is used. By reducing the no of switches the cost reduction can be achieved. Moreover switching and conduction losses can be reduced. So here Four Switch VSI (FSVSI) topology is attempted. By using the Sensor less control the cost of the sensors are also eliminated.

III. ANALYSIS OF THREE-PHASE BLDC MOTOR DRIVE

The analysis is based on the following assumption

1) The motor is not saturated

2) Stator resistances of all the windings are equal and self and mutual inductances are constant.

3) Power semiconductor devices in the inverter are ideal.

4) Iron losses are negligible. Under the above assumptions, a BLDC motor can be represented as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} --- (1)$$

where e_a, e_b, and e_c, are trapezoidal shaped back Emf**.** The electromagnetic torque is expressed as

$$T_{em} = \frac{1}{\omega_r}(e_a i_a + e_b i_b + e_c i_c) --- (2)$$

And, the interaction of T_{em}**,** with the load torque determines how the motor speed builds up:

$$T_{em} = B\omega(t) + J\frac{d\omega(t)}{dt} + T_L - - - (3)$$

Based on the equivalent circuit of Fig. 1.3**,** the system equations can be expressed by using Laplace transform as

$$V_t(s) = E_a(s) + (R_a + sL_a)I_a(s)$$

$$E_a(s)= k_e\omega_r(s)$$

$$T_e(s)= k_tI_a(s)$$

$$T_e(s)=T_L(s)+(B+sJ)\omega_r(s)$$

From (4), superposition principle yields

$$\omega_r = \frac{k_t}{(R_a + sL_a)(sJ + B)k_tk_e} - \frac{R_a + sL_a}{(R_a + sL_a)(sJ + B)k_tk_e}T_L(s) - - - -(4)$$

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IV. TRANSFER FUNCTION MODEL OF BLDC MOTOR

The permanent magnet brushlessmotors and their control drives are penetrating into themarket of home appliances, high voltage alternating current industry and automotive applications in recent years. They arecharacterised with high efficiency, noiseless operation, compact form, reliability and low maintenance**.** However PMBLDCmotors areunstable in their operation due to the significant variation in their mechanical load. The dynamics of the machine are described by a set of differential equations.

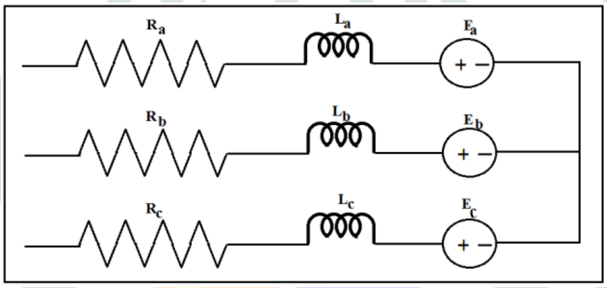

Figure 4.1 Equivalent circuit of PMBLDC

To attain the electrical equations for a BLDC machine, basic circuit analysis was used to find the per-phase voltage as shown below. The equation is only shown for phase-A to neutral since the equations for phase B and C only differ in the subscript notation.

$$V_{an} = i_a(t)R_a + L_a\frac{di_a}{dt} + e_a(t) - - - (5)$$

$$T_{em} = B\omega(t) + J\frac{d\omega(t)}{dt} + T_{L---(6)}$$

$$i_a(s) = \frac{V_{an}(s) - K_e\omega(s)}{R_a + sL_a} - - - (7)$$

$$\omega(s) = \frac{T_{em}(s) - T_L}{B + sJ}$$

$$\frac{\omega(s)}{V(s)} = \frac{\frac{k_t}{JL_a}}{s^2 + s\frac{iR_a+BL_a}{JL_a} + \frac{BR_a+k_tk_e}{JL_a}} - - - (8)$$

V.FOUR SWITCH CONVERTER TOPOLOGY

The cost reduction of controllers for PMBLM drives can be considered with the topologies with more than one switch per phase, but less than conventional two switches per phase .But according to the working of BLDCM, at a time only two phases are conducing and the third phase is inactive. A BLDC motor needs quasi-square current waveforms, which are synchronized with the back-EMF to generate constant output torque and have 120 degree conduction and 60 degree non-conducting regions. However, in the four-switch converter, the generation of 120 degree conducting current profiles is inherently difficult Though cost saving is achieved, it introduces distortions in the uncontrolled phase. This problem is solved by using hysteresis current control. In this method pwm pulses produced by the switching ON and OFF the switch when the phase current crosses the Hysteresis Band.

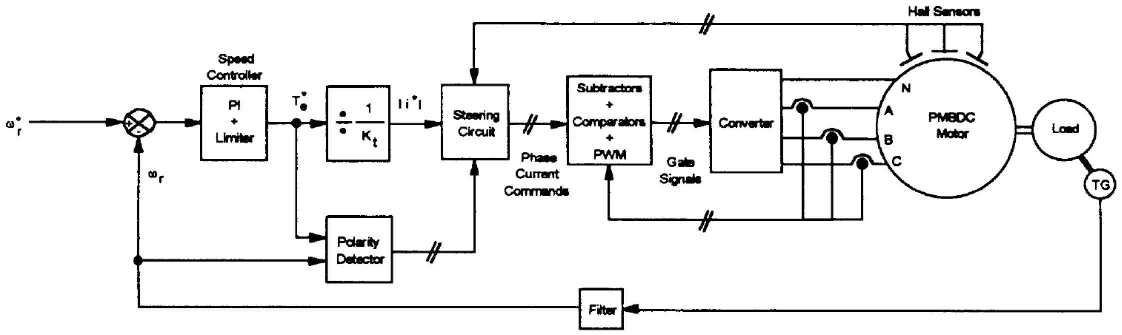

Figure 5.1 schematic of the speed controlled PMBLDC motor drive system

VI.SENSOR LESS CONTROL

A low cost BLDC motor drive with reduced parts that is by reducing the number of switches from six to four is to be developed. The implementation of a low cost, reduced parts BLDC motor is desired with high system reliability. Most of the sensors less methods for a six-switch inverter BLDC motor drive are not directly applicable to the four-switch inverter. The main reason is that in the four-switch topology, some methods detect less than six points, and other commutation instants must be interpolated via software. This paper presents a novel sensor less method for four-switch BLDC motor drive based on zero crossing points of stator line voltages.

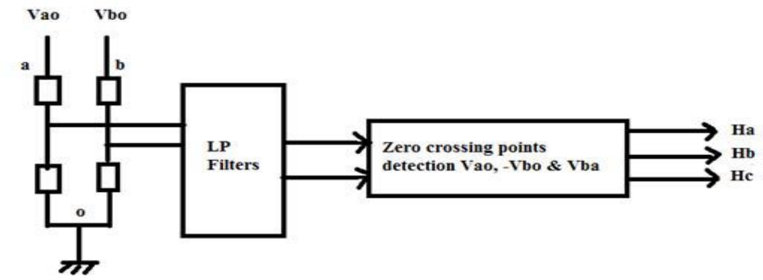

Figure 6.1Position Sensing Using Line Voltages

In four switch converter topology the third phase is connected in between midpoint of two capacitors. Assume that point to be 'O' and is connected to the ground. With point O as reference, the three line voltage waveforms, V_{ao} ,V_{bo} and -V_{bo} . Therefore, by detecting the zero crossing points of three line voltages, six commutation points are obtained. From this commutation points the virtual hall effect signals are produced. Three line voltages are derived from terminal voltages V_{ao} and V_{bo}. They have higher magnitude compared to back EMF voltages that is $\sqrt{3}$ times phase voltages plus drop voltage on the stator impedance.

VII. RESULTS AND DISCUSSION
FOURSWITCH CONVERTER TOPOLOGY

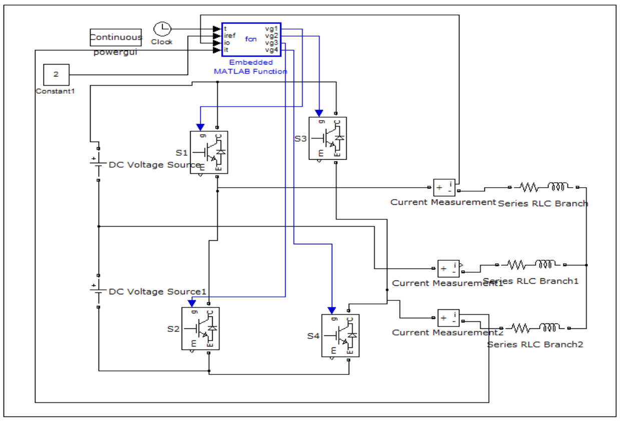

Figure 7.1 Four Switch converter using Direct Control method

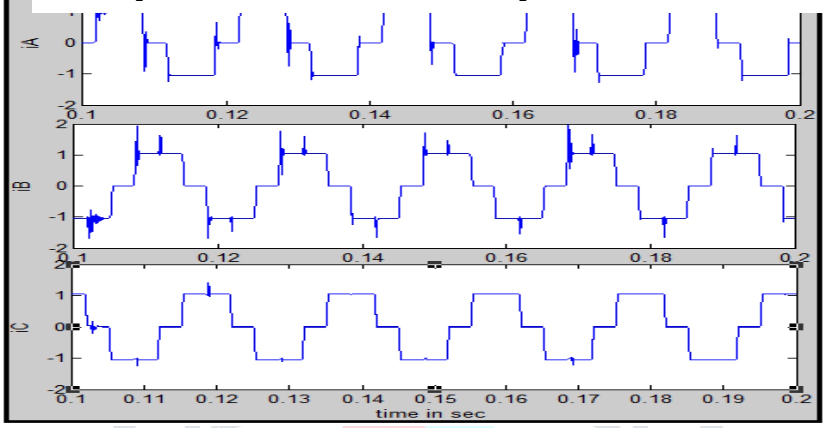

Figure 7.2 Phase current waveform of Four switch converter

SENSOR LESS CONTROL

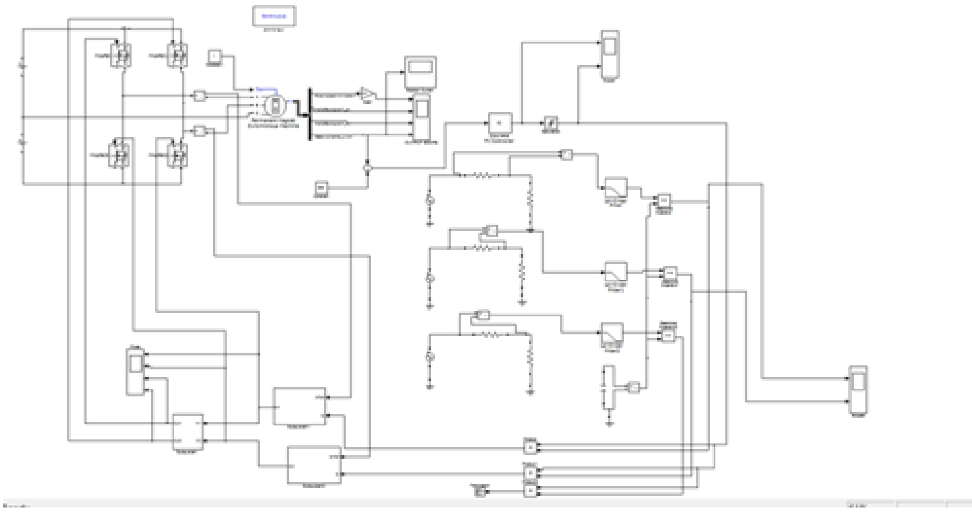

Figure 7.3 Simulink diagram for sensor less control

The system consists of a BLDC motor with the dc link voltage and inverter. The performance of the machine is studied in open loop. A constant speed operation of the drive is simulated in closed loop. Control is achieved via terminal voltage sensing. The three voltage functions are used to get the commutation points. A voltage divider circuit is used first, followed by low pass filter (second order Butterworth) and then a zero crossing detection circuit to get the virtual hall signals. A d-q model of the BLDC motor done is considered in a rotor reference frame and an analytical simulation using a m-file is carried out to study the torque-speed characteristics of the motor under steady state.

On X-axis: Time in second

On Y-axis: Stator current for phase C in Amp

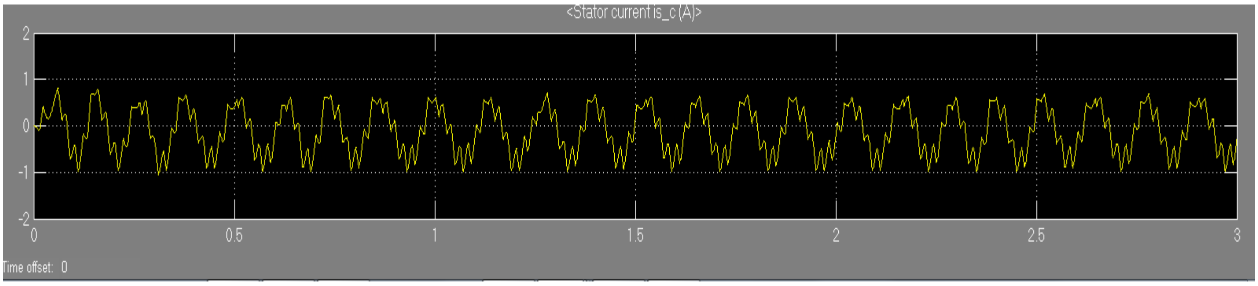

Figure 7.4 Stator current for Phase C

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