Efficient Cost Reduction in BLDC Motor Using Four Switch Inverter and PID Controller

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ABSTRACT: In this paper speed control of three phase BLDC motor using four switch inverter is proposed to simplify the structure of the conventional six switch inverter. It is an adequate try on reducing cost. A strategy which is used as single current sensor control. PID controller is used by the outer loop to develop the performance of speed control. The outer speed loop is designed to improve the static and dynamic characteristics of the system by using Microcontroller. A current control technique is developed to minimize commutation torque for the entire speed range and also intelligent schemes have been introduced. The main focus of the controller design is to improve the performance of the speed controller and to reduce the computational load.

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

I.INTRODUCTION

The adjustable-speed drive is preferred over a fixed speed motor due to velocity or position control and amelioration of transients. The purpose of a motor speed controller is to take a signal representing the demanded speed and to drive the motor at that speed. Brushless DC motors are mostly preferred because they offer several advantages, including long lifetime, reduced noise and good weight/size to power ratio. Brushless DC motors are used in a growing number of applications such as computer hard drives, CD/DVD players and PC cooling fans. Low speed, low power brushless DC motors are used in direct-drive turntables for analog audio records.

Some work has also been done on a sensored four switch BLDC motor drive. The PWM structure for a four-switch three-phase BLDC motor drive produces four floating phases to perceive back electromotive force and to construct six commutations. Based on the crossing points of the voltage of controllable phases, the position information of the rotor can be acquired. The zero crossing points of the stator terminal voltages is detected by using Virtual Hall sensor signals, and there is no need to build a 30∘ phase shift, which is prevalent in most of the sensored algorithms. The PI controller causes the steady state error to reduce to zero. A PI-controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach set point. The system doesn't overshoot, oscillate or hunt regarding the control set point value when the PID loop gains must be reduced.

A four-switch three-phase BLDC motor drive is proposed to simplify the topological structure of the conventional six-switch inverter. The uncontrollable phase current brings about unsymmetrical voltage vector and produces more distortion in its waveform from rectangular. To avoid this problem, direct current control based on hysteresis is used and it senses currents of phases A and B individually by two current sensors and then switches them separately [1] - [4]. The designed four-switch BLDC motor drive shows satisfying performance despite the reduction of current sensor.

In section II discusses about the modeling of BLDC motor. Section III discusses about the conventional method for speed control of BLDC. Section IV introduces a hybrid Micro controller and PID algorithm to the speed regulator to improve the control performances and demonstrates implementation of the control system in detail. The simulation and experimental results are given in section V.

II. MODELING OF BLDC MOTOR

The modeling of BLDC motor drive system is based on the following assumptions
I. All the stator phase windings have equal resistance per phase and constant self and mutual inductances.
II. Power semiconductor devices are ideal.
III. Iron losses are negligible and the motor is unsaturated.

Based on the above assumptions, the three phase input voltages [2] are expressed as follows,

$$V_a = RI_a + L\frac{di}{dt} + e_a \qquad (1)$$

$$V_c = RI_c + L\frac{di}{dt} + e_c \qquad (2)$$

$$V_b = RI_c + L\frac{di}{dt} + e_b \qquad (3)$$

The electromagnetic torque is termed as,

$$T_e = \frac{1}{\omega}(e_a I_a + e_c I_c + e_b I_b) \qquad (4)$$

The electromagnetic torque can also be termed as,

$$T_e = \frac{2EI}{\omega} \qquad (5)$$

$$E = e_a = e_b = e_c \qquad (6)$$

$$I = I_a = I_b = I_c \qquad (7)$$

The electromagnetic torque can be interpreted in terms of mechanical parameters as,

$$T_e = T_L + J\frac{d\omega}{dt} + B\omega \qquad (8)$$

Where
i. The stator phase winding voltages of phase a, b and c are given as V_a, V_b and V_c.
ii. The e_a, e_b and e_c are the back- emfs of phase a, b and c respectively.
iii. The phase currents of phase a, b and c are I_a, I_b and Ic.
iv. T_L is the load torque, J is moment of inertia, ω is angular speed, and B is viscous damping coefficient.

III. CONVENTIONAL METHOD FOR SPEED CONTROL OF BLDC

Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed calculates only on the amplitude of the applied voltage. The amplitude of the realistic voltage is adjusted by using the PWM technique. The vital speed is controlled by a speed controller. The speed controller is applied as a conventional PI controller. The disparity between the actual and required speed is input to the PI controller and based on this difference, the duty cycle of PWM pulses are controlled by the PI controller, 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

$$u(t) = k_c e(t) + \frac{1}{T1} \int_0^t e(\tau).d\tau \qquad (9)$$
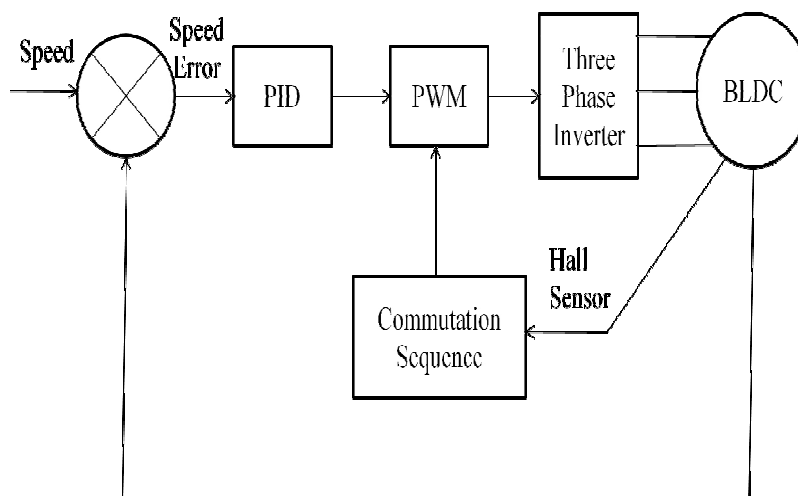

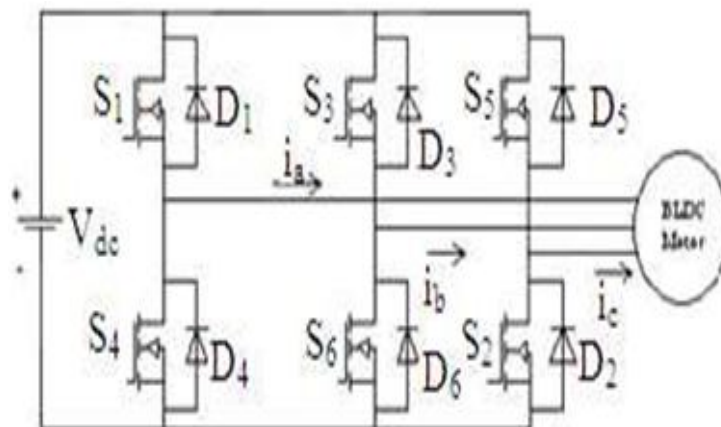Fig.1 Conventional block diagram for Speed control of BLDC

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 theindependent 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 different basic types of power transistor switching and complementary switching, independent switching, which are expressed 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. 2, the phase current cannot hold at zero and it causes an additional and unexpected current, propagate in current distortion in phases a and b and even in the breakdown of the system. The same problem is acquired by the four-switch mode and it causes the produced voltage vectors to be limited and asymmetric, which were important as asymmetric voltage vectors. In Table 1 show the basic operating principle of BLDC.
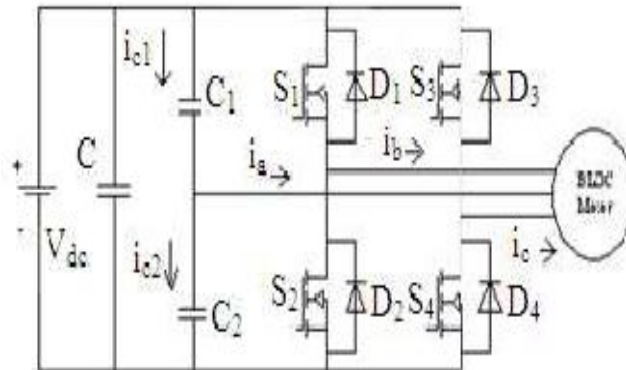

Fig 3.Four-switch inverter for the three-phase BLDC motor

Table 1: Operating Modes of Four Switch Three Phase BLDC

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

IV. PROPOSED METHOD

A. PID Controller

The PID controller is a collective control loop feedback controller widely used in industrial control systems. An error value is the difference between a measured process variable and a desired set point is calculated by using a PID controller calculates. The controller makes an attempt to cut back the error by adjusting the method control inputs [5]. The PID parameters used in the calculation must be regulating according to the kind of the system while the design is standard; the parameters be suspended on the specific system.

The PID controller algorithm implicate three separate parameters, and is therefore sometimes called three-term control: the proportional, integral and derivative values, indicated P, I, and D. The proportional value determines the reaction to this 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 dynamic. The weighted sum of these three actions is employed to regulate the method via a bearing part like the position of a control valve or the power supply of a heating element. Heuristically, these values are taken in terms of time: P depends on the present error, I on the buildup of past errors, and D could be a prediction of future errors, supported current rate of amendment [3].

$$MV(t) = P_{OUT} + I_{OUT} + D_{OUT} \qquad (10)$$
$$P_{OUT} = K_{pe}(t) \qquad (11)$$
$$I_{OUT} = K_t \int_0^t e\,(\tau)d\tau \qquad (12)$$
$$D_{OUT} = K_d \frac{de(t)}{d(t)} \qquad (13)$$

Where Pout is proportional term of output, K_p is proportional gain, I_{OUT} is Integral term of output, K_i 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 PIDcontroller. The controller output is defined as u(t), the final form of the PID algorithm is:

$$u(t) = K_c e(t) + \frac{1}{T_1} \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \qquad (14)$$

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 exaggerated (from zero) till it reaches the definitive gain Ku, at which the output of the control loop oscillates with constant amplitude. Table 2 shows the tuning formula for PID controller tuning method [5] - [6].

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

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

Proposed Control System

The hybrid system adopts the double-loop structure. The inner current loop maintains the oblong current waveforms, limits the utmost current and ensures the steadiness of the system. The outer speed loop is intended to enhance the static and dynamic characteristics of the system. The disturbance caused by the inner loop is restricted by the outer loop because the system performance is set by the outer loop. Thus, this loop adopts the conventional PID controller and therefore the speed loop adopts microcontroller. 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 termed as

$$e(t) = V^* - V(t) \qquad (15)$$

Where V^* is the given speed value and $V(t)$ is the measured speed value at time t. The output of the Micro controller $I^*(t)$ is the threshold value of the current regulator. For the safety of thesystem, $I^*(t)$ cannot pass beyond the maximum setting value. Then, current regulator input is given in the expression.
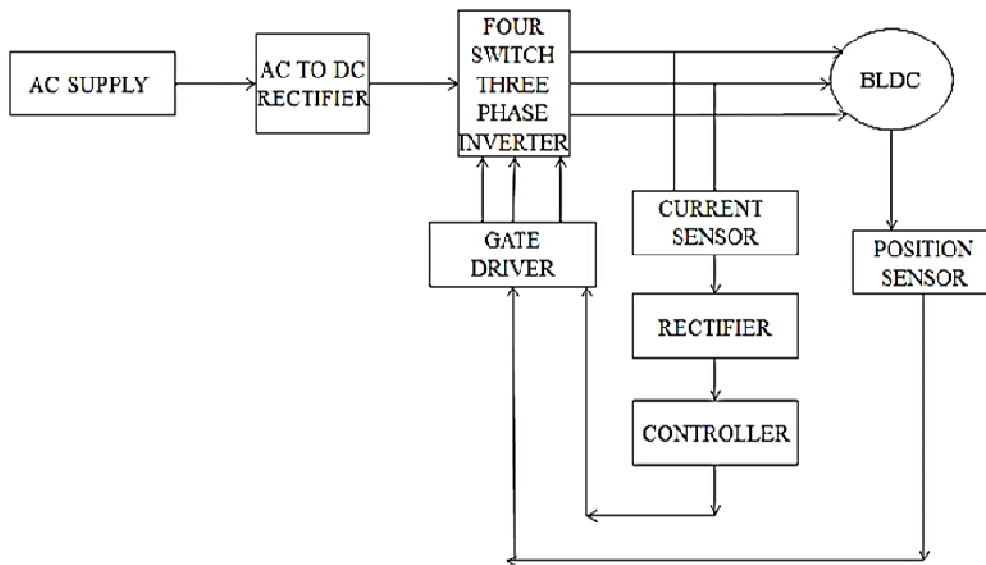
$$e(t) = I^*(t) - i_c(t) \qquad (16)$$

Fig.4 Proposed Controller Diagram

V. SIMULATION RESULTS AND ANALYSIS

Simulink model with the controller for the speed control of BLDC is developed in Matlab 08 as shown in the Fig. 5. The simulation is run for a specific amount of time (say 2 to 3 secs) in Matlab 08 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.
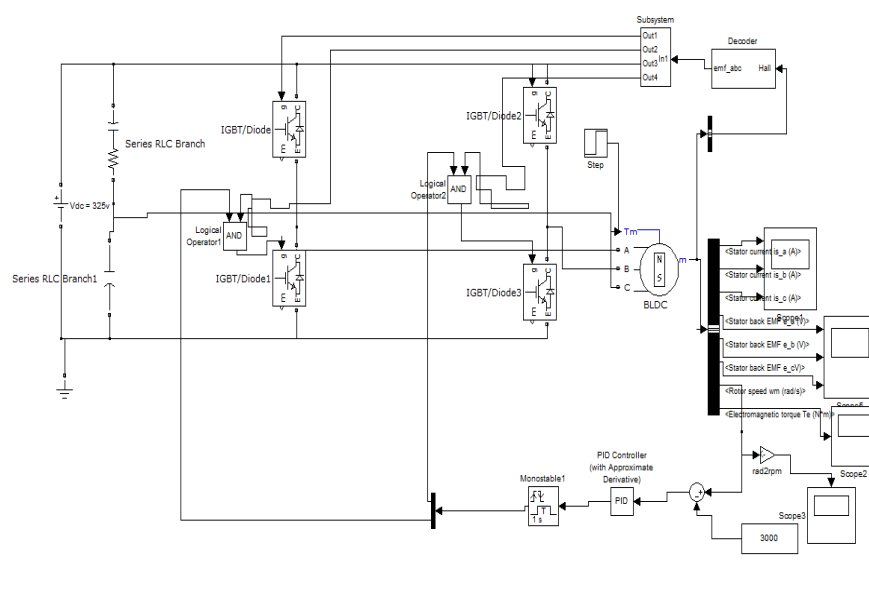
Fig.5 Simulation model of BLDC motor using Micro controller and PID controller.

Simulation using MATLAB 08, the hybrid controller (Micro and PID 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. When the sudden increase in load or a sudden change in rotational speed add, this control system has better robustness and faster tracking capabilities than PID controller [8] - [11]. It can prove that the system used Micro and PID controller can be more effective in achieving parameter tuning.

The input voltage is the fundamental voltage Vs= 190V. The simulation results of speed and torque curve are shown in the fig.6 and fig.7.
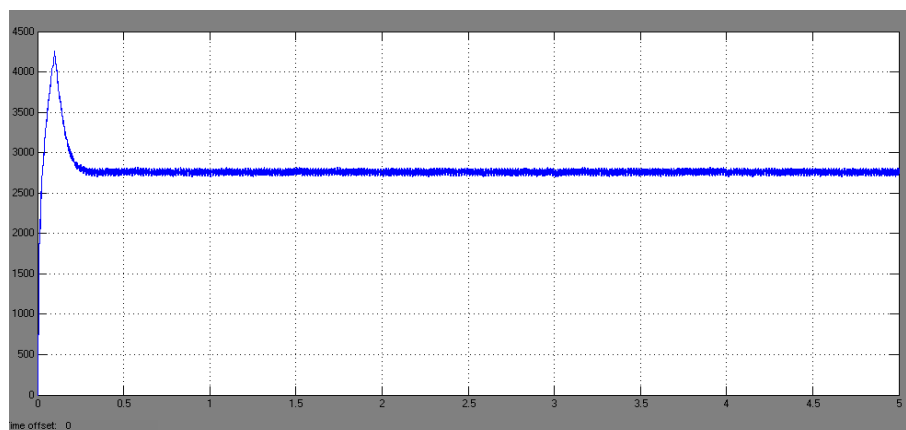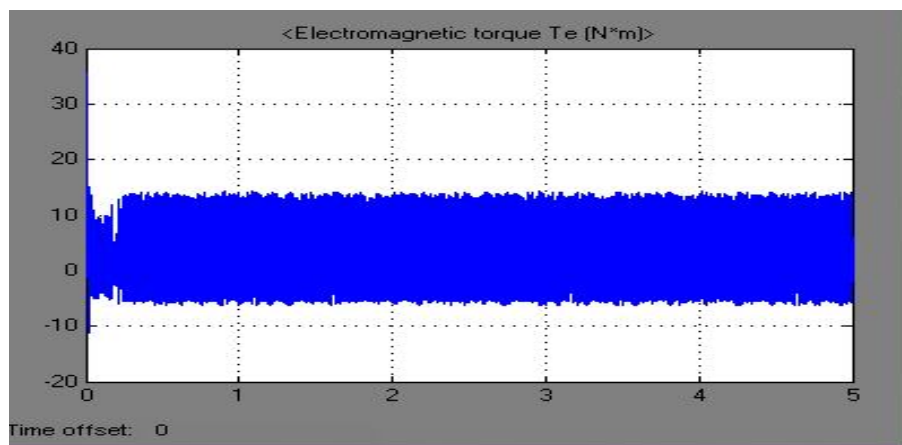

Fig.6 Speed Characteristics of BLDC Motor

Fig.7 Torque Characteristic 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 Matlab 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 amount of current detector certainly brings some negative impacts to the control system, like most current limitation in certain modes. Additionally, the program tends to be difficult because a special algorithm is necessary as compensation on the reduction of current sensor.

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BIOGRAPHY

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