SPEED CONTROL OF THREE PHASE BLDC MOTOR USING FOUR SWITCH INVERTER

M.Vignesh kumar[1]

[1] *P.G. Scholar Karpagam University Coimbatore.*
1 m.vigneshkumarme@gmail.com

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 effective try on reducing cost. A single current sensor control strategy is used. 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:, 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 energy saving, velocityor position control and amelioration of transients. The purpose of a motor speed controller is to take asignal 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. High power BLDC motors are found in electric vehicles, hybrid vehicles and some industrial machinery.

Some work has also been done on a sensored four switch BLDC motor drive. An asymmetricPWM scheme for a four-switch three-phase BLDC motor drive to make six commutations and produce four floating phases to detect back electromotive force. The position information of the rotor can beacquired based on the crossing points of the voltage of controllable phases. Virtual Hall sensor signals are made by detecting the zero crossing points of the stator terminal voltages, and there is no need to build a 30◦ phase shift, which is prevalent in most of the sensored algorithms.[7] The PI controller causesthe steady state error to reduce to zero. A PI-controlled system is less responsive to real and relativelyfast alterations in state and so the system will be slower to reach set point. The PID controllers, whenused alone, can give poor performance when the PID loop gains must be reduced so that the controlsystem does not overshoot, oscillate or hunt about the control set point value. They also have difficultiesin the presence of non-linear ties, may trade off regulation versus response time, do not react tochanging process behavior and have lag in responding to large disturbances.

Afour-switch three-phase BLDC motor drive is proposed to simplify the topological structure of the conventional six-switch inverter. Theuncontrollable phase current causes unsymmetrical voltage vectorand its waveform is much of distortion from rectangular. The direct current control based on hysteresis avoids this problem and it senses currents of phases A and B individually by two current sensors andthen switches them separately [1][2][4].

To exploit the four-switch BLDC motor drive's advantage oflower cost, a single-current-sensor control strategy is proposed. The designed four-switch BLDC motor drive shows satisfying performance despite the reductionof current sensor. In section II discusses about the modeling of BLDC motor. Section III discusses aboutthe conventional method for speed control of BLDC. Section IV introduces a hybrid Micro controller and PIDalgorithm to the speed regulator to improve the control performances and demonstrates implementationof the control system in detail. Finally, simulation and experimental results are given in section V.

II. MODELINGOF BLDCMOTOR

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,

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

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

$$V_b=RI_b+L\frac{di}{dt}+e_b \quad (3)$$

The electromagnetic torque is expressed as,

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

The electromagnetic torque can also be expressed as,

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

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

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

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

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

Where

i. V_a,$V_b$andV_c 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,$I_b$andIc 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 FOR SPEED CONTROL OF BLDC

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

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

ISSN 2229-5518

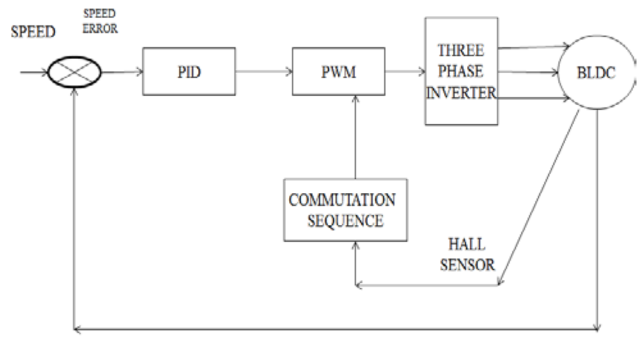

Fig 1. Conventional block diagram for Speed control of BLDC Vdc

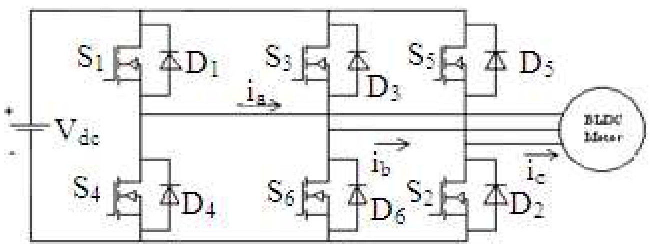

Fig 2.Conventional six-switch inverter used for BLDC motor

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 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 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. 2, 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.

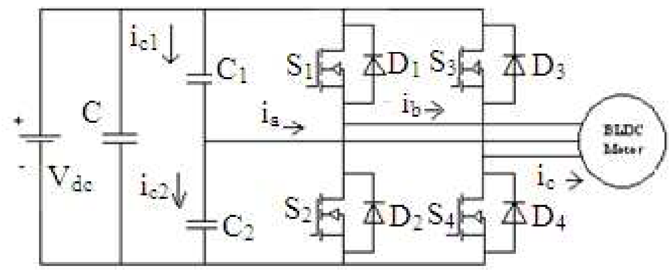

Fig 3.Four-switch inverter for the three-phase BLDC motor

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. PROPOSEDMETHOD FOR SPEED CONTROL OF BLDC

A. PID Controller

The PID controller is a generic control loop feedback controller widely used in industrial controlsystems. A PID is the most commonly used feedback controller. A PID controller calculates an errorvalue as the difference between a measured process variable and a desired set point. The controllerattempts 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

ISSN 2229-5518

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 sometimes called three-term control: the proportional, integral and derivative values, denoted P, I, and D. Theproportional 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].

$MV(t)=P_{OUT}+I_{OUT}+D_{OUT}$ (10)

$P_{OUT}=K_P e(t)$ (11)

$I_{OUT}=K_t\int_0^t e(\tau)\,d\tau$ (12)

$D_{OUT}=K_d\frac{de(t)}{dt}$ (13)

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 PIDcontroller. Defining u (t) as the controller output, the final form of the PID algorithm is:

$$u(t)=k_c e(t)+\frac{1}{T1}\int_0^t e(\tau)d\tau+K_d\frac{de(t)}{dt} \quad (12)$$

The PID controller has the following advantages such as an integral controller gives zero steady stateerror 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 theultimate 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].

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	$K_U/1.7$	$2K_P/T_U$	$K_PT_U/8$

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

ISSN 2229-5518

$$e(t)=V^{*}-V(t) \quad (13)$$

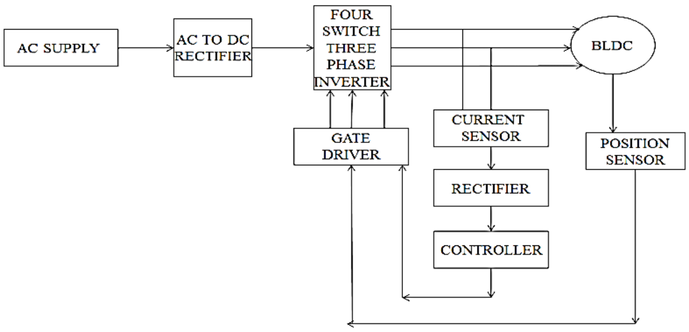

Fig 4. Proposed controller diagram

Where $V^{*}$is the given speed value and V(t)is the measured speed value at time t. The output ofthe Mirco 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, the input of the current regulator is

$$e(t)= I^{*}(t) -i_c(t) \quad (14)$$

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 08with a reference speed of 100 rads / sec (i.e., 314 × 60/2π) = 3000 rpm & with a load torque of 10 N-m.

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.[8].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 [3] [5].It can prove that the system used Micro and PID controller can be more effective in achieving parameter tuning.

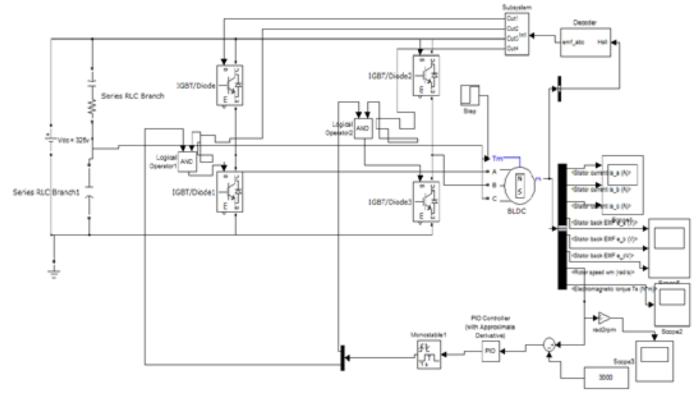

Fig 5.Simulation model of BLDC motor using Micro controller and PID controller.

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.

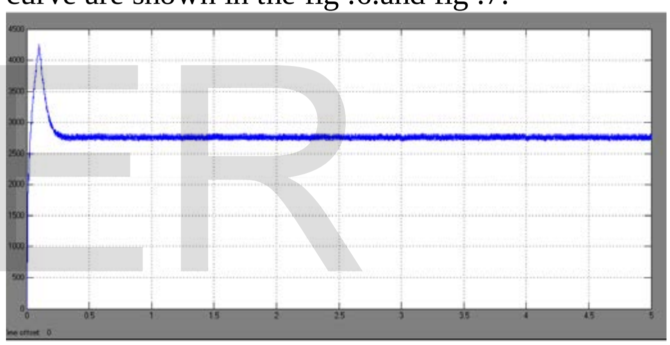

Fig6 . Speed characteristics of BLDC motor

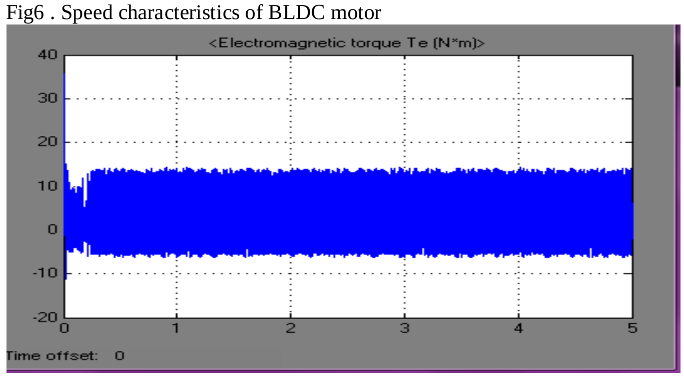

Fig7 .Torque characteristic of BLDC motor

VI. CONCLUSION

In this paper a four-switch three-phase BLDC motor drive is proposed. A PID controller is used bythe 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 theMicrocontroller 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 special algorithm is necessary as compensation on the reduction of current sensor.

REFERENCES

[1] Caricchi.F ,GiuliiCapponi.F, Crescimbini.F and Solero.L "Sinusoidal Brushless Drive with Low-Cost Linear Hall Effect Position Sensors" IEEE Conf. pp.799-804, 2001.

[2] Changliang Xia, Zhiqiang Li, and Tingna Shi "A Control Strategy for Four-Switch Three-Phase
Brushless DC Motor Using Single Current Sensor" IEEE Trans. Ind. Electron, Vol. 56, no. 6, pp
2058 – 2066, June 2009.

[3] Chun-Liang Lin, Horn-Yong Jan, and Niahn-Chung Shieh "GA-Based Multiobjective PID Control for a Linear Brushless DC Motor" IEEE Trans. MECH, Vol. 8, No. 1, pp. 56 – 65, March 2003.

[4] Gui-Jia Su, and John W. McKeever "Low-Cost Sensorless Control of Brushless DC Motors With
Improved Speed Range" IEEE Trans. Pow. Electron, Vol. 19, no. 2,pp. 296–302, March 2004.

[5] Hang C-C. K. J. Astrom and W. K. Ho, ''Refinements of the Ziegler-Nichols tuning formula", IEEE Proc. Part D, vol. 138, No. 2, pp. 11 1-1 18, March 1991.

[6] J.-H. Lee, T.-S.Kim, and D.-S. Hyun, "A study for improved of speed response characteristic in
four-switch three-phase BLDC motor," in Proc. IEEE Ind. Electron. Soc. Conf., 2004, vol. 2, pp.
1339–1343.

[7] Microchip Technology, "Brushless DC (BLDC) motor fundamentals", Application note, AN885,2003.

[8] P. Pillay and R. Krishnan, "Modeling, simulation and analysis of permanent-magnet motor drives. II. The brushless DC motor drive," IEEE Trans. Ind. Appl., vol. 25, no. 2, pp. 274–279, Mar./Apr. 1989.

[9] Q. Fu, H. Lin, and H. T. Zhang, "Single-current-sensor sliding mode driving strategy for four-switch three-phase brushless DC motor," in Proc. IEEE Ind. Technol. Conf., 2006, pp. 2396–2401.

[10] S.-H. Park, T.-S.Kim, S.-C.Ahn, and D.-S. Hyun, "A simple current control algorithm fortorque ripple reduction of brushless DC motor using four-switch three-phase inverter," in Proc. IEEEPower Electron. Spec. Conf., 2003, vol. 2, pp. 574–579.