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SPEED CONTROL OF BLDC MOTOR USING MLI

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ABSTRACT

This paper deals with three phase star connected BLDC motor. Its performance can be predetermined by using multilevel inverters and closed loop PID speed controller. Among the different topologies of multilevel inverters cascaded H-bridge (CHB) is preferred because of special features of it. The performance evolution of the BLDC motor was carried out with the 3-level cascaded H-bridge (CHB) MLI. The dynamics of the PID controller is presented with its control strategy. Different modes of operation of BLDC motor with a specified control signal are analyzed. The simulation results are demonstrated.

***Index Terms*- BLDC motor drive, Multilevel Inverter, PID controller, APOD switching strategy.**

I. INTRODUCTION

BLDC motor found wider applications due to their high power density and ease of control and are widely used in consumer and industrial systems, such as servo motor drives, home appliances, computer peripherals and automotive applications [1-3]. BLDC motor in many cases replaces conventional dc motors [4]. Despite the name, BLDC motors are actually a type of permanent magnet synchronous motors. The design and analysis of complex power electronics system such as motor drives is usually done using software, such as MATLAB/SIMULINK, which can provide accurate predictions of the system behaviour [5]. A simple approach to current sensing pwm control of BLDC motors has been presented [6-7].

The purpose of a motor speed controller in motor drive is to take a signal representing the demanded speed, and to drive a motor at that speed. Closed Loop speed control systems have fast response, but become expensive due to the need of feedback components such as speed sensors. PID controller is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller [8]. A brief introduction to the three main types of multi level converters involves an analysis of diode-clamped, capacitor-clamped and cascade H-Bridge converters.

MLIs divide the main dc supply voltage into several dc sources which are used to synthesize an ac voltage into a stepped approximation of the desired sinusoidal waveform. The stepped approximation is also popularly known as the staircase model. An exhaustive literature survey was done to investigate the research work previously done in the area of MLIs. It is believed that the oldest reference to multi level power conversion is often stated to start with the paper presented by Nabae et al. [9]. Baker [10] patented a method of employing a programmed switching system for an inverter with cascaded stages.

One of the biggest advantages of using a MLI is that the transformer can be eliminated and this helps enhance efficiency and cost effectiveness [11].

This work has been carried out with the objective of, modeling and simulation also to control and performance analysis of cascaded H Bridge, multilevel inverter fed BLDC of the BLDC motor using the software package MATLAB/SIMULINK and to design a speed controller for closed loop operation of the BLDC motor so that the motor runs much closed to the reference speed. Further, for a motor drive with multi carrier PWM modulation technique using the software package MATLAB/SIMULINK.

II. MODELING OF BLDC

Modelling of a BLDC motor can be developed in the similar manner as a three-phase synchronous machine. As any typical three-phase motors, one structure of the BLDC motor is fed by a three-phase voltage source as shown in Fig.1. The source is not necessary to be sinusoidal. Square wave or other wave- shape can be applied as long as the peak voltage is not exceeded the maximum voltage limit of the motor.

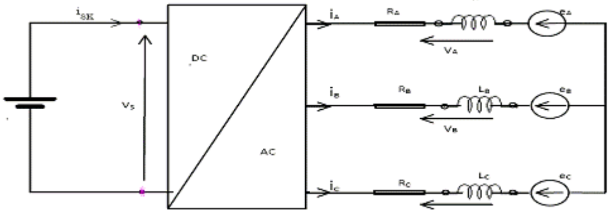

Fig.1. BLDC Model

Applying Kirchhoff’s voltage law for the three phase stator loop winding circuit yields:

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + M_{ab} \frac{di_b}{dt} + M_{ac} \frac{di_c}{dt} + e_a \qquad (1)$$

$$V_b = R_b i_b + L_b \frac{di_b}{dt} + M_{ba} \frac{di_a}{dt} + M_{bc} \frac{di_c}{dt} + e_b \qquad (2)$$

$$V_c = R_c i_c + L_c \frac{di_c}{dt} + M_{ca} \frac{di_a}{dt} + M_{cb} \frac{di_b}{dt} + e_c \qquad (3)$$

Where the back-EMF waveforms e_a, e_b, e_c are functions of angular velocity of the rotor shaft, so

$$e = K_e \omega_m \qquad (4)$$

Where K_e is the back-emf constant

Assume that the rotor has a surface-mounted design, which is generally the case for today’s BLDC motors**,** there is no saliency such that the stator self inductances are independent of the rotor position, hence:

$$L_a = L_b = L_c = L$$

And the mutual inductances will have the form:

$$M_{ab} = M_{ac} = M_{ba} = M_{ca} = M_{cb} = M$$

Assuming three phase balanced system, all the phase resistances are equal:

$$R_a = R_b = R_c = R$$

Electromagnetic torque for this 3-phase BLDC motor is dependent on the current, speed and back-EMF waveforms, so the instantaneous electromagnetic torque can be represented as:

$$T_e = \frac{1}{\omega_m}\left(e_a i_a + e_b i_b + e_c i_c\right) \quad (5)$$

$$T_e = \frac{K_t}{2}\left[f_a(\theta_e)\, i_a + f_b\left(\theta_e - \frac{2\pi}{3}\right) i_b + f_c\left(\theta_e - \frac{4\pi}{3}\right) i_c\right] \quad (6)$$

where K_e and K_t are the back-emf constant and the torque constant. The electrical angle times the number of pole pairs $\left(\theta_e = \frac{p}{2}\theta_m\right)$.

Machine models are often transformed to a rotating reference frame for simplification and to improve computational efficiency. This approach is not used here as it has been shown that when the supply voltage is not sinusoidal, such transformation will not improve computational efficiency.

III. SIMULINK MODEL FOR BLDC MOTOR

As shown in fig.2, the overall block diagram of the developed model for BLDC Motor consists of four main blocks.

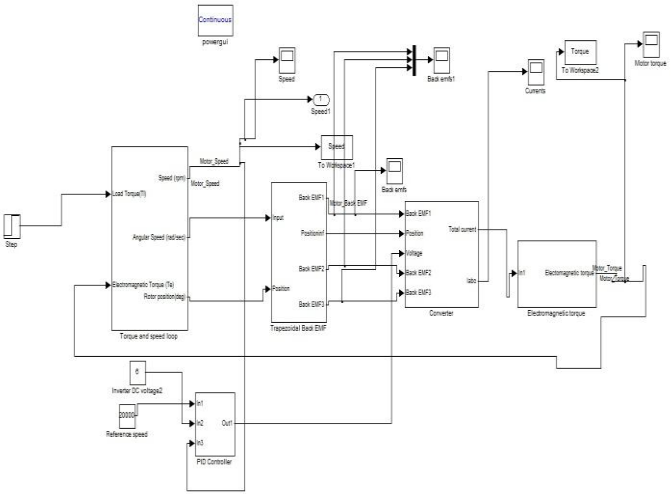

Fig.2. Simulink model for BLDC Motor

A) Speed Control Block

Speed and torque characteristics of the BLDC motor can be explained with equation (7), neglecting the damping factor as

$$\omega = \frac{1}{J}\int \left(T_e - T_L\right) dt;\quad \theta = \frac{1}{J}\int \left(T_e - T_L\right) dt \quad (7)$$

The torque speed block takes in the difference between the electrical torque and mechanical torque and generates the speed and rotor position signals, as shown in fig.3.

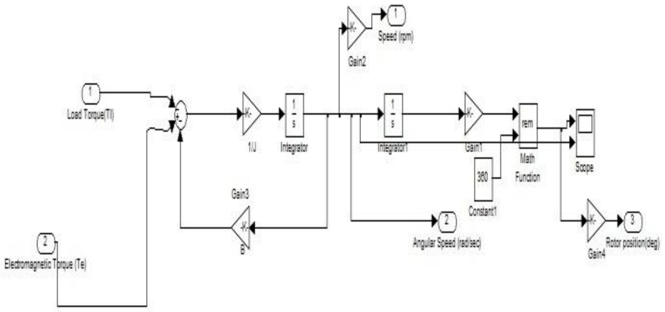

Fig.3. Calculation of Speed – Position signals

B) Back EMF Block

The back EMF is function of rotor position (θ) and the amplitude $E = K_e \cdot \omega_r$ (K_e is the back EMF constant). In this work the modelling of the back EMF is performed under the assumption that all three phases have identical back EMF waveforms.

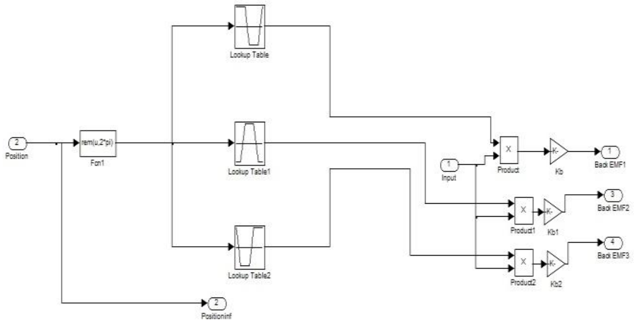

Fig.4. Back-EMF generating block from rotor positions

C) Converter Block

The torque is the function of back emf and rotor position (θ) and phase currents. It is shown in the fig.5. The trapezoidal functions and the position signals are stored in lookup tables.

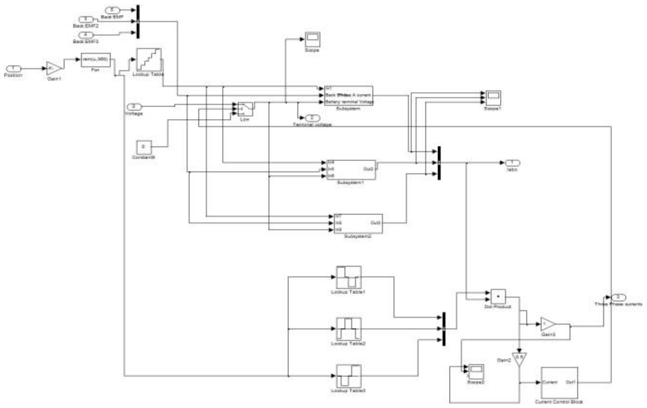

Fig.5. Phase current and torque generating block from rotor positions and Back-EMFs

D) Speed Controller Block

A PID speed controller proposed in this work, for closed loop operation of the BLDC motor is implemented as shown in the fig.8. PID controller is a promotional, integral plus derivative controller whose transfer function is:

$$G_{PID}(s) = K_c\left(1 + \frac{1}{T_i s} + T_d s\right) \qquad (8)$$

The selection of the Proportional, Integral and derivative (PID) controller parameters have been obtained using manual tuning methods. In this method to first Integral gainK_i and Derivative gainK_d values set to zero.

IV. SIMULATION RESULTS

The simulations are done in MATLAB and Simulink using the default solver ode45. The simulation time is 0.15 Seconds.

A plot of torque vs speed is shown in the fig.6. The torque speed characteristics follow a straight line with the exception of the points where notches occur in the torque. The stall torque is about 0.50 mNm which is in accordance with the motor data.

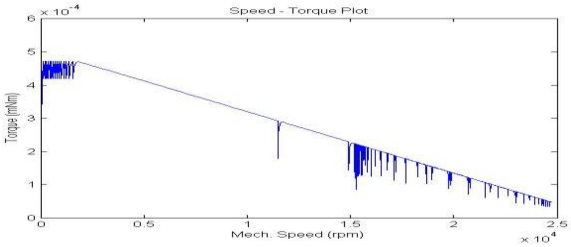

Fig.6. Torque- Speed plot

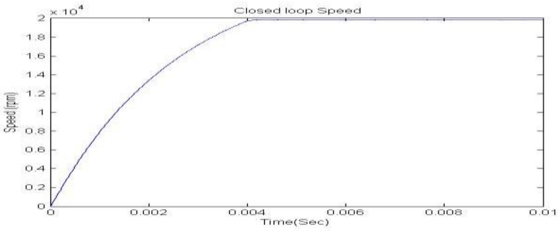

Fig.7. Closed loop Speed

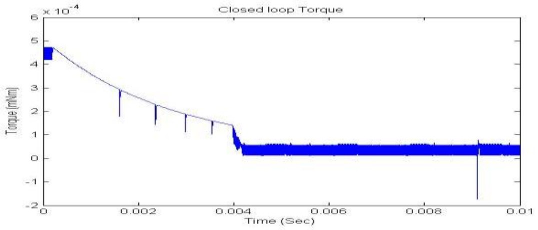

Fig.8. Closed loop Torque

Fig.7 and Fig.8 shows the closed loop speed and torque plots. From the fig.13 it can be observed that, the overshoot in the motor speed response is zero and the steady state error is almost zero. But the speed response is taking more time to reach reference speed the steady state

The model appears to be correct. The torque- speed relationship is linear and the stall torque, no-load speed and no load current all agrees with the values given in the motor’s data sheet.

V. CHBMLI FOR BLDC

This section presents the MATLAB / Simulink implementation of the Cascaded H- Bridge (CHB) multilevel inverter fed BLDC motor. The performance evolution of a 3 level and a 5 level CHB multi level inverter fed BLDC motor with level shifted PWM modulation has been carried out as shown in Fig.9.

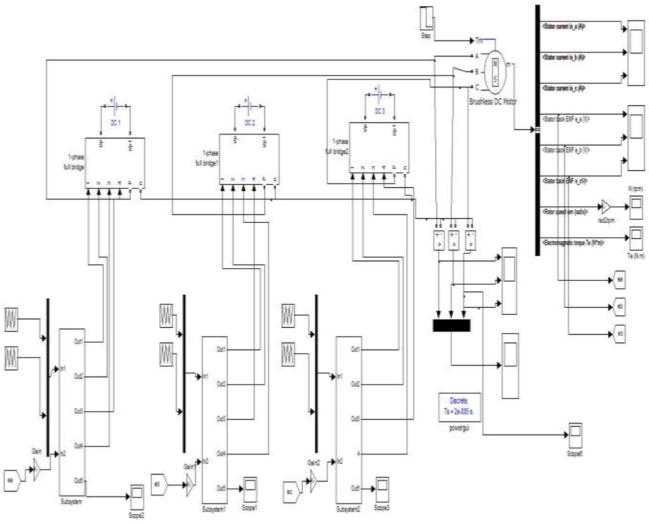

Fig.9. Simulation of the 3- level CHB MLI fed BLDC Motor

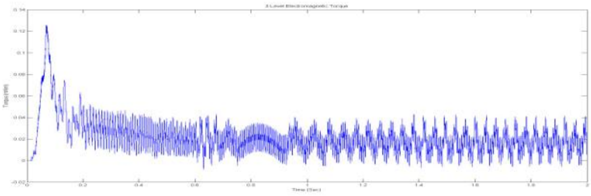

Fig.10. Electro Magnetic Torque

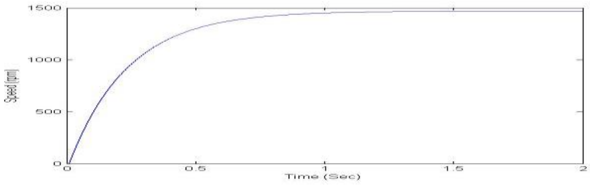

Fig.11. Output Speed

The behaviour of the generated electromagnetic torque is also of vital importance. Fig.10 and Fig.11 shows the generated torque and output speed of the 3-lvel CHB inverter fed BLDC motor.

VI. CONCLUSIONS

This paper presents three phase star connected BLDC motor with six step inverter. By using the provided data sheet of BLDC motor, the performance and parameters are verified. Due to the utilization of BLDC motor manual tuning of PID controller is used. By the PID controller the performance of the motor can be observed. The maximum overshoot value of BLDC motor without PID controller is 25% and with PID controller is nearer to zero. That means it is clear that zero maximum overshoot is a good result for BLDC motor.

The cascaded H-bridge multilevel inverter is successfully implemented to BLDC motor with a level shifted modulation technique. The switching strategy of multilevel inverter with BLDC motor is explained in detail. The modeling of BLDC motor and its performance is demonstrated by using simulation. The performance of the motor is described by using simulation anslysis.

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