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Performance Improvement of BLDC Motor with Hysteresis Current Controller Topology

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Abstract: In the recent past, variable speed driving systems have use in various small scale and large scale applications like automobile industries, domestic appliances etc. This lead to the development in Brushless DC motor (BLDCM). The usage of BLDCM enhances various performance factors ranging from higher efficiency, higher torque in low-speed range, high power density ,low maintenance and less noise than other motors. In this paper hysteresis current controller is implemented with speed feedback loop and it is observe that torque ripples are minimized. Simulation is carried out using MATLAB / SIMULINK. The results show that the performance of BLDCM is quite satisfactory for various loading conditions.

Keywords: Speed controller, feedback loop, Brushless dc (BLDC) motor drive.

I. INTRODUCTION

in permanent-magnet brushless electric motor Over the last few years, with the continuous technology development in power semiconductors , microprocessors, logic ICs, adjustable speed drivers (ASDs) control schemes Due to high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless dc (BLDC) motor, best choice for high performance applications. Due to the absence of brushes and commutator there is no problem of mechanical wear of the moving parts.

As well, better heat dissipation property and ability to operate at high speeds [4] make them superior to the conventional dc machine. However, the BLDC motor constitutes a more difficult problem than its brushed counterpart in terms of modelling and control system design due to dynamics. Due to the simplicity in their control, Permanent-magnet brushless dc motors are more accepted used in high-performance applications. In many of these applications, the production of ripple-free torque is of primary concern. There are three main sources of torque ripple production in BLDCMs: cogging torque, reluctance torque, and mutual torque. Cogging torque is created by the stator slots interacting with the rotor magnetic field and is independent of stator current excitation. Reluctance torque is caused by the variation in phase inductance with respect to position. Mutual torque is created by the mutual coupling between the stator winding current and rotor magnetic field. In general, surface-mounted magnets are used in many high-performance BLDCM's.

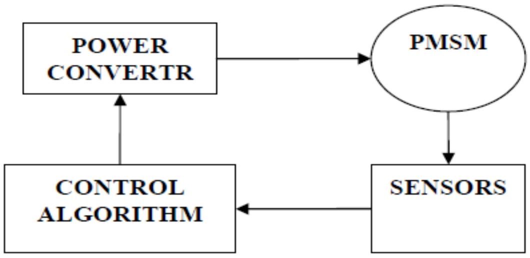

Fig.1 Block Diagram of Bldc motor control

II. MODELLING OF DRIVE SYSTEM

Fig. 1 shows the complete Schematic BLDC drive system with Hysteresis current control loop. It consists of BLDC motor, Inverter, Hysteresis Current Controller, Speed Controller and hall sensor blocks. Each block is modeled separately and integrated together.

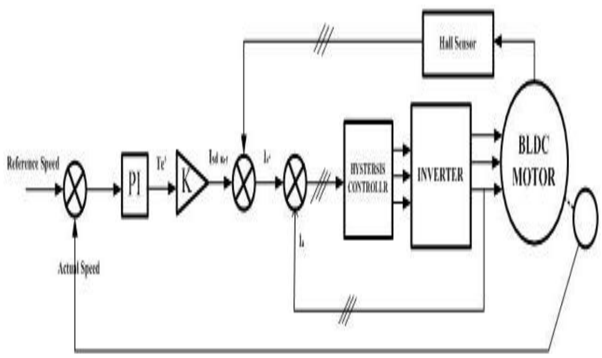

Fig. 2 Schematic of closed loop Two Level Inverter fed BLDC drive with Hysteresis Current controller loop

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A. Modeling of BLDC Motor

Modeling of a BLDC motor can be developed in the similar manner as a three phase synchronous machine. Since its rotor is mounted with a permanent magnet, some dynamic characteristics are different. Flux linkage from the rotor is dependent upon the magnet. Therefore, saturation of magnetic flux linkage is typical for this kind of motors. As any typical three phase motors, one structure of the BLDC motor is fed by a three phase voltage source as shown in Fig. 2. 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. Similarly, the model of the armature winding for the BLDC motor is expressed as follows. Following assumption are made.shown in Fig. 2. 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. Similarly, the model of the armature winding for the BLDC motor is expressed as follows. Following assumption is made.

1. Motor is not saturated as it operated within the rated current
2. There is no changes in the rotor reluctances with angle
3. Three phases are balanced one.

$$va = Ria + Ldia/dt + ea (1)$$

$$vb = Rib + Ldib/dt + eb (2)$$

$$vc = Ric + Ldic/dt + ec (3)$$

Where $L_a = L_b = L_c = L = L_s - M$ [H]
L_s is the armature self inductance
M is the mutual inductance
$R_a = R_b = R_c = R$ Armature resistance in ohm
va,vb,vc Are the terminal phase voltages in volts.
ia,ib,ic Motor input current in amperes
ea,eb,ec Are the motor back emf in volts

Due to the permanent magnet mounted on the rotor, its back emf is trapezoidal as shown in Fig. 3. The expression of back emf must be modified as expressed in

$$e_a\, t = K_E * \emptyset\, \theta * \omega\, t \quad (5)$$

$$eb\, t = KE * \emptyset\, \theta - 2\pi/3 * \omega\, t \quad (6)$$

$$ec\, t = KE * \emptyset\, \theta + 2\pi/3 * \omega\, t \quad (7)$$

Where KE is the back emf constant and ω is the mechanical speed of the rotor.
The permanent magnet also influences produced torques due to the trapezoidal flux linkage. Given that K_T is the torque constant.
The resultant torque, T_E, can be obtained by the following expressions.

$$TE = eaia + ebib + ecic / \omega (8)$$

The resultant torque, T_E, can be obtained by the following expressions.

$$Ta\, t = KT * \emptyset\, \theta * iat \quad (9)$$

$$Tb\, t = KT * \emptyset\, \theta - 2\pi/3 * ibt \quad (10)$$

$$Tct = KT * \emptyset\, \theta + 2\pi/3 * ict \quad (11)$$

$$TE\, t = Ta\, t + Tb\, t + Tct \quad (12)$$

With the Newton's second law of motion, the angular motion of the rotor can be written as follows.

$$TE\, t - TL\, t = Jd\omega\, t/dt + B * \omega\, t$$

Where T_L load torque in N-m
J rotor inertia in [kgm^2]
B damping constant

B. Closed-Loop Controller

The BLDC motor is fed from a three phase two level inverter. The PWM gating signals for firing the power semiconductor devices in the inverter is injected from a hysteresis current controller block, which is required to maintain the current constant within the 60^0 interval of one electrical revolution of the rotor. It regulates the actual current within the hysteresis band around the reference currents.
The reference currents are generated by a reference current generator depending upon the steady state operating mode. The reference currents are of quasi square wave in shape .The magnitude of the reference current is calculated from the reference torque. The reference torque is obtained by limiting the output of the PI controller. Speed error signal i.e. the difference between the reference speed and actual speed of the motor is given to the PI controller which gives the reference torque information. Due to the presence of re outer speed feedback loop the motor will drive at reference speed which is nothing but the closed loop control drive system.

C. Inverter Modeling

Fig. 3 Shows the two level inverter which supplies the input voltage for the three phases of the BLDC motor. It consists of two power semiconductor devices on each phase leg. Firing of the pair power semiconductor devices is based on the hall sensors input. Three phases are commutated for every 60^o. Synchronization between stator and rotor flux is achieved because sensors are the direct feed back of the rotor position,. The inverter is modeled

$$VAn = Q1 * Vdc/2 - Q2 * Vdc/2 \quad (14)$$

$$VBn = Q3 * Vdc/2 - Q4 * (Vdc/2) \quad (15)$$

$$VCn = Q5 * Vdc/2 - Q6 * (Vdc/2) \quad (16)$$

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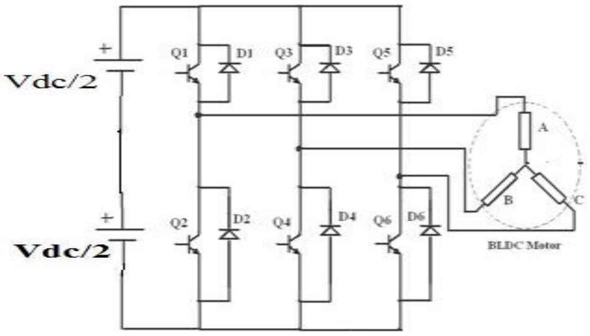

Fig. 3. Two level inverter fed BLDC motor

D. Modeling of Hysteresis current Controller

Fig.4 shows the the block diagram of hysteresis current controller which will generate the gating signals for inverter. The input currents, ia, ib, ic are measured and compared with the reference currents, ia*, Ib*, Ic*. The error is fed to a comparator with a prescribed hysteresis band. Switching of the power semiconductor devices (Q1 ON and Q2 OFF) occurs when the current attempts to exceed a set value corresponding to the desired current. The reverse switching (Q1 OFF and Q2 ON) occurs when the current attempts to become less than iaref. Hysteresis controller is simple to implement and produces a very good quality of waveform. . The drawback of this method is that the switching frequency does not remain constant but varies along different portions of the desired current. The switching pattern is given as:

If ΔIa>H , Q1 is on and Q2 is off. If ΔIa<L , Q1 is off and Q2 is on. If ΔIb>H , Q3 is on and Q4 is off. If ΔIb<L , Q3 is off and Q4 is on. If ΔIc>H, Q5 is on and Q6 is off. If Ic<L, Q5 is off and Q6 is on.

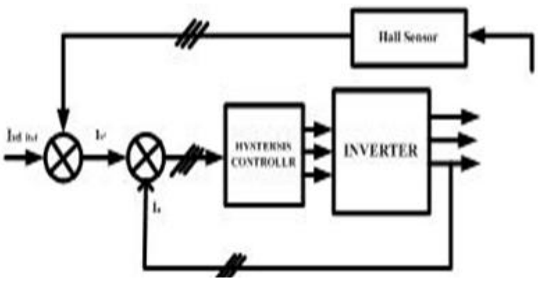

Fig.4 Block dia of hysteresis current controller

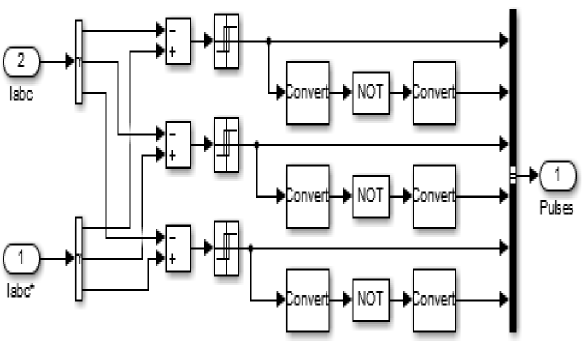

Fig.5 Simulink model of hysteresis current controller

E. Modeling of speed controller block

Fig.5 shows the speed controller block diagram. In this PI controller is used as a speed controller. Speed error i.e. differences between reference speed and actual speed of the motor are the inputs signals to the speed PI controller. Kp and Ki values are determined by trial and error method for each set of speed.

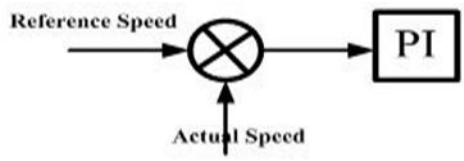

Fig.6 Speed controller block diagram

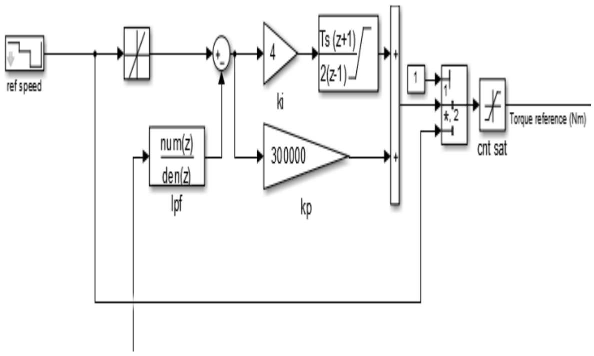

Fig.7 Simulink model of speed controller

The proposed strategy of two level inverter fed BLDC motor Hysteresis current controller is analysed with and without Hysteresis current controller using MATLAB / SIMULINK for the validation of work and results are presented.

III. SIMULATION

A. Without Hysteresis current control loop

Fig.6 Show the simulink block diagram of the closed loop operation of BLDC motor drive without hysteresis control. Fig 07shows that dynamic behavior of the motor when speed reference is set at 3000 rpm.

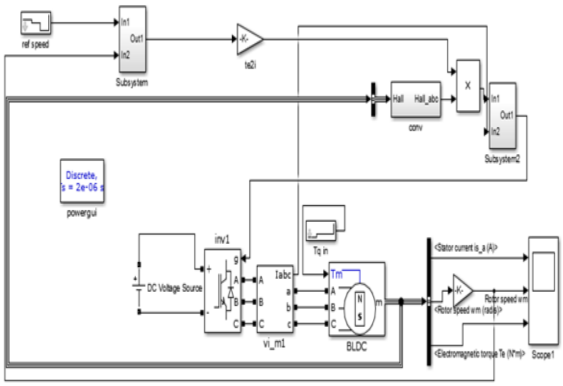

Fig. 8 SIMULINK model of BLDC motor drive without Hysteresis current controller loop.

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A current of 20 amps is observed at the time of starting, at t= 0.04 motor taking a current of 0.1 amps at no load. At t=0.1 second motor is developing a torque of 3Nm and having a steady state stators current of 4.5 amps. Motor speed reached to set value of speed with a very small dip.

B. With Hysteresis current control loop

Fig.06 show the simulink block diagram of the closed loop operation of BLDC motor drive with hysteresis control. Fig. 07 shows the Dynamics of the motor with hysteresis current controller. It is observing that magnitude of starting currents are very less compared with without hysteresis current controller, here the magnitude of starting current is 1.75amps at the time of starting. Fig. 13 shows that motor is developing nearly constant torque from no load to load at t=0.1 sec of 2Nm.

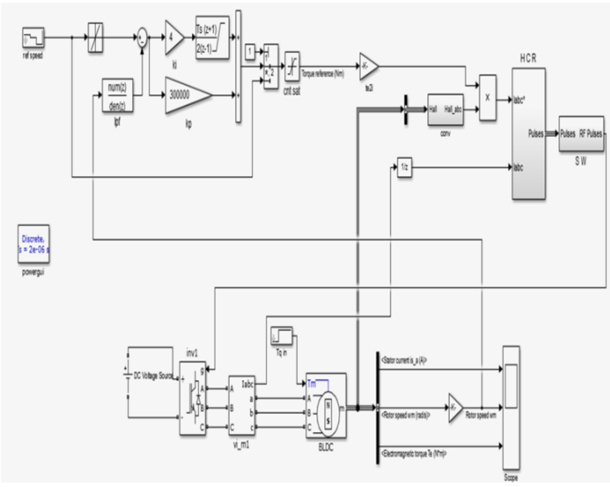

Fig. 9 SIMULINK model of BLDC motor drive without Hysteresis current controller loop

IV SIMULATION RESULT.

i. Without Hysteresis current control loop

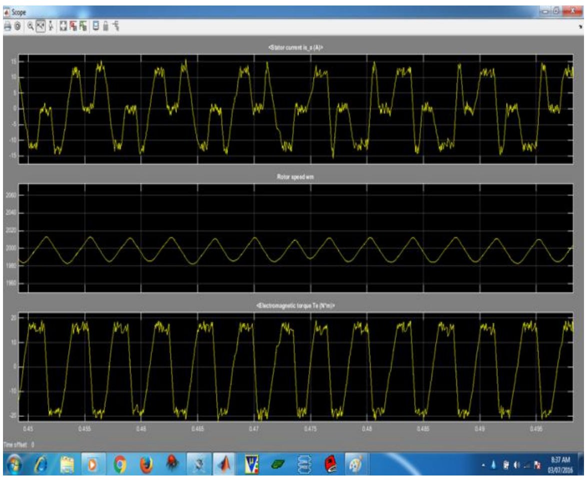

Fig.10 Output waveform of the stator current, speed and torque of the motor

ii. With Hysteresis current control loop

Fig.11 Output waveform of the stator current, speed and torque of the motor

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BIOGRAPHY

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