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Application of Soft Computing Techniques for Speed Control of Brushless DC Motors

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ABSTRACT

Nowadays Brushless DC (BLDC) motors are treated as the most used motors, which areapplied widely due to their higher efficiencyand excellent torque characteristics. Moreover they are operated with DC supply and without using brushes. But BLDC motor operates with wide speed range and therefore required to regulate the speed of DC motor using different advanced techniques. In this work, the fuzzy sliding mode control (FSMC) is employed forregulating the speed of BLDC motor. The proposed method is compared with the conventional sliding mode control (SMC) and the results are analyzed using MATLAB/ Simulink tool.

Keywords: Speed control, Sliding mode control, Fuzzy sliding mode control, Brushless DC motor.

I. INTRODUCTION

Conventional DC motors are widely used because of their easy operation and less maintenance but on the other hand, its brushes offer certain demerits like decreasing of working performance due to problemsin the mechanical commutator, moreover the brushes also runs with high maintenance rate that expands machine functional expenses.Further, BLDC motors deliveroperative solution by disposing thebrushes[1].BLDCmotors are direct current motors and are also called as permanent magnet DC synchronous motors [2], which are veryattractive and employed as a part of variable speed uses. The BLDC motor has rapidlyattractedreputation, due to its better qualities and performance. BLDC motors are electrically commutated,it gives high dynamic response, and improved speed-torque characteristics,better efficiency, noiseless and some other merits such as simple arrangement, quick torque response, better efficiency, large speed variations, silentfunction and high durability. Therefore, the BLDC motors are the suitable choice for industrial applications.

The vital part of this work is to regulatethe speed of BLDC motor. Different techniques [3] have been utilized so far for the speed control of BLDC motor. Controllers like proportional integral (PI), proportional integral derivative(PID) and Fuzzy PID (FPID) are utilised for the above said purpose.The author in [4] presents a robust PI for the speed control of BLDC motor.The PI causes the steady state error reduce to zero.PI with hysteresis or pulse-width modulation(PWM) switching is generally employedfor speed control of BLDC motors. But the PI controller lost its importance due to some disadvantages like low dynamic response and more affected in non-linear system. The author in [5] impliments a PID controller to handle the uncertainties of the BLDC motor outputs. PID parameters like proportional, integral and derivative gain influences system's overall performance. Besides these the PID controller exhibits poor dynamic conduction in non-linear systems.Similarly, the authors in [6-7], propose the Fuzzy Logic control (FLC) based on the fuzzy set theory. FLC is capable in dealing the uncertainty of the system. FLC does not require the knowledge of system model and can operate effectively. FLC is implemented is several industrial applications and the outputs shows that FLC provides a perfect pursuit withoutanyovershoot, but it offers one demerit like long timeresponse.

During the dynamic state, the PI controller is not able to function accurately and therefore, the fuzzy PID controller is a better choice to control the speed of the BLDC motorwhich has improvedeffect in comparision to the PI controller.The authors in [8-9] introduced a Fuzzy PID controller due to its stable algorithm,high reliability and easy adjustment.Fuzzy PID is employed in the industry process with nonlinear systemsand parameter variability.

However, for the faster dynamic response more advance techniques are developed and among them the sliding mode controller (SMC) [10-13]is treated to be one of the robust technique. SMC provides the smooth response in the nonlinear system without any peak overshoot. As in this era we are using many nonlinear loads we have to find a controller which can control the current and speed and can maintain the good efficiency. SMC is a variable design technique which has become more popular in recent years. This is because of its simple design, rapid convergence in finite time, andhigh robustness. The function of SMC is to constrictthe system statetrajectory to attaina given surface which is known as sliding surface orsliding variable. However, it also offers certain demerits like its discontinuous nature, produces high switching frequencies called as chattering factor and to reduce the chattering, several techniques have been used.The authors in [14-15] use a high order sliding modes which is used to reduce the discontinuities, by controlling andcancelingthehigherderivativesoftheslidi ngvariable. There are several ways to optimize the SMC discontinuous membrane gainusing advancedtechniques and one of the efficient is the Fuzzy Sliding Mode Control (FSMC) [16-20] which is the combination of SMC & FLC. FSMC decreases the chattering phenomenon and uncertainties of the system.The FSMC unites the insight of a fuzzy derivation framework with the SMC.

Though the fuzzy technique used in the above study is more robust for a nonlinear system, it has some limitations which affect the efficiency of the controller. The fuzzy technique used in the study somehow has some disadvantages. The main demerit FLC is lack of design techniques and most of these techniques are human knowledge based and rules will vary from individual to individualrather than the same performance of the system. The BLDC motors used in the study have many advantages like high efficiency, high torque to weight ratio, it has some limitations which is reducing its popularity. Due to limited constant power range and the permanent magnet makes the motor more expensive and is not possible for the BLDC motor to attain a peak speed greater than the normal speed.

The objective is to control a nonlinear system. Due to chattering effect the SMC is replaced by FSMC. A proposed FSMC is designed and has compared with a SMC controller. Though Fuzzy theory is a human knowledge based techniques, it is not a robust and efficient controller. So for high performance some advance algorithms can be implemented in the system. An advance Fuzzy SMC can be designed by using Genetic Algorithm and research should be going on in this.

The speed control of BLDC motor is investigated withSMC and for the enhanced performance, the speed curve is compared with theFSMC.The simulation study of SMC and FSMC are compared using MATLAB tool.

II. SYSTEM CONFIGURATION

The block diagram of the proposed model of BLDC motor is illustrated in Fig. 1.The Hall Effect sensors detect the rotor position and the gating signals are generated according to the rotor position by the gate pulse.It can detect the rotor position and according to that the speed is controlled. Error signal is given to the controller block by comparing the reference speed with actual speed by error detector. The FSMCor SMCprovides control output to the converter or DC source according to the error signal and by regulating the DC voltage, the speed of BLDC motor can be controlled. The DC signal then fed to the inverter and for the ac input to the BLDC motor.The stator windings of the permanent magnet brushless motor with a durable magnet rotor rotated such that the back emfgenerated is trapezoidal in nature. Due to rectangular stator phase current a compatible torque is produced.

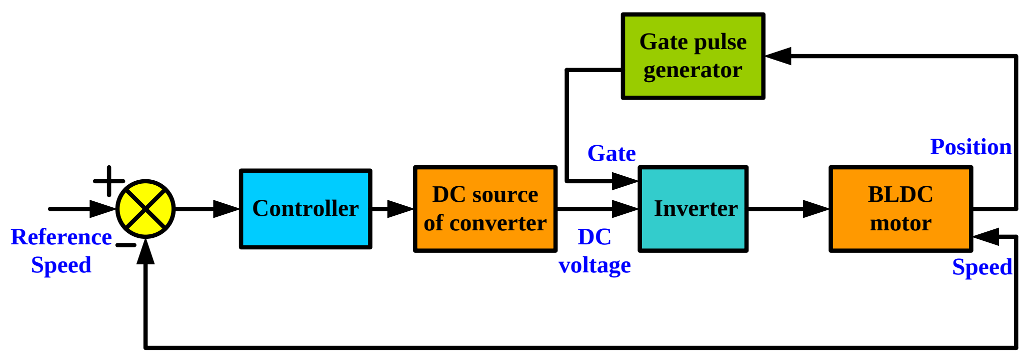

Fig. 1 Block diagram of the proposed model.

The electrical part of the system is governed as:

$$V_{dc} = iR + L\frac{di}{dt} + E \quad (1)$$

Thesymbols V_{dc} ,L, R, E are the voltage applied in DC, winding inductance, winding resistance, back emf of the motor respectively.

In motor, the mechanical part is regulated as:

$$T_e = j\frac{d\omega}{dt} + B_\omega + T_L \quad (2)$$

The symbols T_e, T_L, j, B electromagnetic torque in Nm, load torque, moment of inertia, friction coefficient respectively.

III. CONTROL STRATEGY

A. Sliding Mode Controller (SMC)

For nonlinear control systems and to achieve an adaptable control,the SMC is treated as an alternate to conventional controllers like PI, PWM and PID controller. SMC is implemented in both linear and non-linear frameworks.But SMC has some drawbacks like variable in parameter and aggravations;SMCdelivers powerful operationeven in the event of non-linearsystem. The basic configuration of SMC is illustrated in Fig. 2.

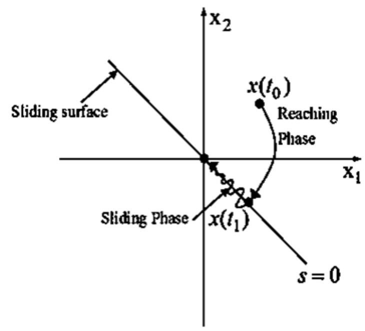

Fig. 2. Basic Structure of SMC

SMC techniquecomprises of two significant assignments, i.e., to design a stable sliding surface and to designa control law as such the sliding surface will move towards the direction of states. The direction coordinates are taken as steady and aultimateobjective is taken to limit the direction over the specified surface, '*S*' and subsequently it will reach to the original position.

The error is calculated in terms of speed as:

$$e(t) = \omega_r^* - \omega_r \quad (3)$$

The term ω_r^* and ω_r are the desired and detected rotor speed.A derivative term is present in the conventional SMC technique.

The derivation of speed equation is presented as:

$$\omega_r(t) = \frac{1.5 * P * \lambda - B * \omega - T_L}{J} \quad (4)$$

The sliding surface is expressed as:

$$S = e(t) = \frac{3 * P * \lambda}{2 * J} \int e(t) dt \quad (5)$$

By combiningequations (4) and (5) we get,

$$u = qe + f * \text{sgn}(s) + \frac{2 * J}{3 * P * \lambda}\omega^* \quad (6)$$

Where, *q* and *f* are the controller gains and *u* is the control law.

The function $Sgn(S)$ is named as sign function and is presented as:

$$Sgn(S) = \begin{matrix} +1 if\ S > 0 \\ -1 if\ S < 0 \end{matrix} \quad (7)$$

The programming code of the controller is provided in TableI.

Table I Programming code of the controller

```
Function output = smc (e, eint, P,B,W, lambda,J,q,f,Tl)
Wdot= 1.5*p*lambda- B*w-Tl;
        S= e+ ((3*p*lambda)/(2*J))* eint;
        If (S>0)
Sat_s=1;
      Else
Sat_s= -1;
     End
    Output=(q*e) + (f*s*sat_s)+ (2*J)/(3*p*lambda))*wdot;
    end
```

B. Fuzzy Sliding Mode Controller (FSMC)

In 1965 LotfyA,Zadehnin proposed a Fuzzy set theory, which is developed to tackle with uncertainty, inaccurate, and has a simple structure. FLC contains a fuzzification, a decision rule and a de-fuzzification unit andprovided in Fig.3.With the use of accurate input membership functions, the fuzzification unit transforms the real inputs to corresponding fuzzy output.The inference operation is done by the decision making unit and it generates the fuzzy valueswhich is based on 'IF-THEN' form of fuzzy rules. The de-fuzzificationtransforms the fuzzy values into the crisp output.

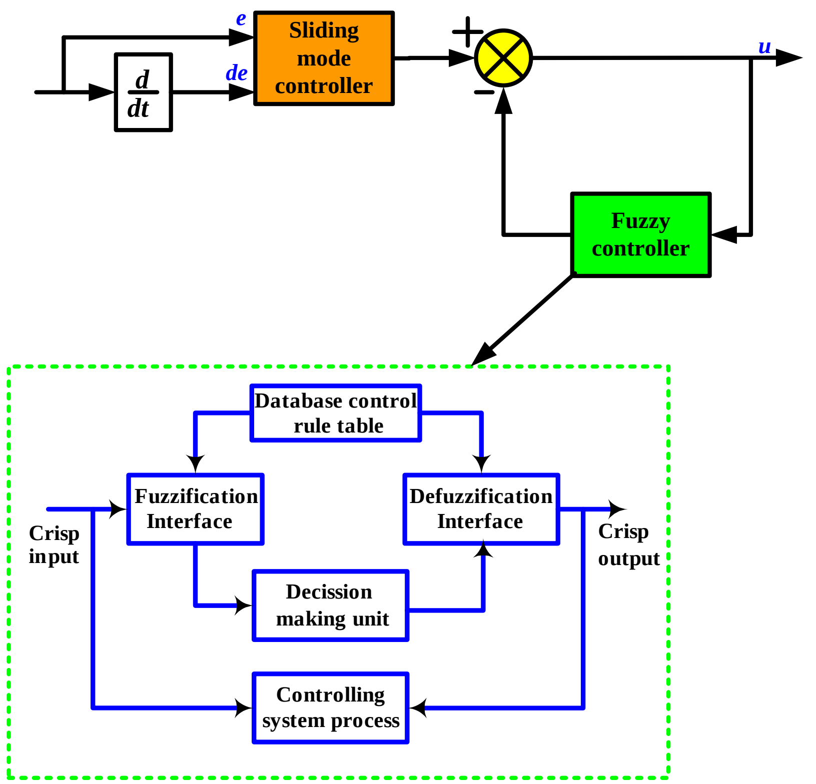

Fig. 3. Block diagram of FSMC.

The FLC with Mamdami based is applied with seven crisp variables having triangular membership functions and is displayed in Fig. 3 and the fuzzy membership rule is presented in Table 2.

Table 2 Fuzzy Membership rule

e(n)	ce(n)						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The SMC manages the speed/torque of the drive and the chattering effect is reduced by the FLC which varies the controlled yield and the new yield isdefined as:

$$u^* = qe + f^* \operatorname{sgn}(s) + \frac{2 * J}{3 * P * \lambda} \omega^* - u_f \quad (8)$$

$$u_f = h \times u^* \quad (9)$$

Where, u_f and u are respectively the output from the FLC and output dependent on the value of gain ‘h’.

IV. Results& Discussion

The speed control of BLDC motor is analyzed using the FSMC. The FSMC technique is analyzed in comparison to the conventional SMC and is validated using MATLAB/Simulink tool.Initially, the system is performed using SMC with two inputs which are given as actual and reference speed. In this proposal, the initial speed is taken at 1500 rpm and final speed at 1000 rpm. The time limit is determined at 0.25 sec, during which the speed control of BLDC has to be completed. The parameters values are assign from the system design equation described in section III and the coding of SMC is presented in Table 1. The load torque difference of BLDC is revealed in Fig 4.

The result of SMC on load torque producespulsation, but FSMC diminishes the effect of chattering on torque.Initially when motor starts running, the current drawn by the motor is very high. Therefore, at startingthe torque is at peak but when the motor is trying to stable itself the torque is gradually decreasing and after 0.25 sec, it will go negative because the motor speed is gradually decreasing at that time. The stator back EMF is regulating the current flowing through the BLDC motor and is proportional to the motor's velocity.The waveform of stator back EMFs which is trapezoidal in nature is shown in Fig. 5.

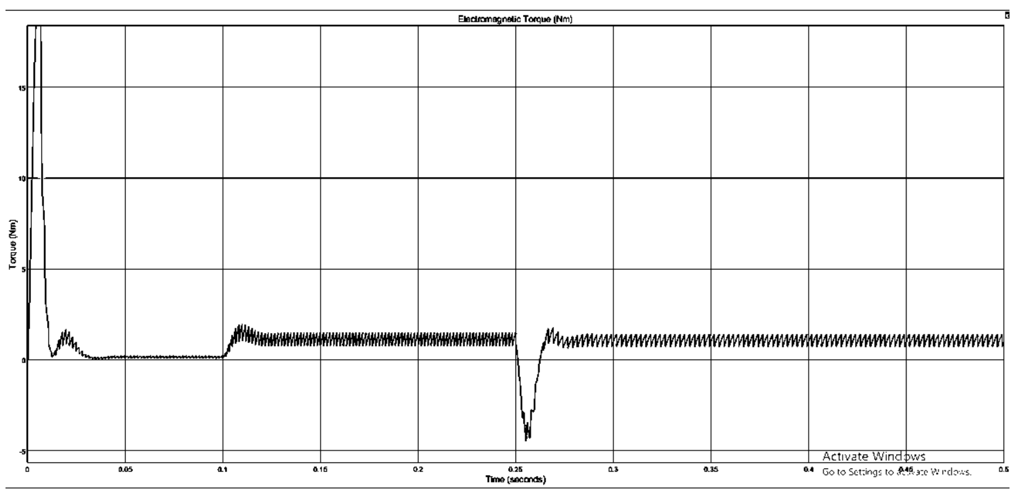

Fig.4 Motor torque waveform of BLDC motor.

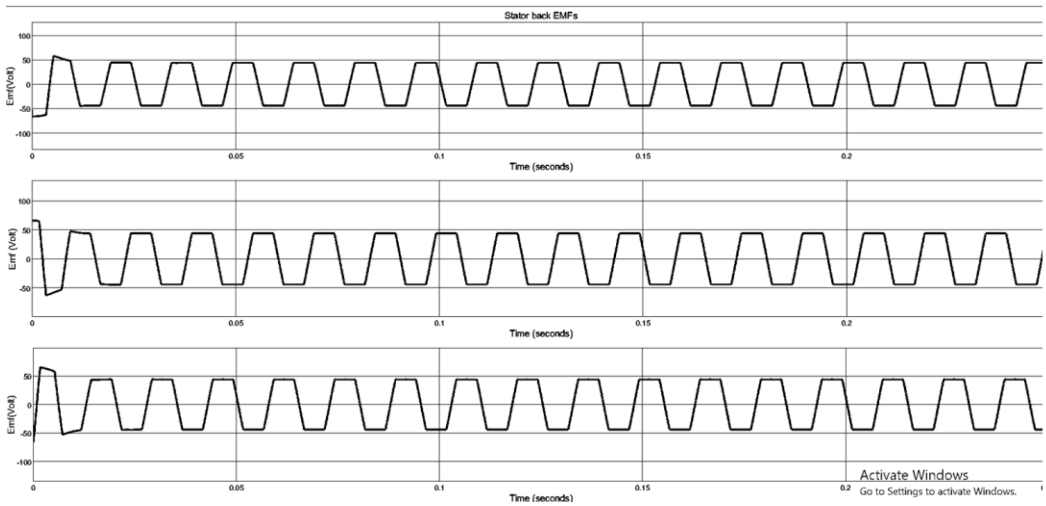

Fig.5 Stator Back–EMFS.

The hall effectsignals implements to detect the rotor position of BLDC motor, so that the motor speed can be controlled according to our preferences. The hall effect signals are displayed in Fig. 6. The three-phase current signals can be realized for a load variation at 0.05 sec of a BLDCmotor. At firstthemotorisrunatrated speed of 150 rad/s. and then the load is varied to 3 Nm at t=0.05 sec. The three-phase current waveform is shown in Fig. 7.

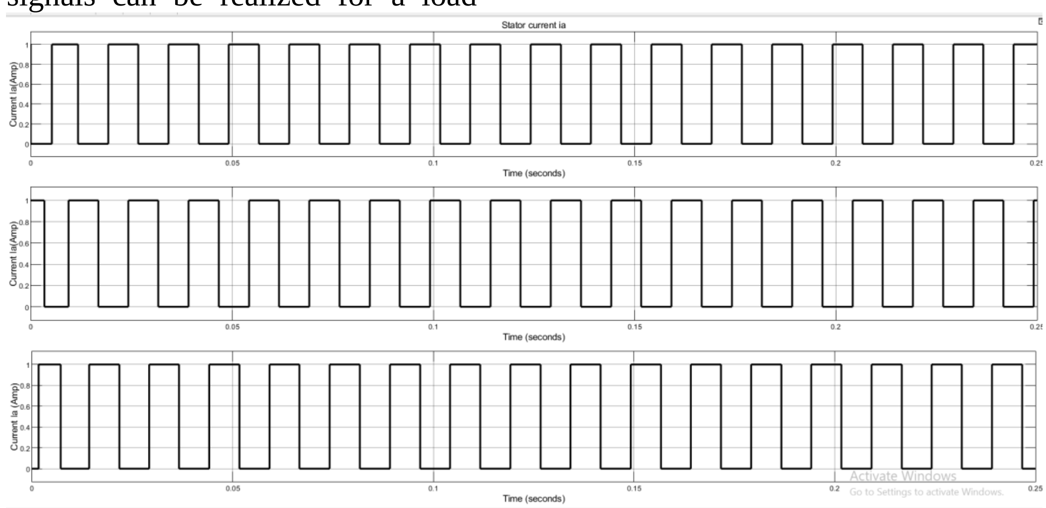

Fig.6.Hall effect signals

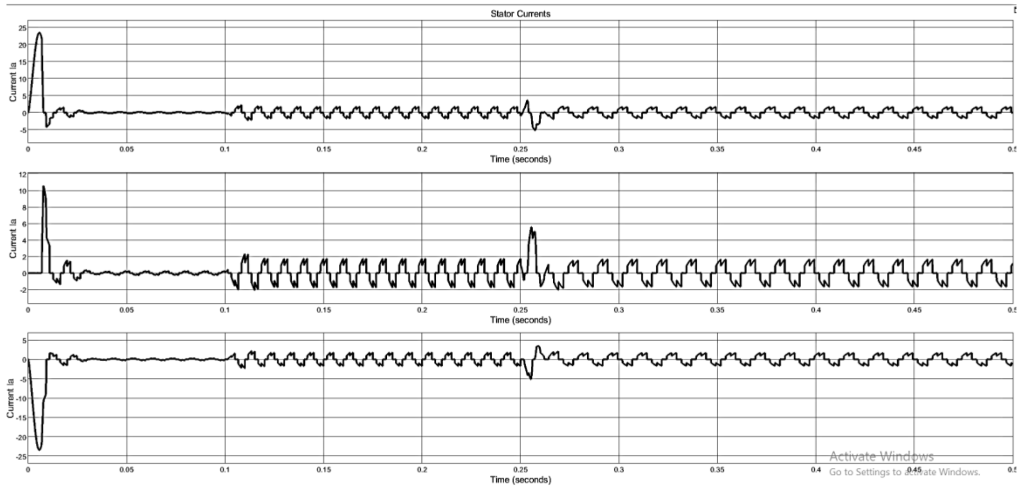

Fig. 7. Stator current of a,b,c phase

The waveform of rotor speed is shown in Fig. 8.In the same operating conditionsthe motor is operating at 150 rad/s. It is clearly depictsthat the hybrid FSMC leads to smooth running of the motor. Loadchanges results in affects the rotor speed. We can clearly see the speed waveform can rise very smoothly upto1500 rpm as shown in graph and after 0.25 second there is a change in speed.The waveform of rotor speed using SMC is shown in Fig. 9. The waveform is proving that it's taking more time to reach to the rated speed.

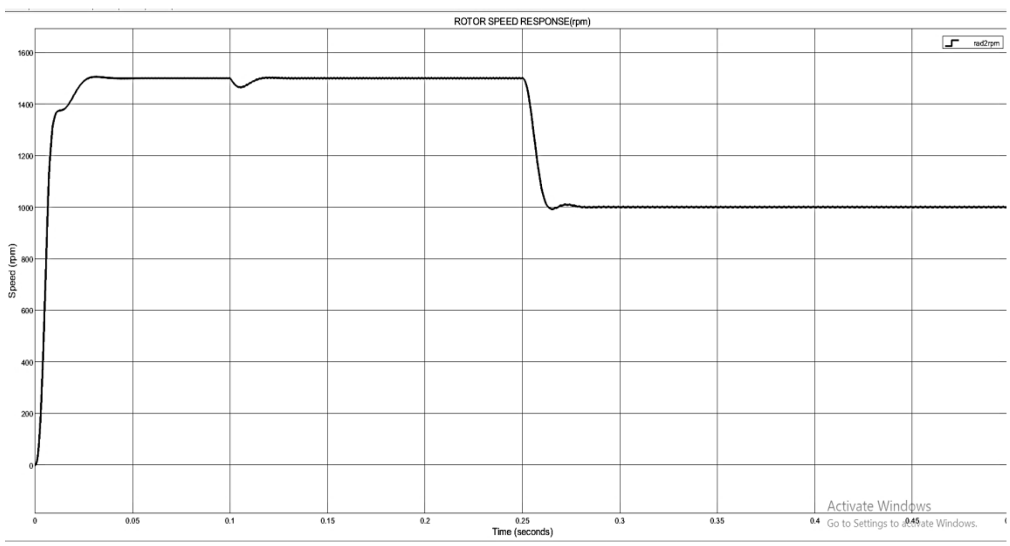

Fig. 8.Rotor speed using FSMC

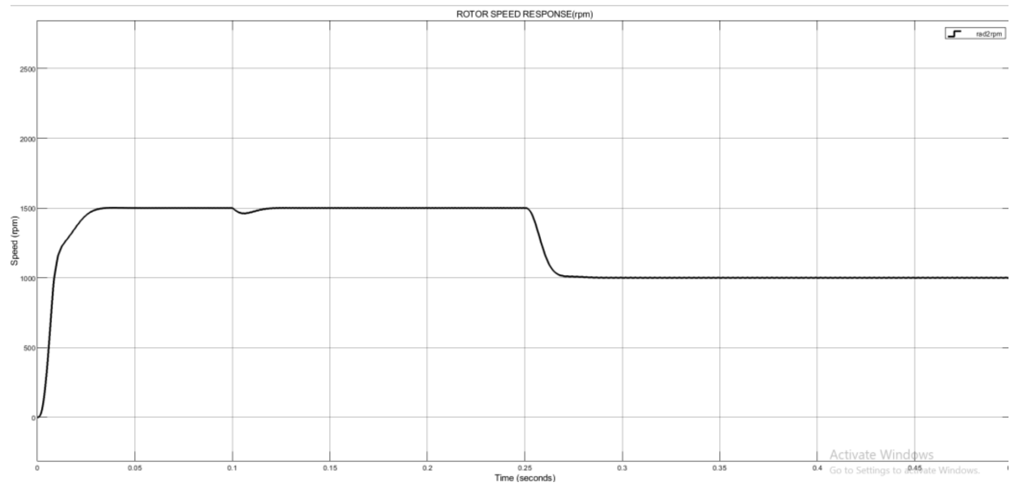

Fig. 9. Rotor speed using SMC

A comparative analysis between SMC and FSMC is done to confirm theeffectiveness of the proposed work. Fig. 10 illustrates the rotor speed of two controlling techniques. From the figure we can depicts that FSMC control can stabilize itself more faster than SMC controller. And it can decline sharply than normal SMC controller. We can recognize small difference between the two.

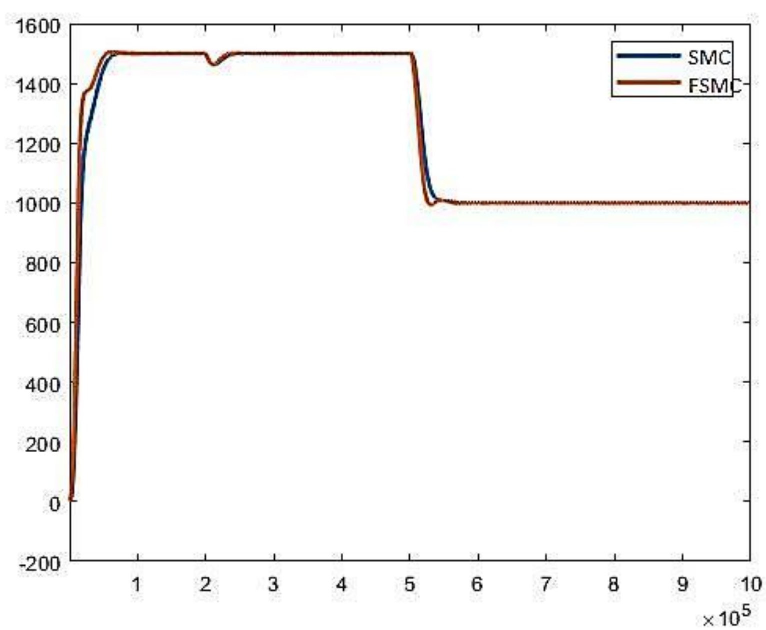

Fig.10Comparison of rotor speeds

V. Conclusion

The speed response of BLDC motor is analysed with FSMCusing nonlinear conditions. The response is compared with the conventional SMC. From the simulation results it is analysed that the motor performance using FSMC is better compared to the SMC control showing peak overshoot, more settlingtimeunder loaded condition. Further, with loaded condition, fluctuation inspeed of the motor is also reduced withFSMC.Due to the chattering effect the SMC is replaced by FSMC. A proposed FSMC is designed and has compared with a SMC controller. Though Fuzzy theory is a human knowledge based techniques, it is not a robust and efficient controller. So for high performance some advance algorithms can be implemented in the system. A advance Fuzzy SMC can be designed by using Genetic Algorithm and research should be going on in this.

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