A Higher Efficiency of Permanent Magnet (PM) Brushless DC Machine for Four-Switch Electronic Commutation

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Abstract— Permanent Magnet (PM) Brushless DC machine has high efficiency, high power density, high power factor, high torque, simple control, and minimal maintenance. Modelling, simulation of drives with converter configuration and control schemes is presented in this project. This project describes modelling of four switch inverter fed BLDC motor, is explained with transfer function model. The simulation of sensor and sensor less control of drive will be done in MATLAB/Simulink. Control with sensor, the controller is used Fuzzy logic Controller/PI Controller and in sensor less control the method is used is terminal voltage sensing.
Key words: FLC/PI Controller, BLDC Motor

I. INTRODUCTION

To improve sensor less control performance, four-switch electronic commutation modes based proportional integral controller scheme is implemented. In this project four-switch three phase inverter reduction of switches, low cost control and saving of hall sensor were assimilate. The feasibility of the proposed sensor less control four-switch three phase inverter fed brushless DC motor drive is implemented, analyzed using MATLAB/SIMULINK, effective simulation results have been validated out successfully.

II. PROJECT METHODOLOGY

A. *With Sensor Control:*

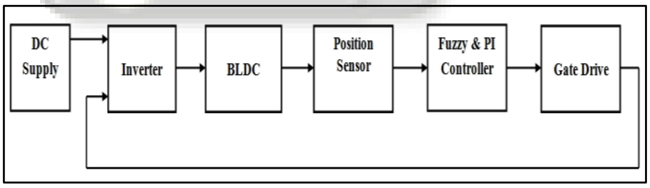

Fig. 1: Block Diagram of Sensor Control

A brushless DC motor (BLDC) is asynchronous 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. 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 isused. By reducing the no of switches the cost reduction canbe achieved. Moreover switching and conduction losses canbe reduced. So here Four Switch VSI (FSVSI) topology is attempted. By using the Sensor less control the cost of the sensors are also eliminated.

B. *Without Sensor Control:-*

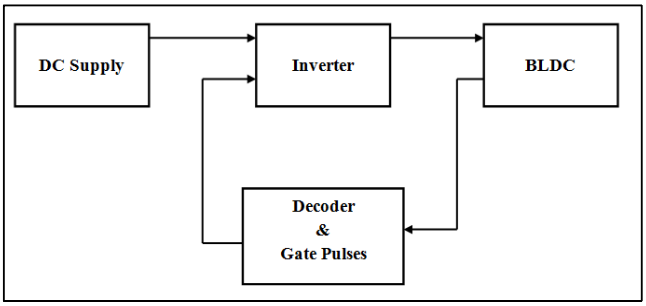

Fig. 2: Block Diagram of Sensor less Control

M Modelling of the BLDC machine and the controller are essential for evaluating their performance. Each of the simulators allows setting of the input parameters. In this work the modelling of BLDCM is explained with transfer function model. The simulation of sensor and sensor less control of drive is done in MATLAB/Simulink. Control with sensor, the controller is used by Fuzzy / PI Controller and in sensor less control the method is used terminal voltage sensing.

Permanent magnet motors with trapezoidal back EMF and sinusoidal back EMF have several advantages over other motor types. Most notably, (compared to dc motors) they are lower maintenance due to the elimination of then mechanical commutator and they have a high-power density which makes them ideal for high-torque-to weight ratio applications. The permanent magnet brushless dc(BLDC) motor is gaining popularity being used in computer, aerospace, military, automotive, industrial and household products because of its high torque, compactness, and high efficiency. A conventional BLDC motor drive is generally implemented via a six switch, three-phase inverter and three Hall-effect position sensors that provide six commutation points for each electrical cycle. Cost minimization is the key factor in an especially fractional horse-power BLDC motor drive for home applications. It is usually achieved by elimination of the drive components such as power Switches and sensors. Therefore, effective algorithms should be designed for the desired performance. Recently, a four switch, three-phase inverter (FSTPI) topology has been developed and used for a three-phase BLDC motor drive .Reduction in the number of power switches, dc power supplies, switching driver circuits, losses and total price are the main features of this topology. It results in the possibility of the four-switch configuration instead of the six switches.

III. VOLTAGE SOURCE INVERTER

The main objective of static power converters is to produce an AC output waveform from a DC power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static varcompensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable

A. SINGLE –PHASE INVERTER

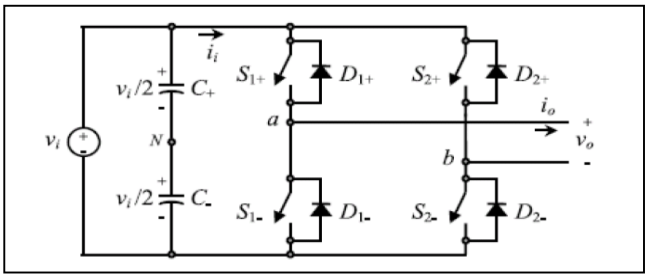

Fig. 3: Single phase Inverter

Single-phase voltage source inverters (VSIs) can be found as half-bridge and full-bridge topologies. Although the power range they cover is the low one, they are widely used in power supplies, single-phase UPSs, and currently to form elaborate high-power static power topologies, such as for instance, the multicell configurations. Fig.3.1 shows the power topology of a full-bridge VSI. This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, both switches S1+ and S1- (or S2+ and S2-) cannot be on simultaneously because a short circuit across the dc link voltage source Vi would be produced.

B. THREE PHASE INVERTER

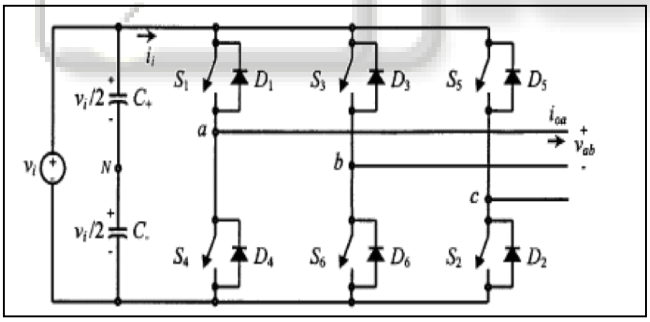

Fig. 4: Three Phase Inverter

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators).

The standard three-phase VSI topology is shown in Fig. 3.2 As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. In this case, the ac line currents freewheel through either the upper or lower components.

The remaining states (1 to 6) produce non-zero ac output voltages.

C. INVERTER MODELING

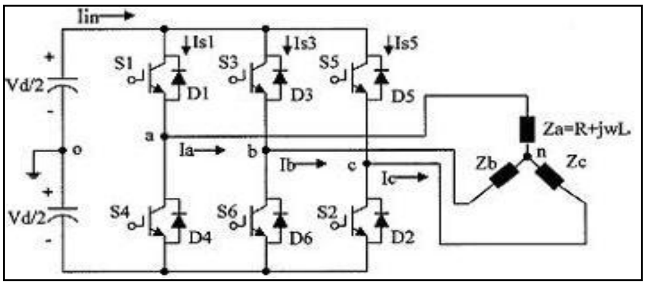

Fig. 5: Three Phase MOSFET-Based Inverter

VAN = S1*(Vd/2)- S4 *(Vd/2)-VF ………………(3.1)
VBN = S3*(Vd/2)– S6 *(Vd/2)-VF ..……………. (3.2)
VCN = S5*(Vd/2)– S2 *(Vd/2)-VF . …………….(3.3)

Where, VAN, VBN, VCN are line neutral voltages
Vd is the Dc link voltage.
VF is the forward diode voltage drop

IV. SENSOR LESS CONTROL OF BLDC MOTOR

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, Vao ,Vbo and –Vbo. 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 Vao and Vbo. They have higher magnitude compared to back EMF voltages that is times phase voltages plus drop voltage on the stator impedance. Because the drive employs the Direct Current Control (DPC) method, in order to make the current as quasi square waveform in accordance with the trapezoidal back emf, motor adopts 120 degree conducting mode and only two phases are energized at one time. So,the current in the two phases has the same amplitude and opposite direction, while in the third phase, the current is zero.

The PI and Fuzzy controller are widely used in industry due to its ease in design and simple structure. The rotor speed ωr(n) is compared with the reference speed ωr(n)∗and the resulting error is estimated at the nth sampling instant as:

we(n)=we(n)n-we(n)……………………………(1)

The new value of torque reference is given by-

T(n)=T(n-1)+Kpwe(n)-w(1)+Kiwe(n)2………………………(2)

Where, ωe(n - 1)‟ is the speed error of previous interval, and „ωe(n)‟ is the speed error of the working interval. KP and KI are the gains of proportional and integral controllers respectively.By using Ziegler Nichols method the KP and KI values are determined.Reference Current Generator Unlike a brushed DC motor, the commutation of a

BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Rotor position is sensed by Hall Effect sensors embedded into the stator which ives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. The magnitude of the reference current (I∗) is determined by using reference torque (T∗) and the back emf constant (Kb);I^n=T^n/Kb. Depending on the rotor position,the reference current generator block generates three-phase eference currents (ia∗, ib∗, ic∗) considering the value of reference current magnitude as I∗, - I∗and zero.

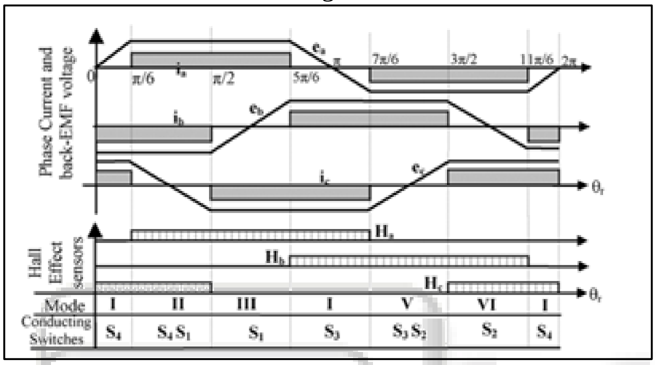

Fig. 6: Back EMF, Current profile, modes, conducting switches in the four-switch converter for three-phase BLDC motor drives

Rotor Position Signal θ_r	Reference Currents (i_a*, i_b*, i_c*)		
330°-0° to 0°-30°	0	−I*	I*
30° - 90°	I*	−I*	0
90° -150°	I*	0	−I*
150° - 210°	0	I*	−I*
210° - 270°	−I*	I*	0
270° - 330°	−I*	0	I*

Table 1: Rotor position signal Vs. reference current

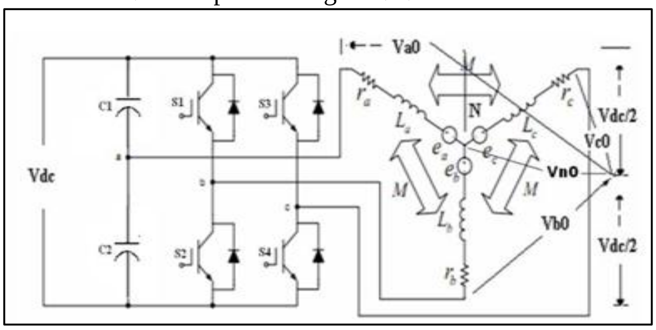

Fig. 7: Inverter circuit with PMBLDCM drive

Terminal voltages of a BLDC motor in the four switch inverter with respect to the mid-point of the dc bus are as follows:

$$Vao = Ria + L\frac{dla}{dt} + ea + Vno \qquad (3)$$

$$Vbo = Rib + L\frac{dlb}{dt} + eb + Vno \qquad (4)$$

$$Vco = Ric + L\frac{dlc}{dt} + ec + Vno \qquad (5)$$

MODES	ACTIVE PHASES	SILENT PHASES	SWITCHING DEVICES
Mode 1	Phase B and C	Phase A	S_4
Mode 2	Phase A and B	Phase C	S_1 and S_4
Mode 3	Phase A and C	Phase B	S_1
Mode 4	Phase B and C	Phase A	S_3
Mode 5	Phase A and B	Phase C	S_2 and S_3
Mode 6	Phase A and C	Phase B	S_2

Table 2.Switching Sequence of Four Switch BLDC motor

As shown in Table 2, the two-phase currents need to be directly controlled using the hysteresis current control method by four switches. Hence, it is called the direct current controlled pwm scheme. Based on the direct current controlled pwm, implementation of the switching sequence and current flow are depicted.

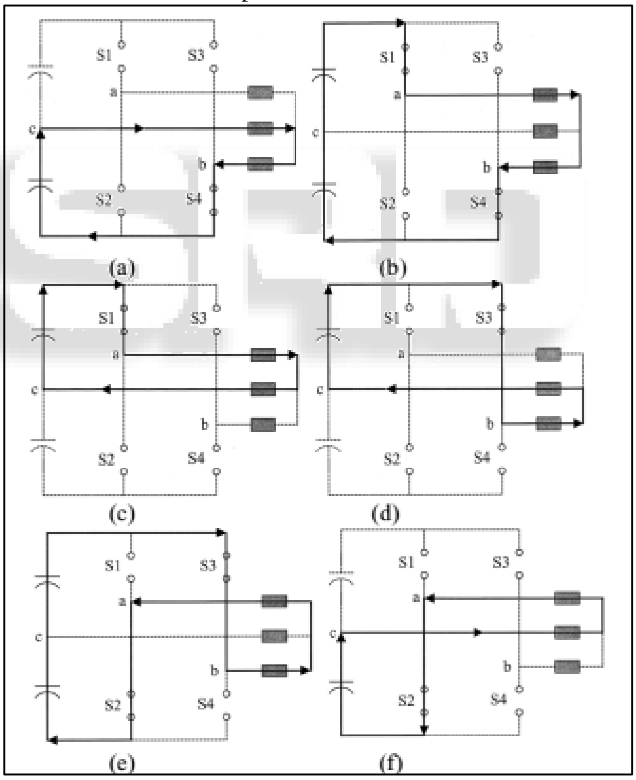

Fig.18: Implementation of the direct current controlled pwm strategy. (a) Mode I (S4). (b) Mode II (S1 and S4). (c) Mode III (S1). (d) Mode IV (S3). (e) Mode V (S3 and S2). (f) Mode VI (S2).

V. COMPARATIVE ANALYSIS OF SENSOR AND SENSOR LESS CONTROL OF FOUR SWITCH INVERTER FED BLDC DRIVE

A. Sensorless Control of Four Switch Inverter Fed BLDC Drive:

The simulation of proposed research four-switch Brushless DC Motor is carried by Simulink and its Simulink model. To generate the pulse width modulation signals subsystems are proposed. The reference speed is set and rotor positionsensor speed sensed are given to the controller if it is equal it is send to the controller or error is generated and rectified and it is given to the controller then the switches generates the Pulses. The Pulse width modulation signals generated by the switches from the output of controller. It is carried out by voltage and time period and the results are taken from Simulink environment. The DC voltage which is fed an input supply gives the output after then rectification which is present inbuilt gives pure DC voltage of 40V it also consists of voltage regulator whose output .The Brushless DC motor proposed in this research is three phase compare to [11] [12], from four-switch . Simulation model of proposed four-switch three phase inverter system. S. K. Shanmugam et al. 731. Subsystem of Pulse width modulation generation for switches (T1-T4). PWM generation for switches (T1-T4). DC voltage waveform of four-switch three phase inverter. S. K. Shanmugam et al. 732 inverter the input voltage is fed better one is obtained. Each phase can varied at the input voltage of 40V. It is carried out by voltage and time period the output of Phase A, B, C are structured by using Simulink model. The main propose of this research is to concentrate on speed and back emf compared to conventional as in [13] [14]. To determine the speed all other parameters values are taken in to important consideration DC voltage of pure after from voltage regulation is inverted and is fed to Brushless motor three phase whose current are sensed by rotor position sensor whose phase currents and the speed of the motor is excellent enough achieved of 800 rpm with less number of switching losses compared to six-switch inverter. It is speed of 1450 rpm is measured using tachometer compared to the Six switches our proposed work achieves less speed is achieved with low loss. The trapezoidal Back Emf generated using four-switch inverter which is high enough. Sensorless control so for angle position hall sensing fully avoided. Brushless DC drives which is preferable for compact, low maintenance and high reliability system in order to reduce the mechanical strength so it proposed and convenient simulation results are carried out. The simulation of the brushless DC motor is done using the software MATLAB/SIMULINK whose back EMF, phase voltage phase current, rotor speed waveform are analyzed and incorporated the speed of rotor is 800 rpm are analyzed. In this proposed converter used less number of insulated bipolar switches which evaluate the conventional converter. In this research, the back electromotive force compensating and direct current controlling for brushless DC motor drives analyzed and switch leg failure are avoided. In this scheme, the pulse width modulation is applied to high side switches of the converter. This pulse width modulation scheme can eradicate the offset voltage in the back electromotive force signal caused by the voltage drop of the insulated bipolar insulator and also increase system efficiency by reducing the conduction loss is achieved. There are no hall sensors, therefore, the system becomes robust, optimized design of the brushless DC motor achieves higher efficiency and better speed, current is formulated.

B. Sensor Control of Four Switch Inverter Fed BLDC Drive:

The performance of a PI and fuzzy-logic-controller (FLC)-based cost-effective drive system of interior permanent-magnet synchronous motor (IPMSM) for high-performance industrial applications. PI and FLC is used as a speed controller and the motor is fed from a four-switch three-phase (4S3Ph) pulse width-modulation (PWM) inverter instead of a conventional six-switch three-phase (6S3Ph) inverter. This reduces the cost of the inverter, the switching losses, and the complexity of the control algorithms and interface circuits to generate six PWM logic signals. Furthermore, the proposed control approach reduces the computation for real-time implementation. The closed-loop vector control scheme of the proposed 4S3Ph-inverter-fed IPMSM drive incorporating the PI and FLC is implemented. The robustness of PI and FLC-based 4S3Ph-inverter-fed IPMSM drive is verified by theoretical and experimental results at different operating conditions. A comparison of the proposed 4S3Ph-inverter-fed IPM drive with a conventional 6S3Ph inverter system is also made in terms of performance and harmonic analysis of the stator current. The proposed inverter-fed IPMSM drive is found quite acceptable considering its performance, cost reduction, and other inherent advantageous features.

VI. Conclusion

In this project, the transfer function model is explained. The simulation is performed in MATLAB/SIMLINK motor model fed by four-switch inverter with hysteresis current control first with sensor less and then fuzzy controller with the hall effect sensors. Due to the hysteresis control the current waveforms are rectangular without any distortion. The virtual Hall Effect signals are produced the phase voltages and thus applicable in four switch inverter topology. The disadvantages of back emf method will overcome by The Sensor less method via terminal voltage sensing . But the Sensor less control method is not suitable for higher speed changes The fuzzy controller that is sensor control responds faster and smoother. For reference speed changing . But if minimun cost is the mandatory and motor speed is not an issue, then Sensor less control will be the better choice.

VII. Future Scope

For the realization of low cost and high performance three-phase BLDC motor drive system to provide that possibility by The four-switch converter topology . From the observation, one should note that the development of the proper PWM control strategy should be accompanied with the reduced parts converter. As a solving a problem, we initiate the direct current controlled PWM and examine the performance. With the developed control scheme, it is expected that the proposed system can be widely used in commercial applications with a reduced system cost.

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