Speed Control of DTC based Brushless DC Motor using PI, PID, SMC Controllers

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Abstract: *In this paper a comparative study on speed control of Brushless DC motor is presented. The mathematical model of the DTC based BLDC motor is developed and it is used to examine the performance of the controllers. Initially a PI controller is developed for the speed control of the given BLDC motor. Then the controller is upgraded to PID, and the performance of the BLDC motor is verified. It is difficult to tune the parameters and get satisfied control characteristics by using conventional PI, PID controllers. This paper proposed an improved Sliding Mode Controller (SMC) to control speed of Brushless DC motor. Through extensive simulations it is observed that the performance of SMC is better than PI, PID controllers. The modeling, control and simulation of the BLDC motor have been done using the software package MATLAB/Simulink.*

Keywords—*PI, PID and SMC controllers, BLDC motor, DTC, MATLAB/Simulink*

I. INTRODUCTION

a. *Permanent Magnet BLDC motor*

BLDC motors have many advantages over brushed DC motors and induction motors. A few of those have better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation. The permanent magnet brushless dc motor is gaining popularity because of its usage in computers, aerospace, military and robots. The BLDC motor is inherently electronically controlled and requires rotor position information for proper communications of the current. The only drawback of conventional dc motors is that they need a commutator and brushes which are subjected to wear& tear and require regular maintenance. In BLDC motors the functions of brushes and commutator were implemented by position sensor and inverter. There are several methods to vary the speed of the BLDC motor over a wide range. The most modern technique is direct torque control method (DTC) [1].The DTC offers many advantages like fast torque response, no need of coordinate transformation and less dependence on the rotor parameters. The conventional PI, PID control methods are widely used in motor control system due to the simple control structure and easiness of design. However tuning the parameters of PI and PID controllers is a difficult task. In conventional PI, PID controllers, the performance of the motor may cause unexpected torque disturbances. In order to resolves the speed tracking problem for DTC of BLDC motor drive various approaches have been suggested such as sliding mode controller (SMC) [2] and Fuzzy controller, ANFIS controller etc. The proposed sliding mode controller (SMC) is one of the modern controller used to solve speed tracking problems for DTC of BLDC motor drive. This controller works irrespective of the parameter variations and load torque disturbances. The SMC method is an excellent control technique and a promising approach for solving the conventional PI controller parameters problem.

b. *Purpose of the present work.*

The objective of the present work is to provide an alternative approach to solve speed tracking problems for DTC of BLDC motor drive. This method uses the principle of Direct Torque Control, which is based both on field oriented control (FOC) as well as on the direct self-control theory. DTC offers direct control of stator flux and electrical torque there by reducing the speed error resulting in better speed control of BLDC drive. In this paper one of the modern controller called sliding mode controller (SMC) is used to reduce the speed error of BLDC motor, hence overcoming the major drawbacks of conventional PI and PID controllers.

II. MATHEMATICAL MODEL OF BLDC MOTOR

Typically, the mathematical model of a brushless DC motor is not totally different from the conventional DC motor. The major difference is the phases involved in the operation of BLDC motor drive will peculiarly affect the resistive and the inductive nature of the BLDC model arrangement. The BLDC motor has three stator windings and permanent magnets on the rotor [3]. The mathematical model of the BLDC motor is modeled based on the equations illustrated below.

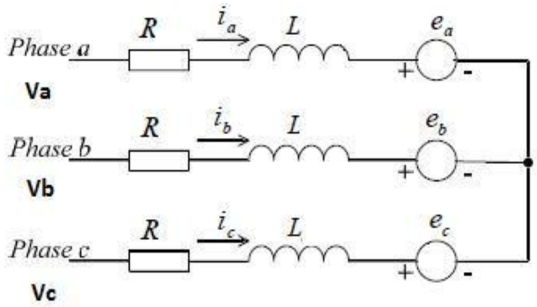

Fig.1 Electrical equalent circuit of BLDC Motor

The coupled equations of stator windings in terms of motor electrical constraints are

$$V_{an} = i_a R + e_a + L\left(\frac{di_a}{dt}\right) \quad (1)$$

$$V_{bn} = i_b R + e_b + L\left(\frac{di_b}{dt}\right) \quad (2)$$

$$V_{cn} = i_c R + e_c + L\left(\frac{di_c}{dt}\right) \quad (3)$$

Where L - armature self-inductance[H]

V_a, V_b, V_c Terminal phase Voltages[V]

R - Armature resistance [Ω]

i_a, i_b, i_c - Motor input currents

e_a,e_b,e_c- Motor Back emf"s[V]

The electromagnetic torque is given by

$$T_e = [e_a i_a + e_b i_b + e_c i_c]\frac{1}{w_m} \quad (4)$$

$$e_a = f_a(\theta_r)\lambda_p\,\omega_m \quad (5)$$

$$e_b = f_b(\theta_r)\lambda_p\,\omega_m \quad (6)$$

$$e_c = f_c(\theta_r)\lambda_p\,\omega_m \quad (7)$$

Where the functions $f_a(\theta_r)$, $f_b(\theta_r)$, $f_c(\theta_r)$ have same shape as induce emfs and λ_p is rotor magnetic flux linkage(w_b).The equation of motion for a simple system with inertia J , friction coefficient B, and load

Torque T_1 is $J\frac{dw_m}{d\theta} + B\omega_m = T_e - T_1 \quad (8)$

III. DIRECT TORQUE CONTROL OF BLDC MOTOR

DTC strategies have been widely implemented in induction machine drives. They allow a direct control of the electromagnetic torque and the stator flux through the application of suitable combinations of the control signals of the inverter switches. Therefore in DTC, Torque is controlled through the selection of optimal inverter switching states. DTC technique is superior to vector control because of the advantages like fast torque response, low inverter switching frequency, low harmonic loss, absence of coordinate transformation. This control strategy in this paper has been applied for BLDC drive.

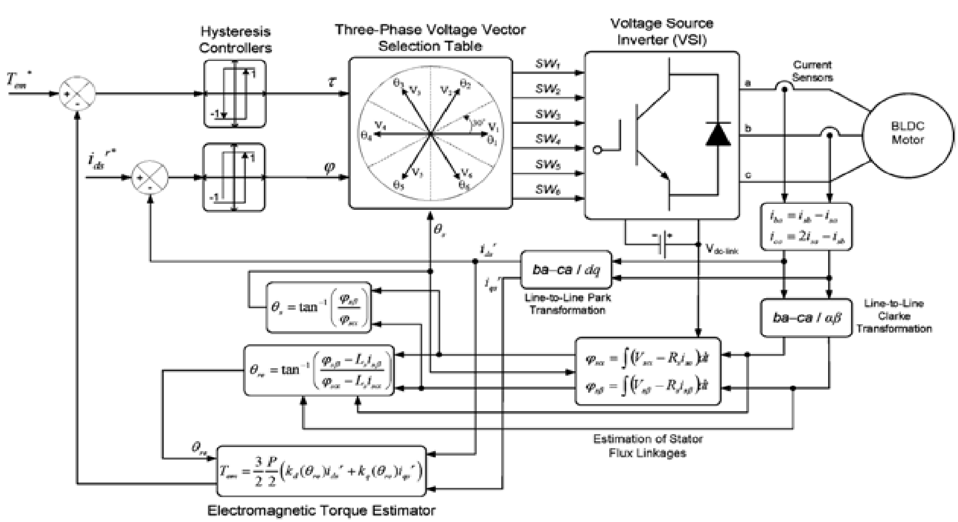

Fig.2 Block Diagram of BLDC Motor with DTC

The instantaneous induced emf's can be written as

The basic control algorithm of DTC consists of two independent hysteresis comparators producing the error signal of Stator flux and electrical torque. A two-level hysteresis flux comparator and a three level hysteresis torque comparator compare the actual values to the reference values produced by flux and torque reference controllers [4-6]. Depending on the outputs from the two hysteresis controllers, the optimum switching logic selects one of the six voltage vectors and two zero voltage vectors generated by a VSI in order to keep stator flux and torque within the limits of two hysteresis bands. The angle of the stator flux vector is used to determine the voltage sector as shown on the Fig.3

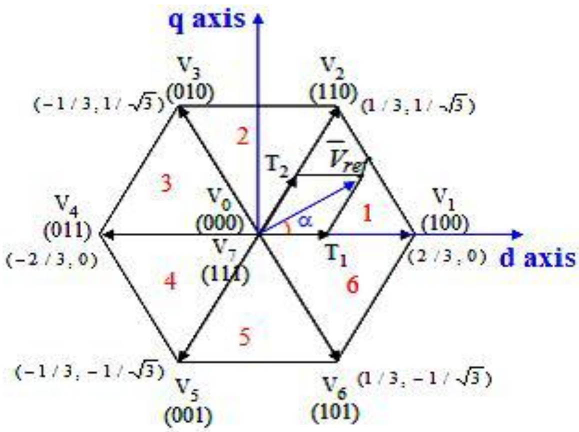

Fig.3: Voltage Vector Diagram

Six nonzero vectors (V1 – V6) shape the axes of a hexagonal as depicted in the above figure and feed electric power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V0 and V7) are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by V0, V1, V2, V3, V5, V6, and V7. Assuming the stator flux vector laid on the sector 1 of the d-q plane, V1, V2, V6 could be selected to increase the stator flux vectors. Conversely, V3, V4, V5 could be selected to decrease the stator flux vector. The zero (null) voltage vectors does not effect on the stator flux vector. Voltage vectors are selected to control the torque also. In general, V2 and V3 vectors can be selected to increase the torque and V5 and V6, vectors will decrease the torque. Table 1 shows voltage vector selection according to stator flux and torque errors [7-10].

S_ψ	S_T	Sector I -30 to 30	SectorI I 30 to 90	Sector III 90 to 150	Sector IV 150 to 210	Sector V 210 to 270	Sector VI 270 to 330
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

Table.1Switching voltage vectors

IV P-I Controller

P-I controller is used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. This controller is mostly used in areas where speed of the system is not an issue. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations.

a. Transient Response of P-I Controller:

Integral action eliminates steady state error. However, it has very poor transient response. Using integral action increases the oscillations in the output of the closed loop systems. This indicates that with P-I control, steady state error is non-zero. However, Integral control causes too many oscillations in closed loop system outputs. The following simulations were done on MATLAB-Simulink to illustrate the performance of P-I control on BLDC motor.

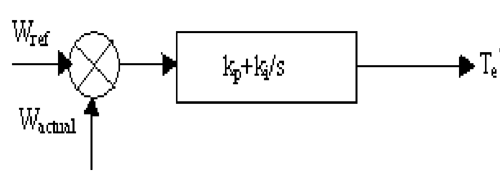

Fig.4 PI Controller Block

V P-I-D Controller

P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energy storage.

a. Transient Response of P-I-D Controller:

P-I-D controller is the optimal controller for high order plants. It has zero steady state error together with acceptable transient response. The only problem with P-I-D control is tuning. MATLAB has automatic tuning option. However, automatic tuning does not usually provide the best results, it only provides optimal results.

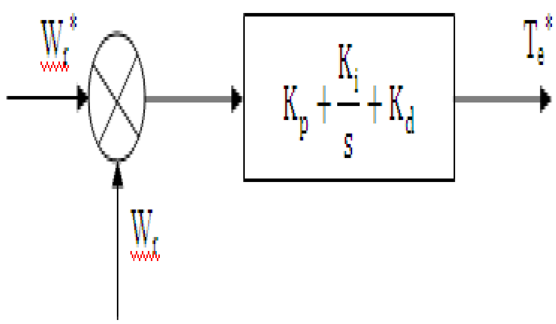

Fig.5 PID Controller Block

VI PROPOSED SLIDING MODE CONTROLLER

A sliding mode controller (SMC) is an adaptive controller that results in robust performance of the drive even under the parameter variation conditions and load torque disturbances.SMC can be employed in BLDC motors, induction motors, synchronous motor drives for applications such as robot drives and machine tool control etc [10].PI and PID controllers are replaced with SMC.

The SMC has been modeled by using the following equation

The electromechanical equation of an BLDC motor is described as,

$$J\frac{dw_m}{d\theta} + B\omega_m = T_e - T_1 \qquad (9)$$

The electromechanical equation can be modifiedfurther as,

$$\omega_m + a\omega_m + d = bT_e \qquad (10)$$

where a= B/J, b = 1/J, d = T_L/J

Consider the electromechanical equation with uncertainties as,

$$\omega_m = -(a + \Delta_a)\omega_m - (d + \Delta_d) + (b + \Delta_b)T_e \qquad (11)$$

Δa , Δb and Δd represents the uncertainties of the terms a, b and d respectively introduced by system parameters J &B.

The sliding variable with integral component can be defined as,

$$S(t) = e(t) - \int_0^t (h - a)e(\tau)d\tau \qquad (12)$$

where h is a constant gain

Assumtion-1: The gain *h* must be chosen so that the term (*h-a*) is strictly negative and hence *h<0.*

Then the sliding surface can be defined as,

$$S(t) = e(t) - \int_0^t (h - a)e(\tau)d\tau = 0 \qquad (13)$$

Based on the developed switching surface,A switching control that guarantees the existence ofsliding mode, a speed controller is defined as,

$$f(t) = he(t) - \beta sgn(S(t)) \qquad (14)$$

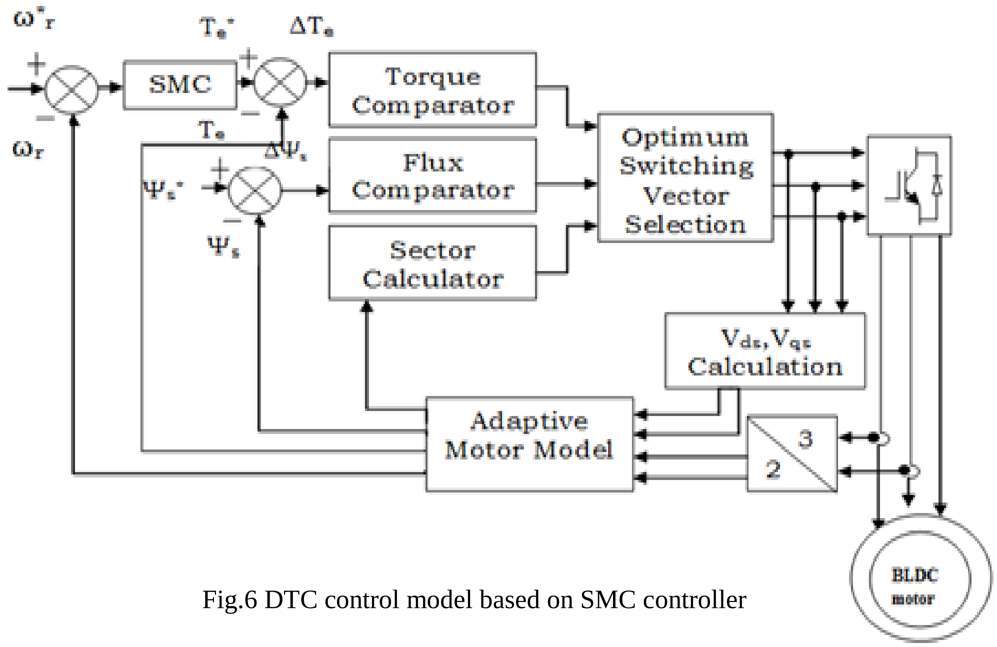

Fig.6 DTC control model based on SMC controller

VII RESULT AND DISCUSSION

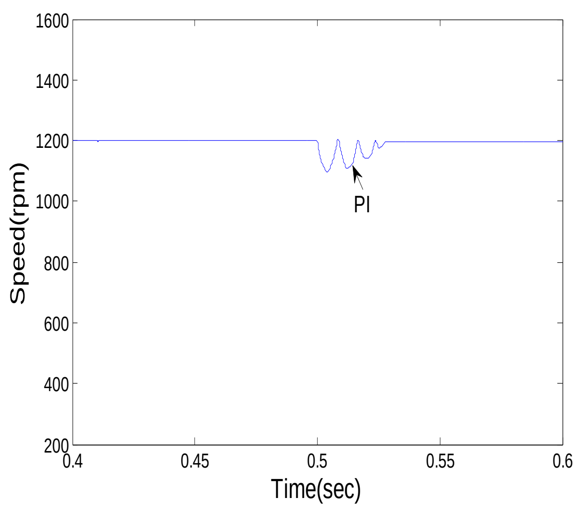

Fig.7 Speed Disturbances PI Controller at 1200rpm

In the Fig.7, it shows the plot of time Vs speed for 1200rpm with conventional PI based DTC of BLDC motor, there are ripples between 0.5 to 0.55 secs.

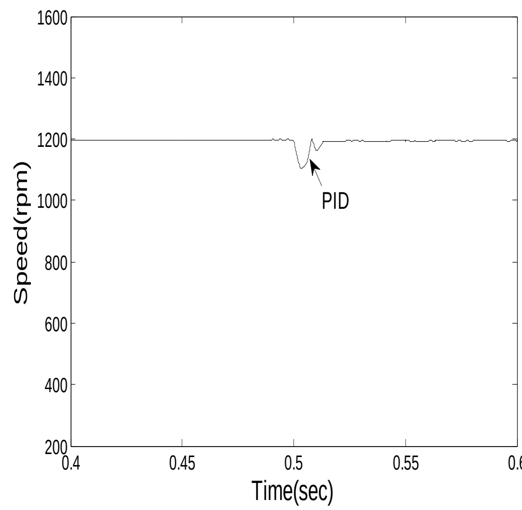

Fig.8 Speed Disturbances PID Controller at 1200 rpm

In the Fig.8, it shows the plot of time Vs speed for 1200rpm with conventional PID based DTC of BLDC motor; ripples appear in between and are less than PI based DTC of BLDC motor.

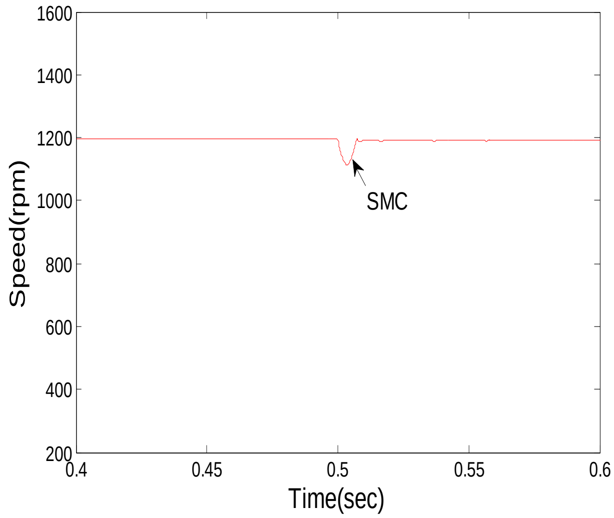

Fig.9 Speed Disturbances SMC Controller at 1200rpm

In the Fig.9, it shows the plot of time Vs speed for 1200rpm with conventional SMC based DTC of BLDC motor.

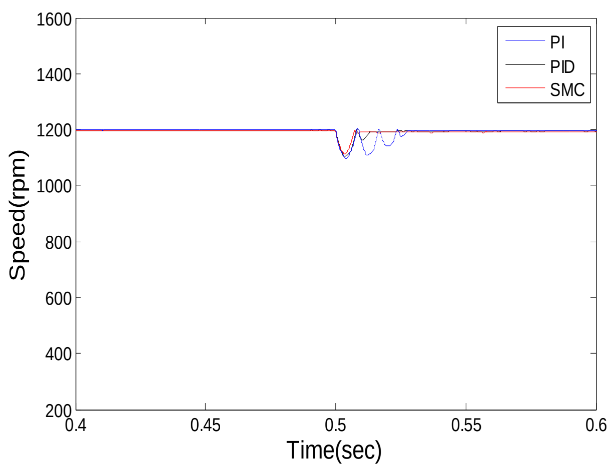

Fig.10 Speed comparison conventional PI PID &SMC based DTC at 1200rpm

In the Fig.10, it shows the plot of time Vs speed for 1200rpm, comparing the speed behavior of conventional PI&PID based DTC with SMC based DTC of BLDC motor, there is less ripple in speed and results in better speed performance of the SMC based DTC.

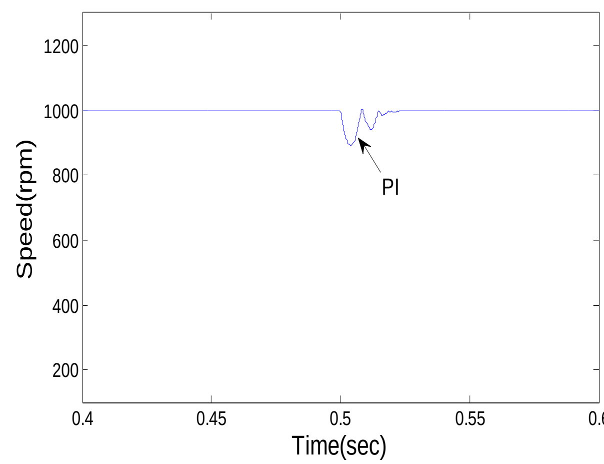

Fig.11 Speed Disturbances PI Controller at 1000rpm

In the Fig.11, it shows the plot of time Vs speed for 1000rpm with conventional PI based DTC of BLDC motor, there are ripples between 0.5 to 0.55 secs.

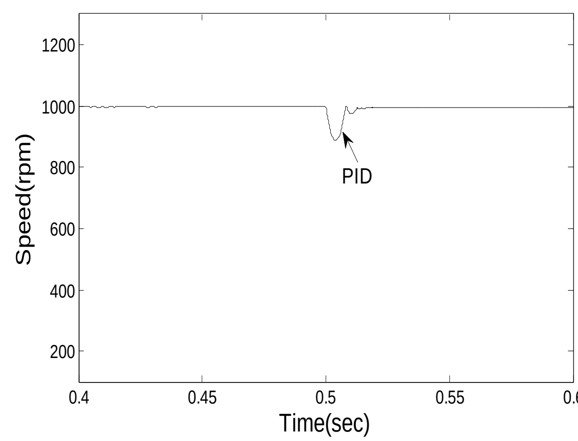

Fig.12 Speed Disturbances PID Controller at 1000rpm

In the Fig.12, it shows the plot of time Vs speed for 1000rpm with conventional PID based DTC of BLDC motor; ripples appear in between and are less than PI based DTC of BLDC motor

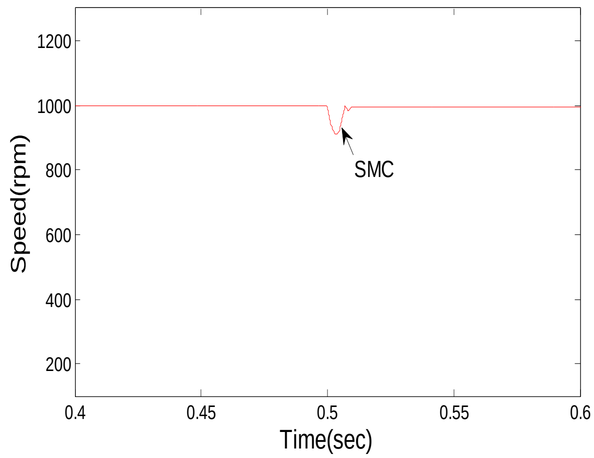

Fig.13 Speed Disturbances SMC Controller at 1000rpm

In the Fig.13, it shows the plot of time Vs speed for 1000rpm with conventional SMC based DTC of BLDC motor.

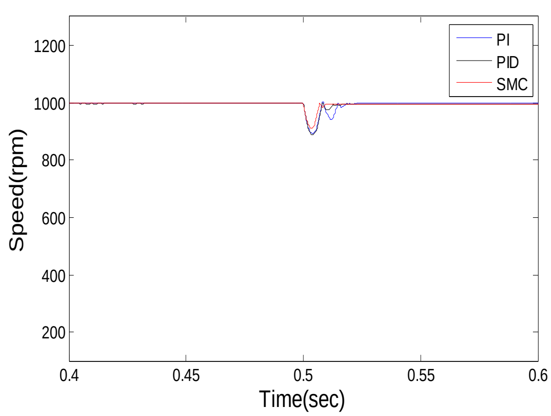

Fig.14 Speed comparison conventional PI PID &SMC based DTC at 1000rpm

In the Fig.14, it shows the plot of time Vs speed for 1000rpm, comparing the speed behavior of conventional PI&PID based DTC with SMC based DTC of BLDC motor, there is less ripple in speed and results in better speed performance of the SMC based DTC.

VIII.CONCLUSION

In this paper the proposed SMC controller based DTC OF BLDC drive control scheme has been implemented, comparing the speed behavior of conventional PI&PID based DTC with SMC based DTC of BLDC motor, there is less ripple in speed and results in better speed performance of the SMC based DTC.

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