# To Study Speed Control and Four Quadrant Operation of BLDC Motor

## Ms. Snehalata Y. Dhenge,  Prof. V.S. Nandanwar

(Department of Electrical Engg. PCE, Nagpur, India)
(Department of Electrical Engg. PCE, Nagpur, India)

## ABSTRACT

Brushless DC motor drives are becoming more popular in industrial, Traction applications. This make the control of BLDC motor in all four quadrant very vital. This paper deals with the control of three phase BLDC motor. The motor is controlled in all the four quadrants without any loss of power in fact energy is conserved during the regenerative period. In this paper, The BLDC motor drive system along with the control system for speed and current has been present using MATLAB.

*Keyword*s: BLDC Motor, PI Controller, Hysteresis Current Controller, Four quadrant operation.

## I.  INTRODUCTION

Brushless DC Motor has a rotor with permanent magnets and stator with windings. It is essentially a Dc motor turn inside out. The brushes and commutator have been eliminated and the windings are connected to the electronics. The control Electronics replace the function of commutator and energize the proper windings. The motor has less inertia, therefore easy to start and stop. BLDC motor are permanently cleaner, faster, more efficient, less noisy and more reliable .

The brushless DC motor is driven by rectangular or trapezoidal voltage strokes coupled with rotor position. The voltage strokes must be properly aligned, between the phase a, so that the angle between the stator flux and rotor flux is kept close to 90 degree, to get maximum developed torque. BLDC motor either incorporates either internal or external position sensors to sense the actual rotor position or its position can also be detected without sensors. BLDC motor are used in Aerospace, Consumer, Medical ,Industrial Automation equipment and Instrumentation.

In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. BLDC  motor require an inverter and position sensors that exposes rotor position for appropriate alternation of current. the rotation of the BLDC motor is built on the feedback of rotor position that is gained from hall sensors .BLDC motor generally utilizes three hall sensors for deciding the commutation sequence. In BLDC motor the power losses are in stator where heat can be easily shifted

through the frame or cooling system are utilized in massive machines. BLDC motors have many benefits are better speed torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges. Till now 80% of the controllers are PI controllers because they are facile and easy to comprehend.

As the name implies, BLDC motors do not use brushes for commutation; instead they are electronically commutated. Brushless DC motors have been used in various industrial and domestic applications. Due to overweighing merits of this motor, there is continuing trend to propose improved control schemes to enhance the performance of the motor. BLDC Motor considered in these models is star connected with neutral grounding, but several applications require isolated neutral. Keeping merits of these developments in view, in this paper the motor with windings placed in the slots that are axially cut along the inner periphery or around stator salient poles. The rotor is made of permanent magnets and can vary from two to eight pole pairs with alternate north (N) and south (S) poles. In order to rotate a BLDC motor, the stator windings should be energized in a sequence. . It is essential to know the rotor position in order to understand as to which winding must be energized. In the brushless DC motor, polarity reversal is performed by power transistors switching in synchronization with the rotor position. This paper is organized as follows: section II describes the three phase BLDC motor and controllers. In section III, the realization of four quadrant control operation of the BLDC motor. The complete drive system is reviewed in section IV.

## II . BLDC MOTOR And CONTROLLERS

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:
• Better speed versus torque characteristics
• High dynamic response
• High efficiency

• Long operating life
• Noiseless operation
• Higher speed ranges

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and Brushless DC Motors are driven by DC voltage the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not experience the "slip" that is normally seen in induction motors. Brushless DC motors have been used in various industrial and domestic applications. Due to overweighing merits of this motor, there is continuing trend to propose improved control schemes to enhance the performance of the motor. For analysis of the BLDC motor drives system under various conditions, models such as d-q model and a,b,c phase variable models have been developed . Several simulation models were proposed based on non-linear state-space equations. BLDC Motor considered in these models is star connected with neutral grounding, but several applications require isolated neutral . Keeping merits of these developments in view, in this paper the motor is modeled as star connected with isolated neutral and the voltages supplied are line-line but current commutation is controlled by solid state switches. The commutation instants are determined by the rotor position. The rotor shaft position is sensed by a Hall Effect sensor, which provides signals. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating either 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. These signals are decoded by combinational logic to provide the firing signals for 120° conduction on each of the three phases. The rotor position decoder has six outputs which control the upper and lower phase leg MOSFETs.

## [2.1] Mathematical Model of the Brushless DC Motor

The BDCM has three stator windings and permanent magnets on the rotor. Since both the magnet and the stainless steel retaining sleeves have high resistivity, rotor-induced currents can be neglected and no damper windings are modeled. Hence the circuit equations of the three windings in phase variables are

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_B & L_{cb} \\ L_{ca} & Lcb & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

(1 )

Where it has been  assumed that the stator resistances of all the windings are equal. The back EMF's e$_a$, $e_b$, and e$_c$, have trapezoidal shapes. Assuming further

that there is no change in the rotor reluctances with angle, then
$L_a = L_b = L_c$
$L_{ab} = L_{ca} = L_{bc}$
Hence,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

(2)

But,
$$\mathbf{I_a + i_b + i_c = 0}$$

(3)

$$\mathbf{M\, i_b + M\, i_c = Mi_a}$$

(4)

Hence,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

(5)

In state-space form the equations are arranged as follows:

$$P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1/L-M & 0 & 0 \\ 0 & 1/L-M & 0 \\ 0 & 0 & 1/L-M \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} -$$

$R000R000R\ i_a i_b i_c - e_a e_b e_c$    (6)

And the Electromagnetic torque is
$T_e = (e_a i_a + e_b i_b\ e_c i_c)/w_r$    (7)
The equation of motion is
$P_{wr} = (T_e - T_L - B_{wr})/J$

(8)

The currents $i_a$, $i_b$, and $i_c$, needed to produce a steady torque without torque pulsations are shown in Fig. With ac machines that have sinusoidal back EMF's, a transformation can be made from the phase variables to $d$, $q$ coordinates either in the stationary, rotor, or synchronously rotating reference frames. Inductances that vary sinusoid ally in the *a, b,* c frame become constants in the *d,* q reference frame. The back EMF being non-sinusoidal in the BDCM means that the mutual inductance between the stator and rotor is non sinusoidal, hence transformation to a *d, q* reference frame cannot be easily accomplished. A possibility is to find a Fourier series of the back EMF, in which case the back EMF in the *d, q* reference frame would also consist of many terms. This is considered too cumbersome, hence the a, b,c  phase variable model already developed will be used without further transformation.
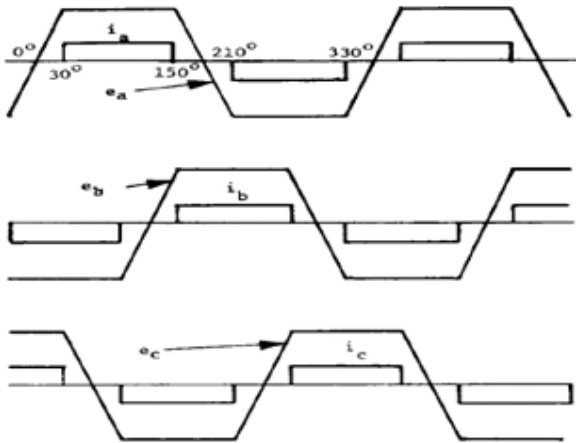
Fig.  Back EMF and current waveform of BLDC motor

## [2.2] PI CONTROLLER

*The speed controllers are conventional PI controller and current controller are the P controllers to achieve high performance.* Conventional PI controller is used as a speed controller for recovering the actual motor speed to the reference. The reference and the measured speed are the input signals to the PI controller. The *KP* and *KI* values of the controller are determined by trial and error method for each set speed. The controller output is limited to give the reference torque.80%of the controller are PI controllers because they are facile and easy to comprehend.

## [2.3] HYSTERESIS CURRENT CONTROLLER

Hysteresis controller limits the phase currents within the hysteresis band by switching ON/OFF the power devices. The switching pattern is given as:
If
$i_a{}^{err} > UL$, S1 is on and S4 is off.
If
$i_a{}^{err} < LL$, S1 is off and S4 is on.
If
$i_b{}^{err} > UL$, S3 is on and S6 is off.
If
$I_b{}^{err} < LL$, S3 is off and S6 is on.
If
$I_c{}^{err} > UL$, S5 is on and S2 is off.
If
$I_c{}^{err} < LL$, S5 is off and S2 is on.
Where
$i_k{}^{err} = i_k{}^{ref} - i_k{}^{mes}$  and UL, LL are the upper and lower limits of hysteresis band. Thus, by regulating the current desired quasi-square waveforms can be obtained. Small hysteresis band however imply a high switching frequency, which is practical limitation the power device switching capability increased switching also implies increased inverter

losses. The shape of the reference current of Hysteresis current controller is rectangular for BLDC Motor. Because of the nonzero inductance of the stator phase windings, the actual phase current unable to assume the desired rectangular form. Instead, the current are trapezoidal due to the finite rise time. This has consequence on the torque production and the drive performance.

## II.  FOUR QUADRANT CONTROL OPERATION

There are four possible modes or quadrants of operation using a Brushless DC Motor. In an X-Y plot of speed versus torque, Quadrant I is forward speed and forward torque. The torque is propelling the motor in the forward direction. Conversely, Quadrant III is reverse speed and reverse torque. Now the motor is "motoring" in the reverse direction, spinning backwards with the reverse torque. Quadrant II is where the motor is spinning in the forward direction, but torque is being applied in reverse. Torque is being used to "brake" the motor, and the motor is now generating power as a result. Finally, Quadrant IV is exactly the opposite. The motor is spinning in the reverse direction, but the torque is being applied in the forward direction. Again, torque is being applied to attempt to slow the motor and change its direction to forward again. Once again, power is being generated by the motor. The BLDC motor is initially made to rotate in clockwise direction, but when the speed reversal command is obtained, the control goes into the CW regeneration mode, which brings the rotor to the standstill position. Instead of waiting for the absolute standstill position, continuous energization of the main phase is attempted. This rapidly slows down the rotor to a standstill position. Therefore, there is the necessity for determining the instant when the rotor of the machine is ideally positioned for reversal. Hall-effect sensors are used to ascertain the rotor position and from the Hall sensor outputs, it is determined whether the machine has reversed its direction. This is the ideal moment for energizing the stator phase so that the machine can start motoring in the CCW direction.

## IV.  SYSTEM CONFIGURATION

Fig. shows the block diagram of the BLDC motor drives system used in the paper. The rotor position information supplied by  the Hall Effect sensors of the BLDC motor. To control motor current, a proportional controller is used to supply proper switching pattern for inverter where three hall sensors are used. As shown in figure to control the BLDC drives system, PI controller and Hysteresis current controller is used.
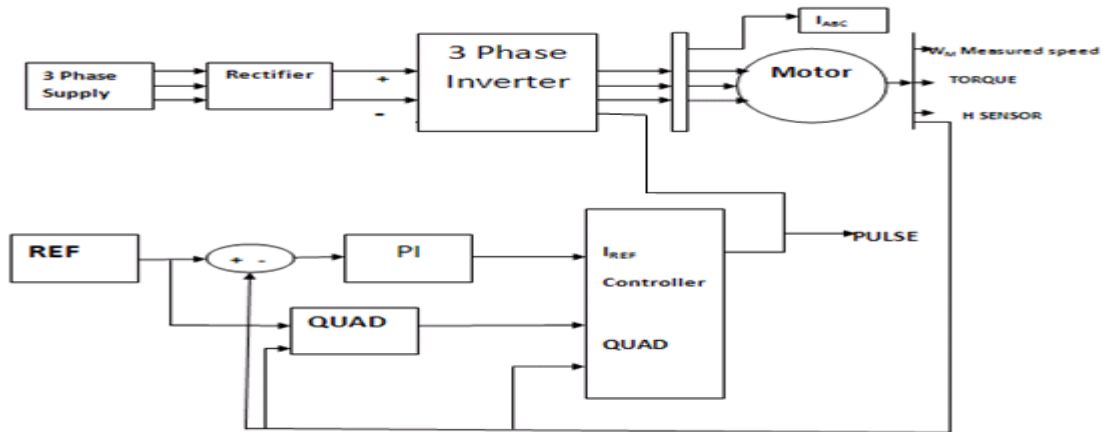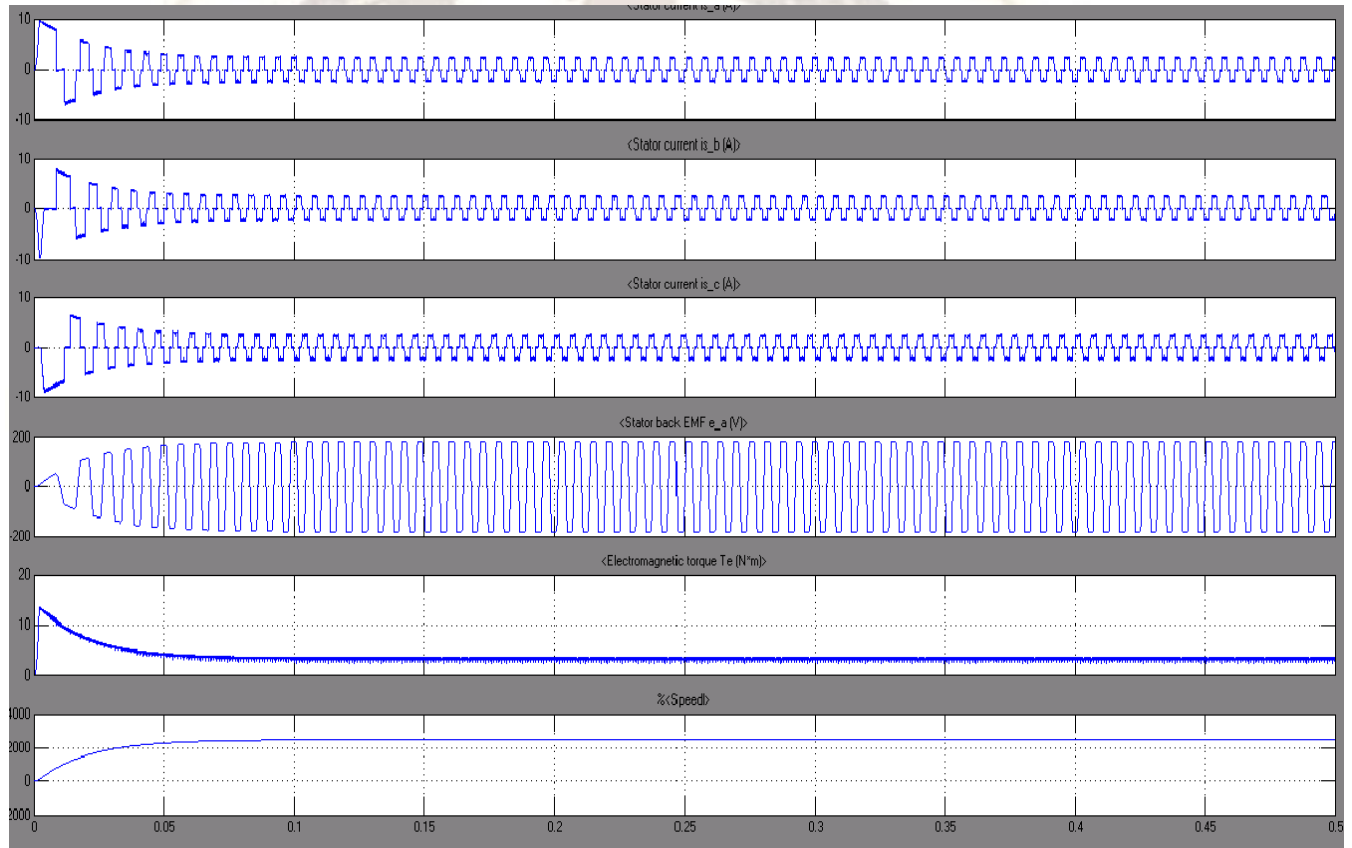
**Fig. Model of BLDC Drive System**

## SIMULATION RESULTS



### V. CONCLUSION

**MOTOR SPECIFICATION**

The performance of the developed BLDC system model is examined using motor parameters as listed in table In this paper, A control scheme is proposed for BLDC motor to change the direction from CW to CCW without going through the standstill position. the time taken to achieve this braking is comparatively less. The generated voltage during the regenerative mode can be returned back to the supply mains which will result in considerable saving of power. The modeling procedure presented in this paper helps in simulation of various operating conditions of BLDC drive system. The performance evaluation results show that, such a modeling is very useful in studying the drive system before taking up the dedicated controller design, accounting the relevant dynamic parameters of the motor.

| V(v) | 380 | $K_b$(v/rad/sec) | 0.13658 |
|------|-----|------------------|---------|
| P | 4 | J(kg-m$^2$) | 0.0022 |
| $R_{s(ohm)}$ | 0.7 | $W_{rated}$ | 4000 |
| $L_t$(H) | 0.00521 | T(N-M) | 2.73 |

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