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Speed Control of Brushless DC Motor using Four Switch Topology

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***Abstract*— In this paper the four switch inverter isimplemented to control the speed of a brushless dc motor. This is the simplification of conventional six switch inverter. The proposed technique is used to reduce the cost and to improve the performance of motor.PID controller is used for outer loop control to develop the concert of the speed control. Designing of the outer speed loop is to improve the static and dynamic characteristics of the system. A current control is to minimize commutation torque for the entire speed and also intelligent schemes have been introduced. The controller design is to improve the enactment of the speed controller and to reduce the computational load. The proposed four level switch inverter using BLDC motor is modeled in Matlab-Simulink environment.**

Index:Brushless DC (BLDC) Motor, Four-switch three phase inverter, Proportional–Integral-Derivative (PID) Controller.

I. INTRODUCTION OF BLDC MOTOR

In the year of 1980s new type of permanent magnet brushless motor has been developed, the permanent magnet brushless motor has classified into two types brushless DC motor and brushless AC motor based on the back emf waveform.

BLDC motor has trapezoidal back EMF and quasi-rectangular current waveform. BLDC motors are rapidly becoming popular in industries such as Appliances, HVAC industry, medical, electric traction, automotive, aircrafts, military equipment, hard disk drive, industrial automation equipment and instrumentation because of their high efficiency, high power factor, silent operation, compact, reliability and low maintenance.

To replace the function of commutator and brushes, the BLDC motor requires an inverter and a position sensor that detects rotor position for proper commutation of current. The rotation of the BLDC motor is based on the feedback of rotor position which is obtained from the hall sensors. BLDC motor usually uses three hall sensors for determining the commutation sequence. In BLDC motor the power losses are in the stator where heat can be easily transferred through the frame or cooling systems are used in large machines. BLDC motors have many advantages over DC motors and induction motors. Some of the advantages are better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation higher speed ranges[1][2][4].

II. MODELLING OF BLDC MOTOR

The flux distribution in BLDC motor is trapezoidal and therefore the d-q rotor reference frames model is not applicable. Given the non-sinusoidal flux distribution, it is prudent to derive a model of the PMBDCM in phase variables. The derivation of this model is based on the assumptions that the induced currents in the rotor due to stator harmonic fields are neglected and iron and stray losses are also neglected. The motor is considered to have three phases even though for any number of phases the derivation procedure is valid. Modeling of the BLDC motor is done using classical modeling equations and hence the motor model is highly flexible. These equations are described based on the dynamic equivalent circuit of BLDC motor.

For modeling and simulation purpose assumptions made are the common star connection of stator windings, three phase balanced system and uniform air gap. The mutual inductance between the stator phase windings are negligible when compared to the self-inductance and so neglected in designing the model. Modeling equations involves,

Dynamic model equation of motion of the motor,

$$W_m = (T_e - T_l) / Js + B \quad (1)$$

T_e = electromagnetic torque, T_l = load torque,
J = moment of inertia, B = friction constant

Rotor displacement can be found out as,

$$\Theta_r = (P/2)\, W_m /s \quad (2)$$

P = Number of poles

Back EMF will be of the form,

$$E_{as} = k_b f_{as} (\Theta_r)\, W_m \quad (3)$$

$$E_{bs} = k_b f_{bs} (\Theta_r)\, W_m \quad (4)$$

$$E_{cs} = k_b f_{cs} (\Theta_r)\, W_m \quad (5)$$

K_b = back EMF constant

Stator phase currents are estimated as,

$$i_a = (V_{as} - E_{as}) / (R+Ls) \quad (6)$$

$$i_b = (V_{bs} - E_{bs}) / (R+Ls) \quad (7)$$

$$i_c = (V_{cs} - E_{cs}) / (R+Ls) \quad (8)$$

R = resistance per phase, L = inductance per phase

Electromagnetic torque developed,

$$T_e = (E_{as} i_{as} + E_{bs} i_{bs} + E_{cs} i_{cs}) / W_m \quad (9)$$

Where

i) V_a,V_b,V_C and are the stator phase winding voltages of phase a, b and c respectively.

ii) The e_a, e_b, and e_c are the back-emfs of phase a, b and c respectively.

iii).I_a,I_b,andI_c, and are the phase currents of phase a, b and c respectively.

iv). T_L is the load torque, J is moment of inertia, ω is angular speed, B is viscous dampingcoefficient.

III. CONVENTIONAL METHOD

Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed depends only on the amplitude of the applied voltage. The amplitude of the applied voltage is adjusted by using the PWM technique. The required speed is controlled by a speed controller. The speed controller is implemented as a conventional PI controller. The difference between the actual and required speed is input to the PI controller and based on this difference, the PI controller controls the duty cycle of PWM pulses, which corresponds to the voltage amplitude required to keep the required speed. The speed controller calculates a Proportional-Integral algorithm according to the following equation

$$u(t)=k_c e(t)+\frac{1}{T1}\int_0^t e(\tau)d\tau \qquad (10)$$

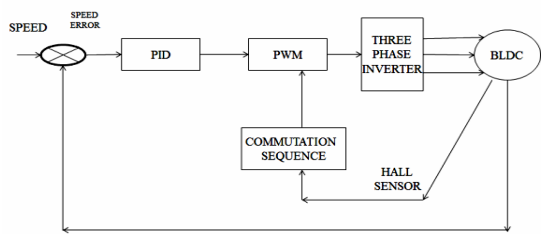

Fig 1. Conventional block diagram for Speed control of BLDC Vdc

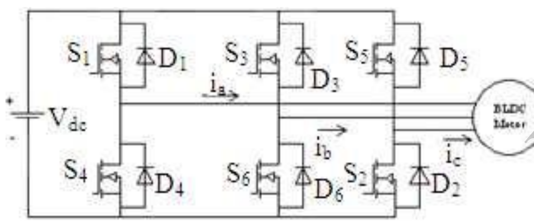

Fig 2.Conventional six-switch inverter used for BLDC motor

Conventional six - switch inverter BLDC motor is used for the common 3-phase BLDC motor, as illustrated in fig 2. The power stage utilizes six power transistors with switching in either the independent mode or complementary mode. In both mode, the 3-phase power stage energizes two motor phases concurrently. The third phase is unpowered. Thus, six possible voltage vectors are applied to the BLDC motor using a PWM technique. There are two basic types of power transistor switching, independent switching and complementary switching, which are discussed in the following sections. Fig. 3 shows the configuration of a four-switch inverter for the three-phase BLDC motor.

It has two common capacitors, instead of a pair of bridges are used and phase c is out of control because it is connected to the midpoint of the series capacitors. From fig. 1, the phase current cannot hold at zero and it causes an additional and unexpected current, resulting in current distortion in phases a and b and even in the breakdown of the system. The same problem is inherited by the four-switch mode and it causes the produced voltage vectors to be limited and asymmetric, which were well known as asymmetric voltage vectors. In Table 1 show the basic operating principle of BLDC.

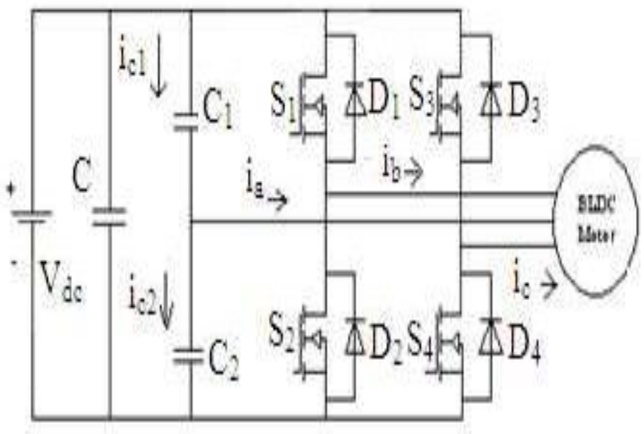

Fig 3.Four-switch inverter for the three-phase BLDC motor

Mode	Hall Value	Working Phases	Current	Conducting Devices
Mode1	101	+a,-b	$I_a=I^*$, $I_b=-I^*$	VS_1,VS_4
Mode2	100	+a,-c	$I_a= I^*$	VS_1
Mode3	110	+b,-c	$I_b=-I^*$	VS_3
Mode4	010	+b,-a	$I_b=I^*$, $I_a=- I^*$	VS_2, VS_3
Mode5	011	+c,-a	$I_a=- I^*$	VS_2
Mode6	001	+c,-b	$I_b=-I^*$	VS_4

Table 1: Operating Modes of Four Switch Three Phase BLDC

IV. PROPOSED METHOD FOR SPEED CONTROL OF BLDC

A. *PID Controller*

The PID controller is a generic control loop feedback controller widely used in industrial control systems. A PID is the most commonly used feedback controller. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs [5]. In the absence of knowledge of the underlying process, a PID controller is the best controller. However, for best performance, the PID parameters used in the calculation must be tuned according to the nature of the system while the design is generic, the parameters depend on the specific system.

The PID controller algorithm involves three separate parameters, and is accordingly sometimescalled three-term control: the proportional, integral and derivative values, denoted P, I, and D. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change [3].

$MV(t)=P_{OUT}+I_{OUT}+D_{OUT}$ (11)

$P_{OUT}=K_P e(t)$ (12)

$I_{OUT}=K_I\int_0^t e(\tau)\, d\tau$ (13)

$D_{OUT}=K_d\frac{de(t)}{dt}$ (14)

Where P_{out} is proportional term of output, K_p is proportional gain, I_{out} is Integral term of output, Ki is integral gain, D_{out} is derivative term of output and K_d is derivative gain.

The proportional, integral and derivative terms are summed to calculate the output of the PID controller. Defining u (t) as the controller output, the final form of the PID algorithm is:

$$u(t)=k_c e(t)+\frac{1}{T1}\int_0^t e(\tau)d\tau+K_d\frac{de(t)}{dt} \quad (15)$$

The PID controller has the following advantages such as an integral controller gives zero steady state error for a step input and a derivative control terms often produces faster response.

B. Tuning Method for PID controller

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. It is performed by setting the I and D gains to zero. The P gain is increased (from zero) until it reaches the ultimate gain Ku, at which the output of the control loop oscillates with a constant amplitude. Ku and oscillation period Tu are used to set the P, I, and D gains depending on the type of controller used. Table 2 shows the tuning formula for PID controller tuning method [5] [3].

Control Type	**K_P**	**K_I**	**K_d**
P	$K_U/2$	-	-
PI	$K_U/2.2$	$1.2K_P/T_U$	-
PID	$K_U/1.7$	$2K_P/T_U$	$K_PT_U/8$

Table 2 Determine the P, I and D Gains by using Ku and Tu Value

C. Proposed Control System

The hybrid control system adopts the double-loop structure. The inner current loop maintains the rectangular current waveforms, limits the maximum current and ensures the stability of the system. [6] The outer speed loop is designed to improve the static and dynamic characteristics of the system. As the system performance is decided by the outer loop, the disturbance caused by the inner loop can be limited by the outer loop. Thus, the current loop adopts the conventional PID controller and the speed loop adopts micro controller. Then, the parameter can be regulated online and the system is adaptable to different working conditions. The whole system is shown in fig. 4. A PID controller is used here as a current regulator.

According to Hall signals, controller works when the motor runs at modes 2, 3, 5 and 6. The Micro controller is taken as a speed controller. The speed difference can be represented as

$e(t)=V^*-V(t)$ (16)

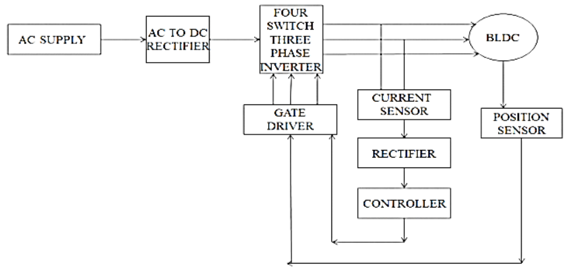

Fig 4. Proposed controller diagram

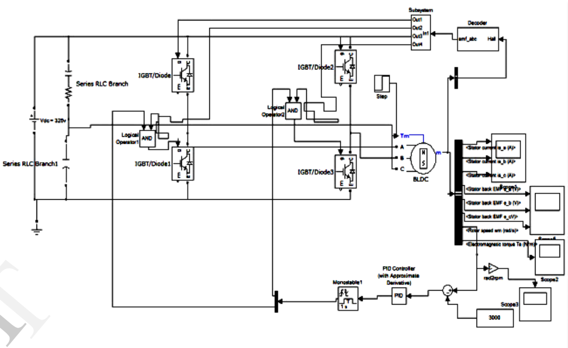

Fig 5. Simulation model of BLDC motor using PID controller.

Where $V^*$is the given speed value and V(t) is the measured speed value at time t. The output of the controller $I^*(t)$ is the threshold value of the current regulator. For the safety of the system, $I^*(t)$ cannot pass beyond the maximum setting value. Then, the input of the current regulator is

$e(t)= I^*(t) - i_c(t)$ (16)

V. SIMULATION RESULTS AND ANALYSIS

Simulink model with the controller for the speed control of BLDC is developed in Mat lab as shown in the Fig. 5. The simulation is run for a specific amount of time (say 2 to 3 secs) in Mat lab with a reference speed of 100 rads / sec (i.e., $314 \times 60/2\pi$) = 3000 rpm & with a load torque of 10 N-m. Simulation using MATLAB, the hybrid controller is more effective than traditional PID controller and micro controller. As the picture shows, the PID controller is non-overshoot and initiate speed curve stable. [8]. When the sudden increase in load or a sudden change in rotational speed adds, this control system has better robustness and faster tracking capabilities than PID controller [3] [5]. It can prove that the system used Micro and PID controller can be more effective in achieving parameter tuning.

The simulation diagram for pulse width modulation inverter is shown in the Fig .6. The input voltage is shown in fig.7 such that the fundamental voltage Vs= 190V. The simulation results of speed and torque curve are shown in the fig .6.and fig .7.

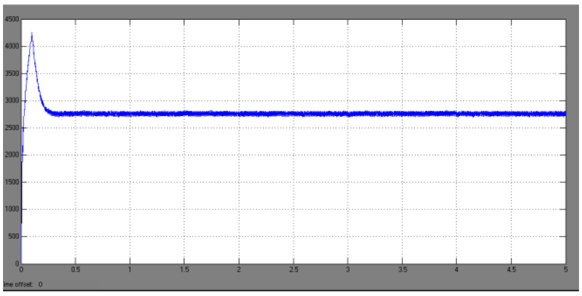

Fig 6.Speed control of BLDC motor

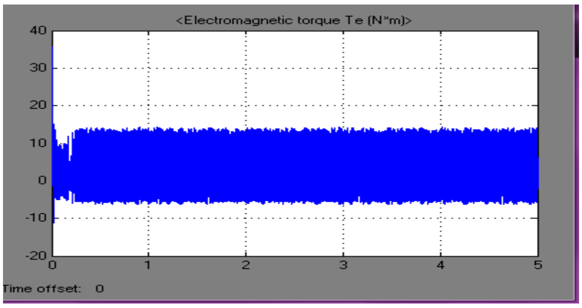

Fig 7. Torque characteristics of BLDC motor

VI. CONCLUSION

In this paper a four-switch three-phase BLDC motor drive is proposed. A PID controller is used by the outer loop to develop the performance of speed control. Simulink models were developed in Mat lab 08 with the PID controller and Micro controller for the speed control of BLDC motor. The main advantage of designing the Microcontroller coordination scheme to control the speed of the BLDC motor is to increase the dynamic performance and provide good stabilization. The cost of the whole system is lowered because only one current sensor is required. It should be noted that reducing the quantity of current sensor surely brings some negative impacts to the control system, such as maximum current limitation in certain modes. Additionally, the program tends to be complicated because a specialalgorithm is necessary as compensation on the reduction of current sensor.

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