INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

SLIDING MODE CONTROL FOR SPEED CONTROL OF BRUSHLESS DC MOTOR

Bharathi.N
Department of EEE
Anna University, Chennai.

Dr.A.Kavitha
Assistant professor
Anna University, Chennai.

B.Barathy
Research Scholar
Anna University, Chennai.

Abstract— This paper presents a effective speed control of permanent magnet brushless DC motor drive using sliding mode controller based on reaching law. This drive system provides the advantages of PMBLDC motor and can be used in light electric vehicles and other adjustable speed drive applications. Speed regulation of a permanent magnet BLDC motor drive with various cases of reaching law based on sliding mode controllers is implemented for outer loop speed control of the drive. Performance of the speed tracking is then compared with a classical PI controller. Advantages of the proposed sliding mode control related with reduction of steady state error, settling time and percentage overshoot are summarized.

Keywords- *BLDC motor, exponential reaching law and sliding mode***.**

1.INTRODUCTION

Sliding Mode Control is a typical non-linear control technique [5, 6], that modifies system performance by continuous switching of the controlled variable according to the current status of the known system state. Sliding Mode Control designed is proposed and analyzed. This control system provides advantages for PMBLDC motor and can be used in light electric vehicles and any other adjustable drive applications. [7, 9]. Reaching law is a differential equation which specifies the dynamics of a switching function **s(x).** The differential equation of an asymptotically stable **s (x)** is itself a reaching condition [1,4]. The reaching space representation shows that overshoot of the process state cannot be large due to the form of the reaching law. In addition, the reaching mode is less sensitive to system perturbations and external disturbances if the reaching law method is used in designing the VSC system.

In this paper existing design method for inner current control loop and outer speed loop are discussed. An improved exponential reaching-law based on the sigmoid function is proposed and by applying the proposed technique, stability of the entire loop and the smoothness of the converging process of the system are better than those obtained by using the classical PI controller. The sliding surface can be reached quickly and the system chattering can be reduced at the same time, facilitating the design of variable-structure control. Simulation results using the developed control scheme is carried out on MATLAB/SIM ULINK platform show that the proposed method is feasible and effective.

2. MODELLING OF BLDC MOTOR

The model of BLDC motor is similar to that of a DC motor. Only here the presence of an electronic commutator causes the state trajectory to switch between different models.The differential equation governing the electrical part of the model can be written as

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

Where,

V = DC voltage applied in Volts.
L = Inductance of the windings in Henry.
R = Resistance of the windings in Ohms.
E = $K_b \omega$=Back emf of the motor.
K_b=Back emf constant in Volts/ rad/ sec .
ω = Speed in rad/ sec .

Equation (1) can also be written as

$$\frac{di}{dt} = (-E - iR + V)\frac{1}{L} \qquad (2)$$

Where, i = Current in Ampere
V = Voltage as input.

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

$$T = J\frac{d\omega}{dt} + B\omega + T_L \qquad (3)$$

Where,

T = Torque in Newton-meter
J = Moment of inertia in K g.m2
T_L = Disturbance input.

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

B = Coefficient of friction in K g / ms.

The above equation in (3) can also be written as

$$\frac{d\omega}{dt} = \frac{1}{J}(-B\omega + T + T_L) \qquad (4)$$

SPEED CONTROL OF BLDC MOTOR

Closed loop control of PMBLDC motor is required in applications where speed control is necessary and the current must be controlled to achieve desired torque.The drive consists of an outer speed control loop and an inner current loop, they are used for controlling speed and current respectively. The speed loop is relatively slower than the current loop. An encoder is used to determine the speed of the motor. The rotor speed (ω_{act}) is estimated by the encoder and is compared with the reference speed (ω_{ref}). The obtained error is processed by the proposed speed controller to generate the current reference. The phase current are sensed (I_{act}) and compared with I_{ref} and the error is fed to the current controller. Based on the output of the current controller and hall sensor information the commutation unit decides, which of the phases of the PMBLDC motor are to be switched. The switching signals are applied to the inverter, which controls the voltages applied to the windings and hence the speed control of the motor is achieved.

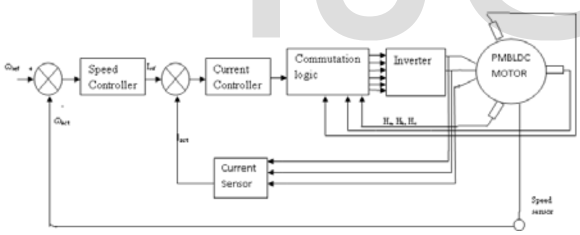

Figure I. Block diagram of closed loop control of PMBLDC

3. CONCEPT OF SLIDING MODE AND REACHING LAW

Sliding Mode Control is a typical non linear control technique that modifies the system performance by continuous switching of the controlled variable according to the current status of the known system state and thereby causes the trajectory to move on a predefined sliding surface.

The Sliding mode design involves two major tasks:

(i) The selection of a stable sliding surface in state space on which the state trajectory must ultimately lie in.

(ii) Designing a suitable control law that makes this sliding surface attractive for the state trajectory to reach it in finite time. Sliding mode control thus can be broadly divided into two phases, the Reaching Phase and the Sliding Phase. In the reaching phase the trajectory reaches the sliding mode and in the sliding phase the trajectory stays on the sliding mode for all further time. To ensure that the trajectory reaches the sliding mode the reaching condition has to be satisfied and for the sliding phase to exist the existence condition has to be satisfied. The sliding surface can be basically defined as a stable attractor plane that exists in the state space where the state trajectory must finally stay in. If the origin of the coordinate axes is taken as the stable equilibrium then the ultimate objective is to force the trajectory onto the sliding surface, ' S' and then it should move towards the origin. Consider a single input non linear system of the form

$$\dot{X} = f(X) + b(X)u \qquad (5)$$

Where,

b = uncertainty in input

u = control input

Then the states of the system are,

$$X = [x_1, x_2, x_3, \ldots \ldots, x_n] \qquad (6)$$

The sliding surface is thus $S = C^T X$.

Where, 'C'is the sliding surface parameter that can be designed on basis of pole placement method, such as Eigen value method, LQR method etc. With major advantages like parametric variations and disturbance rejection capabilities, one of the dis-advantages is chattering. Chattering results because the system tries to converge onto the switching surface by its inherent inertia velocity. If the trajectory of motion and the velocity of the system with which the switching surface is attained can be controlled then the dynamic characteristics of the trajectory can be improved. For convergence of the state trajectory onto the sliding surface by control of the dynamic characteristics, Reaching Law approach is employed here.

Any reaching law developed must satisfy the reaching condition of sliding modes $S\dot{S} < 0$, which is obtained basically from the second theorem of stability by Lyapunov.

.

REACHING LAW METHOD FOR VSC DESIGN

The reaching law is a differential equation which specifies the dynamics of a switching function **s(x).** The differential equation of an asymptotically stable **s(x)** itself a reaching condition. In addition, by the choice of the parameters in the differential equation, the dynamic quality of VSC system in the reaching mode can be controlled. A practical general form of the reaching law is

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

$$\dot{S} = -Q\,sgn(s) - kf(s) \tag{7}$$

Where, signum function sgn(s)is defined as

$$Sgn(s) = \begin{pmatrix} 1 & S > 0 \\ -1 & S < 0 \end{pmatrix}$$

$$Q = diag\,[q_1, \ldots, q_m], \qquad q_i > 0$$

$$k = diag\,[k_1, \ldots, k_m], \qquad k_i > 0$$

Three practical special cases of (7) are given below.

i) Constant rate reaching

$$\dot{s} = Q\,sgn(s) \tag{8}$$

This law forces the switching variable S(x) to reach the switching manifold **S** at a constant rate. The merit of this reaching law is its simplicity. If q_i is too small, the reaching time will be too long. On the other hand, a q_i too large will cause severe chattering.

ii) Constant plus proportional rate reaching

$$\dot{s} = -Q\,sgn(s) - ks \tag{9}$$

Clearly, by adding the proportional rate term ***-Ks,*** the state is forced to approach the switching manifolds faster when **s** is large. It can be shown that the reaching time for **x** to move from an initial state $\mathbf{x_0}$ to the switching manifold S_i is finite, and is given by

$$T_i = \frac{1}{k} \ln \frac{k_i s_i + q_i}{q_i}$$

iii) Power rate reaching

$$\dot{s} = -k_i |s_i|^{\alpha} sgn(s_i) \quad 0 < \alpha < 1,\ i = 1 \text{ to } m \tag{10}$$

This reaching law increases the reaching speed when the state is far away from the switching manifold, but reduces the rate when the state is near the manifold. The result is a fast reaching and low chattering reaching mode. Integrating (10) from $s_i = s_{i0}$ to $s_i = 0$ yields

$$T_i = \frac{1}{k_i(1-\alpha)} s_{i0}^{(1-\alpha)} \quad i = 1 \text{ to } m$$

Showing that the reaching time T_i is finite. Thus power rate reaching law gives a finite reaching time. In addition, because of the absence of the -*Q* sgn (s) term on the right-hand side of (10), this reaching law eliminates the chattering.

4. PROPOSED CONTROL ALGORITHM

For the controlling purpose of speed loop consider

Sliding surface (s) = error = e
ω^* - ref speed, ω - act speed

$$s = e = \omega^* - \omega \tag{11}$$

Differentiate equation (11) we can get,

$$\dot{s} = \frac{d\omega^*}{dt} - \frac{d\omega}{dt} \tag{12}$$

From modeling of bldc motor we get,

$$\frac{d\omega^*}{dt} = \left[\frac{-B\omega - T_L + T}{J}\right] \tag{13}$$

Constant rate reaching:

Equate eqn (8) and (12) and using equation (13), we get

$$T = J\left[-Q\,sgn(s_i) + \frac{d\omega^*}{dt}\right] + T_L + (\omega^* - e_i)B \tag{14}$$

Constant plus proportional rate reaching:

Equate eqn (9) and (12) and using equation (13), we get

$$T = J\left[Q\,sgn(s) + ks + \frac{d\omega^*}{dt}\right] + T_L + (\omega^* - e_i)B \tag{15}$$

Power rate reaching:

Equate eqn (10) and (12) and using equation (13), we get

$$T = J\left[k_i |s_i|^{\alpha} sgn(s_i) + \frac{d\omega^*}{dt}\right] + T_L + (\omega^* - e_i)B \tag{16}$$

TABLE 1: PARAMETERS

S.NO	QUANTITY	VALUE
1	Friction coefficient	1e-3 kg/ms
2	Moment of inertia	1.6e-3 kgm²/s²
3	Torque constant	0.49N-m/Amp
4	Inductance	6.57e-3 Henry
5	Resistance per phase	3.07 ohms
6	No of poles	4
7	Rated voltage	310V
8	Rated speed	4000rpm

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

5. SIMULATION RESULTS

The closed loop speed response for the PMBLDC with PI controller is shown in fig 1. The response of the drive system is obtained by setting the reference speed to 2000 r.p.m. From the response of pi controller shows clearly actual speed also 2000 r.p.m.The speed response of PI controller shows in figure 1.1 has high starting overshoot from the set point. It approximate to 2030 rpm.

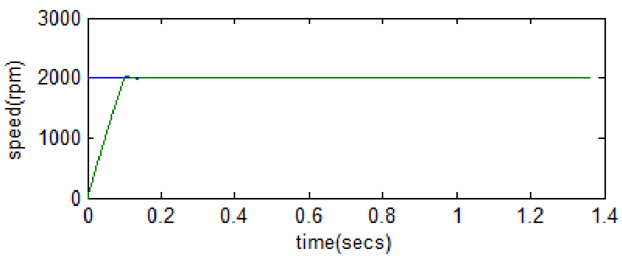

Fig 1. Closed loop speed response of PMBLDC with PI controller

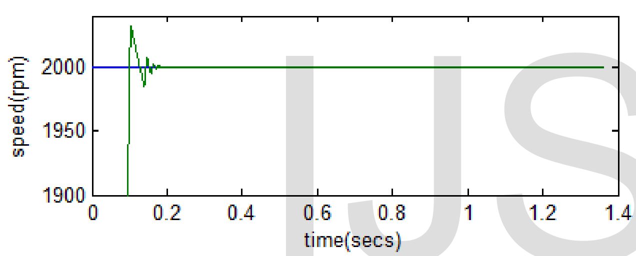

Fig 1.1 Closed loop speed response of PMBLDC with PI controller with accurate settling time

The response of the drive system is obtained by setting the reference speed to 3000 r.p.m. the system speed response of smc controller is shown in fig 2. In constant reaching law, variable Q is too small means the reaching time will be too long. On other hand, a Q too large means will cause severe chattering. For accurate settling time and starting overshoot calculation, zooming the fig 2. Closed loop speed response of PMBLDC with SMC controller with accurate settling time is viewed in Fig 2.1. The speed response of SMC controller shows in fig has severe chattering due to variable Q.

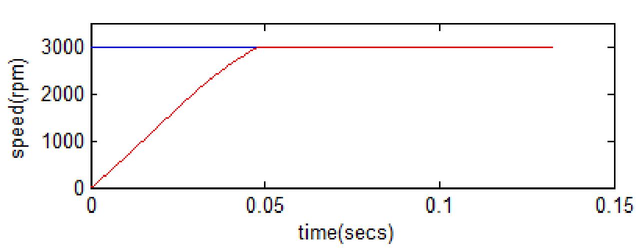

Fig 2. Constant rate reaching law based SMC controller

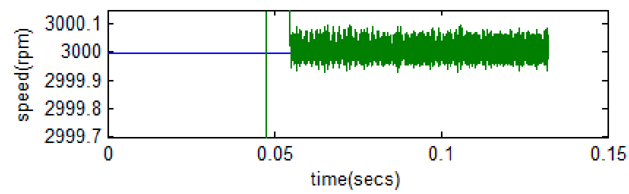

Fig 2.1.Constant rate reaching law based SMC controller with chattering

From fig 3, the speed response of SMC controller shows in figure has settling time and chattering is reduced compare to constant rate reaching method.

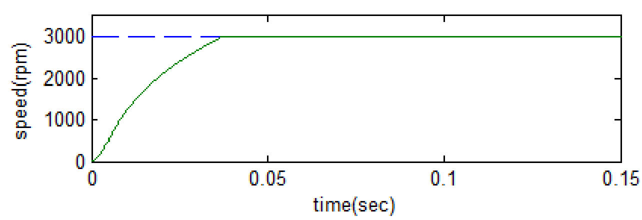

Fig 3. Proportional rate reaching law based SMC controller

In proportional rate reaching law method, some time we obtained speed error is 0.1 because a disturbance d slightly larger than **q** was simulated. Here the VSC system never reached its second mode. Therefore, for a disturbance greater than the magnitude of signum, the VSC system will loose its robustness feature, creating a steady-state error. In conclusion, **q** should be kept large enough to cover the expected maximum perturbation, but not too large to avoid unnecessarily large chattering.

Power rate reaching mode is a fast reaching and low chattering compare to previous method. Chattering is fully reduced due to absence of Q variable. The response of the controller is viewed in fig 4.

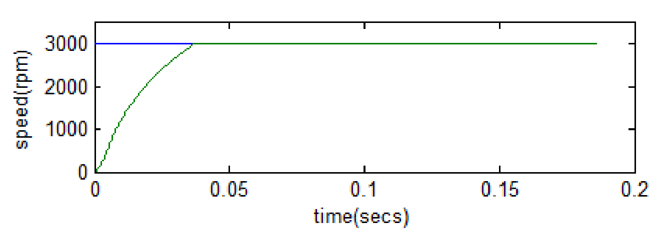

Fig 4. Power rate reaching law based SMC controller

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

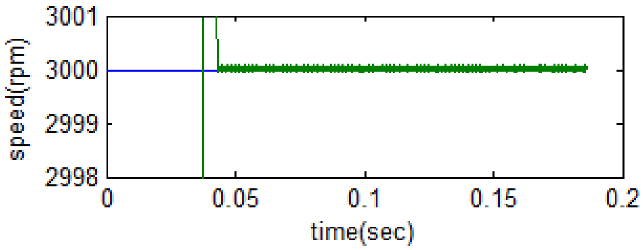

Fig 4.1.power rate reaching law based SMC controller without chattering

6. COMPARISON OF PI AND SMC SPEED RESPONSES

The speed response of both SMC and PI controller are shown. We can see that the settling time for SMC controller is less than the PI controller.

	M_p (%)	Settling Time(sec)	Speed Error
PI	**1.5**	**0.2**	**0**
CONSTANT RATE	**0.4**	**0.05**	**0**
CONSTANT PLUS PROPORATIONAL	**0.9**	**0.04**	**0**
POWER RATE	**1.2**	**0.04**	**0**

7. CONCLUSION

The simulation model of PMBLDC motor drive system in MATLAB/SIMULINK application is shown. Speed control using SMC controller is performed. The speed controller regulates the rotor movement by varying the frequency of the pulses based on signal feedback from the Hall sensors. The performance of the BLDC drives system based on SMC speed controller is satisfactory. The implementation of SMC controller shows better control performance and good robustness. In comparison with conventional PI controller, PMBLDC drives system with SMC controller reaches its set speed with less settling time. Thus we see that the SMC controller is better than the PI controller for the speed control of PMBLDC.

REFERENCES

1. Weibing Gao, "Variable Structure Control of Non-linear Systems: A New Approach", IEEE transactions on Industrial Electronics, VOL 40.No.I,February 1993
2. John Y Hung, WeibingGao and James C. Hung, "Variable Structure Control:A Survey" in IEEE transactions on Industrial Electronics, VOL 40.No.I, February 1993
3. S.E.Ghazi, "Analysis of vsc system designed via the reaching law approach ", Southeastcon '96',Bring together Education, Science and Technology', IEEE proceedings, 1996
4. G.K.Singh and K E Hole, "Guaranteed performance in reaching mode of sliding mode controlled systems ", Sadhana, VOL 29, Part I, February 2004, pp. 129-141
5. Slotine, J.J.E., and Li, W., Applied Nonlinear Control, Prentice-Hall, 1991
6. Utkin V.I, "Sliding mode control design principles and applications to electric drives", Industrial electronics, IEEE transactions, 1993
7. New Adaptive Sliding Observers for Positionand Velocity-Sensorless Controls of Brushless DC Motors Zhiqian Chen, Student Member, *IEEE*, Mutuwo Tomita, Member, IEEE, Shinji Doki, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 47, NO. 3, JUNE 2000
8. A Variable-Sampling Controller for Brushless DC Motor Drives With Low-Resolution Position Sensors Chung-Wen Hung, Cheng-Tsung Lin, Chih-Wen Liu IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 54, NO. 5, OCTOBER 2007
9. Nonlinear Speed Control for PMSM System Using Sliding-Mode Control and Disturbance Compensation Techniques Xiaoguang Zhang, Lizhi Sun, Senior Member, IEEE, KeZhao, and *Li* Sun, Member, *IEEE* TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 3, MARCH 2013
10. Yan Xiaojuan, Liu Jinglin , " simulation and implementation of bldc motor using SMC controller", 3rd International Conference on Advanced Computer Theory and Engineering, 20 10
11. G.K. Dubey: Power Semiconductor Control Drives, Prentice-hall, Eaglewood Cliffs, 1989.
12. T.J.E Miller, Brushless Permanent Magnet and Reluctance Motor Drives, Clarendon press, oxford, 1989.

INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 4, APRIL-2014
ISSN 2229-5518

13. M.H. Rashid, Power Electronics, 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1993.

14. Ned Mohan, W.P. Robin, and T.Undeland, Power Electronics: Converters, Applications and Design, 2nd ed. New York: Wiley, 1995.

15. B.K. Bose, Modern Power Electronics and AC Drives. Upper Saddle River, NJ: Prentice-Hall PTR, 2002.

16. P.C. Crause, Oleg Wasynzuk, Scott D.Sudhoff, Analysis of Electric Machinery and Drive system, 2nd ed. IEEE press Wiley India, 2010.