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Simulation of BLDC motor control with Reduced Order Model of the System with Observer State using SMC technique

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ABSTRACT : *This paper shows a reduced order model of the system with observer state sliding mode control (SMC) to control speed of Brushless DC motor. This paper gives an overview of performance conventional PI controller and reduced order model with measured and observer state SMC controller and also the fast response, insensitivity, and disturbances rejection to parameter variations. It is difficult to tune the parameters and get satisfied control characteristics by using normal conventional PI controller. In SMC with unmodelled dynamics chattering phenomenon is eliminated by constructing the sliding manifold based on reduced order model of the system with observer state and has the ability to satisfied control characteristics and having fast response. The experimental results verify that a reduced order model of the system with observer state SMC controller has better control performance than the conventional PI and reduced order model of the system with measured state controller SMC. Performance of the speed tracking is then compared with a classical PI (Proportional and Integral) controller implemented for the speed loop and the advantages of the sliding mode scheme related with reduction of steady state error, settling time, percentage overshoot and disturbance rejection . The modelling, control and simulation of the BLDC motor have been done using the software package MATLAB/SIMULINK.*

Keywords: *Sliding mode control, PI, BLDC motor.*

I. INTRODUCTION

Brushless DC motor has the characteristic of simple structure, large torque, has long use time, and good speed regulation. For the advantages mentioned above now electric vehicles and micro electric motor cars in the market mostly adopt BLDC machine [1]. The traditional BLDC controlling system requires hall sensor signals to drive the motor. The reliability of the whole controlling system is greatly reduced; also the cost of controller is increased. In recent years, some of these developments like Proportional-Integral controllers have been implemented for the speed control of BLDC motors. Different advanced control theories like the optimal and adaptive strategies have been used. Neural network control has also been used to control BLDC motors but its performance under load disturbance and parameter uncertainty due to the non-linearity is not satisfactory. Sliding mode control was first proposed with Variable structure control (VSC) with and elaborated in early 1950 in USSR by Emelyanov and several co researchers. VSC has developed into a general design method for wide spectrum of system types including MIMO systems, nonlinear system, discrete time models, infinite dimensional systems and large scale [2],[3]. The most distinguished feature of VSC is its ability to result in very robust control systems; in many cases invariant control systems results. In this paper sliding mode control strategies are formulated for speed control of BLDC machine. All the design procedures are carried out in the physical coordinates to make explanations clear. Simulation results will be presented to show their agreement with theoretical predication. Implementation of sliding mode control (SMC)[3] implies high frequency switching. It don't cause any difficulties when electric drives are controlled since the "on –off" operation mode is the only admissible one for power converters.

II. BLDC MOTOR AND ITS MATHEMATICAL MODELLING

2.1 Brushless Direct Current Motor:

Now a day's electric vehicles and micro electric motor cars in the market mostly adopt BLDC motor. This motor is also called Permanent Magnet DC Synchronous motors. And also this motor is a synchronous electric motor that from a modeling perspective and looks exactly like a DC motor and having a linear relationship between current and torque as well as voltage and rpm. The control of BLDC motors can be done in sensor or sensor less mode, but to reduce overall cost of actuating devices, sensor less control techniques are normally used. The advantage of sensor less BLDC motor control is that the sensing part can be omitted and overall costs can be considerably reduced. Because of their high power density, reliability, efficiency, maintenance free nature and silent operation, permanent magnet (PM) motors have been widely used in a variety of applications in industrial automation, computers, aerospace, military (gun turrets drives for combat vehicles), automotive (hybrid vehicles) and household products. However, the PMBLDC motors are inherently electronically controlled and require rotor position information for proper commutation of currents in its stator windings. It is not desirable to use the position sensors for applications where reliability is of almost importance because a sensor failure may cause instability in the control system. A PM brushless drive that does not require position sensors but only electrical measurements is called a sensorless drive BLDC motor is widely used because of its advantages like high efficiency, high power density, torque, fast response and low inertia. Fast dynamic response, higher steady precision and stronger anti-interference capability is required in many applications for the motor speed regulation system. These motor also has better speed vs. torque characteristics, High dynamic response, long operating life, Noiseless operation, high speed ranges and Low maintenance. The permanent magnet brushless motor has a permanent magnet rotor and the stator windings are wound such that the back emf is trapezoidal. It requires rectangular shaped stator phase currents to produce constant torque. The trapezoidal back emf implies that the mutual inductance between the stator and rotor is non-sinusoidal. 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. Here the model of a BLDC similar to that of a DC motor is developed. By incorporating the presence of an electronic commutator the developed model can be used as a BLDC drive model. The below Fig. 1.shows the equivalent circuit of DC motor,

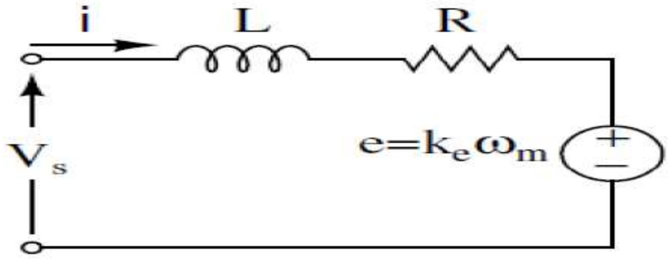

Fig.1: Equivalent circuit of DC motor

The parameters of the motor model used in this paper are illustrated in Table 1

Table 1: Parameters of the motor

Sr. No.	Symbol	Description	Value
1	B	Friction Coefficient	10^{-2} Kg/ms
2	J	Moment of Inertia	3.99×10^{-5}Kgm^2/S^2
3	Kb	Back emf constant	0.105Volts/rad/sec
4	Kt	Torque constant	0.0980N-m/Amp
5	L	Inductance	1.1×10^{-3} Henry
6	P	No. of Poles	4
7	R	Resistance per phase	0.525Ohms

2.2 Dynamic Modelling of BLDC Machine:

Fig. shows the model of DC motor with constant excitation is given by Following state equations

$$L\frac{di}{dt} = u - Ri - \lambda_0\omega \quad (1)$$

$$j\frac{d\omega}{dt} = k_t i - \tau_l \quad (2)$$

Where

i	armature current	ω	shaft speed
R	armature resistance	λ_0	back emf constant
τ_l	load torque	u	terminal voltage
j	inertia of the motor rotor and load	L	armature inductance

k_t toque constant

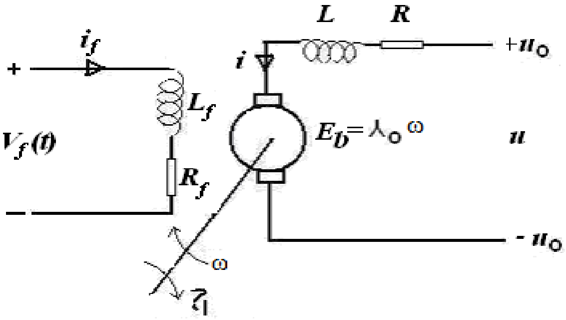

Fig.2: Dynamic modeling of DC machine

Its motion is governed by second order equations 1 &2 with respect to armature current i and shaft speed w with voltage u and load torque τ1. A low power-rating device can use continuous control. High power rating system needs discontinuous control. Continuously controlled voltage is difficult to generate while providing large current. Fig.3 below shows the speed control of BLDC motor based on reduced order model and observer state.

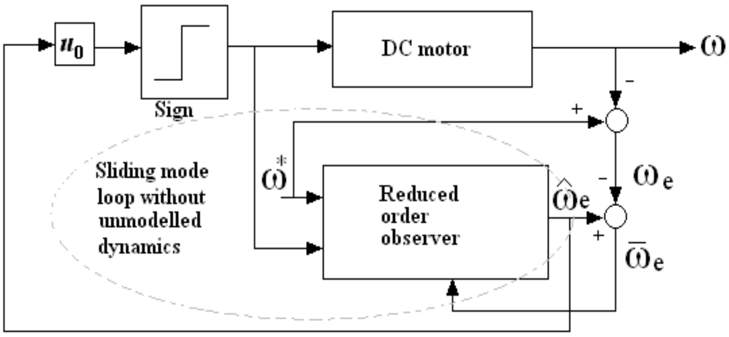

Fig.3: Speed control based on reduced order model and observer state

III. SLIDING MODE CONTROL

3.1 Concept of Sliding Mode Controller

In this control technique the concept of reaching law algorithm emphasizing on the benefits of exponential reaching law are used to control the inner current loop and outer speed loop of the BLDC motor. 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.

Fig.4 represents the phase trajectory of a sliding mode representing two modes of the system. In the first part, the trajectory starting from anywhere on the phase plane moves towards the sliding surface and reaches the surface in finite time. This is known as reaching, hitting, or non-sliding phase and the system is sensitive to parameter variations and disturbance rejection in this part of the phase trajectory. The second part is the sliding phase in which the state trajectory moves to the origin along the sliding surface and the state never leave the sliding surface. During this period, the system is defined by the equation of the sliding surface and thus it is independent of the system parameters and external disturbances. Sliding mode design involves two major tasks:

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

b. Designing a suitable control law that makes this sliding surface attractive for the state trajectory to reach it in finite time.

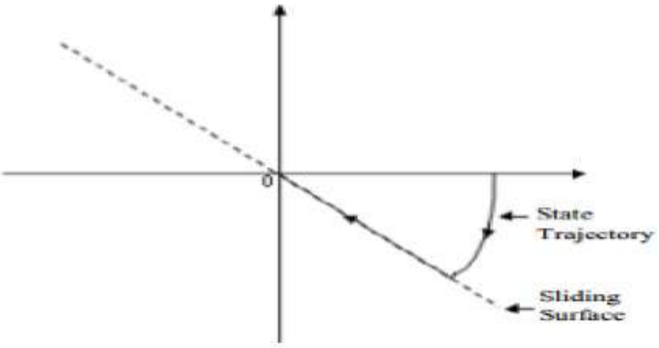

Fig.4: Phase Portrait of a sliding motion

Sliding surface can be either linear or nonlinear. For simplicity, only a linear sliding surface is used. 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. The idea behind SMC is to define a surface along which the process can slide to its desired final value. The structure of the controller is intentionally altered as its state crosses the surface in accordance with a prescribed control law. Thus, the first step in SMC is to define the sliding surface s(t). s(t) is chosen to represent a desired global behavior for instance stability and tracking performance. The objective of control is to ensure that the controlled variable be equal to its reference value at all times means that error e(t) and its derivatives must be zero. Once the reference value is reached, it indicates that sliding surface s(t) reaches a constant value. To maintain s(t) at this constant value, means that error e(t) is zero at all times; it is desired to make that,

$$\dot{s} = \frac{ds(t)}{dt} = \frac{d(\text{constant})}{dt} = 0 \tag{3}$$

Once the sliding surface has been selected, attention must be turned to design of the control law that drives the controlled variable to its reference value and satisfies above equation. The SMC control law, u, consists of two additive parts; a continuous part, ueq, and a discontinuous part, usw. That is ,

$$u = ueq + usw \tag{4}$$

Slotine proposed a form of general equation to determine the sliding surface which ensures the convergence of a variable towards its desired value as:

$$S = \left(\frac{d}{dt} + \alpha\right)^{n-1} e \tag{5}$$

Where, **n** is the system order, **e** is the tracking error signal and **α** is a positive constant that determine the bandwidth of the system.

For the controlling purpose of two loops we consider and two sliding surfaces are taken as,

$$S1 = e1 = iref - i \tag{6}$$

And $S2 = e2 = \omega ref - \omega$ (7)

Where

iref =Reference current

and ωref = Reference speed.

Having chosen the sliding surface at this stage, the next step would be to choose the control law (u) that will allow the error to reach the sliding surface. To do so, the control law should be designed in such a way that the following condition, also named reaching condition, is met:

$$s\dot{s} < 0 \tag{8}$$

In order to satisfy this condition, exponential reaching law [1,2] technique is adopted. The general representation of the exponential reaching law approach is given as,

$$\dot{s} = -\epsilon \operatorname{sgn}(s) - Ks \tag{9}$$

Where K,ε are positive constants known as the hitting control gain or parameter, s is the sliding surface, and sign is the signum function defined as,

$$\operatorname{sign}(s) = \begin{cases} 1 \text{ if } s > 0 \\ -1 \text{ if } s < 0 \end{cases} \tag{10}$$

The discontinuous control law described by Equations presents high robustness, insensitive to parameter fluctuations and disturbances. However, using a sign function often causes chattering phenomenon.

IV. SIMULATION AND RESULTS

The performance of the system the simulation result for the speed control of BLDC machine is represented. Rated parameters of the BLDC motor used to verify the design principle are 5 hp, P = 4, R = 0.525Ω, L = 1.1mH, J = 0.000039kgm2/s2, K_t = 0.0980N-m/Amp, K_b = 0.105volts/rad/sec, B=10^{-2} kg/ms. Simulation results are obtained by using the MATLAB-12a.

In this paper we have shown the speed control of BLDC motor with three different controllers and compared them with the respective settling time are as follows.

4.1 Simulation result using PI speed control:

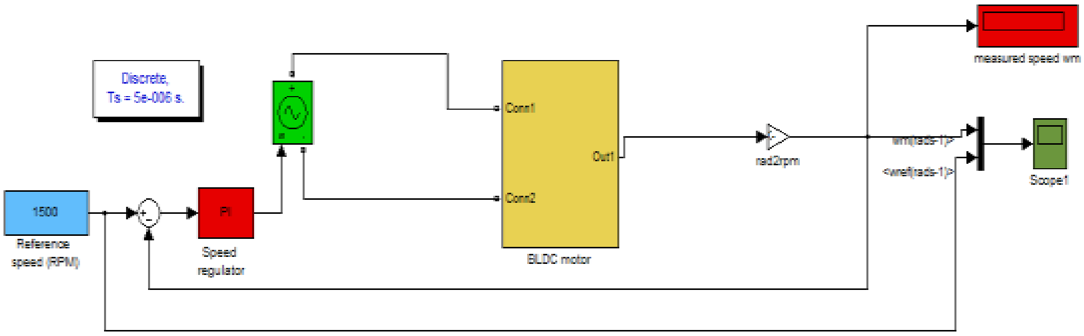

Fig.5: Simulink model of BLDC motor speed control using PI.

The value of the integral constant and proportional constant is K_i=16.61 and Kp=0.013 with these value the simulation results is obtained as shown in Fig.6. From the waveform we can see that settling time is much larger and at time 0.02 sec the speed achieved is 1342 rps.

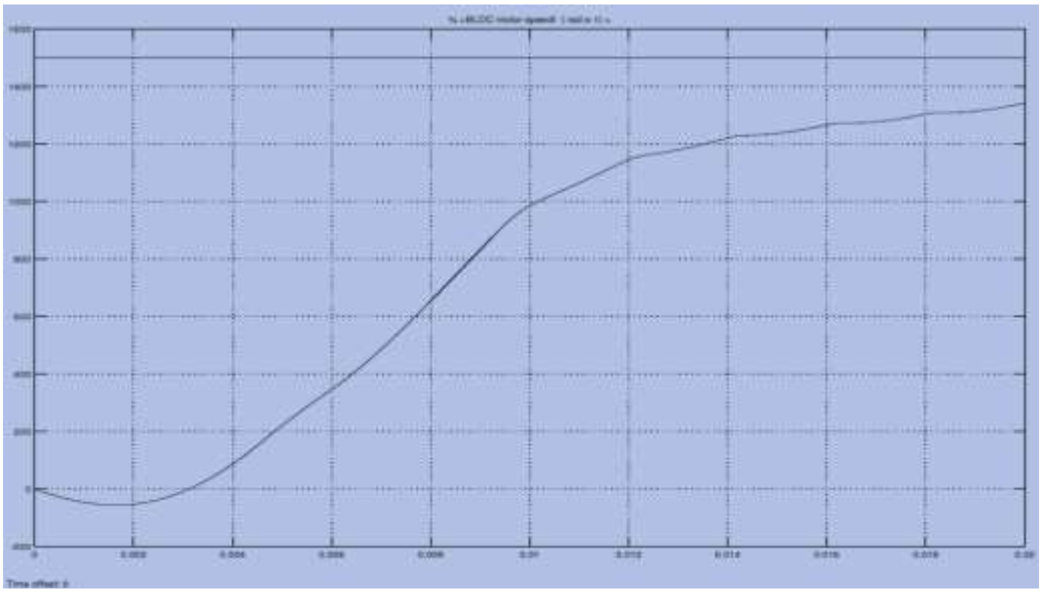

Fig.6: Response of BLDC motor speed control using PI.

4.2 Simulation result using SMC reduced order with measured state:

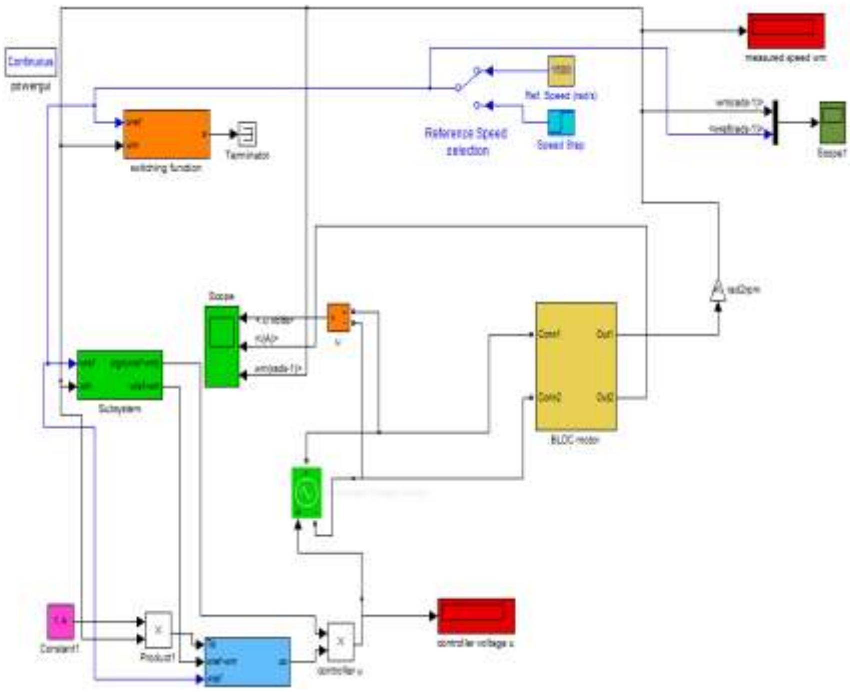

Fig.7: Simulink model of BLDC motor speed control using SMC reduced order with measured state.

The above Simulink model shows the speed control of BLDC motor; in this method the sliding mode control reduced order with measured state is used for controlling the speed and we can see in the speed vs. time response shown in Fig.8 and at time 0.02 sec the speed achieved is 1495 rps i.e. speed is 4 nearer to its reference value therefore this method overcomes the PI control method but still there is some chattering effect.

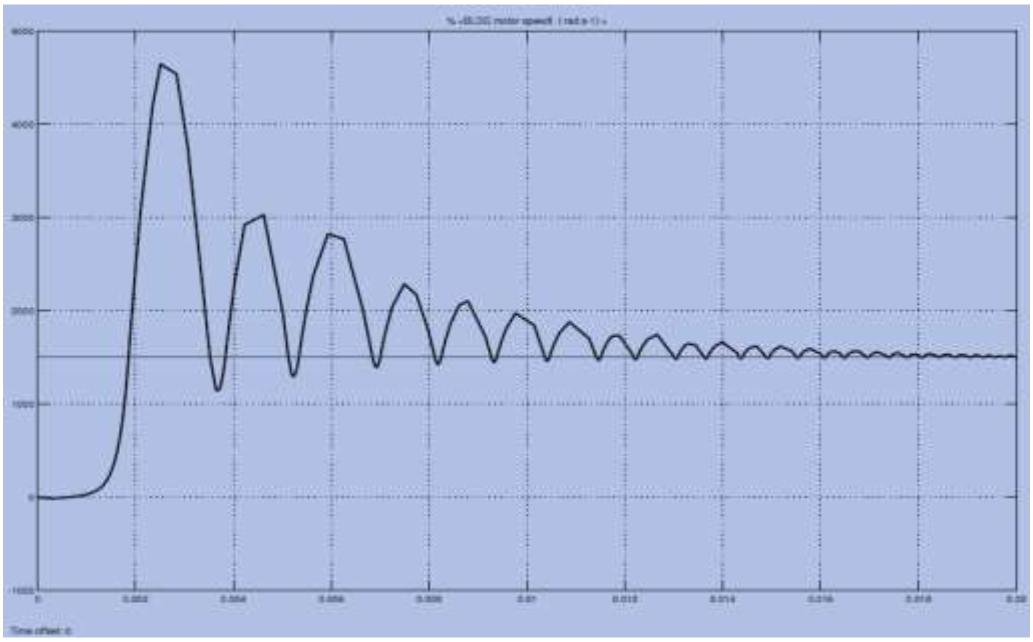

Fig.8: Response of BLDC motor speed control using SMC reduced order with measured.

4.3 Simulation result using SMC reduced order with observer state:

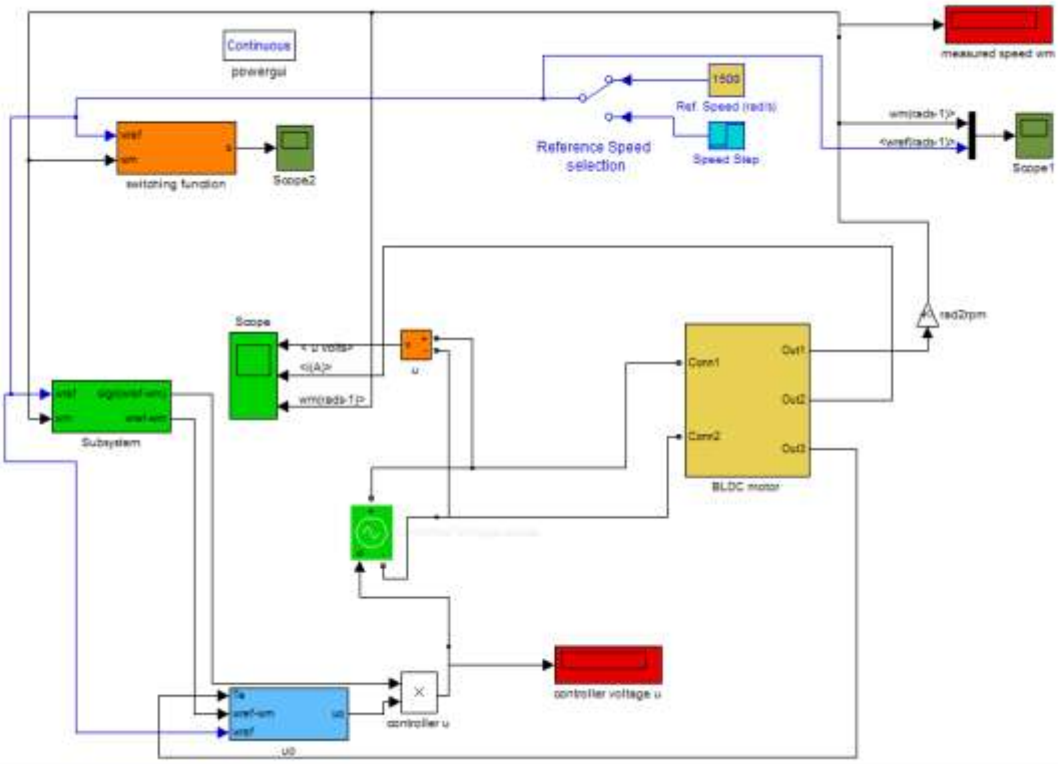

Fig.9: Simulink model of BLDC motor speed control using SMC reduced order with observer state.

The above Simulink model shows the speed control of BLDC motor; in this method the sliding mode control reduced order with observer state is used for controlling the speed and we can see in the speed vs. time response shown in Fig.10 and at time 0.02 sec the speed achieved is 1494 rps. The above two method problems are overcome in this method and chattering problem is reduced.

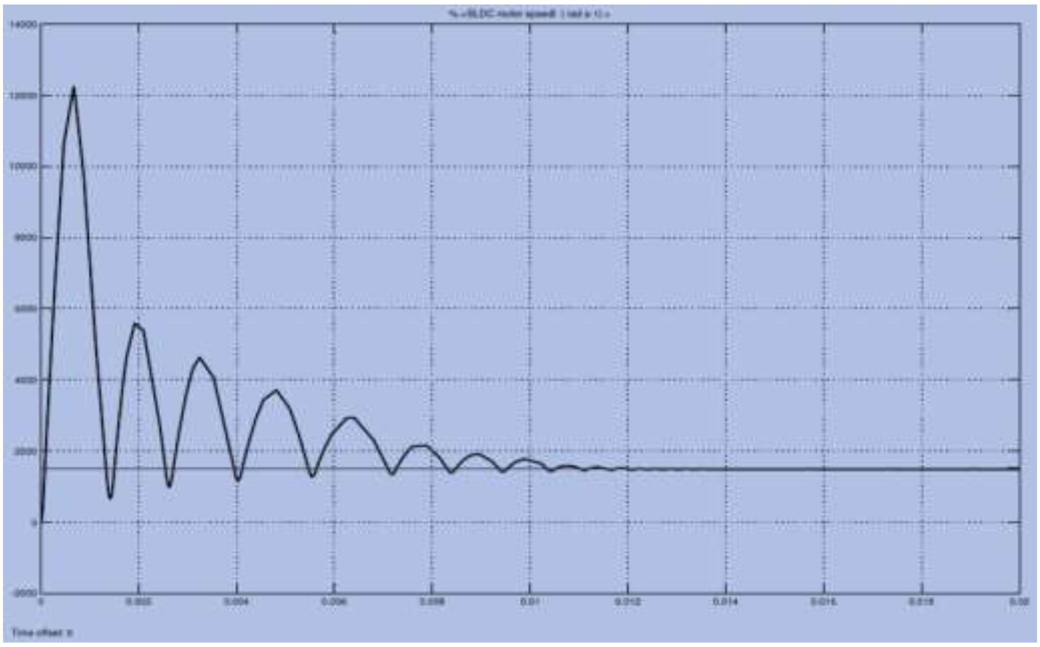

Fig.10: Response of BLDC motor speed control using SMC reduced order with observer.

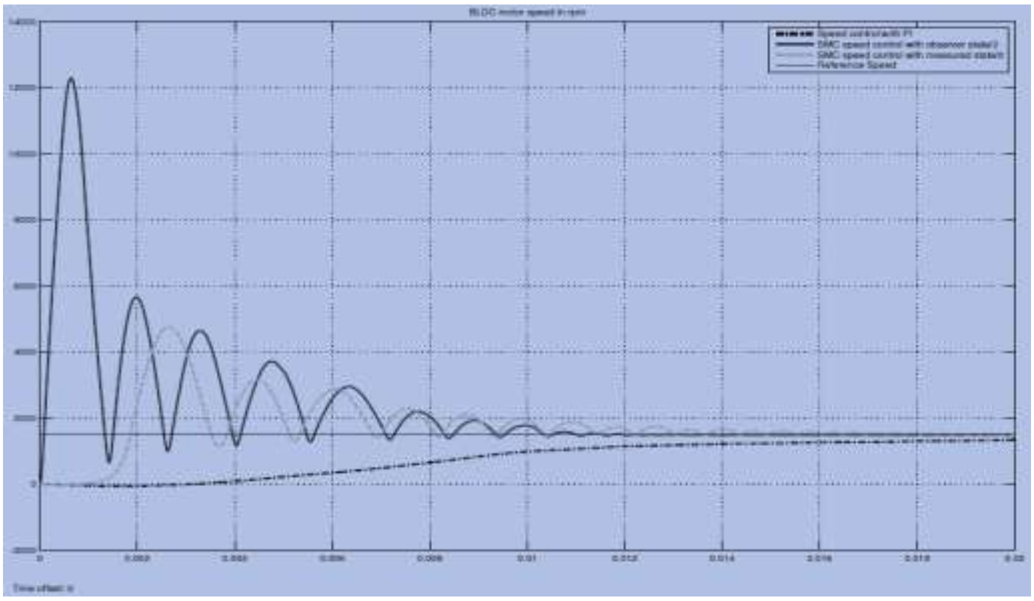

Fig.11: Combined response of BLDC motor speed controllers.

Fig.11 shows the combined result for the BLDC motor speed control with reference 1500 rps, from waveform we can see that the speed control with PI requires large settling time it is greater than time 0.02 sec and the error is large here.

SMC speed control with measured state reduces the error but as we can see from the response the time taken to settle down is more its nearly 0.03 sec. SMC speed control with observer state reduces the chattering phenomenon and it overcomes all the above methods here the settling time is nearly 0.012 sec, comparing other speed control methods this has less settling time.

V. CONCLUSION

The sliding mode control approach to speed control of BLDC machine is discussed. The implementation result speed control based on PI and reduced order with measured speed and reduced order with observer speed, using simulation are conducted. Reduced order observer deals with the chattering problem, encounters often in sliding mode. By seeing Fig.6, Fig.7 reveals that reduced order speed control with observer speed produces smaller oscillation than the reduced order speed with measured speed. Therefore system is proved to be robust and has fast response.

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