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Performance and Comparative Analysis of Slide Mode Control and PID Control for Three Phase Induction Motors

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***Abstract*—In this paper, the performance and comparative analysis of two control schemes for three phase induction motor controls are discussed: - including slide mode control and PID (Proportional Integral Derivative) control schemes. The performance comparative analysis is according to speed control and torque control. The result shows that a sliding mode controller (SMC) is much better than PID controller. The slide mode controller is widely used in controlling an induction motor, which has the ability to keep a constant speed when the load of the induction motor varies and maintain the electromagnetic torque. The simulation of the controllers was done by using MATLAB/ Simulink software.**

Keywords*—Induction motor, SMC, PID.

I. INTRODUCTION

AC induction motor are getting increasingly more popular with their integration in large variety of applications like pumps, conveyors, presses, elevators, and packaging system etc. In industries, electric motor performs a very critical role. It is a chief component or the heart of the industries machine. Now a day the performance of the system is taken into consideration in phrases of efficiency, accuracy and smoothness of operation.

Induction motor are extensively utilized in industries and also broadly used in excessive-overall performance pressure. It is also utilized in industrial and home application of variable speed drives. It is powerful in nature and additionally the they have no brushes and commutator. The predominant advantages of the use of AC motor in a system Improved reliability, performance, performance, scalability, torque and speed control with the aid of different kinds of control strategies. The control strategies such as Rotor Resistance Control, Stator Voltage Control, Variable frequency, scalar V/F Control, VVF control, Slip Energy Recovery Scheme and many others. Play substantial function in precisely controlling the rate of Induction motor speed. Many researchers have suggested the work on speed manage of AC machines employing different control strategies in [1-3]. The Induction motor has easy mechanical structure; more dependable and also low renovation is needed. However, it greater complicated to be controlled. As a different research shows, sensor less manipulate of induction motor drive has acquired extensive interest inside the industry in last a long time [4]. This returns back to many benefits for the induction motor consisting of less upkeep and rugged production, and concurrently the development of much less steeply-priced and speedy controllers. The progress of sensor-much less drives can be considered to have all started around three decade ago in [5]. This concept, now referred to as field-oriented manipulate (FOC), became a big flip in the subject of electrical drives, then it will become properly mounted and typical by using the industry. But this scheme has some disadvantages like dependent on motor parameters, and very complex which is needed to referencing the transformations. Therefore, there was a want for a brand-new strategy that may produce high overall performance much like FOC with decreased complexity. Direct torque control (DTC) by means of [6] for low and medium energy software and direct self-discipline by way of [7] for high electricity application are the two strategies increasingly being used within the industry.

Scalar Control or V/F manage approach could be very famous for induction motor drives. It is quite simple technique to enforce. It only requires value of the magnitude of supply. In this method the disadvantages are, torque and flux are directly or indirectly not controlled and also the flux variant is slow because of coupling. Control is furnished via a frequency and voltage reference generator to get a constant volt consistent with hertz output. Because of that it gives limited speed accuracy and bad torque reaction [8]. Some advanced techniques are practiced in motor control applications. Among those PID is maximum famous Algorithm.

In this work, two different control methods are proposed and analysis to determine their stability and accuracy for three phase induction motor on controlling the speed and torque of the induction motor. The performance and comparative analysis of SMC and PID operation are presented by using MATLAB-Simulink simulations.

II. MODELLING OF THREE PHASE INDUCTION MOTOR

The three-phase induction motor is modelled in terms of in state space representation in equation (1). The models of induction motor of rotor and stator frames are explained in [9]. Induction motor stator current is written as a vector in d-q axes. The d-axis is used to manipulate the rotor flux and q-axis is to control output torque. In other words, torque and flux are independently manipulated. Fig.1 demonstrates the d-q axes and the explanation of voltage and current in the axis [10]. Fig. 2 shows the d-q axis circuit.

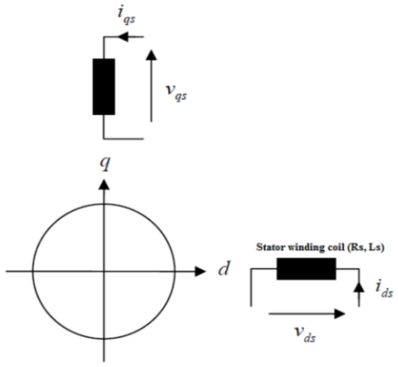

Figure 1. d-q axes in the stator

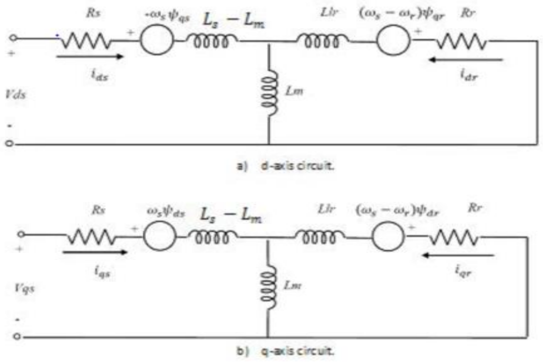

Figure 2. d-q axis circuit

State space is represented by

$$\dot{x} = Ax + Bu \tag{1}$$

$$y = Cx$$

Where:

$$A = \frac{1}{K}\begin{bmatrix} R_sL_r & W_sL_sL_r - W_rL_m{}^2 & -R_rL_m & 0 \\ W_rL_m{}^2 - W_rL_sL_r & R_sL_r & 0 & -R_rL_m \\ -RsLm & 0 & R_rL_s & W_rL_sL_r - W_sL_m{}^2 \\ 0 & -R_sL_m & W_sL_m{}^2 - W_rL_sL_r & R_rL_s \end{bmatrix}$$

$$B = \frac{1}{K}\begin{bmatrix} Lr & 0 & -Lm & 0 \\ 0 & Lr & 0 & -Lm \\ -Lm & 0 & Ls & 0 \\ 0 & -Lm & 0 & Ls \end{bmatrix}$$

The electromagnetic torque is in proportion to the current of the stator in the q frame of the induction motor:

$$T_e = K_T i_{qs} \tag{2}$$

Where: $K_T = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_{dr}$

The mechanical part of the induction motor can be explained as:

$$T_e = JW_m + B\dot{W}_m + T_L \tag{3}$$

By using equation(2into3): $bi_{qs} = f + w_m + aw_m$

$$a = \frac{B}{J};\, b = \frac{K_T}{J};\, f = \frac{T_L}{J}$$

$$e(t) = \dot{W}_m(t) - W_m(t) \tag{4}$$

Where; *X* and *u as below*

$$X = \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad u = \begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix}$$

ψds & ψqs: d-axis and q-axis stator flux
ψdr & ψqr: d-axis and q-axis rotor flux
ids &iqs: d-axis and q-axis stator current
idr & iqs: d-axis and q-axis rotor current
Vds &Vqs: d-axis and q-axis stator voltage

III. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

For AC source drive, application of sinusoidal voltage sources (SVS) is no longer used [11]. They are replaced by the usage of six power transistors like IGBTs that act as on/off switches to the rectified DC bus voltage. The basic and well-used inverter is two-level inverter, which is the most popular power circuit topology of a three-phase voltage source inverter, supplying star-connected three-phase load for the induction motor. Fig. 3 and Fig. 4 illustrate the configuration and different on/off states (shown in Fig. 5) of the inverters.

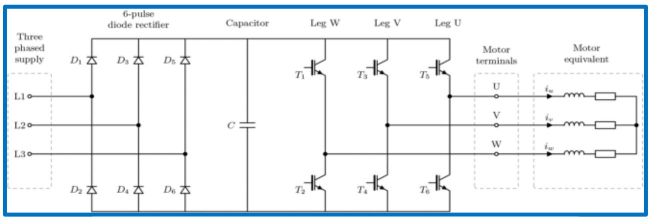

Figure 3. Three phase voltage source

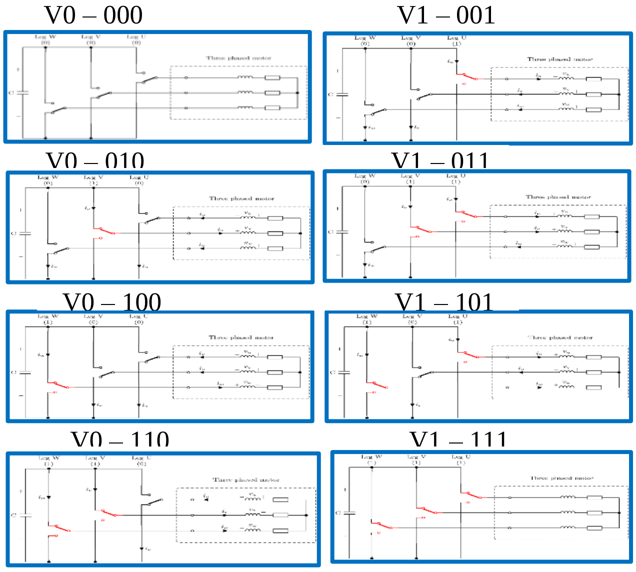
V0 – 000
V1 – 001
V0 – 010
V1 – 011
V0 – 100
V1 – 101
V0 – 110
V1 – 111

Figure 4. Eight switching states of VSI.

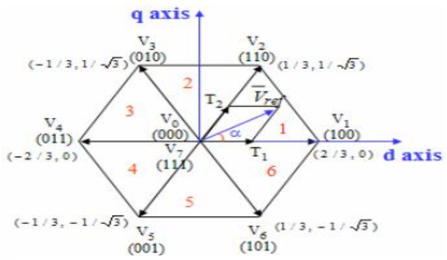

Figure 5. switching vectors and sectors

IV. CONTROL METHODS

Controlling induction motor is very important in industrial and engineering applications, which aims to reduce operating costs, smooth and stabilize the output by using effective control strategies. In this section, two different controllers are explained and the corresponding control systems are modeled in Simulink. Fig. 6 shows the block diagram of the control system. The detailed control methods are discussed as below.

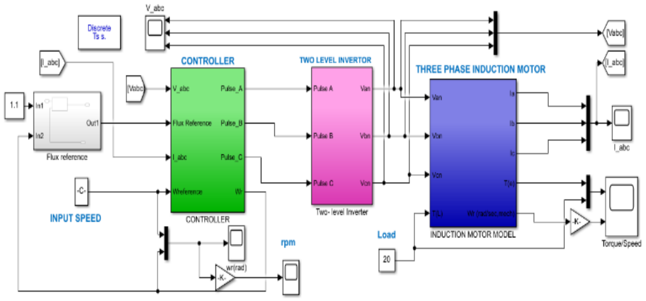

Figure 6. Model of the control system for induction motor

1. SMC based on direct torque control

A SMC uses a nonlinear control schem that have a power to control the systems to slide along a defined surface to robustly stabilize, it alters the system dynamics to adapt to these behaviors.

The block diagram and model of the induction motor using torque and speed controller are illustrated in Fig. 7 and Fig. 8, respectively. In these figures, the value of the electromagnetic torque and actual speed generated by the induction motor were designed to be compared to the desired value to generate an error signal, and the error was controlled by the SMC.

In PID control, there are problems such as the induction motor speed, in a particular time, varying command inside the presence of controller imprecision, unstable of speed as well as load torque ripples disturbances. In sliding mode control, the system is well-controlled in this manner that the tracking blunders(error) and its value of exchange constantly flows in the direction of a sliding surface. The sliding surface is defined as in the state space representation by way of the equation: $S(e,\dot{e},t)=0$ (5)

$$S(t)=e(t)-\int_{0}^{t}(K-a)e(\tau)d(\tau)=0 \qquad (6)$$

Where the sliding variable S is, $S=\dot{e}+\lambda e$ & $e=\dot{w}_{ref}-w_r$

λ is the positive constant which depend on bandwidth of the models. The command for q-axis stator voltage charging the torque. It explains as: -.

$$\dot{V}qs=-K\,\mathrm{sgn}(s)$$
$$u(t)=bi_{qs}-aW_m(t)-f(t)+W_m(t) \qquad (7)$$

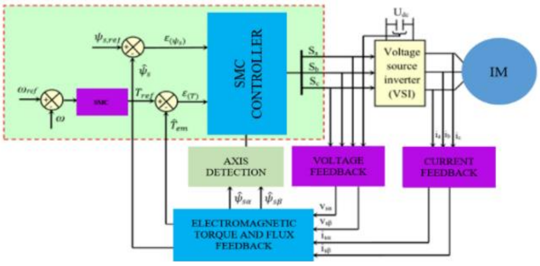

Figure 7. Full structure of slide mode controller

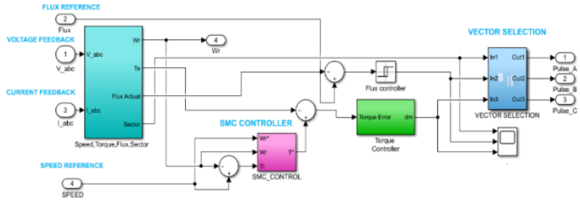

Figure 8. Simulink of SMC controller Model

2. PID controller Based on Direct Torque control

A PID controller, shown in Fig. 9, is one of the classical controllers, which is well-known for its smooth implementation and performance in non-complex structures. The steady state error can be reduced by using the proportional controller (P). But the proportional controller will not eradicate the error. Therefore, the integral controller can be used to minimize the error close to zero value and increase the stability of the system. But, the disadvantage of using the integral controller is that it will effectively increase the response time. To expect the future behavior of the error signal, the derivative control can be used to correct actions basing on the rate of change in the error signal. Thus, it minimizes the error, increasing the stability, and improving the transient response of the system [12].

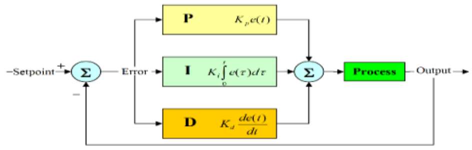

Figure 9. Internal of PID controller

A PID controller was used to control an induction motor (modeled in Fig. 10 and Fig. 11). The analysis of its performance and the comparison with SMC controller would be discussed in the next section.

The equation of PID controller can be explained as:

$$u(t)=Kp*e(t)+Ki\int e(t)dt+Kd*\frac{de(t)}{dt} \qquad (8)$$

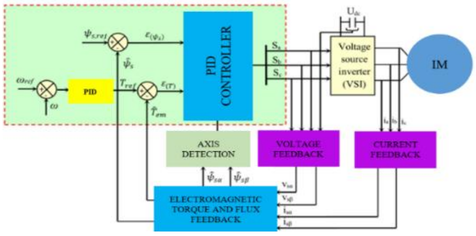

Figure 10. Full structure of PID controller

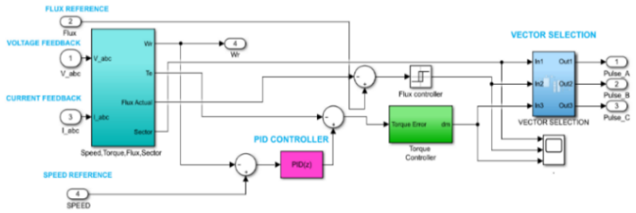

Figure 11. Simulink of PID controller Model

V. SIMULATION RESLTS

In this section, simulation results of the suggested torque and speed controllers using MATLAB/Simulink software are presented to analyze and compare the performance of three-phase induction motor using PID and SMC separately.

The MATLAB/Simulink model is shown in scenarios. In this model simulation, a three-phase induction motor is used, 10 HP, 380V, 50Hz, and with other parameters listed in Table 1.

Table1. Parameter of three phase induction motor

Parameter	Symbol	Unit	value
Stator resistance	Rs	Ω	4.125
Rotor resistance	Rr	Ω	2.486
Mutual inductance	Lm	mH	0.2848
Stator inductance	LIs	mH	0.0156
Rotor inductance	LIr	mH	0.0156
Inertia	J	kg.m^2	0.139
Friction factor	F	N.m.s	0.1
Pole pairs	P	( )	4

The performance of the proposed SMC and PID controller, which are speed and torque controller for the three-phase squirrel cage induction motor were analyzed under different operating scenarios and comparations were made between the two controllers. For both controllers, the simulation time intervals are fixed at 5 second. The simulation results showed as below scenarios.

Scenario 1. At No load, T= 0N.m

The results of using SMC and PID controller to control the electromagnetic torque and speed characteristics of the three-phase induction motor at no load are shown as below. (the gain value of PID, Kp= 10, Ki=2, Kd=0.1 and SMC gain β=28).

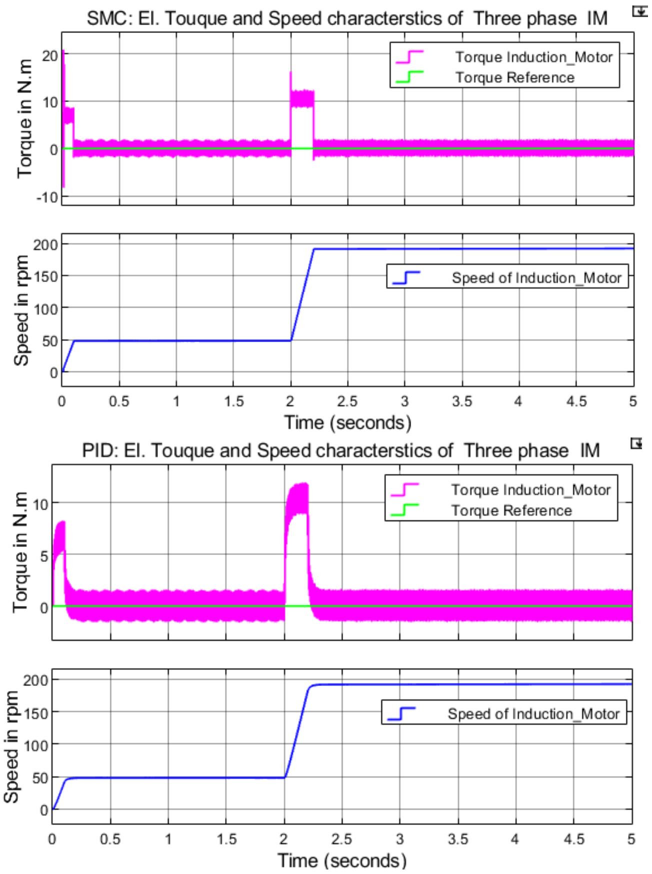

Figure 12. Electromagnetic torque and speed at no load(T=0Nm)

Fig. 12 shows that electromagnetic torque in (Nm.) for the PID controller has unaccepted ripple torque and over shoots in torque. While, as for SMC, the ripple torque is minimized to an acceptable value, and the over shoots of torque are also reduced. By using SMC and PID controller, the speed of the induction motor at no load was shown in Fig. 13.

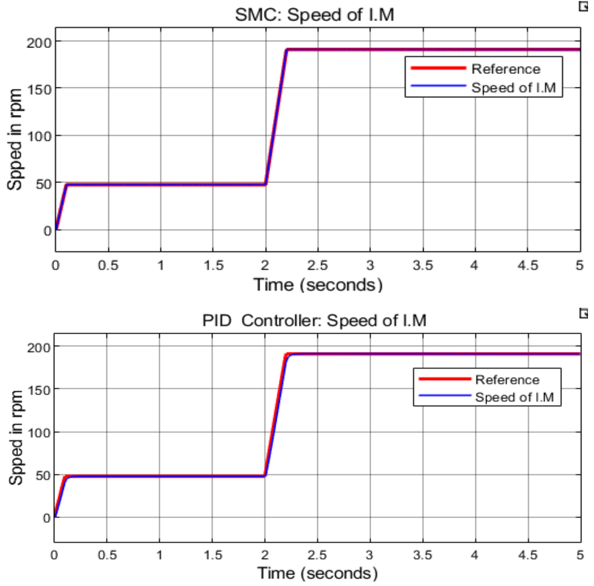

Figure 13. Speed of induction motor at no load(T=0Nm)

Scenario 2. At load 15N.m

At the load of T= 15N.m, using SMC and PID controller respectively, and the speed of the motor references set to be from 0 to 50rpm and from 50rpm to 190rpm in a ramp style, with the rate of change of 1000rpm/s, the simulation results are shown in Fig. 14. It can be learnt that the measured speed using SMC is stabled and accurate, while in case of PID controller, it is not a stable operation.

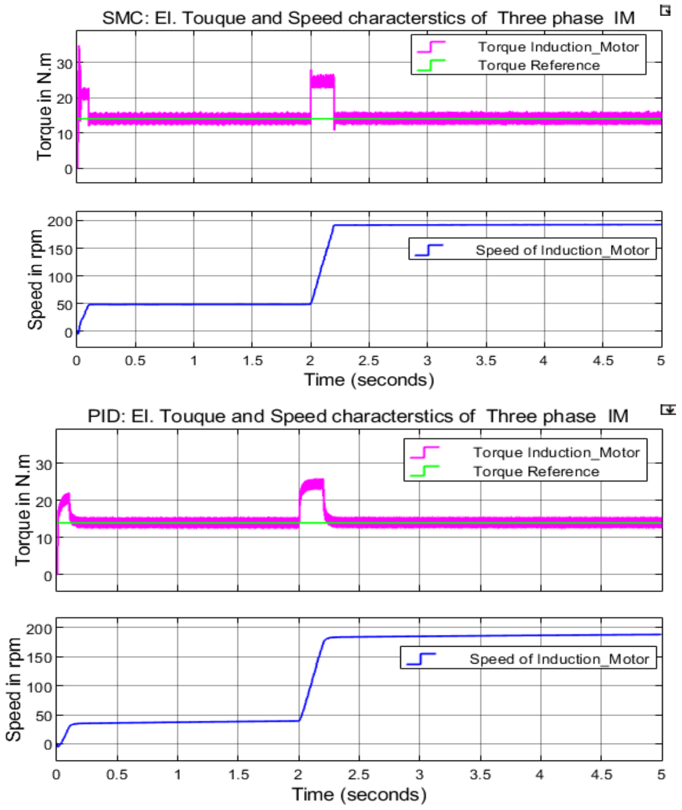

Figure14. Electromagnetic torque and speed at load (T=15Nm)

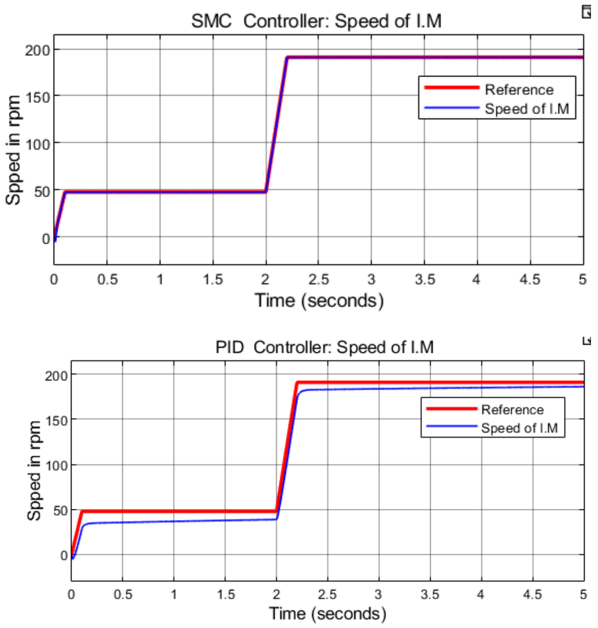

Figure 15. Speed of induction motor at load(T=15Nm)

For speed of induction motor, the SMC is stable but the PID is unstable when the load is added, as is shown in Fig. 15.

Scenario 3. At load 20 Nm.

At the load of T= 20N.m, the corresponding results are shown in Fig. 16 and Fig. 17.

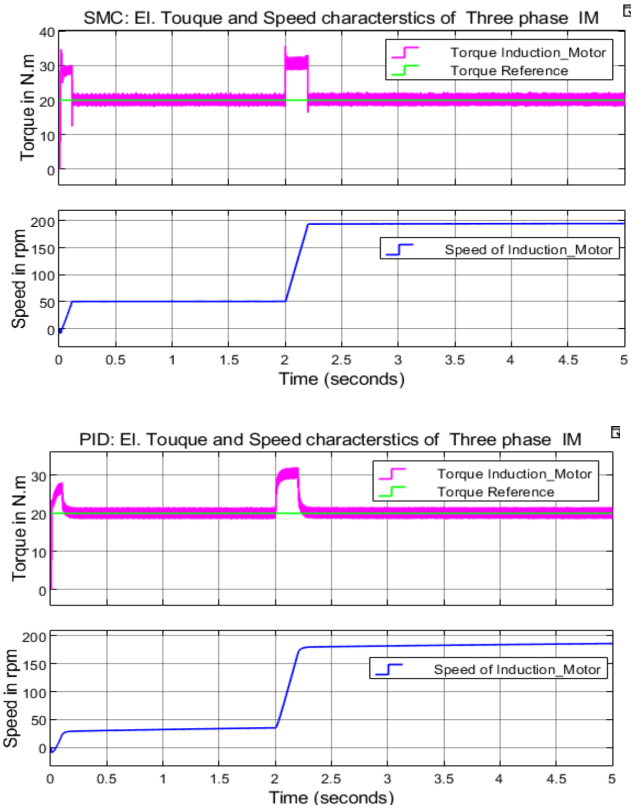

Figure 16. Electromagnetic torque and speed at load (T=15Nm)

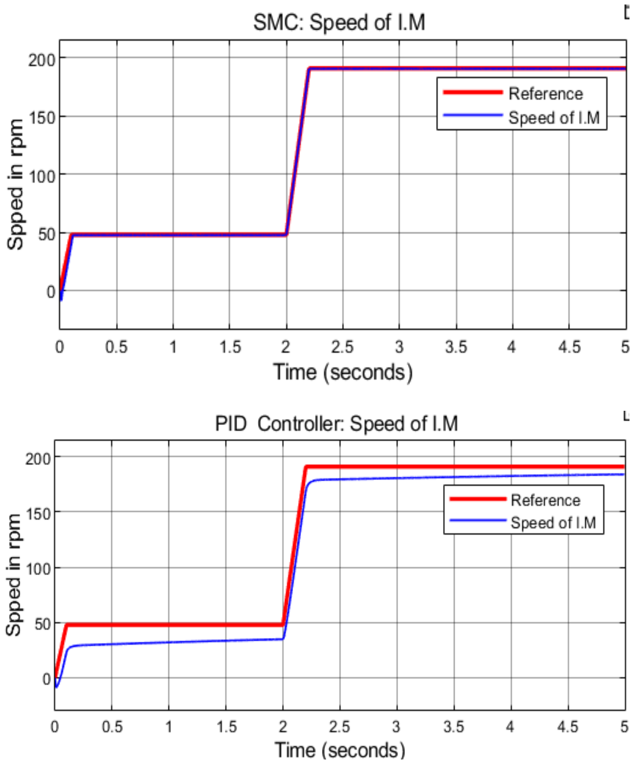

Figure 17. Speed of induction motor at load(T=20Nm)

It can be learnt from the results that the PID controller is getting to fail, when the load is increased to a certain value, but the SMC is still stable.

VI. CONCULUTION

This work presents the performance and comparative analyses of SMC and PID controller using as switching vector state selector based on direct torque control. It can be observed from the different scenarios of simulation that the electromagnetic torque in (Nm.) of induction motor for the PID controller had unacceptable ripple torque and over shoots illustrated in the results of torque. While as for SMC, the ripple torque value was minimized which was acceptable, and also the overshoots of torque were reduced. The performance comparative analysis was depending on speed in rpm and electromagnetic torque control. When the load was increased, the PID controller was not stable in the speed of the motor, while the SMC was more stable. During the simulation for no load (T=0Nm.) in PID controller the speed of the IM was stable but the electromagnetic torque of the motor had more torque ripples. It can be concluded from the result that SMC is better than PID control methods. The sliding mode control is greatly used for controlling induction motor which has the ability to keep a constant speed when the load of the induction motors varies and maintain the electromagnetic torque. Therefore, by using the sliding mode control method, the three-phase induction motor can be controlled in accurate performance and stable. Generally, SMC improves the performance of the motor and make the whole system more stable than using a PID controller.

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