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Analysis of Resonant Converter fed PMDC Motor with Sliding Mode Control

M. Santhosh Rani[1] and Subhransu Sekhar Dash[2]

ABSTRACT

The classical proportional- integral (PI) controller is still widely used for the control of motors due to its simplicity in implementation. However, due to load disturbances, un-model states, parameter variations and friction forces, PI controllers are unable to provide effective solutions to many practical problems. To avoid these problems, a nonlinear controller namely Sliding Mode Control (SMC) is used for speed control of PMDC motors. In this work, the resonant converter is implemented for speed control of the PMDC motor. Simulation is carried out in MATLAB for open loop and closed loop control of the PMDC motor. Hardware is implemented for closed loop control with PI controller and Sliding Mode Controller (SMC), and their performance is analyzed. On comparing the results of both techniques, it is observed that SMC shows a good dynamic behaviour with a rapid rise time and settling time and better performance than the PI controller. It is observed that for the change in speed, the response of SMC is better than the PI controllers with respect to both peak overshoot.

Keywords: PMDC Motor, Sliding mode control, PI controller, Non-linear control

I. INTRODUCTION

Permanent Magnet DC motors widely used in robotics and electrical equipments are simple in construction and are used as the starter motor in automobiles, for blowers in heaters and air conditioners, windshield wipers, washer, to raise and lower windows and more extensively in toys. PMDC drives have uncertain and nonlinear characteristics because the magnetic field strength of a permanent magnet is fixed and it cannot be controlled externally. Small fractional and sub-fractional kW motors are designed with a permanent magnet. Field control of this motor is not possible.

II. OPEN LOOP CONTROL OF PMDC MOTOR

The schematic circuit for open loop control of PMDC motor using LCC resonant converter is shown in Figure 1. The voltage available between the points A and B is rectified and fed to load through low pass filter C_o. It is assumed that the converter operates in the continuous conduction mode and the semiconductors have ideal characteristics. The parameters chosen for the Simulink model are output voltage 51V, L_s=4.26μH,C_p=C_s=2.87μF and source voltage V_s=12V. The output voltage obtained is 51V and the current is 2.7 A as shown in Figure 2.A PMDC motor is chosen as load, and the simulation is carried out.

III. HARDWARE IMPLEMENTATION FOR OPEN LOOP CONTROL

Hardware is implemented with PMDC motor as load. The output of the LCC converter is 51.8V, which is supplied to the PMDC motor.The chosen parameters of the hardware model are comparatively similar to that of the simulation model. The converter is designed for 52 V, 55W output with an input voltage of 12 V and at a switching frequency of 50 KHz. The electrical parameters chosen are as follows; series capacitance

[1] Department of Mechatronics, E-mail: *Santhoshrani.m@ktr.srmuniv.ac.in*

[2] Department of EEE SRM University, *E-mail: munu_dash2k@yahoo.co.in*

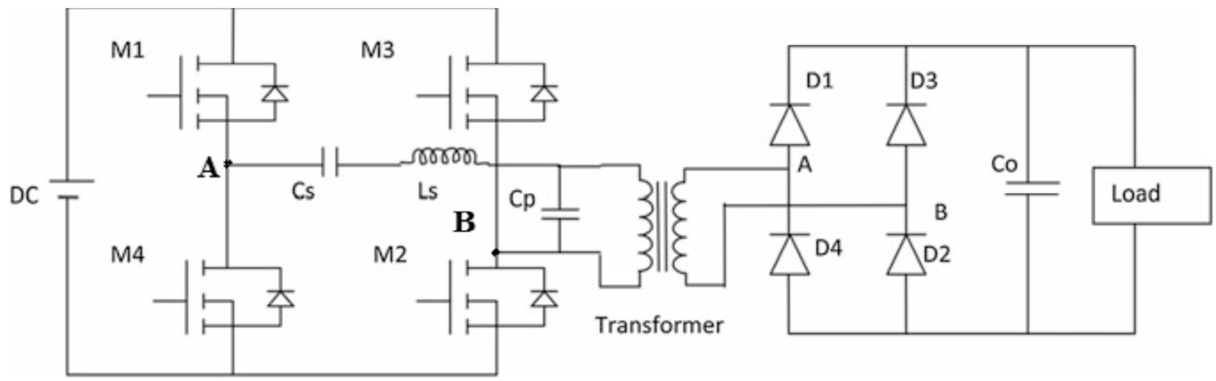

Figure 1: Schematic circuit of LCC Converter

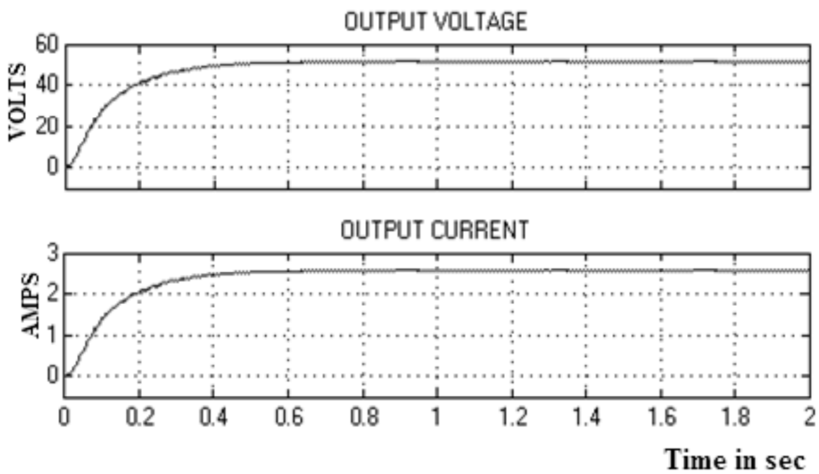

Figure 2: Output voltage and current of LCC Converter

and parallel capacitance C_p=C_s=0.1μF, series inductance, L=2.2μH, filter capacitance, C_o=47 μF and load resistance, R=10K. The transformer turns ratio is taken to be 12:48. The output voltage obtained is 51.8V as shown in Figure 3.The simulation and experimental results closely match. Hence SPRC LCC is found suitable for applications involving light to heavy loads.

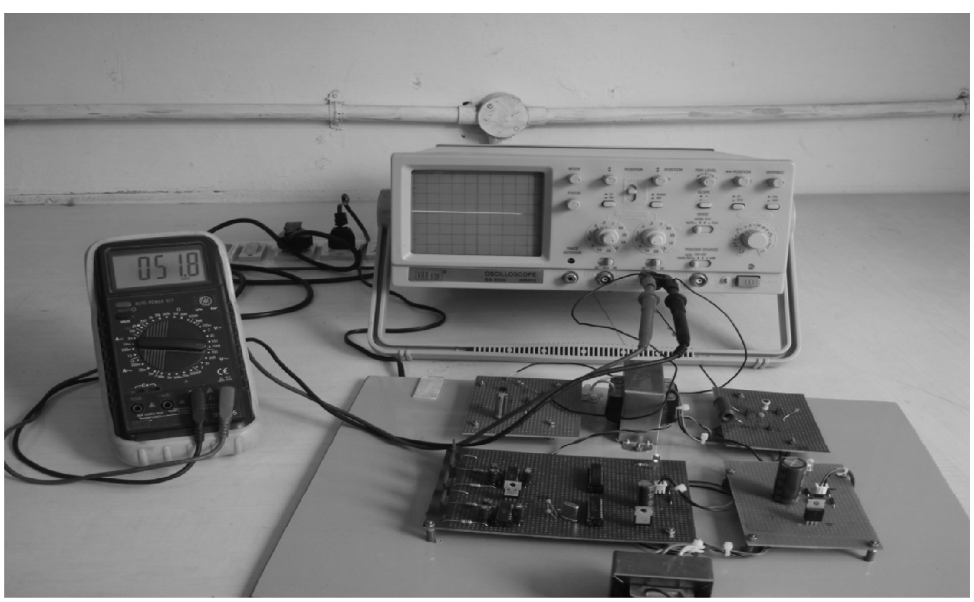

Figure 3: Output voltage of LCC resonant converter

IV. CLOSED LOOP CONTROL OF PMDC MOTOR

Simulation for Closed loop control of PMDC motor with LCC resonant converter is carried out in MATLAB with PI and SMC controllers. Hardware is implemented for the same and the results are compared. Sliding Mode Control(SMC) method is regarded as the most efficient nonlinear control method to improve the disturbance rejection and robustness properties of PMDC drives[2].One of the disadvantages of sliding mode control method is the chattering phenomenon caused by discontinuous control law and frequent switching action near the sliding surface. By proper selection of switching gain for the sliding control law, chattering can be eliminated. SMC modifies the dynamics of a nonlinear system by applying a discontinuous control signal. This signal forces the system to “slide” along a cross-section of the system’s normal behaviour. The state-feedback control law is a discontinuous function of time. Instead, it switches from one continuous structure to another based on the current position in the state space. Therefore, sliding mode control is a variable structure control method. Any variable structure system under SMC, can be viewed as a special case of a hybrid dynamic system as the system both flows through a continuous state space but also moves through different discrete control modes[1]-[4].The Block diagram of PMDC Drive control system using PI/SMC is shown in Figure 4.

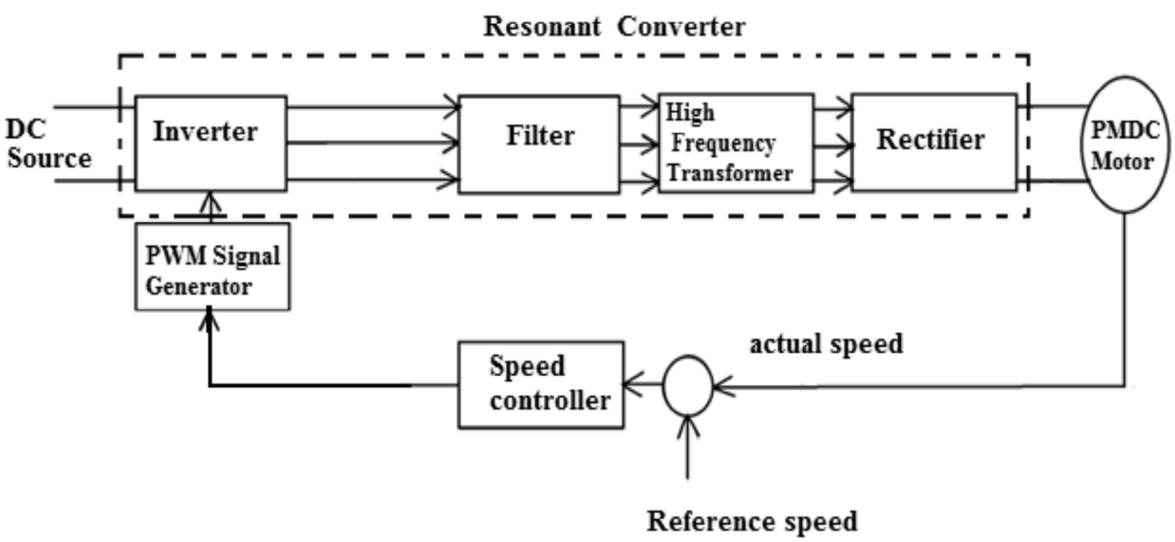

Figure 4: Block Diagram of PMDC Drive control system using PI/SMC

The equivalent circuit of PMDC machine is shown in Figure 5, and the equations are given by (1), (2) and (3) where K_m, ω_m and B_m represent the velocity constant, armature speed and damping coefficient respectively.

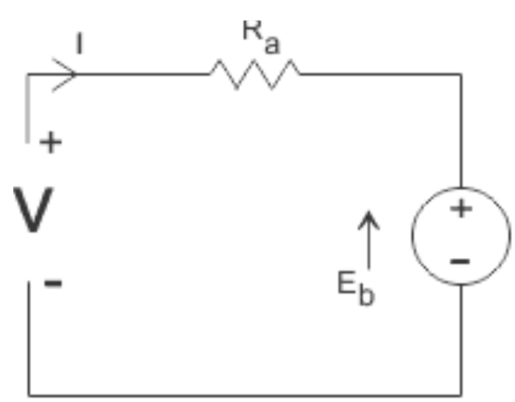

Figure 5: Equivalent circuit of PMDC Motor

$$V_t = I_a R_a + L_{aa} \frac{dI_a}{dt} + K_m \omega_m \tag{1}$$

$$T_e = K_t I_a \tag{2}$$

$$J \frac{d\omega_m}{dt} = T_e - T_L - B_m \omega_m \tag{3}$$

The equations (1), (2) and (3) are rearranged into (4) and (5).

$$\frac{dI_a}{dt} = \frac{1}{L_{aa}} (V_t - I_a R_a - K_m \omega_m) \tag{4}$$

$$\frac{d\omega_m}{dt} = \frac{1}{J} (T_e - T_L - B_m \omega_m) \tag{5}$$

In SMC, the dynamics of a nonlinear system is changed by applying a high-frequency switching control. SMC is easy to implement using a simple control equation and can control the speed accurately [5].The main control objective is to track a reference speed ω_{ref} with the actual rotor speed ω_e. The error between the reference and actual speeds can be written as

$$e = \omega_{ref} - \omega_e \tag{6}$$

which represents the sliding surface s. Since the speed control loop of the PMDC is a first order system, its design is conventional and is based on the concept of Lyapunov stability. In regulated control system, Lyapunov candidate function is selected to be a function of the state dynamics and must be a positive definite. In this case, the objective is speed tracking, and the error signal e will represent the sliding surface s. Taking the Lyapunov function as

$$V = \frac{1}{2} s^2 \tag{7}$$

Which must be positive definite. The sliding surface s of the form,

$$s = \omega_{ref} - \omega_{act} \tag{8}$$

Differentiating the above equation we get

$$\frac{dS}{dt} = \frac{d\omega_{ref}}{dt} - \frac{d\omega_{act}}{dt} \tag{9}$$

Then I_a can be given as

$$I_a = \frac{1}{K_m} \left[J \frac{d\omega_{ref}}{dt} + T_L + B_m \omega_{act} - J K_m sign(\omega t) \right] \tag{10}$$

The closed loop control of PMDC motor drive system with PI/SMC is simulated in MATLAB.The simulation was carried out for with load torque 10 Nm and a set speed of 1100 rpm. The speed response of PMDC motor with PI and SMC are shown in Figure 6 and Figure 7 respectively.

It is observed from Figures 6 and 7 that stable speed of 500rpm is obtained after 0.06 seconds with PI controller whereas with SMC; stable speed is achieved at 0.015 seconds itself.

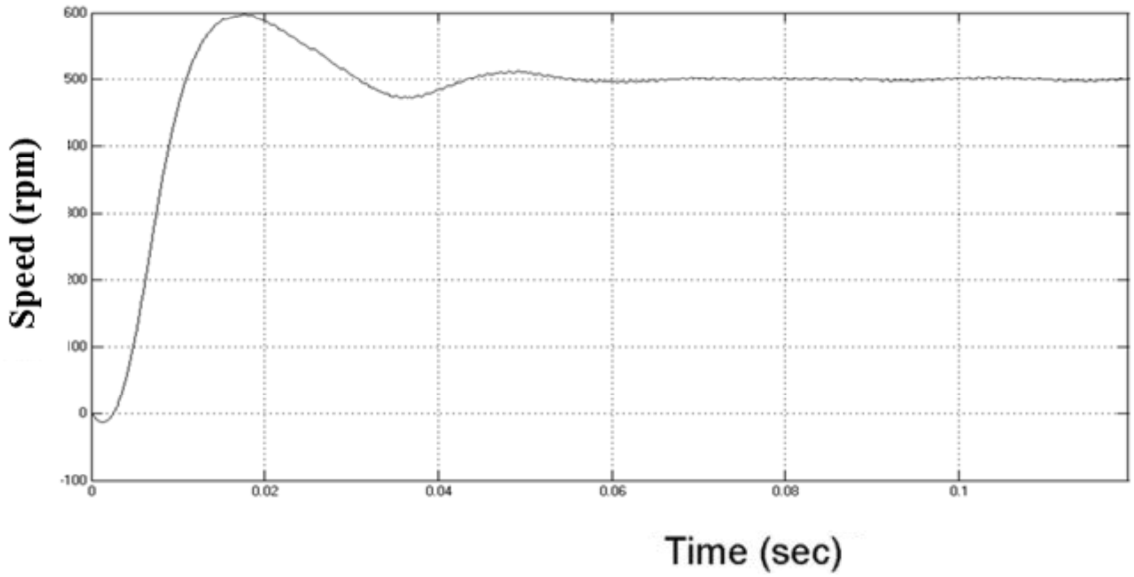

Figure 6: Speed Response of PMDC drive with PI controller

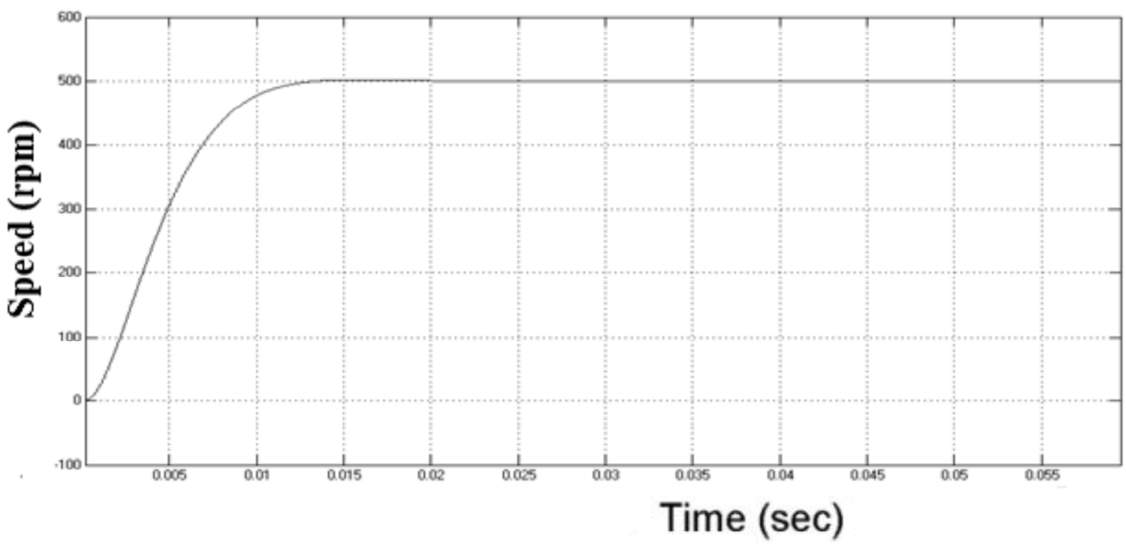

Figure 7: Speed Response of PMDC drive with SMC

V. HARDWARE IMPLEMENTATION OF RESONANT CONVERTER FOR PMDC MOTOR USING PI CONTROLLER AND SMC

A MOSFET based prototype converter is built and tested for closed loop control of PMDC motor. PI Controller and Sliding Mode Controller (SMC) are used in the speed control loop of PMDC, and their performances are compared. The prototype is shown in Figure 8. There are two major advantages of sliding mode control. By suitably choosing a sliding function, the desired dynamic behaviour of the system can be obtained. Secondly, the closed loop response can be made insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance, and non-linearity that are bounded[6]-[10]. Output voltage of Inverter is shown in Figure 9.

With PI controller, the speed of the motor is changed from 400rpm to1300rpm.The motor settles down at 1300rpm after a overshoot in speed. In the same way, the speed change is carried out from 1300rpm to 1600rpm, 1600rpm to2000rpm.In all the cases, the speed overshoots each time before settling down and it is shown in Figure 10.

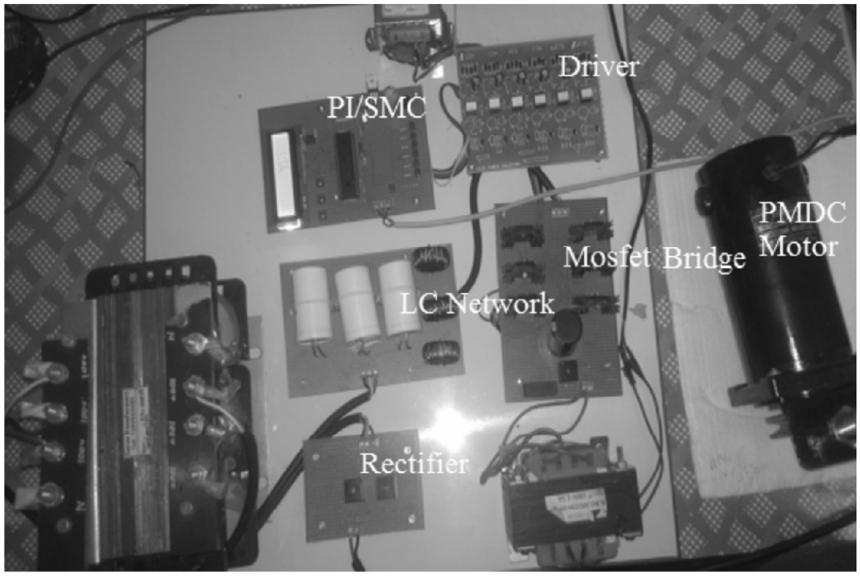

Figure 8: Prototype of Converter

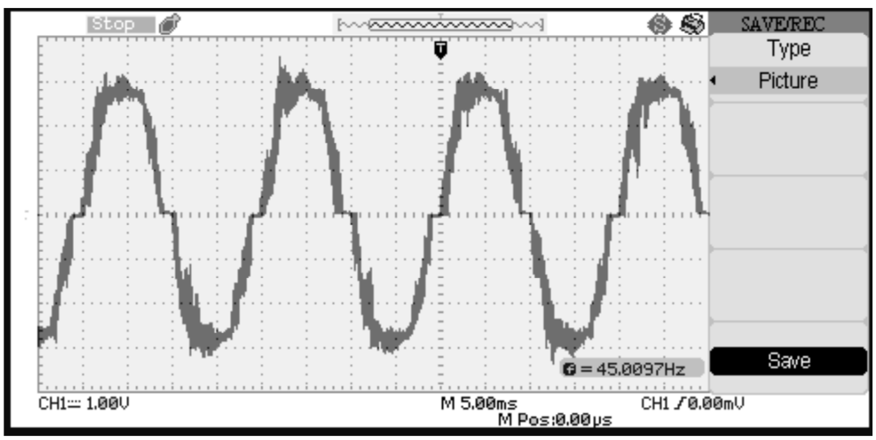

Figure 9: Output Voltage of Inverter

With Sliding Mode controller (SMC) also, speed of the motor is changed from 600 rpm to 800rpm,800rpm to 1200rpm and 1200rpm to 1800 rpm. As can be seen from the figure 11,there is no overshoot and its changeover from one speed to the other is very smooth. A PMDC motor of rating 200W,80V, 2.5A and

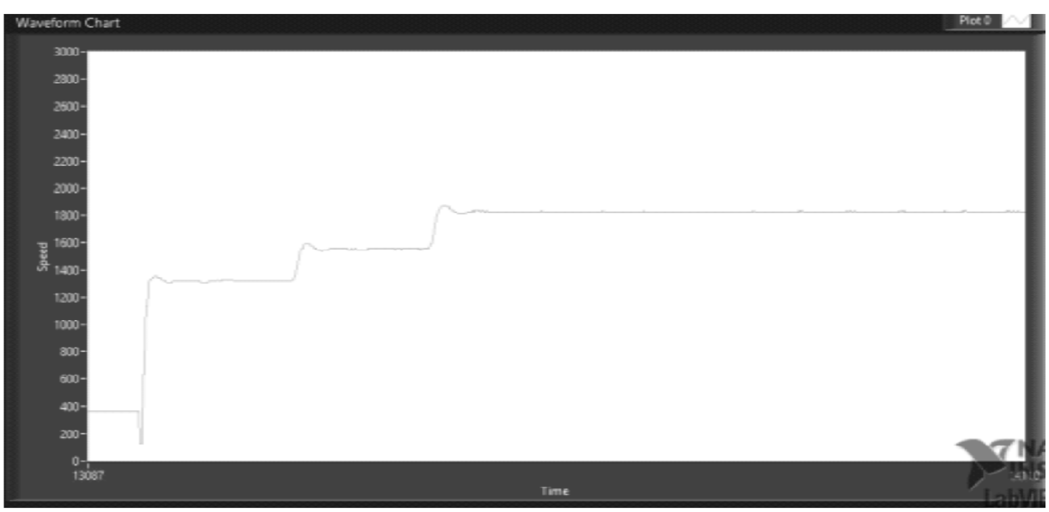

Figure 10: Speed response of PMDC using PI controller

3300 rpm is used for implementation of the SMC. An Inductive proximity sensor is used along with the PMDC for sensing its speed.Labview is used to analyse the performance of the PI and SMC .It is observed that the PI controller overshoots and takes a longer time to settle as compared to SMC. In contrast, smooth settling time and a rapid rise time are observed in SMC.

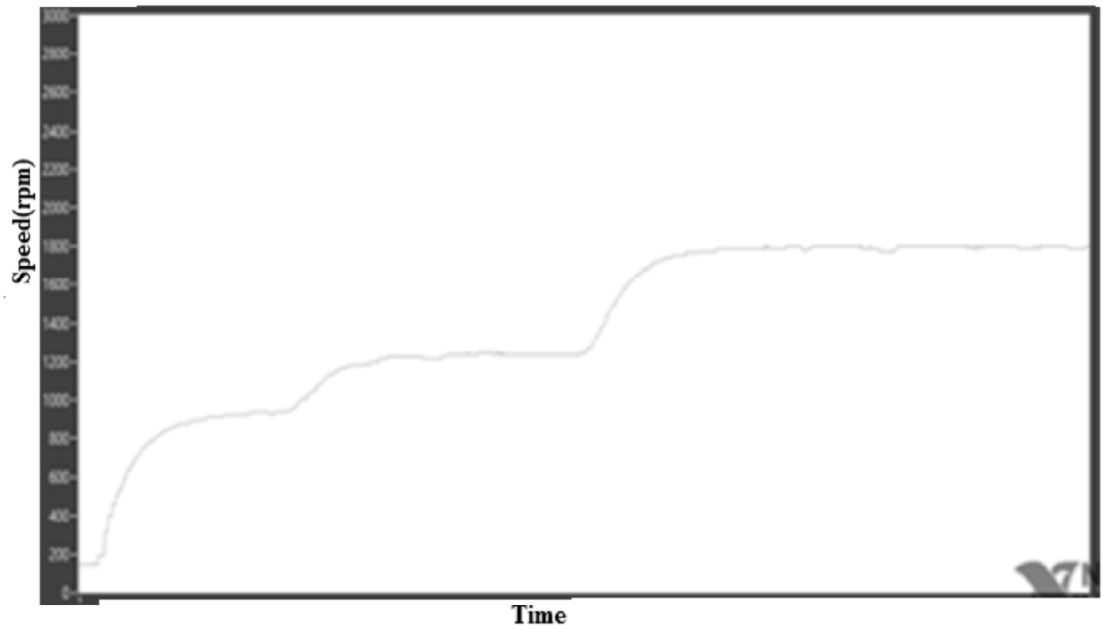

Figure 11: Speed response of PMDC using SMC

VI. CONCLUSION

Hardware is implemented for speed control of the PMDC motor using resonant converters and the performance of the circuit is analysed. Open loop control of PMDC is carried out with LCC converter. Closed loop control of PMDC is carried out with resonant converter with Proportional and Integral (PI) and Sliding mode controller (SMC) in the feedback path.

On comparing the simulation results of both techniques, it is observed that SMC shows a good dynamic behaviour with a rapid rise time and settling time and better performance than the PI controller. It is observed that for the change in speed, the response of SMC is better than the PI controllers with respect to both peak overshoot. The SMC also gives better performance under load disturbances and parameter variations which ensures its robust performance. Hence in many of the applications where speed control is very important and critical , SMC can be used as an effective controller.

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