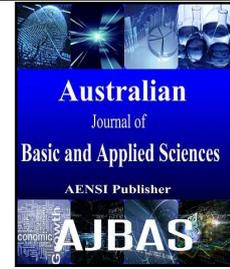




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Direct Torque And Speed Control Of A BLDC Motor Using Sensorless Control

¹S.Kaliappan and ²R.Rogini

^{1,2}Electrical and Electronics Engineering, Kumaraguru College of Technology, India.

Address For Correspondence:

R.Rogini, Electrical and Electronics Engineering, Kumaraguru College of Technology, India.
E-mail: rogini55@gmail.com, phone: 9500484527

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ABSTRACT

This paper provides a technical review of sensorless method for controlling Brushless Direct Current (BLDC) motor drives. The performance and reliability of BLDC motor drivers have been improved because the conventional control and sensing techniques have been replaced through sensorless technology. With the help of SVPWM and PI controller dynamic stability is obtained. This proposed scheme aims to cut down the lower order harmonics and torque ripple in a BLDC motor and attain the stability in no time using sensorless technique. Here sensorless advances are reviewed and recent developments in this area are introduced with their inherent advantages and drawbacks. The study includes a deep overview of the back-EMF sensing, which includes Terminal Voltage Sensing, Terminal Current Sensing, Back-EMF and PWM strategies.

INTRODUCTION

Today the use of BLDC motor have increased and it's competing with induction motor and DC motors. Brushless DC motors (BLDC) are variable frequency permanent magnet synchronous motors having very similar torque speed characteristics to that of DC motors that's why the name Brushless DC came. It has a very wide area of applications due to their higher efficiency and easy control strategies. It requires an electronic circuit for commutation instead of brushes. For controlling the BLDC motors we use three phase converters. In BLDC motors only two phases are supplied and the third phase is kept off. Two phases which are to be supplied is determined on the basis of the position of the rotor. Based on the position of the rotor, switching devices in the inverter are commutated for every 60 degree. Rotor position sensors are used to sense the position of the rotor at every instant of time whereas here sensorless technique is introduced. Inverters are used to convert dc power into ac power in which controlled ac is the source to BLDC motor. The output voltage and output frequency of the inverter is changed as per our requirement. The output waveform of the inverter depends on the switching state of the inverter. Studies are carried out for meeting the requirement of inverters such as reduce harmonic content in the output, switching frequency of the inverter and better consumption of the available dc voltage. One of the most common methods used for inverter switching is Pulse width modulation (PWM) Techniques. In this technique we control the output voltage by varying the on-off time of the switching elements in the inverter. Sinusoidal PWM and Space Vector PWM (SVPWM) are the most used techniques today in which Sinusoidal PWM is the simplest and mostly used but it has many flaws. The newly invented Space Vector PWM technique reduces these flaws such as it reduce switching loses, harmonic content in the output and better utilization of the available dc-bus voltage. This thesis makes use of PI controller for the speed control of BLDC motor fed by a SVPWM inverter. The PI controller leads to improve the behaviour of the motor. Speed control for BLDC motor is simulated using MATLAB software package.

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II. Brushless dc motor:

A BLDC motor is a permanent magnet synchronous motor. Position sensors are used to sense the rotor position according to the rotor position inverter control the stator currents thus the speed of motor. The term dc comes in the name of BLDC because its torque speed characteristics are similar to that of dc motors. BLDC requires an electronic commutation circuit instead of mechanical or brushed commutation used in dc motor. BLDC motor are divided into two types based on the shape of back-emf waveform induced in the stator are sinusoidal type and trapezoidal type. Sinusoidal motor have a sinusoidal shaped back-emf and its require phase current to be sinusoidal for torque ripple free operation on the other hand trapezoidal motors need rectangular shaped current for torque ripple free operation. The trapezoidal motor is more popular for most of the application due to its simple operation, low price and high efficiency. Many different configurations of BLDC motor exists three phase motors with star connected windings are most popular in use today because of its high efficiency and lower torque ripple.

III. Principle of operation of brushless dc motor:

The three phase BLDC motor is operated by energizing two phase at a time, i.e. the only two phase are energized at an instant of time while the third phase is off to produce the highest torque. The two phases which are energized determine by an electronic commutation circuit depends on the output of the sensors. Hall-effect sensors are most commonly used to sense the rotor position and feed it to the controller. The signal from the sensors changes every 60° (electrical degree). Each interval starts with the rotor and stator flux is 120° apart and ends when they are 60° apart three phase winding of BLDC motor with its trapezoidal back emf which is shown in figure 1

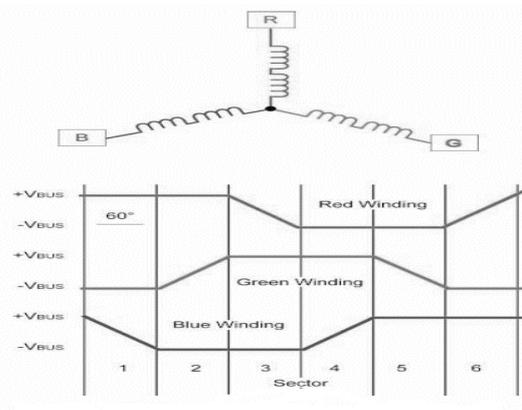


Fig.1. BLDC motor winding and trapezoidal back emf waveform

Highest torque is reached when the field are perpendicular to each other. Commutation is done by a Voltage source inverter. The switching devices used are MOSFET or IGBT.

IV. Operation of BLDC motor with inverter:

A trapezoidal PM machine gives performance closer to a dc motor. It requires a three-phase inverter to the driving side for feeding power into the machine. The machine is represented by its equivalent circuit, which consists of stator resistance R_s , self-inductance L_s , and a back-emf. The inverter works as an electronic commutation which performs the switching according to the output from the position sensors whereas here the stator voltage and stator current is taken to do control of motor. The inverter operates in the following two modes:

- 1) $2\pi/3$ angle switch-on mode
- 2) Voltage and current control PWM mode

Trapezoidal back emf, armature current, flux linkage, gating signal and its step transition is shown below in figure 2

V. six step VSI:

BLDC motor drives mostly uses three-phase bridge inverters for supplying power to it. The circuit diagram of a six-step VSI fed to a BLDC motor is shown in Figure3 where the three phase voltages are shifted by 120° degree.

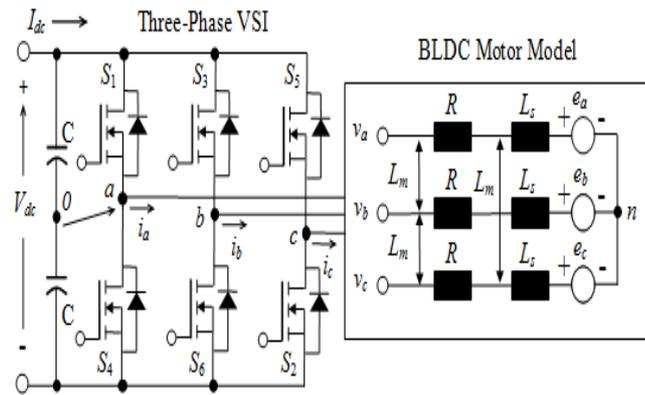


Fig. 3: Three phase VSI fed BLDC motor

VI. Pulse-width modulation technique:

Pulse-width modulation is a technique in which the ON-OFF time of switches is controlled by reference wave. In this the intersection between a reference wave and a carrier wave produces the pulses according to which the switches are switched ON and OFF. PWM have a wide field of applications such as motor speed control, converters, communication, etc. For example PWM is used to control the switches of inverter to control the power supplied to the motor. By controlling the ON-OFF time of the switches we can control the speed of the motor. When we need more speed we increase the ON time of the switches similarly when we need to slow down the motor we decreases the OFF time of the switches. Higher switching frequency for the switches so that the power losses is insignificant as compare to the power supplied by the source. here are different PWM techniques used for motor control application. We use the following techniques

- 1) Sinusoidal PWM
- 2) Space Vector PWM

VII. Space vector PWM:

The Space Vector PWM (SVPWM) is the most widely used inverter switching mechanism for three-phase inverter used for BLDC motors. The eight sector and their voltagess are shown in fig4 and table1.

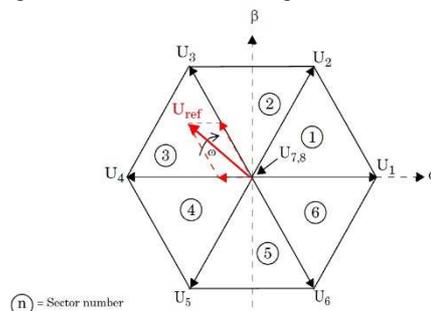


Fig. 4: six sectors of SVPWM

For example for switching state (0, 0, 1) for the phase (a, b, c) of the three-phase inverter. The lower gates of phase A and B are turn ON and upper gate of phase c is turn ON. For any reference voltage vector which falls in the three-phase frame, we can resolve this vector using the combination of the eight voltage vectors. It achieves the voltage vector control by adjusting the timing and duty ratio of the eight switching states of the three-phase inverter. Assuming that stator coils in the three phases are identical, each switching state of the three phase inverter corresponds to a voltage vector in the three-phase stator coil frame. The eight switching state and their eight voltage vector are V_0 to V_7 . V_0 and V_7 are the zero vectors having zero magnitude. V_1 to V_6 are six active vectors with fixed magnitude and 60° apart from each other.

VIII. Speed controller structure:

Electronic commutation circuit assure a proper rotation of BLDC motor, but the speed of the motor depends on the amplitude of the voltage fed to the motor. PI controller is the most commonly used controller for industrial use because it is easy to implement. The input to the controller is the error between reference speed and actual speed of the motor. Based on the error signal the PI controller produces a control signal for the PWM block which changes the ON-OFF time of the switching devices in the inverter thus control the voltage fed to the motor. The speed of the BLDC motor depends on the stator current value so controlling the speed of motor

we have to control the stator current fed into the motor. The value of stator current is controlled by controlling the average output voltage of the three-phase inverter which further depends on the on/off time of the six switches. Since the speed of BLDC motor is directly proportional to the inverter output voltage by varying the on/off time of the six switches.

The speed to voltage transfer function of BLDC motor is given by

$$G(s) = \frac{\omega_m}{V_s}$$

The main objectives of the tuning of the PI controllers are as follows:

1. To minimize the rise time of the system.
2. Minimize the peak overshoot of the system.
3. Minimize the settling time of the system.

With the help of SVPWM and PI controller, vector control is done and

IX. Stator voltage & current transformation:

Initially the stator current and stator voltages are taken to do the abc to dq transformation. Here three phase to two phase transformation is done.

$$V_d = \frac{2}{3} \left[V_a \cos \theta + V_b \cos \left(\theta - \frac{2\pi}{3} \right) + V_c \cos \left(\theta - \frac{2\pi}{3} \right) \right] \quad (1)$$

$$V_q = \frac{2}{3} \left[V_a \sin \theta + V_b \sin \left(\theta - \frac{2\pi}{3} \right) + V_c \sin \left(\theta - \frac{2\pi}{3} \right) \right] \quad (2)$$

Since it's a sensorless control only the stator voltage and current values are taken.

X. Instantaneous active and reactive current estimation:

This step is done to calculate the reference current with motor terminal parameter values alone.

$$I_d^* = \int \frac{V_d}{L_d} - I_d^* \left(\frac{R_s}{L_d} \right) + \omega_e \times I_q^* \quad (3)$$

$$I_q^* = \int \frac{V_q}{L_q} - I_q^* \left(\frac{R_s}{L_d} \right) - \omega_e \times I_d^* - \omega_e \left(\frac{flux}{L_q} \right) \quad (4)$$

Where

V_d - dc link voltage

L_d -Inductance of the motor

I_d^* - Reference current

ω_e - estimated speed

XI. Electrical parameter estimation:

This estimation is done to calculate the reference speed value from estimated current and speed in above steps.

$$\text{Speed reference} = I_d I_q^* - I_d^* I_q - (I_q - I_q^*) \left(\frac{flux}{L_q} \right) \quad (5)$$

$\omega_e = K_p \times \text{Speed reference} + \int K_i \times \text{Speed reference}$ where,

I_d, I_q^*, I_d^*, I_q are calculated from previous steps

Integration of that speed gives the theta value this speed control gives the torque reference. ($\theta = \int \omega_e$)

XII. Space vector transformation:

A three phase inverter provides a three phase ac supply which could be given to a three phase motor. The switches must be controlled so that at no time are both switches in same leg turned ON or else D supply would be shorted. Each switch have the specified time period of conduction when the sector number is selected using the voltage values obtained from above step

$$N = [0.5V\alpha] + \left[\left(\sqrt{3} \frac{V\beta}{2} - 0.5V\alpha \right) \times 2 \right] + \left[\left(\sqrt{3} \frac{V\beta}{2} - 0.5V\alpha \right) \times 4 \right] \quad (8)$$

Where N= sector number

Only positive values of V_α, V_β are taken.

Each sector has two fixed time periods using that ON and OFF period are calculated.

XIII. Overall block diagram and working:

To perform sensorless control the stator voltage and the stator current are the major parameters which are taken to perform control process.

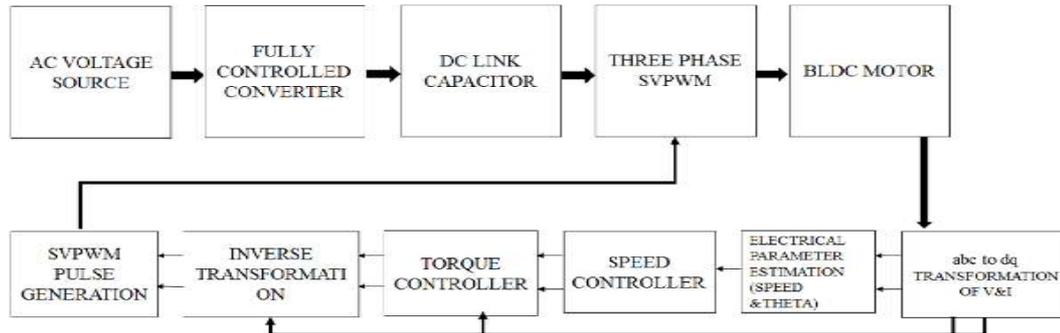


Fig. 6: Overall block diagram

The overall block diagram in controlling the motor speed is shown above in figure 6. Taking the stator voltage and current value whole control process is carried out. Initially the stator voltage and current of three phases are taken and abc to dq transformation is done. V_{abc} to V_{dq} and I_{abc} to I_{dq} is calculate With the motor parameters itself the active and reactive current values are estimated. From the calculated and estimated values speed and torque control is carried out. The obtained value is transformed from V_{dq} to $V_{\alpha\beta}$ using inverse clarks transformation Time period and switching angle are calculated with the help of $V_{\alpha\beta}$, time, and V_{dc} voltage using SVPWM technique. From which gate pulse generation is done and controlled three phase output voltage of inverter is fed to BLDC motor.

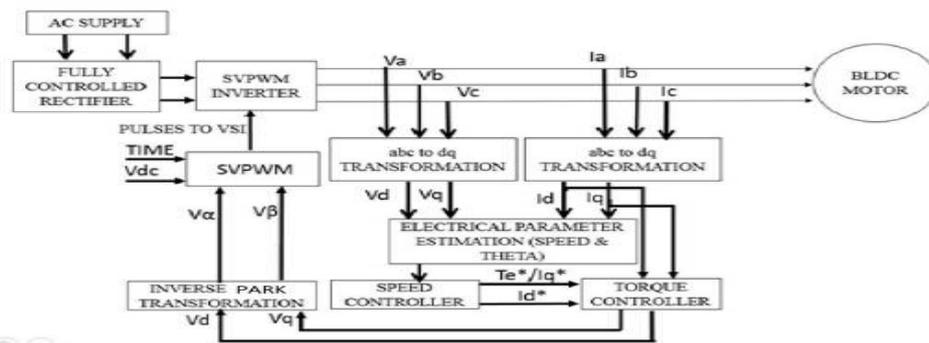


Fig. 7: Schematic diagram

XIV. Discussion on simulation results:

The overview of simulation diagram and the result obtained are shown below.

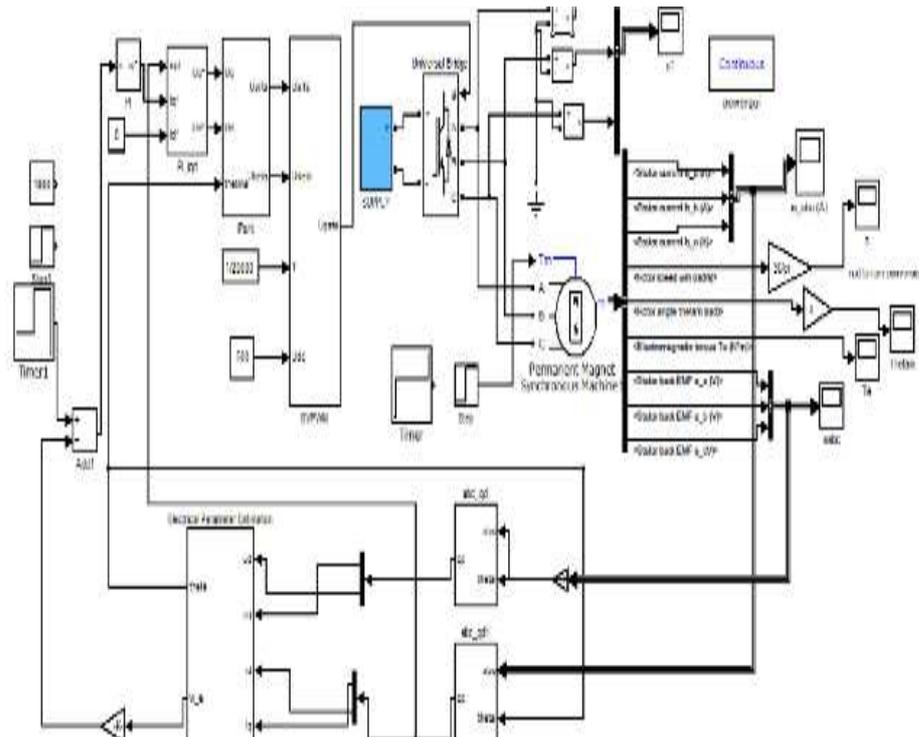


Fig. 8: Overall Simulation diagram

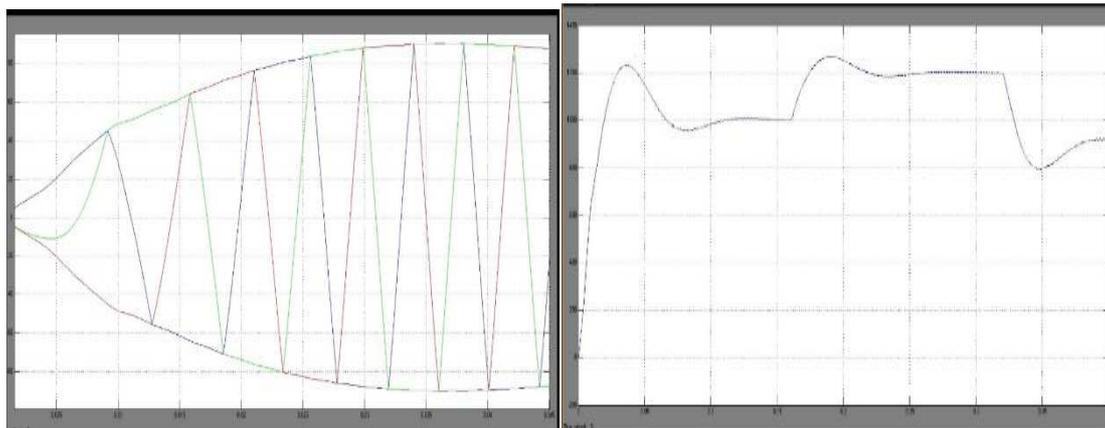


Fig. 9: Trapezoidal back emf of BLDC motor Fig10 Dynamic stability attainment of BLDC motor

XV. Three phase current waveform:

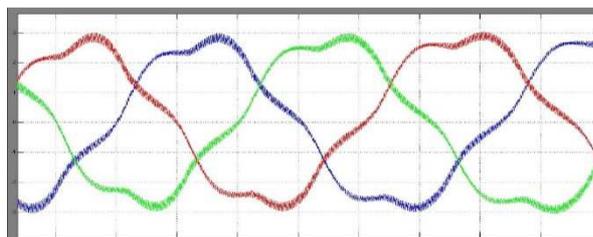


Fig. 11: Three phase current waveform

XVI. Discussion on result:

This sensorless techniques aims at reduction of harmonics, torque ripple and obtaining stability as soon as possible. Here 0.1s is the response time within which the stability is attained for any specified speed and torque ripple is greatly reduced.

Conclusion:

The performance of the proposed system is executed in MATLAB and simulation results are obtained. It shows that the system stability is attained soon and torque ripple is greatly reduced. These are the types of applications where a variable speed and keeping the accuracy at a set speed is important. In these applications the load is directly coupled to the motor shaft, and this happens in fans, pumps, air compressors and blowers, which demand low-cost controllers. In these applications the load on the motor varies over a speed range and may demand high-speed control accuracy and good dynamic responses. Home appliances such as washers, dryers and refrigerators are good examples. Also, fuel pump control, electronic steering control, engine control and electric vehicle control are examples of these in the automotive industry. In aerospace, there are a number of applications, such as centrifuges, pneumatic devices with electro actuators, pumps, robotic arm controls, gyroscope controls and so on. These applications may use speed feedback devices and run in total closed loop by using the controller.

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