International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-10, Jan 2019

A Comparative Study of PID, 1-SMC & 2-SMC Performances for Vector Control of Single Phase Induction Motor

Oinam Manganleiba Meetei, Assistant Professor, **Department of Electrical Engineering, Manipur Technical University(MTU), Imphal, India**, mangal.oinam@gmail.com

Abstract The performance of an electric drive is highly influenced by the type of controllers employed. For a high performance of single phase induction motor drive, Field Oriented Control technique are more preferred over other methods. Due to the nonlinear relation between the motor current and the resulting torque, controlling the speed of induction motor is difficult. This paper investigates the performance of different controllers 1-SMC, 2-SMC and PID in Indirect Field Oriented Control of single phase induction motor at various reference signal. The experiment is performed in Matlab/Simulink and comparative results of 1-SMC, 2-SMC and PID are presented and also concludes that 2-SMC is the best controller among the mentioned controllers for the induction motor drive.

Keywords—PID, Sliding Mode Control, Field Oriented Control, Referenc Fram, Kron's Primitive machine model, Indirect Field Oriented Control.

I. INTRODUCTION

Variation of speed over a wide range of AC drives has many applications. To achieve such goal, advanced control technique has been developed [1,2,3]. Field Oriented Control is one of them which has fulfilled the dreams of many scientists. Field Oriented Control is divided into two types, Direct FOC (Field Oriented Control) [4,5] and Indirect FOC (Field Oriented Control) [6,7]. Commonly IFOC is being utilized, as in close loop mode, it operates better overall the speed range from zero speed to high-speed field weakening. Induction motors are nonlinear machines hence motor parameter like rotor resistance, the value can increase up to 100% when motor temperature rises[8] the flux could not be measured accurately also. Hence accurate control of motor can't perform. It is required to develop a new strategy to solve such problem. PID controller was used as a controller but in some situations where there is parametric variations and uncertainty, the PID controller does not give the optimal performance.

Sliding mode control is the nonlinear control technique [9] which incorporates some kind of value discontinuous control law. Sliding mode control have the ability to robustness against the parameter uncertainties and correction of error within a finite time. There are various orders of sliding mode control namely 1-SMC, 2-SMC & 3-SMC etc. All of these orders possess unique characteristics.

This paper studies the comparison of 1-SMC, 2-SMC & PID control in the single phase induction motor using Matlab Simulink and also examine the best control strategy among three controllers.

II. MODELLING OF SINGLE PHASE INDUCTION MOTOR IN STATOR REFERENCE FRAME

The variables present in circuit elements of single phase induction motor can be considered as the model of an unsymmetrical 2-phase (a,b) induction machine. Single phase induction motor scheme with the stator current and the rotor flux as the state variables after the direct and quadrature (d-q) transformation is illustrated in figure1.

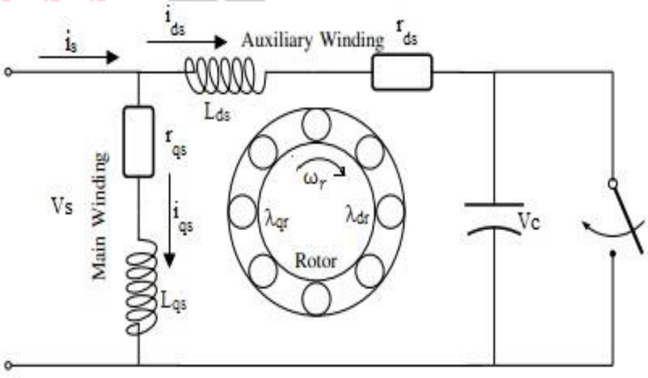


Figure 1 Single phase induction motor

The single phase induction motor can be modelled in Kron's Primitive machine model. The starting and main winding can be represented in d-q axis hypothetical model as shown in figure 2. Corresponding nomenclatures are shown in table I.

DOI : 10.18231/2454-9150.2018.1294

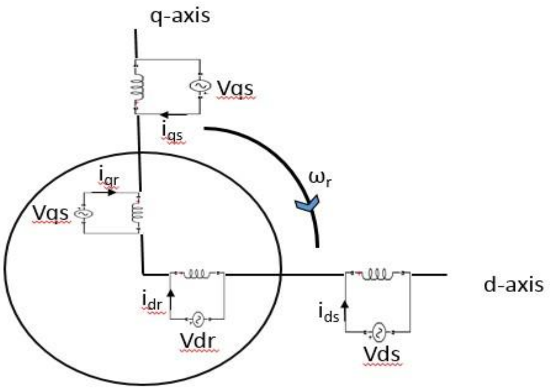


Figure 2 Kron's Primitive machine model

Stator voltage equations in a stationary reference frame

$V_{ds} = r_{ds} i_{ds} + p\lambda_{ds}$

(1)

$V_{qs} = r_{qs} i_{qs} + p\lambda_{qs}$

(2)

where,

p —— derivative operator = d/dt

λ_{ds}& λ_{qs} —— flux linkage d and q axis

Rotor voltage equation referring the rotor *d* and *q* axes

$V_{dr} = r_{dr} i_{dr} - \omega_r\lambda_{qr} + p\lambda_{dr}$

(3)

$V_{qr} = r_{qr} i_{qr} + \omega_r\lambda_{dr} + p\lambda_{qr}$

(4)

where,

ω_r —— motor speed

stator and rotor flux linkage in the stationary reference frame

$\lambda_{ds}=L_{ds}i_{ds} + L_{md}\,(i_{ds} + i_{dr})$

(5)

$\lambda_{dr}=L_{dr}i_{dr} + L_{md}\,(i_{ds} + i_{dr})$ (6)

$\lambda_{qs}=L_{qs}i_{qs} + L_{mq}\,(i_{qs} + i_{qr})$

(7)

$\lambda_{qr}=L_{qr}i_{qr} + L_{mq}\,(i_{qs} + i_{qr})$ (8)

where

L_{mq} & L_{md} – mutual inductance between stator and rotor of q and d axis respectively.

2.1 Indirect Field Oriented Control (IFOC)

The rotor flux vector λ_r is a flux vector i.e is rotating in the space at the synchronous speed ω_e the reference frame is so chosen such that the reference is attached to rotor flux vector.

Hence λ_{dr} = Constant

(9)

and λ_{qr} = 0

(10)

Substituting equation (9) and (10) in equation (3) and (4) yields

$I_{dr} = 0$

(11)

$$\omega_r = \frac{-r_{qr}I_{qr}}{\lambda_{dr}}$$

(12)

Substituting equation (10) in equation (8) yields

$$I_{qr} = \frac{-\,Lmq}{Lqr}\, i_{qs}$$

(13)

Substituting equation (13) in equation (12) yields

$$\omega_r = \frac{LmqI_{qs}}{\Gamma_r\lambda_{dr}} \quad where\ \Gamma_r = \frac{Lqr}{r_{qr}}$$

(14)

Substituting equation (11) in equation (6) yields

$\lambda_{d\,r=}\ L_{md}\, i_{ds}$

(15)

Substituting equation (15) in equation (14)

$$\omega_r = \frac{I_{qs}}{\Gamma_r I_{ds}} \quad where\ \Gamma_r = \frac{Lqr}{r_{qr}}$$

(16)

Rearranging equation (6) & (8) yields

$$I_{dr} = \frac{\lambda_{dr} - L_{md}I_{ds}}{L_{dr}} \tag{17}$$

$$I_{qr} = \frac{\lambda_{qr} - L_{mq}I_{qs}}{L_{qr}} \tag{18}$$

Torque is given by the following equation:

$$T = \frac{3}{2}\frac{P}{2}L_m\left(I_{qs}I_{dr} - I_{qr}I_{ds}\right) \tag{19}$$

Substituting equation (17) and (18) in equation (19)

Required torque is

$$T = \frac{3}{2}\frac{P}{2}\frac{L_m{}^2}{L_r}\left(I_{qs}I_{ds}\right) \tag{20}$$

Stator d & q axis currents are

Rearranging equation (15) gives

$$I_{ds} = \frac{\lambda_{dr}}{L_{md}} \tag{21}$$

Substituting equation (21) in (20) gives

$$I_{qs} = \frac{2}{3}\frac{2L_r T}{PL_{mq}\lambda_{dr}} \tag{22}$$

2.2 Calculation of Rotor Field Angle

In Indirect vector control, rotor field angle θ is calculated by addition of rotor speed ω_r and slip speed ω_{sl} as given in equation 23

$$\theta = \int(\omega_r + \omega_{sl})\, dt \tag{23}$$

$$\omega_r = \frac{L_m I_q}{T_r\lambda} \qquad where\ T_r = \frac{L_r}{R_r}$$

The hypothetical d-q model of the Single phase induction motor can be converted into real machine model by using the following matrix.

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = \begin{bmatrix} \sin\theta_s & \cos\theta_s \\ -\sin\theta_s & \cos\theta_s \end{bmatrix} \begin{bmatrix} I_{ds} \\ I_{qs} \end{bmatrix} \tag{24}$$

Where I_a & I_b are phase a & b current respectively.

DOI : 10.18231/2454-9150.2018.1294

III. PID CONTROLLER

PID controller is a close loop-feedback based controller which required continuous modulated control. The speed of induction motor is measured and compared with a reference speed. If a difference is detected in the speed, a correction is calculated and applied. Further rechecked the speed, if it doesn't achieved target speed, recalculate and applied. Designing of PID controller it includes two steps.

3.1 Tuning

So as to accomplish the craving yield, tuning is obligatory. To tune the PID controller, amendment factors are determined by contrasting the yield an incentive with the reference esteem and supply picks up that limit overshoot and swaying while affecting the change as fast as would be prudent. PID tuning entails establishing appropriate gain values for the process being controlled, these gains are obtained either by manual tunning or by some other method Zeigler-Nichols.

3.2 The Controller

The ideal version of the PID controller is given by the formula

$$u(t) = K_p(t) + K_d\frac{de_{rr}(t)}{dt} + K_i\int e_{rr}(t)dt \qquad (25)$$

Where, $e_{rr}(t) = w_r(t) - w_m(t)$ is the tracking error signal.

and u(t) is the control signal

It requires the tunning of increases Kp, Ki and Kd. The control flag is consequently an entirety of three terms, a relative term that is corresponding to the error, a integral term that is relative to the integral of the error and a derivative term that is relative to the derivative of the error. The controller parameters are proportional gain k_p, integral gain k_i, and derivative gain k_d. The control signal u(t) is shaped altogether from the error. The PID controller of induction motor is shown in figure 3.

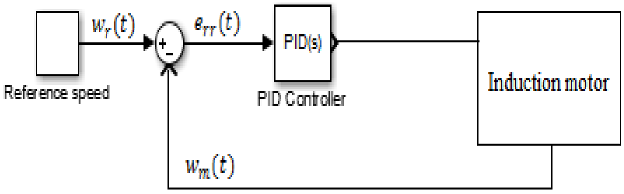


Figure 3 PID controller block diagram for Induction motor

IV. GENERAL CONCEPT OF SLIDING MODE CONTROL

Sliding mode control(SMC) is a nonlinear control method that adapts the dynamic of a nonlinear system by applying a discontinuous control signal forcing the system to move from initial states towards a chosen surface called sliding surface. SMC design follows two steps procedure. The first one is the defining of trajectories to be followed by the system. The second step is the design of control law that drives the system state trajectories onto the sliding manifold after a fix transient.

4.1 Sliding manifold

In general, the design of sliding manifold for a motor includes the combination of the tracking error $e_{rr}(t)$ and a number of derivatives is the choice commonly adopted.

$$e_{rr}(t) = s_o(t) - s^*(t) \qquad (26)$$

Sliding variable equation is defined in equation 27 for the induction motor.

$$\sigma = \frac{de_{rr}(t)}{dt} + c\ e_{rr}(t) , \qquad c>0 \qquad (27)$$

where c & σ is the gain & sliding variable respectively

Figure 4 Matlab Simulink block diagr

The finite time convergence of σ =0 can be concluded by the following argument. Due to the convergence of σ =0, the system guarantees the asymptotic exponential tracking of the predefined tracking.

$$\sigma(t) = 0 \quad t \geq T_1$$

$$e_{rr}(T_1)e^{-c(t-T1)} \qquad t \geq T_1 \qquad (28)$$

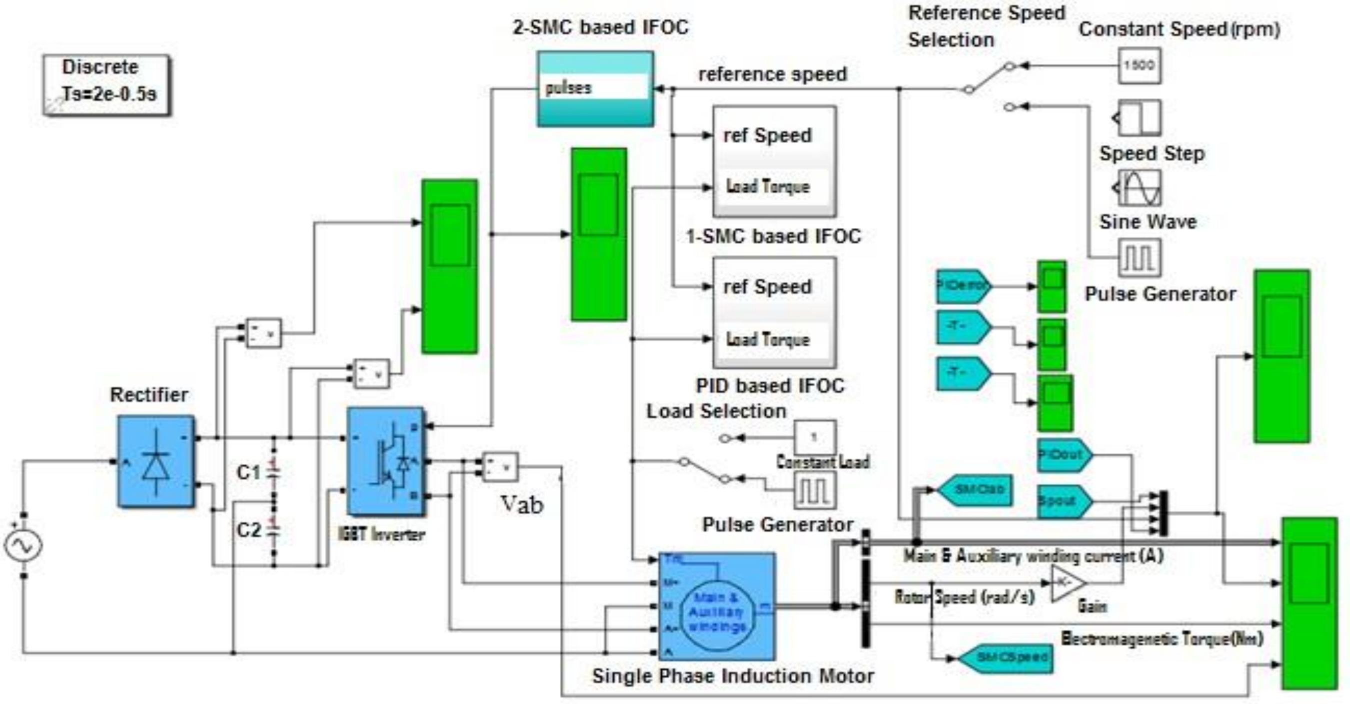
From equation 28 it concludes that convergence rate can be made faster by appropriately increasing the constant value.

When system reached the sliding surface, the system σ = 0 and $\dot{\sigma} = 0$

To reach the sliding surface system must satisfied equation 30

$$\dot{\sigma}\sigma = \frac{-\alpha}{\sqrt{2}}|\sigma| \qquad \alpha < 0 \qquad (29)$$

DOI : 10.18231/2454-9150.2018.1294



Switching functions are commonly used for SMC in order to make the system converge to desired operating point (σ=0). Some unwanted phenomenon is associated in a real situation since switching delay time are not zero.

$$V_n = Ksign(\sigma) \qquad (30)$$

$$\text{Where } sign(\sigma) = \begin{cases} 1 & \sigma > 0 \\ 0 & \sigma = 0 \\ -1 & \sigma < 0 \end{cases}$$

Since the sign function is not continuous function it is associated with a problem called chattering problem.

4.2 Adaptive Sliding mode control

In integral sliding mode control [10,11,12] an integral term was incorporated which guaranteed that the system trajectories would start in the manifold from initial time.

$$U_n = -K_1\sqrt{|\sigma|}sign(\sigma) - \int K_2 sign(\sigma)dt \qquad (31)$$

Where k_2 is the constant of the integral term.

The use of sign function as a switching function introduces chattering in the plant output. The chattering can be eliminated by means of an integral compensator, to maintain the maximum endeavour the integral term is added to the switched control.

To avoid unwanted oscillations in system response caused by the addition of the integral term, the anti- windup Back [12] calculation method is used. The controller is shown in figure 4.

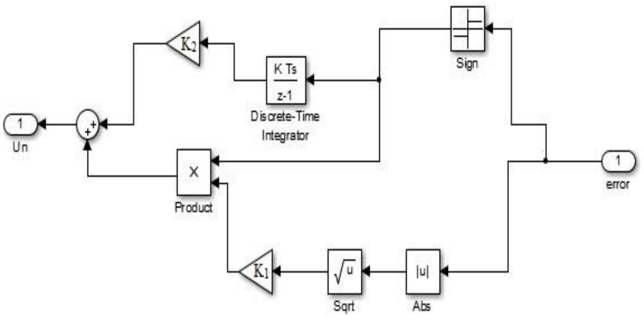


Figure 5 2-SMC Control Law simulation diagram.

Where K_1 is the constant of the anti-windup. In the proposed controller considered K_1 & K_2 >0 to achieve a stable operation of the system necessary condition is.

$$K_1 >= 2\sqrt{K_2} \qquad (32)$$

The above equation 31 is known as second order sliding mode control. The problem faces in 1–SMC i.e chattering problem can be overcome in this switching strategy.

V. RESULTS AND DISCUSSION

This section discusses the comparative result of controllers PID,1-SMC and 2-SMC applied in vector control which is subject to different reference input. These results are obtained from the Matlab Simulink using the blocks as represented in figure 5.The motor parameter is given in appendix table IV. Optimal values of tunning parameters for PID & 2-SMC are shown in appendix table II & III respectively.

DOI : 10.18231/2454-9150.2018.1294

Figure 6a, 6b & 6c illustrates the trajectory error at 1500rpm with disturbances at different intervals for PID, 1-SMC & 2-SMC respectively. Tracking error is more in PID i.e can't reach to zero whereas in 1-SMC tracking error is zero after few seconds (0.5sec), it fluctuates only when disturbances are present. In the case of 2-SMC, due to –ve feedback tracking initials from –ve side & reach to zero within few seconds(0.45sec), it slightly deviates from the path when disturbances occur.

Figure 7a, 7b & 7c shows the main & auxiliary winding current at 1500rpm with disturbances for PID, 1-SMC & 2-SMC respectively. In PID undesired amount of current is generated throughout the response even in the un disturbance area also. This will consumed more power while designing in real time whereas in 1-SMC more current is generated at the initial stage but less amount of current is generated at no disturbance period, only the required amount of currents are generated when disturbances is present. In case of 2-SMC high amount of currents are generated at the initial stage & disturbance time but the current wave is more smoother than 1-SMC & PID. Hence 2-SMC will conserve power & more lifespan of drives.

Figure 8a, 8b & 8c illustrates the response of torque when disturbances are present at 1500rpm. In PID, torque response is not stabilized throughout the period & more fluctuating occurs when disturbances occurred, this kind of response may reduce the lifespan of the machine. In 1-SMC at initial stage fluctuating occurs up to time period 0.42sec. At the trajectory path, response is more stabilized but when disturbance occur torque is fluctuating raise more than 2 amplitude whereas for 2-SMC at the initial stage fluctuating torque occurs up to 0.28sec. At the trajectory path response is more smoother but when disturbance occur torque is fluctuated, raise less than 1-SMC. So, a more good response is obtained by 2-SMC.

Figure 9 shows the PID, 1-SMC & 2-SMC response at constant speed 1500rpm & constant load 1 Newton of handling disturbance but more chattering. PID takes 1 sec to reach the reference speed, 1-SMC takes 0.6 sec and 2-SMC takes 0.48sec. From the graph shows that 2-SMC takes less time to reach the reference speed.

Figure 10 shows the PID, 1-SMC & 2-SMC response at disturbances at a varying interval at high-speed 1500rpm. PID have less disturbance rejection whereas 1-SMC have good disturbance rejection only at small load variation but possess chattering. In 2-SMC have good disturbance rejection and also less chattering, only problem is choosing of tunning values.

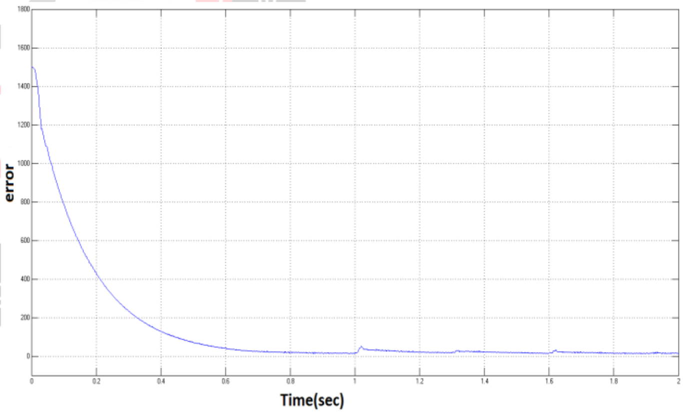
Figure 11 illustrates the PID, 1-SMC & 2-SMC response at load changes (1-5) Newton at high speed 1500rpm. PID possess more chattering. 1-SMC can't reject the high disturbance whereas 2-SMC rejected disturbance even at high load changes also.

Figure 12 illustrates the PID, 1-SMC & 2-SMC response at load changes(1-3) Newton at low-speed 300rpm. PID doesn't show smooth response this will kill the devices. 1-SMC capable of handling disturbance but more chattering whereas 2-SMC capable of handling load changes & also less chattering than 1-SMC.

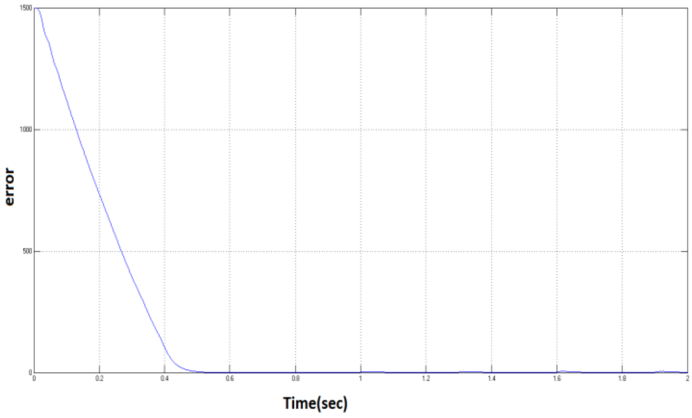
Figure 13 illustrates the PID, 1-SMC & 2-SMC response at pulse wave as the reference. Response of PID is oscillating & disturbance rejection is less 1-SMC & 2-SMC have a similar response.

Figure 14 shows the PID, 1-SMC & 2-SMC at sine wave 500 amplitude & 5 Hz frequency as the reference. PID response is oscillating but 1-SMC & 2-SMC are smooth & track the path.

Figure 15 shows the PID, 1-SMC & 2-SMC response at step signal 1500rpm at +ve side & -1500rpm at –ve side as reference. At -ve side PID takes 0.34sec to correct the error. 1-SMC takes 0.57sec & 2-SMC takes 0.52sec. At –ve side PID response is oscillating & correction time is 0.29sec but 1-SMC takes 0.69sec & 2-SMC takes 0.64sec doesn't oscillate at all.

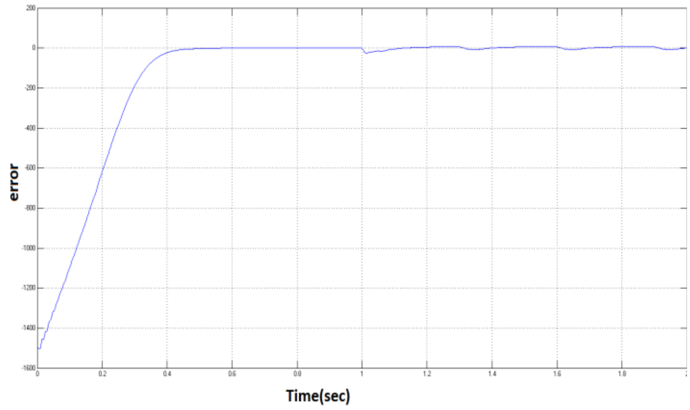


a



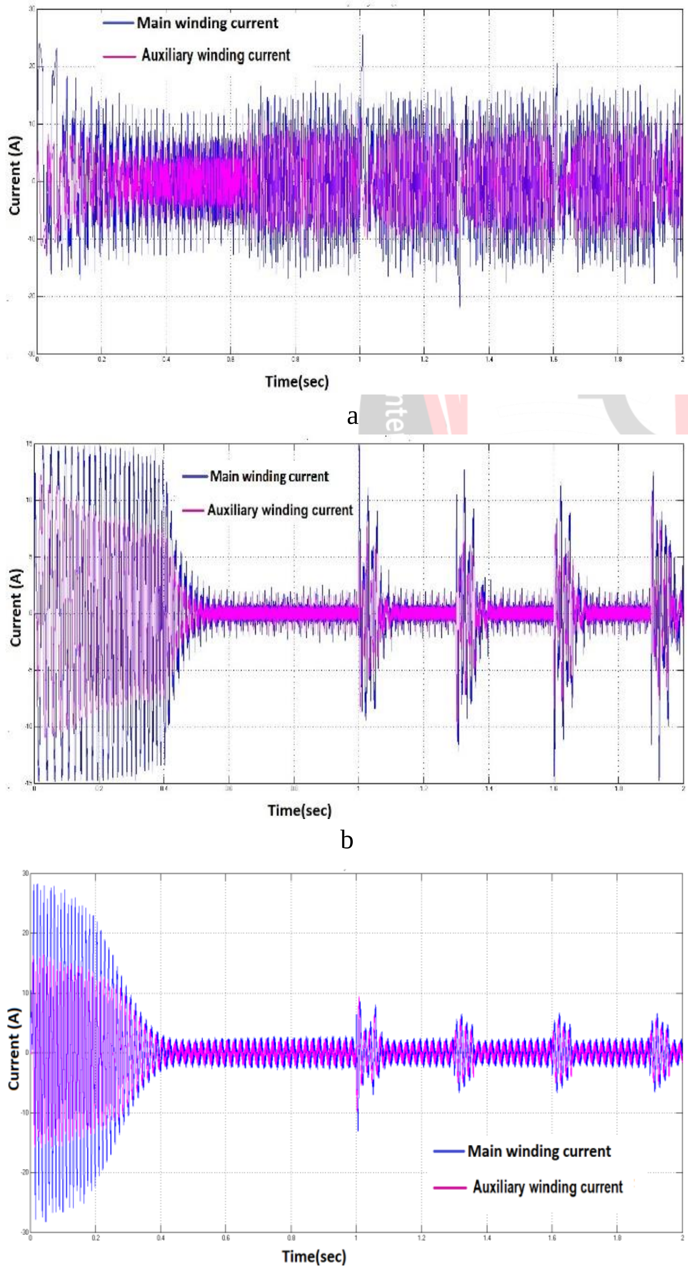
b

DOI : 10.18231/2454-9150.2018.1294



c

Figure6 Tracking error at 1500 rpm with disturbances at different interval.
a PID control
b 1-SMC
c 2-SMC

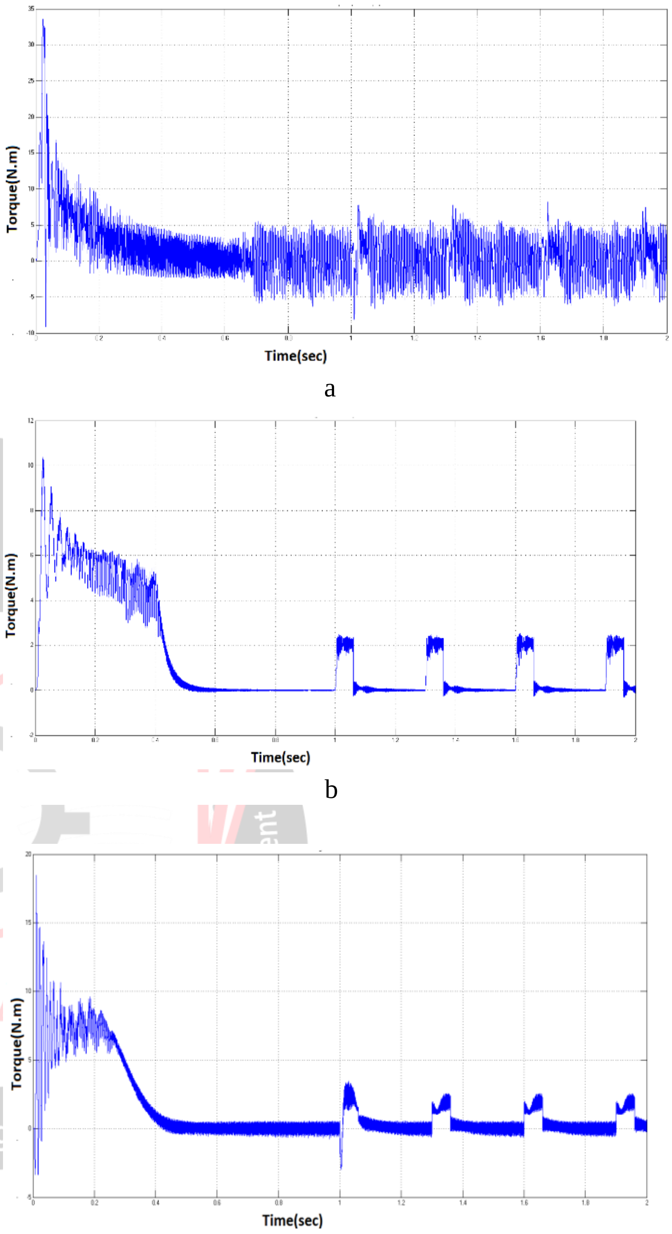


a

b

c

Figure7 Main and Auxiliary winding current at 1500rpm with disturbances at different interval.
a PID Control
b 1-SMC
c 2- SMC



a

b

c

Figure8 Torque response at 1500rpm with disturbances at different interval.
a PID Control
b 1-SMC
c 2-SMC

DOI : 10.18231/2454-9150.2018.1294

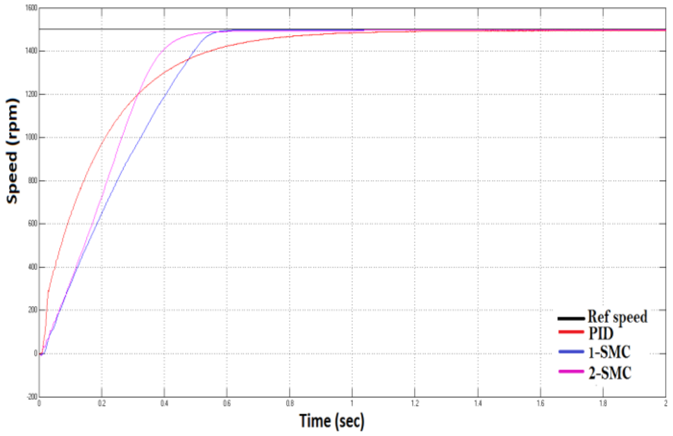


Figure9 PID, 1-SMC & 2 SMC response at constant speed and constant load(1Newton)

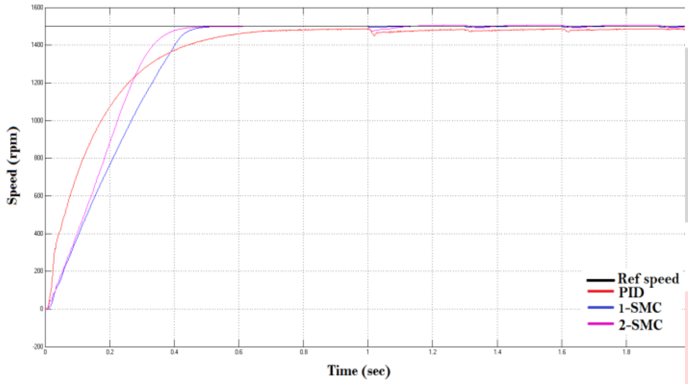


Figure10 PID, 1-SMC & 2-SMC response at different disturbances created at different interval at high speed 1500rpm

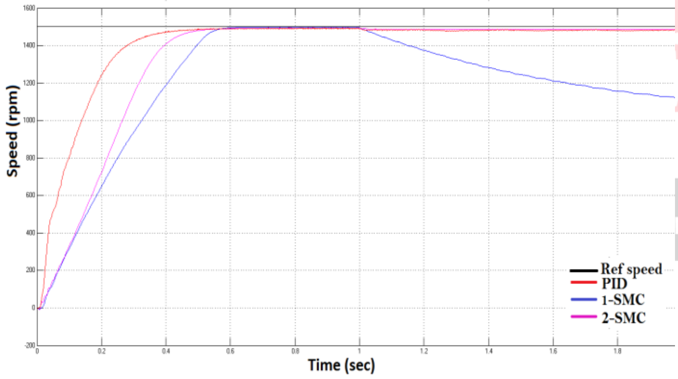


Figure11 PID, 1-SMC & 2-SMC response at load changes at high speed

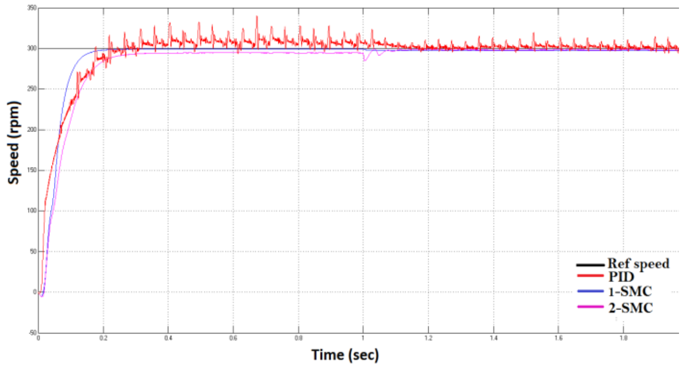


Figure12 PID, 1-SMC & 2-SMC response at load changes at Low speed

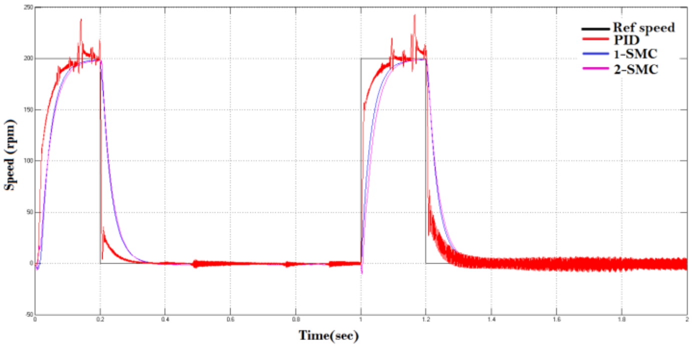


Figure13 PID, 1-SMC & 2-SMC response at pulse wave as reference

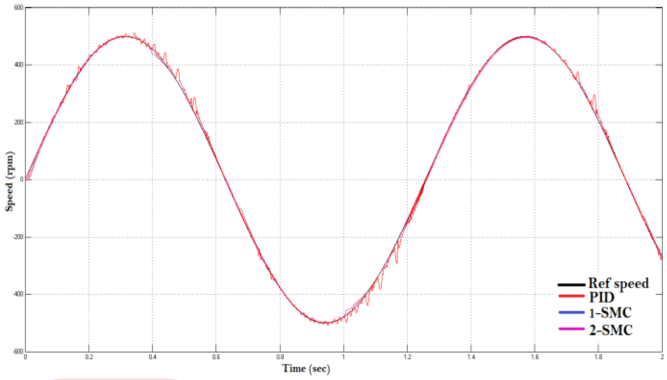


Figure14 PID, 1-SMC & 2-SMC response at sine wave as reference

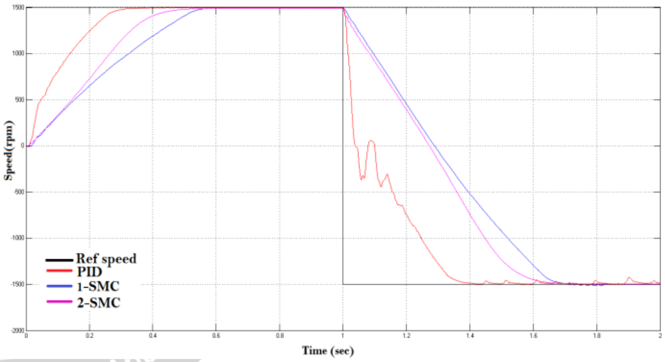


Figure15 PID, 1-SMC & 2-SMC response at step signal as reference.

VI. CONCLUSION

2-SMC is the effective method for controlling the single phase induction motor. Simulation structure for controlling of 1-stage enlistment engine utilizing PID, 1-SMC and 2-SMC is set up and actualized in MATLAB. Simulation result demonstrates that 2-SMC has great unique execution and steadiness at various working modes.

ACKNOWLEDGEMENT

The authors would like to acknowledge faculties and students of Electrical Engineering department, Manipur Technical University for valuable suggestions, continuous motivation & their cooperation.

REFERENCE

[1] Casadei, D., et al., “Control of induction motors for wide speed range for electric vehicle drives,”.*Electrical*

Machines, ICEM,18th International Conference on. IEE, 2008.

[2] Kubota, Hisao, Kouki Matsuse, and Takayoshi Nakano., "New adaptive flux observer of induction motor for wide speed range motor drives," *Industrial Electronics Society, IECON'90*, 16th Annual Conference of IEEE, 1990.

[3] Osama, Mohamed, and Thomas A. Lipo., "Modeling and analysis of a wide-speed-range induction motor drive based on electronic pole changing," *IEEE Transactions on Industry Applications*, 33.5, 1997: 1177-1184.

[4] Kumar, Amit, and Tejavathu Ramesh.,"Direct field oriented control of induction motor drive," *Advances in Computing and Communication Engineering (ICACCE)*, Second International Conference on. IEEE, 2015.

[5] Quintero-Manríquez, Eduardo, Edgar N. Sanchez, and Ramón A. Félix., "Real-time direct field-oriented control of induction motor for electric vehicles applications," *Power, Electronics and Computing (ROPEC)*. IEEE International Autumn Meeting on. IEEE, 2014.

[6] Ahallianath, K. G. R., and Waheeda Beevi.,"Indirect Field Oriented Control of induction motor using Predictive Current Controller,"*Control Communication & Computing India (ICCC)*, International Conference on. IEEE, 2015.

[7] Shrawane, Prasad.,"Indirect field-oriented control of induction motor," *Power Electronics Congress (CIEP)*, 12th International. IEEE, 2010.

[8] Aurora, Claudio, and Antonella Ferrara., "A sliding mode observer for sensorless induction motor speed regulation," *International Journal of Systems Science* 38.11, 2007: 913-929.

[9] Utkin, Vadim.,"Variable structure systems with sliding modes," *IEEE Transactions on Automatic control* 22.2, 1977 : 212-222.

[10] Floquet, Th, J. P. Barbot, and W. Perruquetti.,"Second order sliding mode control for induction motor," *Decision and Control. Proceedings of the 39th IEEE* Conference on. Vol. 2. IEEE, 2000.

[11] Rubio, Guillermo J., et al. "Integral high order sliding mode control of single-phase induction motor," *Electrical Engineering, Computing Science and Automatic Control (CCE)*, 10th International Conference on. IEEE, 2013.

[12] Oliveira, Carlos MR, et al.,"Integral sliding mode controller with anti-windup method analysis in the vector control of induction motor," *Industry Applications (INDUSCON)*. 12th IEEE International Conference on. IEEE, 2016.

APPENDIX

Table I Nomenclatures

Symbol	Description
V_{ds} & V_{qs}	*d & q* - axis stator voltage
V_{dr} & V_{qr}	*d* & q axis rotor voltage
i_{ds} & i_{qs}	*d* & q axis stator current
i_{dr} & i_{qr}	*d* & q axis rotor current
r_{ds} & r_{qs}	d & q axis stator resistance
r_{dr} & r_{qr}	d & q axis rotor resistance
λ_{ds} & λ_{qs}	d & q axis stator flux linkage
λ_{dr} & λ_{qr}	d & q axis rotor flux linkage
L_r	Rotor inductance
L_m	Magnetizing inductance
L_{md} & L_{mq}	d & q axis Magnetizing inductance
L_{ds} & L_{qs}	d & q axis stator inductance
L_{dr} & L_{qr}	d & q axis Rotor inductance

Table II Gain values of PID for different reference signals

Reference Signal	**Reference Speed**	**Disturbances (Y/N)**	K_p	K_i	K_d
Constant speed	1500	N	160	4	30
		Y(Pulse disturbance)	400	4	60
Constant speed	1500	Y (1-5) Newton	9	4	0.6
Constant speed	300	Y(1-3) Newton	9	4	0.6
Pulse Generator	200	Y	9	2	0.2
Speed step	1500	Y	170	4	18
Sine wave	500	Y	160	4	4

Table III Gain values of SMC for different reference signals

Reference Signal	**Reference Speed**	**Disturbances (Y/N)**	K_1	K_2
Constant speed	1500	N	0.12	2.5
		Y(Pulse disturbance)	0.12	1.5
Constant speed	1500	Y (1-5) Newton	0.12	5.5
Constant speed	300	Y(1-3) Newton	0.12	5.5

DOI : 10.18231/2454-9150.2018.1294

Pulse Generator	200	Y	0.5	2.5
Speed step	1500	Y	0.12	2.5
Sine wave	500	Y	0.6	1.5

Table IV Motor Parameter

Parameter	**Value**	**Unit**
λ_{dr}	0.3	Wb/m
L_{md}	0.1772	H
L_r=Ll'r +Lm	68.92	mH
P	2	
L_{mq}	92.9	mH
L_m	66.8	mH
R_r	4.12	ohm
$T_r = L_r/R_r$	0.0444	sec
Voltage	220	V
Frequency	60	Hz

DOI : 10.18231/2454-9150.2018.1294