SPEED CONTROL SYSTEM FOR BLDC MOTOR BY USING TERMINAL VOLTAGE SENSING TECHNIQUE

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Abstract: *This paper presents a high-performance speed control system for Brushless DC motor over a wide speed range using terminal voltage sensingtechnique. The terminal voltage sensing technique is one of the simplest techniques of back EMF sensing technique, and is based on detecting the instant at which the back EMF in the unexcited phase crosses zero. This zero crossing triggers a timer, which may be as simple as an RC time constant, so that the next sequential inverter commutation occurs at the end to this timing interval. In this paper, the closed loop variable speed control of 52W, 8pole, 12V BLDC motor and detail simulations of BLDC motor speed control are described. This paper deals with the modeling of the BLDC motor drive system by using MATLAB/SIMULINK.*

Key Words: *Brushless DC motor, closed loop speed control, PI controller, terminal voltage sensing technique.*

1. INTRODUCTION:

In variable-speed control of AC motor drives, utilization of BLDC motor has been widely used because the BLDC motor has simpler structure and lower cost than the other AC motors [1]-[2].They have better speed versus torque characteristics, high efficiency and better dynamic response and also the torque delivered to the motor size is higher making it useful where space and weight are critical factor.

A three phase BLDC Motor has three phase stator winding on stator and permanent magnet rotor. The torque developed in BLDCM is affected by the waveform of back EMF waveform. Usually the BLDCM has trapezoidal back EMF waveform and stator is fed by rectangular stator current and theoretically it gives a constant torque but the torque ripple exists due to EMF waveform imperfection, current ripple and phase current commutation. BLDCM also need position information for torque producing and this information is obtained by using hall sensors or sensorless techniques [5] [6].

Various sensorless methods for BLDC motors are analyzed in. Speed control of BLDC based on PI controller is explained in. Direct torque control and indirect flux control of BLDC motor with non sinusoidal back EMF method controls the torque ripple-free control with maximum efficiency. Direct back EMF detection method for sensorless control is given in. Fixed gain PI speed controller has the limitations of being suitable for a limited operating range around the operating point and having overshoot. To eliminate this problem a fuzzy based gain schedule PI speed Controller is proposed in. A fixed structure controller (PI or PID) using time constrained output feedback is given in. In this paper, the terminal voltage sensing technique is used to detect the back EMF zero cross point and to control the speed of BLDC motor with a closed loop control using PI controller[4].

2. Mathematical Model of BLDC Motor:

BLDC motor can be modelled in two ways: abc phase variable model and d-q axis model. The trapezoidal back EMF of a BLDC motor indicates that the mutual inductance between stator and rotor is non-sinusoidal, therefore transforming to d-q axis does not provide any particular advantage, and so abc phase variable model is preferred. In the present model, the motor is assumed to be star connected with isolated neutral [1] [2] [3].

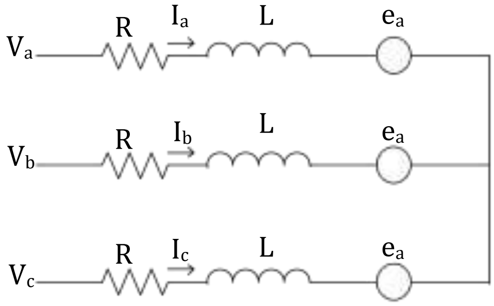

Fig.1 Equivalent circuit of BLDC motor

The model of three phase eight poles BLDC motor is built by using the state space equations. It consists of three portions.

(i) Current generation
(ii) Back EMF generation
(iii) Speed generation

(i) Current Generation Model

The general equations linking the current, $i_{a,b,c}$, the voltages, resistance (R), inductance (L), mutual inductance (M) and electromotive forces e_a, e_b and e_c are expressed as follows.

$$i_a + i_b + i_c = 0$$

$$\frac{di_a}{dt} = \frac{1}{3L}[2V_{ab} + V_{bc} - 2e_a + e_b + e_c - 3Ri_a]$$

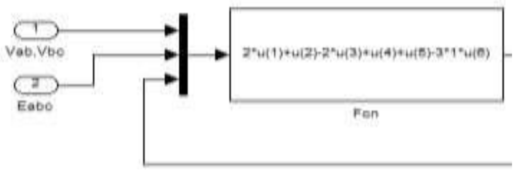

Fig.2 State i_a of Current Generation Subsystem

$$\frac{di_b}{dt} = \frac{1}{3L}[-V_{ab} + V_{bc} + e_a - 2e_b + e_c - 3Ri_b]$$

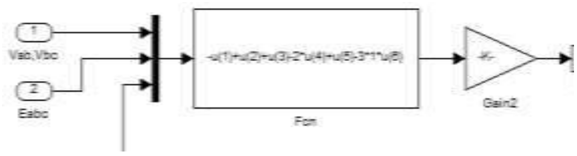

Fig.3 State i_b of Current Generation Subsystem

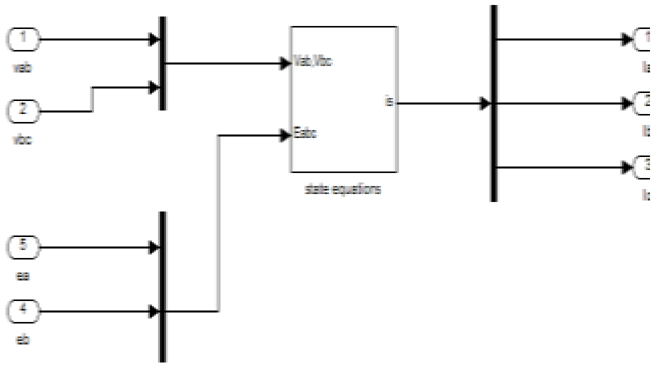

Fig.4 Current Generation Block

(ii) EMF Generation Model

$$e_a = \frac{K_e}{4}\omega_e f_a(\theta_e)$$

$$e_b = \frac{K_e}{4}\omega_e f_b(\theta_e - \frac{2\pi}{3})$$

$$e_c = \frac{K_e}{4}\omega_e f_c(\theta_e + \frac{2\pi}{3})$$

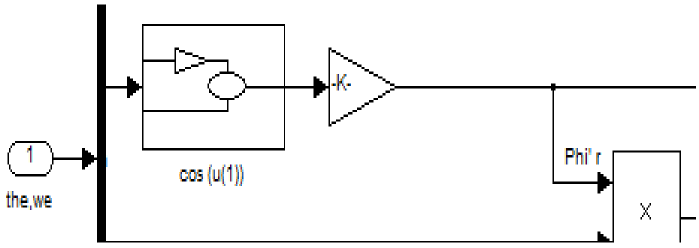

Fig.5 Phase a of Back EMF Generation Subsystem

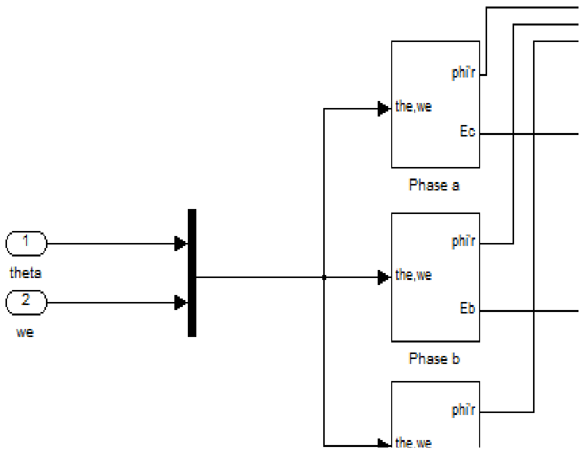

Fig.6Back EMF Generation Subsystem

(iii) Speed Generator Model

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_m}$$

$$T_e - T_L = J\frac{d\omega_m}{dt} + B\omega_m$$

$$\omega_m = \frac{d\theta_m}{dt}$$

$$\frac{d\theta_e}{dt} = 4 \times [\frac{1}{s} \times \frac{1}{J}[T_e - T_L - B\omega_m]]$$

The function $f(\theta_e)$ gives the trapezoidal waveform of the back EMF. One period of the trapezoidal wave function can be written as

$$F(\theta_e) = \begin{cases} 1 & 0 \le \theta_e < \frac{2\pi}{3} \\ 1 - \frac{6}{\pi}(\theta_e - \frac{2\pi}{3} & \frac{2\pi}{3} \le \theta_e < \pi \\ -1 & \pi \le \theta_e < \frac{5\pi}{3} \\ -1 + \frac{6}{\pi}(\theta_e - \frac{5\pi}{3}) & \frac{5\pi}{3} \le \theta_e < 2\pi \end{cases}$$

After solving above the Equations, the complete State-Space Model representation is

$$\begin{pmatrix} i_a' \\ i_b' \\ \omega_m' \\ \theta_m' \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & 0 & 0 & 0 \\ 0 & -\frac{R}{L} & 0 & 0 \\ 0 & 0 & -\frac{B}{J} & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ \omega_m \\ \theta_m \end{pmatrix} + \begin{pmatrix} \frac{2}{3L} & \frac{1}{3L} & 0 \\ -\frac{1}{3L} & \frac{1}{3L} & 0 \\ 0 & 0 & \frac{1}{J} \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} V_{ab} - e_{ab} \\ V_{bc} - e_{bc} \\ T_e - T_L \end{pmatrix}$$

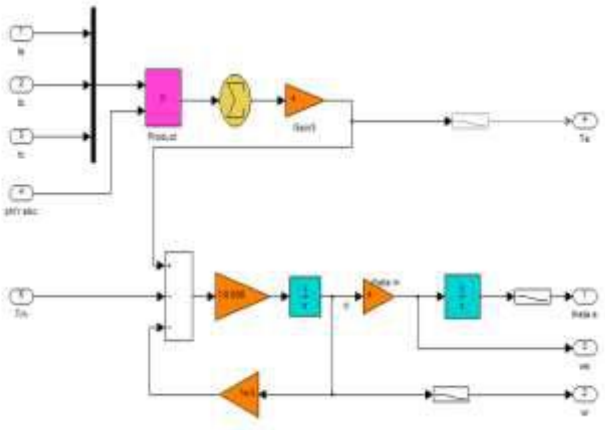

Fig. 7 Speed Generator Block of BLDC Motor

3. Closed loop control system for BLDC:

A BLDC motor is driven by voltage strokes coupled by rotor position. The rotor position is measured using back EMF detection circuit. For three-phase BLDC motor at one time instant, only two out of three phases are conducting current and the no conducting phase carries the back-EMF. If the zero crossing of the phase back EMF can be measured, we can know when to commutate the current.

By varying the voltage across the motor, we can control the speed of the motor. The speed and torque of the motor depend on the strength of the magnetic field generated by the energized windings of the motor, which depend on the current through them. Hence adjusting the rotor voltage and current will change motor speed [4].

Commutation ensures only proper rotation of the rotor. The motor speed depends only on the amplitude of the applied voltage. This can be adjusted using PWM technique. The required speed is controlled by a speed controller. This is implemented as a conventional proportional-Integral controller. The difference between the actual and required speeds is given as input to the controller. Based on this data PI controller controls the duty cycle of the PWM pulses which correspond to the voltage amplitude required to maintain the desired speed. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal.

In case of closed loop control the actual speed is measured and compared with the reference speed to find the error speed. This difference is supplied to the PI controller, which in turn gives the duty cycle.

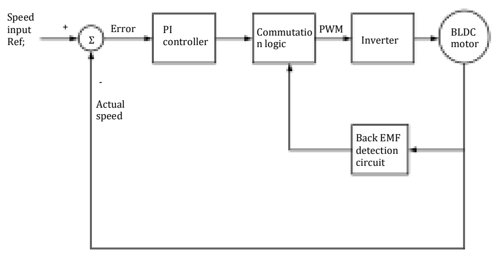

Fig.8 closed loop speed control system for BLDC

4. Simulation of BLDC motor using terminal voltage sensing :

Simulation model is established using MATLAB/SIMULINK to evaluate the performance of the system. The main parameters of BLDC motor for simulation are listed in Table 1.

Table 1. Simulation parameter of BLDC motor

Parameter	value
Phase resistance	0.333Ω
Phase inductance	6.7mH
Number of poles	8
Number of phase	3
Motor inertia	0.005kgm^2
Voltage constant	0.763V/rad/s
DC link voltage	12V

The proposed complete simulation model for 52W BLDC motor can be seen in Figure 11.In sensorless mode from the sensed terminal voltages with respect to negative DC bus (V_{ab}, V_{bc}, V_{ca}), line voltages and subsequently their differences (V_{abbc}, V_{bcca}, V_{caab}) are determined. The model consists of two control loops which are the inner loop and outer loop. The inner loop synchronizes the inverter line voltage different zero crossing signals with the electromotive force. The outer loop controls the motor speed by varying the DC bus voltage [5] [6].

Two control loops are used. The inner loop synchronizes the inverter line voltage different zero crossing signals with the electromotive force. The outer loop controls the motor speed by varying the DC bus voltage. From the line voltage different waveforms, the zero crossing points are detected using the zero crossing detection modelwhich is illustrated in Figure 9.

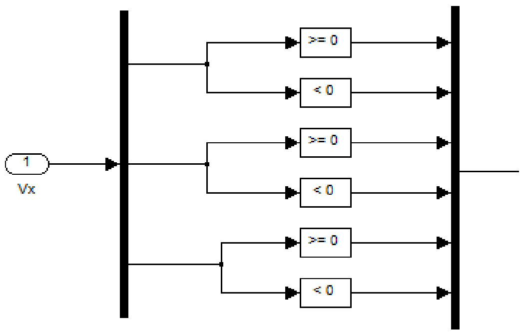

Fig.9 Zero Crossing Detection Model

The zero crossings are decoded to corresponding signals using zero crossing detection decoding system which is shown in Figure 10.

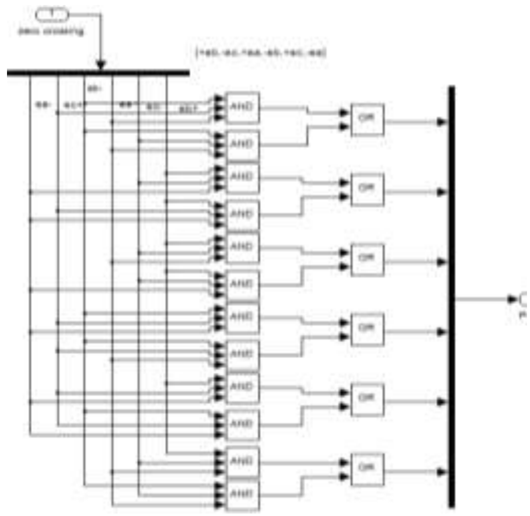

Fig.10 Zero Crossing Decoding Model

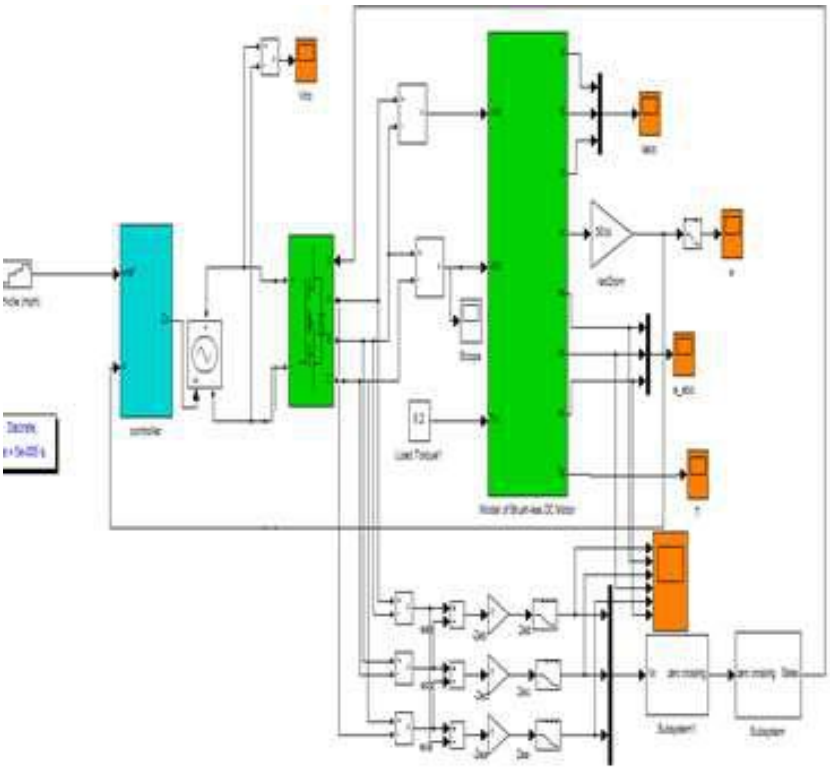

Fig.11 Simulink Closed loop control of BLDC motor with terminal voltage sensing

5. Results:

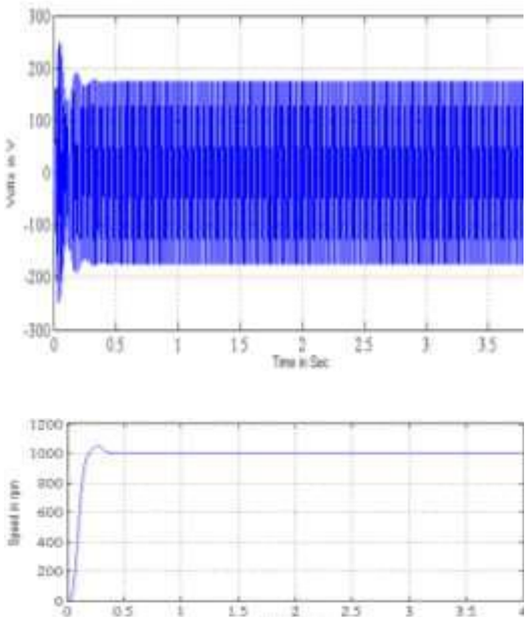

Fig.12 Output voltage and Speed response of BLDC Motor with PI Controller at 1000rpm

The output voltage and speed waveform of speed control for BLDC motor is shown in Figure 12. The speed waveform of speed control rose steadily about 1070rpm during 0.3s period and then reached its steady state condition 0.4s at which the speed was stable at 1000rpm during the simulation period. According to the results, between t = 0.4s and 4s, speed is the constant for 0.2Nm load condition.

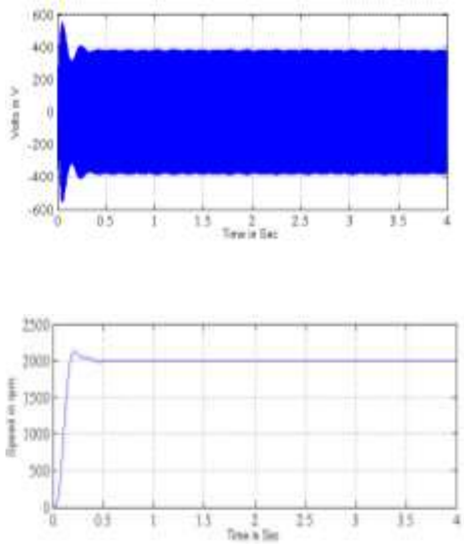

Fig.13 Output voltage and Speed response of BLDC Motor with PI Controller at 2000rpm

The closed loop speed response of BLDC motor described in Figure 13 is considered at 2000rpm at the speed was very quickly with PI controller. When the line to line voltage is unstable during this time, the speed is unstable between 0s and 0.25s. At t = 0.3s, speed is stable from 0.4s to 4s. According to the results, between t = 0.4s and 4s, speed is the constant for 0.2Nm load condition.

6. CONCLUSION:

This paper presents the speed control of BLDC motor using terminal voltage sensing technique with PI controller was implemented using MATLAB/SIMULINK. In sensorless speed control system, a closed loop speed control technique is used for the BLDC motor. In simulation results with PI controller, the speeds of BLDC motor are stable 1000rpm at 0.4s and 2000rpm at 0.4s in 4s durations.

The sensorless speed control system based on the back EMF zero crossing detection method with PI controller produces the best speed error and no steady state error. Therefore, the results of sensorless speed control system with PI controller are able to perfect the stability of the speed variation and less error speed. Therefore, it can be concluded that the simulation of sensorless BLDC motor speed control system is one of the most important applications in electrical engineering field.

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