Implementation of SMC for BLDC Motor Drive

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Abstract – *BLDC drives are used in aerospace, instrumentation systems, space vehicles, electric vehicles, robotics, and industrial control applications. In such applications, conventional controllers like P, PI, and PID are being used with the BLDC drive control systems to achieve satisfactory transient and steady-state responses. However, the major problem associated with the conventional PID controller is that the tuned gain parameters obtained for such BLDC drive control systems do not yield better transient and steady-state responses under different operating conditions such as parameter variations, load disturbances, etc. Here we design and implement sliding mode controller and its performance is compared with PI controller to show its capability to track the error and usefulness of Sliding mode controller in control applications. The sliding mode control technique for permanent magnet brushless DC motor is used to improve its dynamic performance with high accuracy. The proposed novel sliding mode controller (SMC) method is used to drive at all speed levels. The SMC controller is the most attractive and simple in modeling for its insensitivity to parameter variations and external disturbances.*

Key Words: **BLDC; SMC; PI;Chattering**

1.INTRODUCTION

Brushless DC motor (BLDC) is widely used in industrial applications, electric vehicles and micro electric motor cars and food and chemical industries, because is the most efficient in energy conversion compared to other commercial electric motors. BLDC motors are characterized to have: low inertia that allow faster torque changes or rotation sense changes, dissipate heat in an optimal manner by having the windings on the stator, compact structure, high electric efficiency up to 95%, less noisy and low service requirements with respect to brushed DC motor and induction motor.

BLDC motor is a Permanent Magnet Synchronous Machine (PMSM), called synchronous machine by synchronizing the rotor magnetic field with the rotating stator magnetic for yielding the mechanical torque. Unlike a conventional DC synchronous motor, BLDC motor has permanent magnets mounted on the rotor and in the stator has the windings distributed on three phases (a; b; c) with a separation of 1200 electrical degrees between them. Also due to its construction the BLDC motor does not have brushes nor electro-mechanic commutator therefore its commutation is electronic and its operation is more complex.

One of the main challenges in this field of drives was to achieve a perfect control for speed regulation even under the disturbances and parameter variations. One of the prominent methods for the control design is the SMC (Sliding Mode Control) approach. Sliding mode controller is suitable for a specific class of nonlinear systems. This is applied in the presence of modeling inaccuracies, parameter variation and disturbances, provided that the upper bounds of their absolute values are known. Modeling inaccuracies may come from certain uncertainty about the plant (e.g. unknown plant parameters), or from the choice of a simplified representation of the system dynamic. Sliding mode controller design provides a systematic approach to the problem of maintaining stability and satisfactory performance in presence of modeling imperfections.

2. Modeling Of Brushless Dc Motor

For BLDC motors, three reference frames are normally used to describe the dynamic behavior of a motor, the coordinate reference systems is shown in Figur

e 1; the phase frame a-b-c coordinate frame; the stator frame α-β coordinate frame and the field oriented frame d-q coordinate frame.

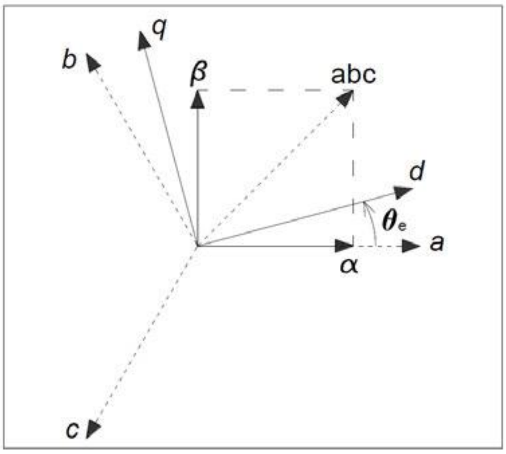

Fig. 1. Transformations of coordinate systems

The differential equations governing the electrical subsystem of the non-salient pole BLDC motor in the *d; q* coordinate frame can be written as,

$$\dot{i_d} = \frac{1}{L}\left[v_d - R_e\, i_d + L n_p w_m i_q\right] \quad (1)$$

$$\dot{i_q} = \frac{1}{L}\left[v_q - R_e\, i_q + L n_p w_m i_d - \lambda_m n_p w_m\right] \quad (2)$$

Where,

i_d, i_q are stator currents in *d; q* coordinates,

$v_d,\ v_q$ are stator voltage in *d; q* coordinates,

L is stator inductance,

R_e is stator resistance,

λ_m is rotor permanent magnet flux,

n_p is number of pole pairs,

w_p is rotor angular speed.

The relation between torque and speed can be obtained by the following differential equation as,

$$\dot{w_m} = \frac{1}{J}\left[\frac{3}{2}\lambda_m n_p i_q - B_m w_m - \tau_l\right] \quad (3)$$

Where,

J is rotational inertia,

B_m is viscous friction coefficient,

τ_l is load torque.

The mathematical model, equations (1) and (2), we can rewrite in a state space representation as,

$$\dot{x} = A(x)x + Bu \quad (4)$$

Where, state vector is $x = [x_1\, x_2 x_3]^T = [i_d\, i_q w_m]^T$

and inputs vector is $\mathrm{u} = [\,u_1\, u_2]^T = [\,v_d\, v_q]T$.

Sliding Mode Controller

The sliding mode control (SMC) which is derived from the theory of variable structure control, is a known discontinuous control technique which takes in account the time varying topology of the controlled system [8]. So, the sliding mode control has been widely applied to power converters due to its operation characteristics such as fastness, robustness, and stability under large load variations.

The basic idea behind the sliding control is the specification of a surface, which is known as the sliding surface, in such a way that the control feature is to maintain a system within the surface and hence, assuming a desired system behavior. Below sliding mode control technique is discussed for calculation of reference torque T*.

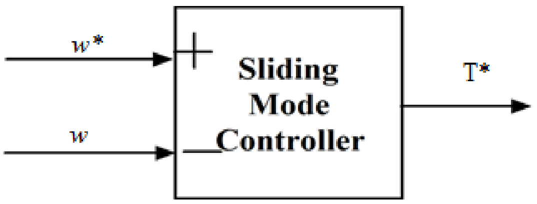

Fig. 2. Speed Regulation using Sliding Mode Controller

SMC Law

Better operation of the speed controller is guaranteed if the motor speed is maintained at the desired speed. The SMC controller is used to regulate the speed. This is done as below

The reference torque required can be generated as follows. The speed error e can be calculated as the difference between the reference speed ω^* and the measured speed ω.

Let

$$e(n) = \omega^* - \omega = x_1 \quad (1)$$

The change in error or the derivative of error,

$$x_2 = \dot{x}_1 = \frac{1}{T}[e(n) + e(n-1)] \quad (2)$$

where, T is the sampling time interval and x_1, x_2 are the state variables.

In Sliding Mode Control, the values of switching functions y_1, y_2 are defined as follows.

$$y_1 = sgn(zx_1)$$

$$y_2 = sgn(zx_2)$$

Where z is sliding plane function, given by

$$z = c_1x_1 + c_2x_2.$$

The output of the sliding mode controller u(n) is taken as reference torque T* as

$$u(n) = c_3x_1y_1 + c_4x_2y_2$$

Chattering Problem Elimination

Due to use of signum function for designing SMC law introduces chattering effect which is undesirable in any dynamic system due to its infinite switching frequency. Chattering problem can be overcome by smoothing out the signal with continuous function like Saturation, which closely approximate the signum function especially around the neighborhood of the sliding surface. The saturation function allows the introduction of a small boundary layer near the surface. So we can substitute sgn(s) by sat (s/μ) as follows:

$$sat\left(\frac{s}{\mu}\right) = \frac{s}{\mu} \qquad ; \text{if } |s| < \mu$$

$$= sgn(s)$$

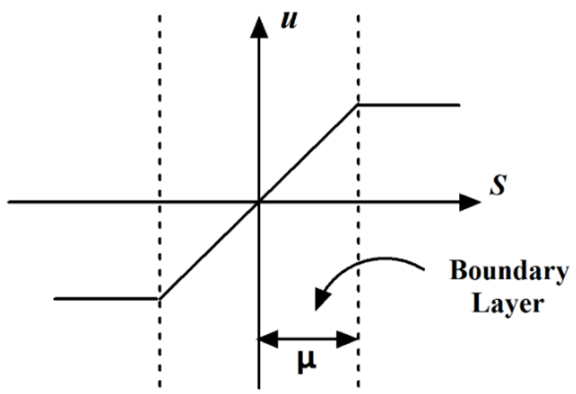

Fig. 3. Boundary Layer for Sliding Mode

Fig. 4 shows boundary layer control by using saturation function, where "u" is magnitude of control action.

Peak value of required current to accelerate the motor with above torque is given by,

$$i = \frac{T^{*}}{2 * P * \lambda}$$

Where,

P:- Number of pole pairs

λ:- Flux induced by magnets in Wb

The instantaneous values of reference currents (I^{*}_{abc}) are calculated using Hall Effect signals.

The Hysterisis Current Controller

Hysteresis Current Controller, an instantaneous feedback system which detects the current error and produces directly the drive commands for the switches when the error exceeds an assigned band. The hysteresis controller as shown in fig. 5 is used to control the current and determine the switching signals for the chopper.

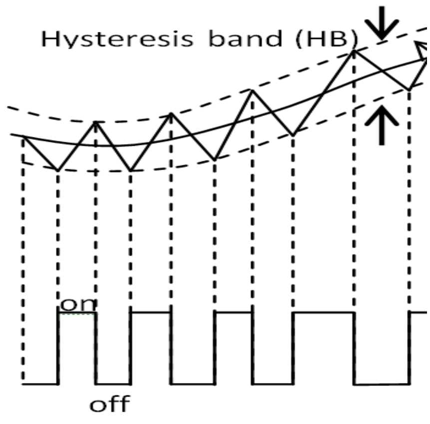

Fig. 4. Hysterisis Current Controller

When $I_a > I^{*}_{ref} + (HB/2)$ then hysteresis controller gives output 0. When $I_a < I^{*}_{ref} - (HB/2)$ then it gives output equal to one. In this way, Hysteresis PWM is used as pulse generator for chopper, so that current tracks the reference.

Simulation Results

In order check the applicability of the developed control systems to the practical drive systems, the physical model of the DC motor in the MATLAB SIMULINK has been used with $R_s = 0.2\ Ohm$, $L_s = 8.5\ mH$, J=0.089 kg.m^2, pole pairs p=4 with trapezoidal back emf. The simulations were carried out and simultaneously compared with the results of conventional controller performances.

CASE I:

The simulation for the load torque 5 Nm and a set speed of 300 rpm.

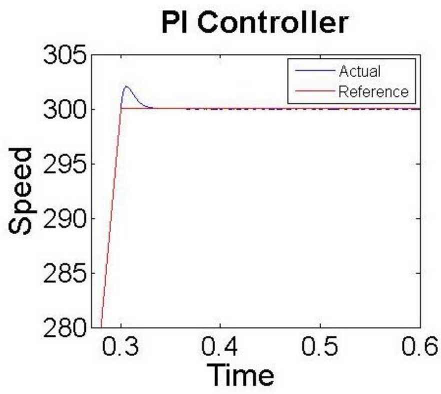

Fig. 5. Simulation results with PI

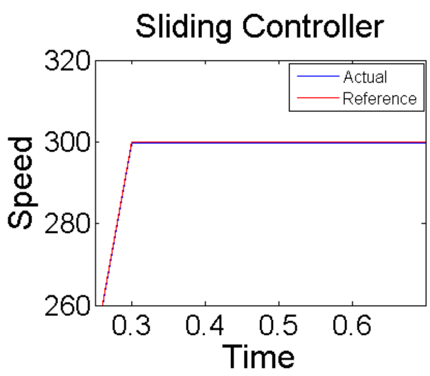

Fig. 6. Simulation results with SMC

From the above figures (6) and (7), we can observe that there is almost zero overshoot for the SMC controller where as there is a significant overshoot for the PI controller, also the time required for SMC controller to reach the reference is very less as compared to that of the PI controller.

CASE II:

Now, the set/reference speed is kept constant and the load torque has been given a step change form 10 Nm to -10 Nm.

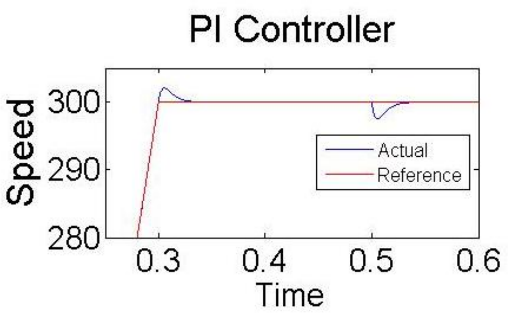

Fig. 7. Simulation results with PI

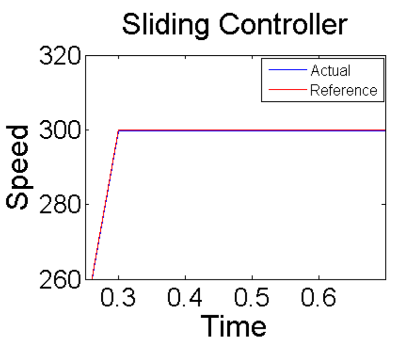

Fig. 8. Simulation results with SMC

In this case, there is significant overshoot in PI controller and also the time required to reach the reference speed of PI controller is more than that of the SMC controller. There is also variation in the response when there is the step change at 1sec which is not present in the SMC case; this proves that the SMC controller gives robust performance for the load disturbances.

3. CONCLUSIONS

The PI and Sliding mode control techniques are successfully implemented for the BLDC drive system. The effect of parameter variations on the performance of the BLDC drive system is investigated with simulation results. The Simulation results shows the speed response of Sliding mode controller-based BLDC drive is found to be better than the speed response of PI controller-based BLDC drive. PI controller-based BLDC drive failed to provide improved performance under parameter variations of the system. But, the simulation results clearly show that Sliding mode controller based BLDC drive can provide an improved speed response with consistently same rise time, and settling time when the system is subjected to load disturbance, parameter variations, and step change in reference speed. Since the Sliding mode control system is effective in dealing with the uncertainties and parameter variations and has better overall performance, Sliding mode controller-based BLDC drive system may be preferred over PI controller-based BLDC drive for automation, robotics, position and velocity control systems, and industrial control applications.

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