SPEED CONTROL AND MINIMIZATION OF TORQUE RIPPLES IN BLDC MOTOR USING PI, SMC AND SMC-PWM TECHNIQUES

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Abstract - *Brushless DC motors Controlled through electronic commutation whose motor position is sensed using Hall Sensors. In this paper, initially the responses of BLDC motor are observed by using PI and SMC Controllers. The Sensitivity of PI towards the constraint variations and unexpected torque disturbances, PI Controller replaced with Sliding Mode Controller (SMC). SMC is an effective synthesis technique for Non-Linear uncertain systems with fast and robust transient responses. This paper deals with a new control technique based on PWM control of brushless DC motor (BLDC). PWM technique is broadly used in motors which are controlled using power converters. Also it controls analog systems with digital processing outputs.*

Key Words: BLDC, Sliding Mode Control (SMC), PWM, Matlab Simulink.

1. INTRODUCTION:

A brushless DC motor (BLDC) is a PMSM motor with trapezoidal back emf and electronically commutated system [1]. The permanent magnet synchronous motors (PMSM) have the advantage of high efficiency, high torque density, less volume and less maintenance which are satisfied with EV accurate necessities [2-3]. BLDC motors have less noise and large durability. The main advantage of this motor is that it can be controlled by using feedback mechanisms for faster speed responses and less ripples in torque. In conventional PI controller, the motor performance may result disturbances in torque due to variations in parameters and its sensitivity towards the uncertainty nature of the system. In order to conquer this disadvantage, Sliding mode control (SMC) is adopted. Generally the practical BLDC motor is non linear and there are number of disturbances, to overcome these disadvantages and to improve the performance of motor SMC is adopted. Even though SMC is vigorous to changes that occur in motor, the increment of gains which is used for controlling purpose causes chattering effect which is not desirable and causes ripples in the responses and also results high frequency switching in converters.

To overcome these disadvantages PWM technique with SMC controllers is implemented in this paper. PWM technique encodes the analog value to digital values by controlling duty cycle

The method of implementing SMC controller:

1. Initially observing the convergence and setting of the control law.
2. Later establish the sliding mode at the initial time to give the robust behaviour of the implemented control law all over the system response.
3. The making of the path enabling the convergence in finite time [5], [6].

In this work overview of control of BLDC motor using PI controller and sliding mode control is observed. Later the control of motor with SMC PWM technique is observed. The results obtained in simulation and a conclusion where we emphasize the interest of this method of control.

2. CONTROL OF BLDC MOTOR

The control methods of DC motor are divided into two categories. One of them is scalar control which the required speed of motor is obtained by controlling the stator voltage amplitude and frequency. This method is suitable for the constant loads but it is not applicable for the motors with the dynamical varying loads. And the other is vector control which has the best dynamic responses.

Controlling the motor simply by varying the supply voltage is the open loop control of the motor. In order to overcome the external disturbances and deviation from the required results and the torque ripples closed loop control is implemented. This is obtained by using the sensors which senses the output of the motor, controller and PWM circuit to generate the pulses to the inverter for proper flow of current to the each phase windings.

3. BLOCK DIAGRAM:

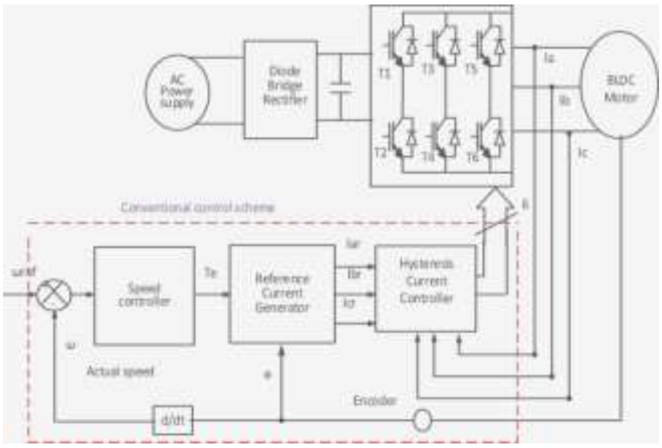

Fig.1. Overall control structure of BLDC motor

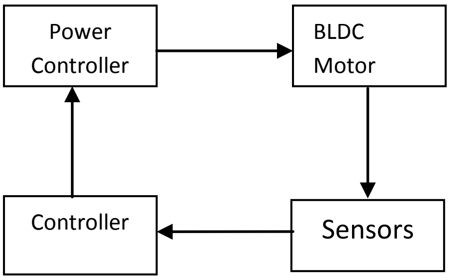

Fig.2. Block Diagram of BLDC motor with Hall Sensors

The BLDC motor is powered by DC supply via inverters whose gate pulses are given based on the rotor position sensed by the sensors and by using PWM technique.

There exists an error between the measured value and the desired value. So, to correct that error controllers are implemented in controlling of BLDC motors.

3.1 Design of PI controller:

There are two separate modes i.e., Proportional mode & integral mode present in PI controller. The proportional mode rectifies the current error that is caused in system and the integral mode calculates the recent error.

PI controller is implemented as,

Reference Torque=Output= $K_p e(t) + K_I \int_0^t e(t)\, d\tau$

Where, $e(t) = \omega_{ref} - \omega_m(t)$

K_p & K_I = gain of controller

ω_{ref} = Reference value

ω_m = desired value

3.2 design of SMC controller:

PI controller is simple but sensitive to the variations caused in parameters due to temperature variations etc and external disturbances and non linear nature of the motor. SMC is well suited for tracking the performance of the system against the uncertainties and disturbances in practical motors.

Sliding Mode Design involves two tasks:

1. Selection of state sliding surface.

2. Designing control law.

Origin of co-ordinate axes considered as the stable equilibrium, the control law is designed in such a way to force the trajectory into the sliding surface, S and to travel towards the stable equilibrium (where origin is considered).

The sliding surface, $S=(\frac{d}{dt} + \alpha)^{n-1} e$

Where, n= system order

e=tracking error signal

α=constant.

Reaching Condition, $s\dot{s} < 0$

Reaching law, $\dot{s} = -\varepsilon\, \mathrm{sgn}(S) - KS$

The mathematical modeling of BLDC motor is same as the mathematical model of a DC motor. Only the difference is that, in BLDC motor the switching between different modes of state trajectory is caused by the electronic commutator.

The voltage applied to the motor is considered as the electrical part of the motor,

$$V = iR + L\frac{di}{dt} + E$$

i= current in ampere

L=inductance of winding in henry

R=Resistance of winding in ohms

E=back emf of motor

K_b=back emf constant in volts/rad/sec

W=speed of motor in rad/sec

$$\frac{di}{dt} = (-E - iR + V)\frac{1}{L}$$

Mechanical part of model obtained as,

$$T = J\frac{dw}{dt} + Bw + T_L$$

T=Torque in Newton-Meter

J=moment of inertia

T_L=disturbance input

$$\frac{dw}{dt} = (-Bw + T - TL)\frac{1}{J}$$

Block diagram of SMC consists two loops. One controller is current loop and the other is for speed loop.

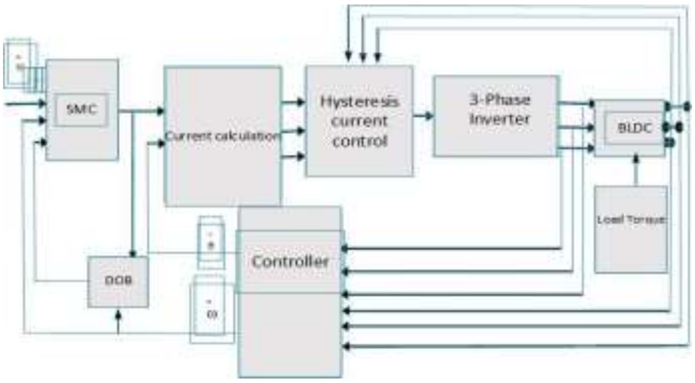

Fig.3. Overall block diagram of SMC with BLDC motor

For inner current loop,

$$V = L[\alpha \operatorname{sgn}(S_1) + \rho S_1 + \frac{d\tilde{i}}{dt}] + E + (\tilde{i} - e_1)R$$

Where, α & ρ are constants,

e_1 is the current error signal,

S_1 is SMC controller for current loop.

i.e. $S_1 = e_1 = \tilde{i} - i$

For over loop,

$$T = J[\Upsilon \operatorname{sgn}(S_2) + \zeta S_2 + \frac{d\tilde{\omega}}{dt}] + T_L + (\tilde{\omega} - e_2)B$$

Where ϒ& ζ are constants,

e_2 is speed error signal,

S_2 is SMC controller for speed loop

i.e. $S_2 = e_2 = \tilde{\omega} - \omega$

4. PROCEDURE OF THE CONTROL SYSTEM DESIGN

Control of system require four feedback signals, which are three rotor position sensed signals and speed of the motor. The speed error is obtained by comparing the sensed motor speed which is given as feedback and the required speed. The error signal thus obtained is given to speed controller. The output of this controller is the torque. By using the torque constant the reference current is derived. This current is compared with the currents obtained at the rotor. This error is given to the another loop caller current controller loop resulting the voltage as output. This voltage obtained is given to the universal bridge. The speed of the motor can be controlled by varying this voltage. There are six switches in this universal bridge as shown in fig 4. The device is protected from the reverse voltages by using the freewheeling diodes across each switch in the universal bridge. Three switches among the six switches are considered as one group, thus creating positive group and negative group. The switches S1, S3, S5 are considered as positive group and the switches S4, S6, S2 are divided as negative group. When the switches are turned on and off the power is controlled and flows to the load. The switching between the group of switches in the universal bridge is created by regulating the gate pulses of the bridge. These gate pulses are controlled by the signals obtained by using the hall sensors and the PWM technique as shown in Figure 5. The voltage vector of BLDC motor is separated into six sectors, which is just a one-to-one Switches Sequence and Pulse Width Modulation. Table I. shows the switches sequence to be followed [5-6]. The current to the each phase winding flows corrects by the proper switching sequence between the switches. As the six timing sequences, the trapezoidal control also called six steps control. In this method, the PWM applied on high side and lower side, the duty cycle of PWM controls the magnitude of the current flows to the controller, and the spinning of BLDC motor becomes fast by increasing the width of the PWM duty.

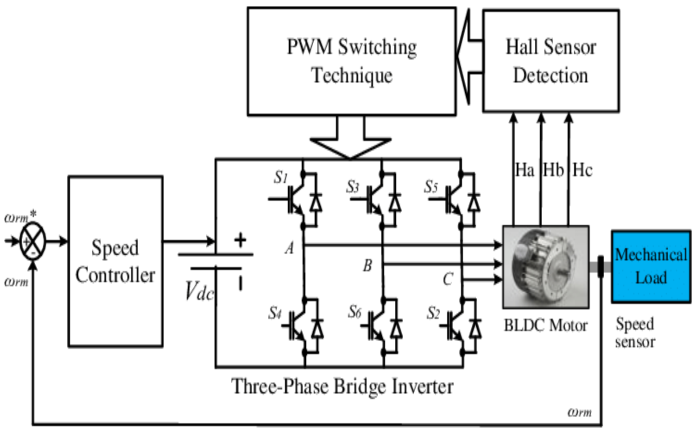

Fig.4. Three-phase bridge inverter consists of six IGBTs switches

Table.1. Truth table of Hall Effect sensors and gate state

Time	Hall Input			Phase A		Phase B		Phase C	
	A	B	C	Q1	Q2	Q3	Q4	Q5	Q6
1	0	0	1	0	0	0	1	1	0
2	0	1	0	0	1	1	0	0	0
3	0	1	1	0	1	0	0	1	0
4	1	0	0	1	0	0	0	0	1
5	1	0	1	1	0	0	1	0	0
6	1	1	0	0	0	1	0	0	1

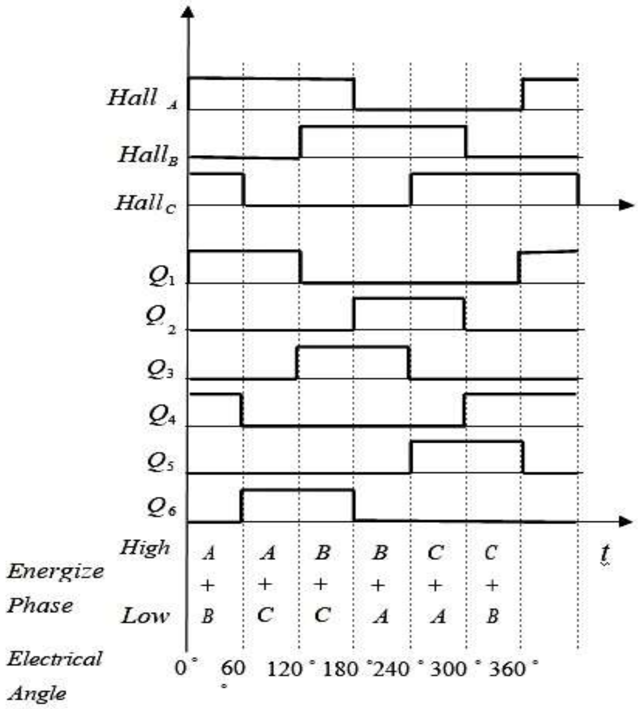

Fig.5. Switches sequence of hall sensors and PWM

4.1 Pulse Width Modulation Control of Bldc Motor

PWM is the most popular method for producing a controlled output for inverters. They are quite popular in industrial applications. The pulsating wavefrom's duty ratio of Pulse width modulation (PWM) is controlled by another waveform. The switches opening and closing is done by the output obtained by the comparision of reference waveform and the carrier waveform. PWM is commonly used in applications like converters, motor speed control, audio amplifiers etc.

Generally the power is delivered to load without any losses only when the source is limited by a resistive element, but PWM is used instead to reduce the total power delivering to the load. Figure 4 shows the conventional PWM control of a BLDC motor drive. The drive consists of a universal bridge rectifier, IGBT based voltage source inverter which feeds the motor, PWM controller, and switching logic from the Hall Effect signals which are used to track the position of rotor of motor at every instant of time by using the hall sensors mounted on the non driving side of the motor. The switching logic from the hall signals is determined to give triggering pulses to the inverter switches. The real and reference is compared to produce an error signal, and then fed to the controller, the required speed is obtained according to the generated control signal from the controller. The system is simulated in MATLAB/Simulink environment.

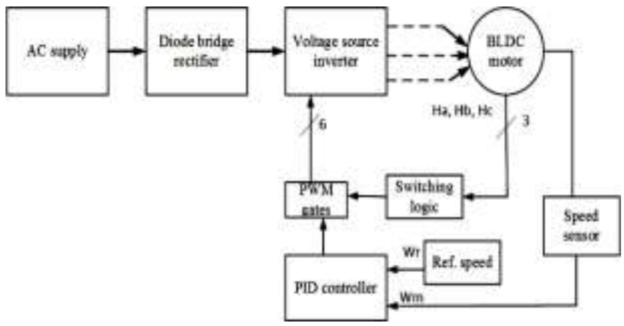

Fig.6. Block diagram for PWM inverter control of BLDC motor

Table.2.: Motor parameters

Symbol	Parameter	Value
J	Moment of Inertia	0.0008 kg
B	Friction Coefficient	0.001 kg/ms
K_v	Back emf constant	146.6 V/rad/sec
K_t	Torque constant	1.4 Nm/Amp
L	Inductance	0.0085 H
P	Number of pole pairs	4
R	Resistance per phase	2.875 ohm
ψ	Maximum flux linkage	0.175 wb
ω	Rated speed	314 rad/sec
T	Rated torque	3 Nm

5. MATLAB/SIMULINK SIMULATION OF BLDC MOTOR:

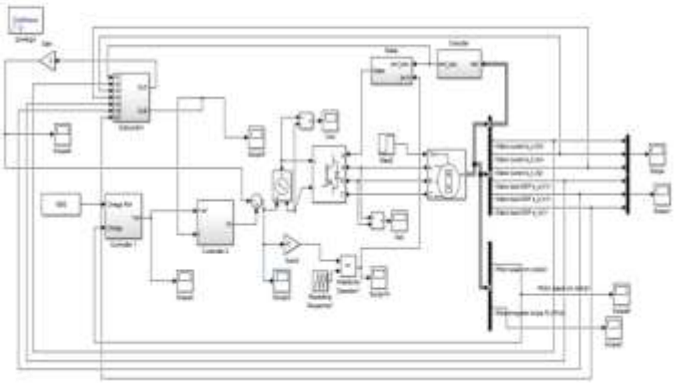

Fig.7. Simulink Block Diagram of BLDC motor with SMC-PWM controller

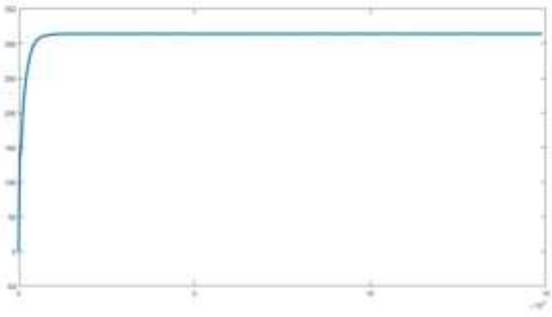

Fig.8. Rotor speed of BLDC motor with PI controller

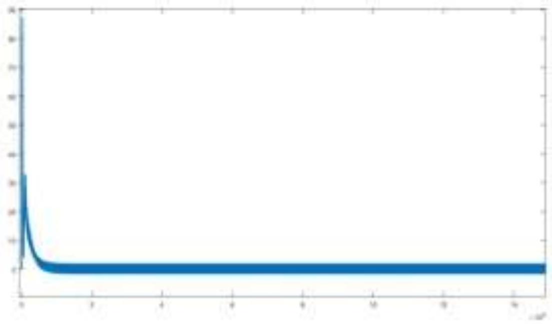

Fig.9. Electromagnetic Torque of BLDC motor with PI controller

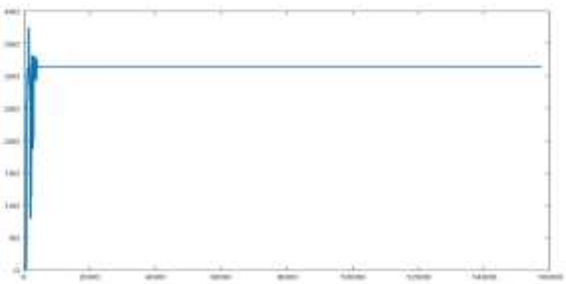

Fig.10. Rotor speed of BLDC motor with SMC controller

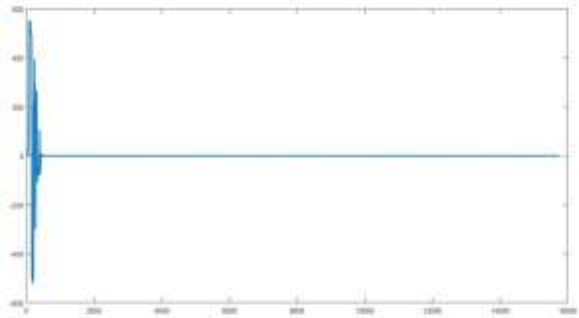

Fig.11. Electro Magnetic Torque of BLDC motor with SMC

controller

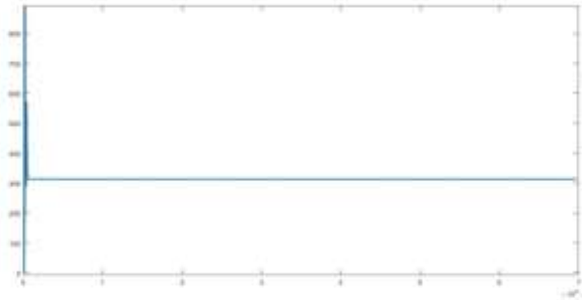

Fig.12. Speed of BLDC motor with SMC-PWM controller

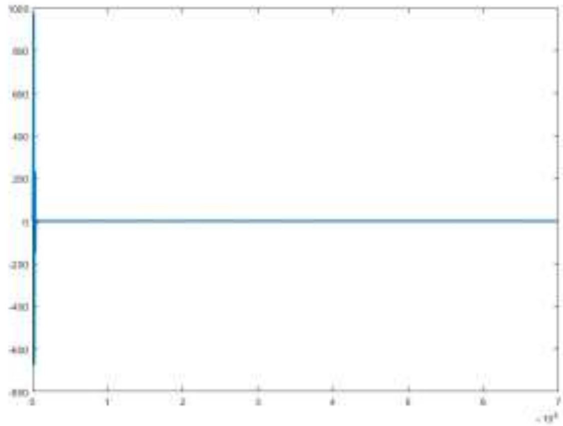

Fig.13. Torque of BLDC motor with SMC-PWM controller

6. CONCLUSIONS AND REMARKS:

SMC is designed to overcome the large overshoot and weak anti-interference ability encountered in the BLDC motor when PI controller is used. However, the gains adjusted in sliding mode controller for the better performance of the motor decreases the robustness of motor and increase the chattering effective in motor. Comparative simulation experiments are performed and simulation results are analyzed respectively. The simulation results obtained by using the traditional sliding mode controller are better than the PI controller results, but the proposed technique in this paper is better than the traditional SMC as it improves the robustness of the motor and reduces the chattering effect compared to prior techniques. High efficiency, high performance of BLDC motor can be realized using SMC-PWM technique. The ripples in the torque for different loading condition are reduced. The proposed method reduces the torque ripples produced due to the flow of motor currents through the freewheeling diodes during the commutation intervals and obtains the faster speed responses.

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