CHAPTER: 3 CLOSE LOOP SYSTEM DESIGN

This chapter reviews & discuses existing close loop system design approaches and the modifications suggested by the researchers for motors & drives systems. It also describes simulation study carried out by different controllers for motors & drives. It also presents design and implementation of various control techniques using signal processing algorithms

3.1 Literature review

Sliding mode control approach has emerged because of its potential for circumventing parameter variation effects under dynamic conditions with a minimum of implementation complexity. In electric drive systems the existence of parameter changes caused by ,for instance ,winding temperature variation, converter switching effect, saturation, unknown loads .Some main features for Sliding mode control approach are order reduction , disturbance rejection , strong robustness and simple implementation by means of power converters. In fact control of electric drives is one of the most challenging applications because of increasing interest in using electric servo mechanisms in control systems, the advances of high speed switching circuitry as well as insufficient linear control methodology for inherent non linear high order multivariable plants such as AC motors. In Sliding mode control Techniques can be used for current control, speed control, observer design and sensor less control of electric drive systems. The current research in the control of induction motors is characterized by a great variety of control methodologies with different control /observation/adaption algorithms combined with different coordinate systems, different state variables and different notations [1]. sliding-mode control has been one of the significant interests in the control research community worldwide [10]. Since it has systematic design procedure, it is one of the most powerful solutions for many practical control designs [12]. It is a robust control scheme based on the concept of changing the structure of the controller in response to changing the state of the system in order to obtain desired output [11]. Sliding mode controller design consist of two phase, Reaching phase- that drives the system to the sliding manifold and sliding Phase-during which the system moves in the sliding manifold. In the sliding-mode control solution is to determine a sliding manifold which is also called sliding surface or sliding function, being a function of the tracking error that is the difference between set point and output measurement, where n is the order of the uncontrolled system and λ is a positive constant. The related sliding surface is given by the following equation [13,16].

$$s(t) = \left(\lambda + \frac{d}{dt} \right)^{n-1} e(t) \tag{3.1}$$

The control signal is sum of the equivalent signal and switching signal. The switching signal is selected to be a signum function. The second method of sliding surface design is based on PID design technique is as shown in the following equation

$$s(t) = k_1 e(t) + k_2 \int_0^{\tau} e(\tau) d\tau + k_3 \dot{e}(t) \tag{3.2}$$

The switching control is selected to be a saturation function [11,16].The third method of sliding surface design is based on PI-PD design technique is as shown in the following equation,

$$s(t) = ae(t) + b\int e(t)dt - cy(t) - d\,\dot{y}(t) \tag{3.3}$$

Tangent hyperbolic function is selected as switching signal [14,16].The forth method of sliding surface design is based on the following equation

$$s(t) = \left(\frac{d}{dt} + \lambda \right)^{n} \int e(t)dt \tag{3.4}$$

The proposed switching signal is based on the following equation is selected [15,16]

$$k_d \frac{s(t)}{|s(t)| + \phi} \tag{3.5}$$

The above different sliding surfaces and switching signals are applied for the electro mechanical systems [16].They may be applied with the slight modification for the other electromechanical drives for different speed control requirements. The sliding surface and switching signal are main cause for the production of Chattering in sliding mode control. Proper selection of both may reduce considerable amount of chattering in the sliding mode control systems.

3.2 Different sliding mode control Approaches

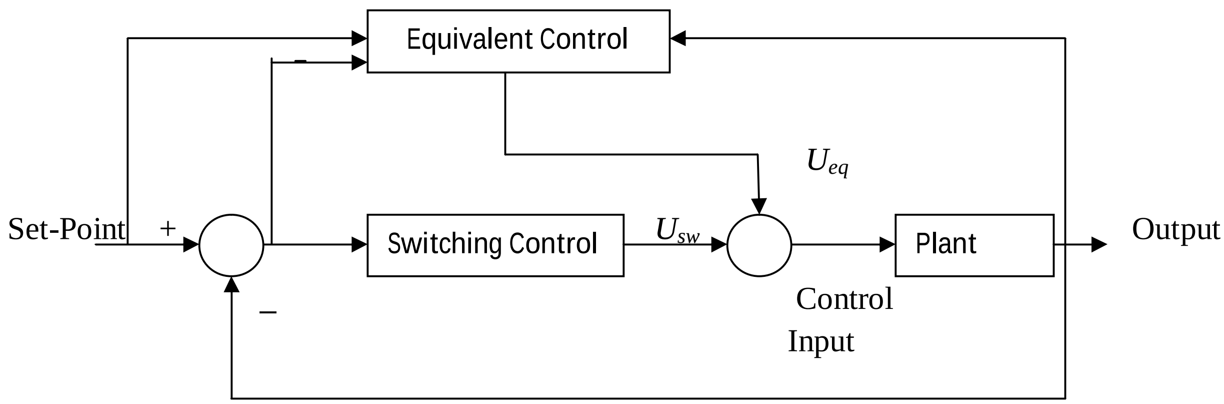

Figure 3. 1 Conventional sliding mode control approach [13, 16]

Conventional Sliding Mode control approach is design for first order systems. It consists of switching control and equivalent control blocks. The most important task is to design the switching control law which enforces the system to the sliding surface. The dynamic performance of the system is directly dependent choosing an appropriate switching control law. Lyapunov technique is generally used to determine the stability of the closed-loop systems.

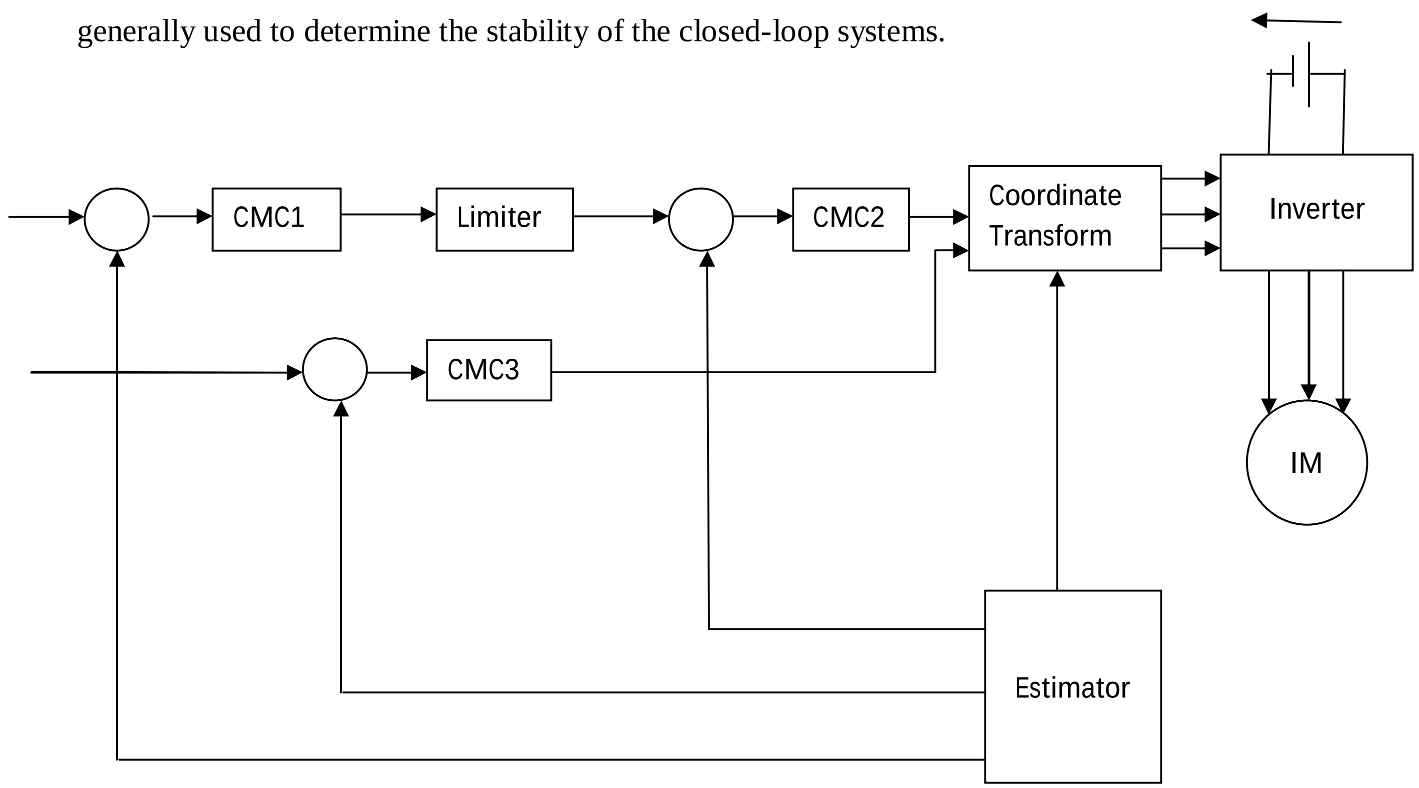

Figure 3. 2 SMC based Speed, Current & Flux controller [2]

Ideal sliding-mode can be found by equivalent control approach First time derivative of Sliding surface along the system trajectory is set equal to zero and the resulting algebraic system is solved for the control law. If the equivalent control exists, it is substituted into sliding surface and the resulting equations are the ideal sliding-mode[13,16].for the control law. If the equivalent control exists, it is substituted into sliding surface and the resulting equations are the ideal sliding-mode[13,16].Sliding mode controllers blocks named CMC1, CMC2 CMC3 are used for the speed controller, the current controller and the flux controller respectively in the above block diagram based on the conventional sliding mode control approach. In this paper limiter block to limits the current and 'coordinate transform' block for the conversion between the synchronously rotating and stationary reference frame are also used with sliding mode controller blocks [2].

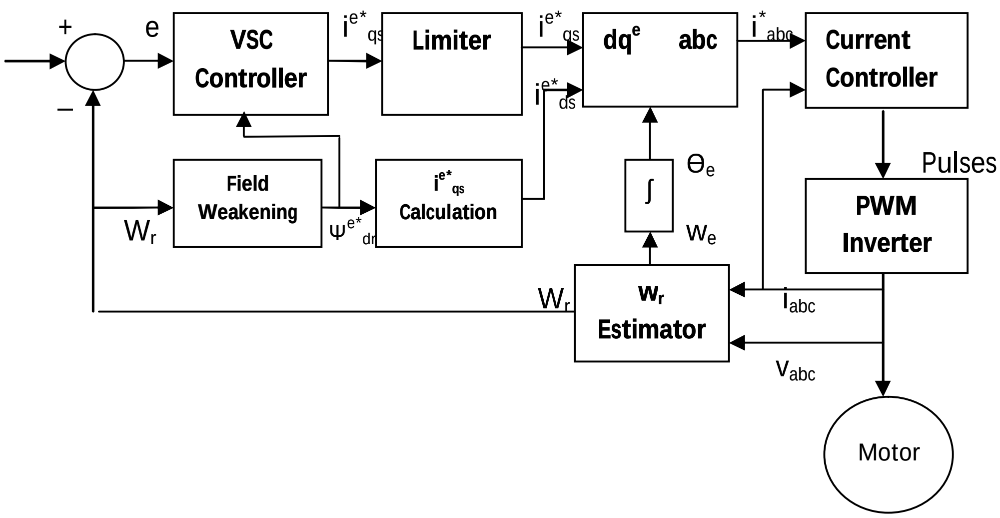

Figure 3. 3 Adaptive VSC controller [3]

Based on conventional sliding mode control approach, in the above block diagram instead of using 3 different sliding Mode controller blocks for speed ,current, flux control, one adaptive sliding-mode controller block is applied shown by VSC controller block in the above block diagram with 'current controller' block consists of a three hysteresis-band current PWM control, where the actual current continually tracks the command current within a hysteresis band[3]. Traditional SMC was limited by a discontinuous control law. There are techniques to limit and eliminate the high-frequency switching associated with traditional SMC. The effective gains of the error compensator can be increased by using a sliding mode controller to tune the observer for both speed adaptation and for rotor flux estimation. Total Sliding mode controller is the combination of the computed torque controller and sliding mode controller, it is one of the effective nonlinear robust control approaches since it provides system dynamics with an invariance property to uncertainties once the system dynamics are controlled in the sliding mode. The total sliding-mode control approach for the uncertain induction servomotor drive system consist of two parts,(a)Base Line Model Design(b)Curbing Controller Design. Baseline Model Design- two controllers are designed in the control effort. The first controller which is a computed toque controller is used to compensate for the nonlinear effects and attempts to cancel the nonlinear terms in the model. After the nonlinear model is linearzed , the second controller is used to specify the desired the system performance. Curbing Controller Design- an additional controller is designed using a new sliding surface to ensure the sliding motion through the entire state trajectory, which totally eliminates the unpredictable perturbations effect from the parameter variations and external load disturbances. The curbing controller are twofold, first is to keep the controlled system dynamics on the sliding surface and curb the system dynamics on to the sliding surface for all time[5].

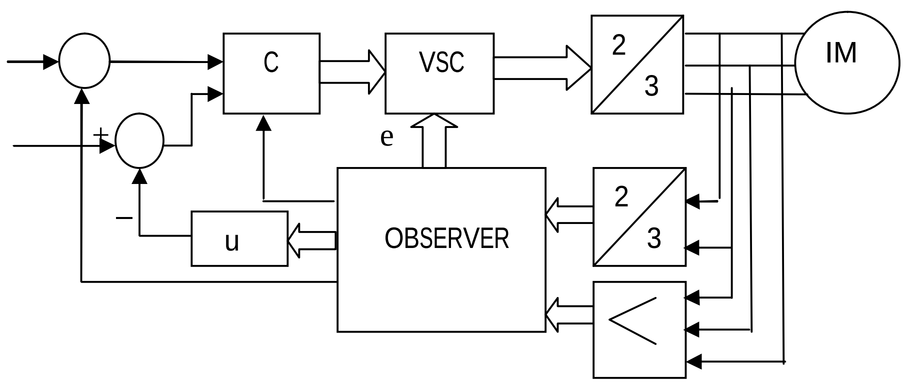

Figure 3. 4 Observer based VSC controller approach [7]

Sliding Mode control approach also used in observer base control system design. Following examples shows the application of sliding mode control observer base design. By combining the variable structure system and Lyapunov design a novel sliding mode algorithm of controller/observer for induction motor is developed as shown in above fig. sliding mode closed loop rotor flux observer for estimation of electromotive force of machine. This signal is then used in nonlinear stator flux and torque control of induction motor and in rotor flux observer for speed and flux estimation [7].

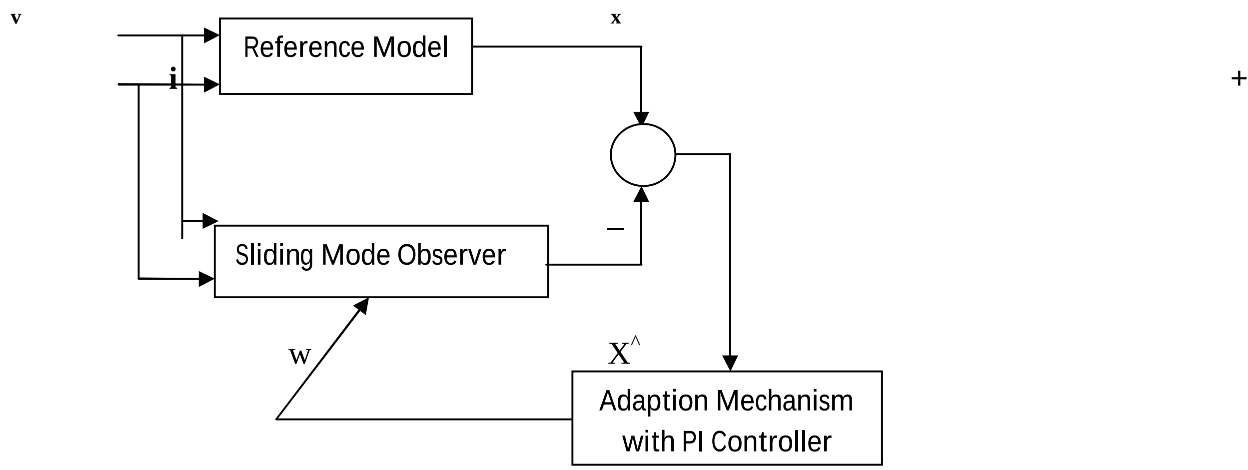

Figure 3. 5 MRAS based Sliding mode controller approach [6]

Model Reference Adaptive System observer gives satisfactory speed estimation in the high and medium speed regions. When working at low speed the observer performance deteriorates due to initial condition problems and sensitivity to current measurement noise. Therefore a sliding mode observer is proposed to replace the conventional adaptive model to improve performance of speed control systems [6].Sensor less vector control of induction motor drive requires an incremental shaft mounted speed encoder for close loop speed or position control. But it adds cost and reliability problems, need for a shaft extension and mounting arrangement. It is possible to estimate the speed signal from machine terminal voltages and currents with the help of a DSP. Induction motor speed estimation techniques are slip calculation, direct synthesis from state equations, Model referencing adaptive system (MRAS),speed adaptive flux observer ,Extended kalman filter (EKF) , Slot harmonics, Injection of auxiliary signal or salient rotor. The experimental system consists of inverters for both motors are controlled by the PC, providing a possibility for full control for experimental purposes of both the driving motor and the load motor. The interfacing is made via a dSPACE1104 control board. The Matlab / Simulink control model can be converted and downloaded to the DSP1104 or on DSP1102. During the real-time operation of the control algorithm, the supervision and capturing of the important data can be done by the Control Desk software provided with the DSP board [8, 9]. Experiments were obtained using motor controller board based on floating point DSP TMS320C32. All measured and controller internal variables are accessible through the serial link to the PC, where graphical data analysis software can be performed. Brushless AC servomotor mechanical connected to the IM under test was used as the Load Machine. The control of both, speed and applied torque, is possible, thus hardware-in-the-loop operation can also be performed [6, 7].

3.3 Simulation Example

To check the effectiveness and robustness of sliding mode control approach for Induction motor speed control ,d-q model of induction motor [49-50] is simulated in Matlab-simulink and results are compared with the P-I controller.

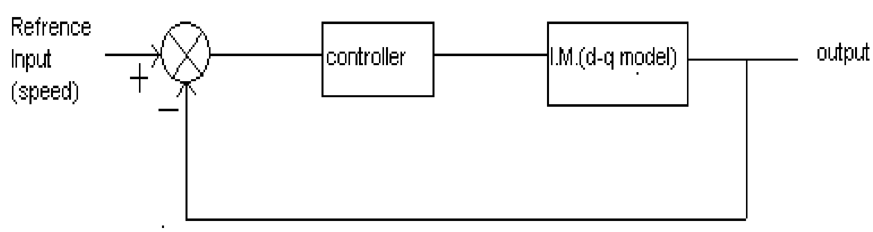

Figure 3. 6 General close loop system

In this study d-q model of induction motor speed control is simulated for the sliding mode controller and P-I controller. Reference Input signal is selected as step input with the initial value 1pu and final value as 0.5pu and step time 3pu. P-I controller is used to control the speed of Induction motor. Gain parameters are adjusted as K_p= 0.6 and K_I=5.6 and with a saturation limit as 0.03pu. Sliding surface is defined based on following equation,

$$s(t) = k_1 e(t) + k_2 \int_0^{\tau} e(\tau) d\tau + k_3 \dot{e}(t) \tag{3.6}$$

The switching control is selected to be a saturation function as

$$u_{sw} = ksat\left(\frac{s(t)}{a}\right) \tag{3.7}$$

Where $sat\left(\frac{s(t)}{a}\right) = \frac{s(t)}{a} \; if \left|\frac{s(t)}{a}\right| \leq 1$ (3.8)

$$sat\left(\frac{s(t)}{a}\right) = sign\left(\frac{s(t)}{a}\right) \; if \left|\frac{s(t)}{a}\right| > 1 \tag{3.9}$$

Gain parameters are adjusted as K_1=4, K_2=0.25, K_3=0.25 and K=4.8 and a=34(thickness of boundary layer) for the sliding mode controller design in Matlab-simulink. Performance of P-I controller and Sliding mode controller is compared with the reference step input signal is as shown below.

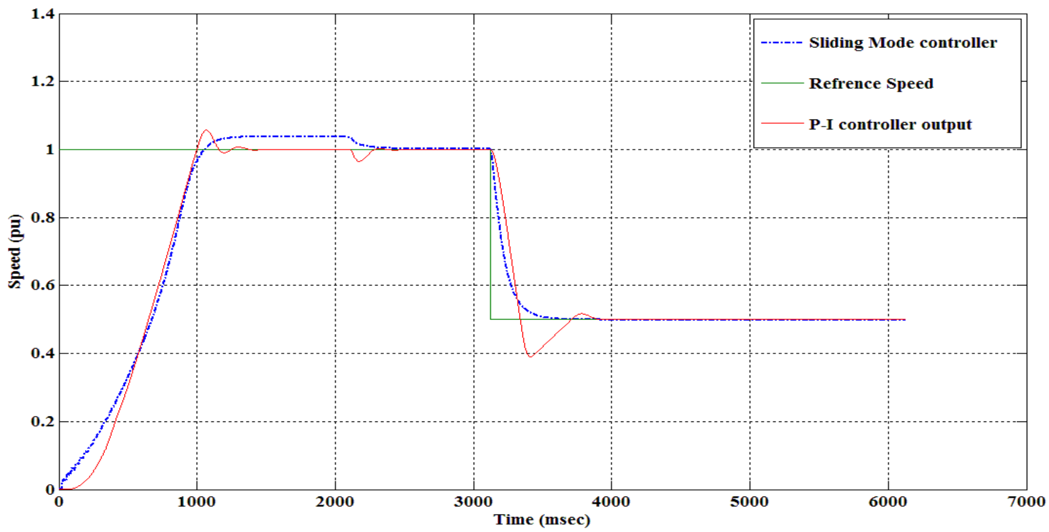

Figure 3. 7 Performance comparison of SMC and P-I controller

Table 3. 1 controller Performance analysis

Controller	T_d(Sec)	T_r (Sec)	T_p (Sec)	M_p (pu)	T_s (Sec)
P-I	0.64	0.613	1.07	0.0572	3.75
SMC	0.67	0.753	1.25	0.0372	3.50

The Sliding Mode control is the approach in which system is controlled with previously defined surface, system is forced to that surface and system slides to equilibrium desired point. The real time DSP implementation of sliding mode controller is used for robust speed control of Induction Motor. Sliding Mode control technique can be extended by selecting different configuration of Inverters such as 3 level voltages source Inverter. In the case study of Induction motor speed control using P-I controller and Sliding Mode controller, Sliding Mode controller has superior performance in terms of less settling time and peak overshoot with some increase in delay time, rise time and peak time compare to P-I controller.

3.4 Multi segment Sliding mode control (MSMC)

3.4.1 Introduction

Sliding mode control (SMC) with a variable control structure is basically an adaptive control that gives robust performance of a drive with a parameter variations and load torque disturbance. The control is non linear and can be applied to a linear or non linear plant. In SMC the drive response is forced to slide along predefined trajectory in a plane by switching control algorithm irrespective of the plant's parameter variation and load disturbances. The controller detects the deviation of the actual trajectory from the reference trajectory and correspondingly changes the switching strategy to restore the tracking [49,62,63,66]. The various control strategies for the control of the inverter-fed induction motor have provided good steady state and poor dynamic response. This can be improved by controlling magnitude and frequency of the stator rotor phase currents and their instantaneous phases. If this all are not controlled, it results in oscillations in speed, torque and may results in large excursions of stator currents. This is undesirable in high performance applications such as in robotic actuators, centrifuges, servos, process drives. Induction motor drives require a coordinated control of stator current magnitudes, frequencies and their phases. As with dc drives independent control of the flux and torque is possible in ac drives. For the control stator current phasor can be resolved along the rotor flux linkages and the component along the rotor flux linkages is the field producing current, the flux phasor is made possible by inverter control. The control is achieved in field coordinates is known as Field oriented control or Vector control. Vector control made the ac drives equivalent to dc drives in the independent control of flux and torque and it also improves dynamic performance. Vector control schemes are classified according to how the field angle is acquired. If the field angle is calculated by using terminal voltages and currents or hall sensors or flux sensing windings that are known as Direct vector control. The field angles can also be obtained by using rotor position measurements and partial estimation with only machine parameters, this field angles leads to a class of control schemes known as Indirect vector control [50,66].In indirect vector control method, the unit vector signals are generated in feed forward manner. Vector control is complex and use of powerful microcomputer or DSP is mandatory. Scalar control is simple to implement but inherent coupling effect gives sluggish response and the system is easily prone to instability [59].The control is extended to a full sliding trajectory control incorporating acceleration, constant speed and deceleration segments. MSMC is applied to vector controlled Induction motor servo drive.

3.4.2 Vector control of Induction motor drive

Field oriented control approach becomes more popular due to flexibility of control the induction motor as a separately excited DC motor. The field-oriented technique guarantees the decoupling of torque and flux control commands for the induction motor. On the other hand, when dealing with indirect field-oriented control of induction motors, a knowledge of rotor speed is required speed control. It depends on parameter variations, external load disturbances, unmodelled and nonlinear dynamics so advanced control techniques such as nonlinear control, optimal control, variable structure system control, adaptive control, neural control and fuzzy control were used[49,59-61]

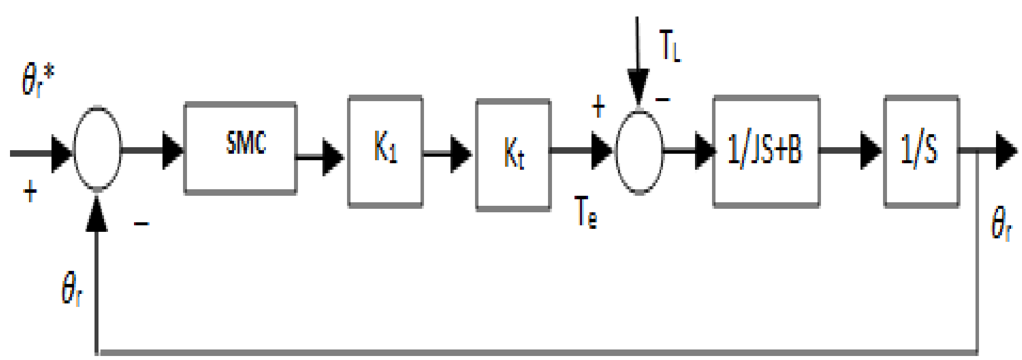

Figure 3. 8 Vector controlled Induction motor with SMC [9]

Fig.3.8 shows the block diagram of an ideal dc machine like transfer function model of a vector drive that incorporates a sliding mode control. Design idea of MSMC is to make output response insensitive to the plant parameters such as torque constant K_t, moment of inertia J, friction damping coefficient B and load torque T_L [49,64,66]. Indirect field oriented control technique is used for the speed and position control of Induction Motor drive as shown in block diagram, following equations are used for the speed and rotor position control of Induction motor drive

$$T_e = K_t\, i_{qs}^* \tag{3.10}$$

$$K_t = \frac{3(n_p)}{2}\left(\frac{L_m^2}{L_r}\right) i_{ds}^* \tag{3.11}$$

$$H(s) = \frac{1}{Js + B} \tag{3.12}$$

3.4.3 MSMC Design

To control the motion in accordance with the trapezoidal voltage profile for incremental motion control system, Multi Segment Sliding Mode Control using MATLAB simulink was designed. To control the speed or velocity of the Induction motor drive, three sliding surfaces s_1 for acceleration, s_2 for constant speed and s_3 for deceleration were selected. Similarly for position control sliding surface s_4 was selected. In Velocity Control Mode three sliding mode segments (s_1, s_2 and s_3) were given, corresponding to the constant acceleration ($\alpha_{d1} > 0$), constant speed ($\omega_d > 0$), and, constant deceleration ($-\alpha_{d2} < 0$). Note that α_{d1} is not necessarily equal to $-\alpha_{d2}$.[52-57,65]

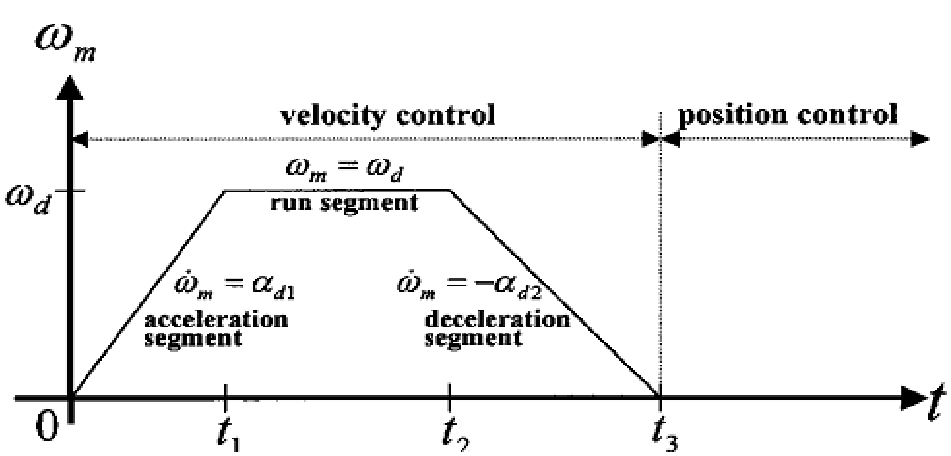

Figure 3. 9 Trapezoidal Velocity profile for incremental motion control [52-57,65]

Acceleration Segment S_{1}: -

The Sliding surface for acceleration segment during the time interval [t_0, t_l], [52-57,65]

$$S_1 = x_1 - \frac{1}{2\alpha_{d1}} x_2^2 - x_{10} = 0 \tag{3.13}$$

Where $x_{10} = \theta_0 - \theta_d$ is the initial position error $x_1 = \theta_m - \theta_d$ and $x_2 = \omega_m$

The above acceleration segment S_1 given by (3.13) implemented using MATLAB Simulink as

Figure 3. 10 Acceleration MATLAB simulink Block

x_1, x_2 were the inputs of Acceleration block and output of this block was sliding surface S_1.

Run Segment S2

The Sliding surface for constant speed segment during the time interval [t_1, t_2], [52-57,65]

$$S_2 = x_2 - \omega_d = 0 \tag{3.14}$$

The above run segment S_2 given by (3.14) implemented using MATLAB Simulink as

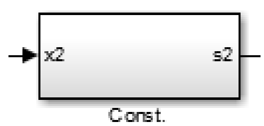

Figure 3. 11 Run segment MATLAB simulink Block

Input of Const. block was x_2 and output of this block was sliding surface S_2.

Deceleration Segment S_3 :-

The Sliding surface for deceleration Segment during the time interval [t_2, t_3], [52-57,65]

$$S_3 = x_1 + \frac{1}{2\alpha_{d2}} x_2^2 = 0 \tag{3.15}$$

The above Deceleration segment S_3 given by (3.15) implemented using MATLAB Simulink as x_1, x_2 were inputs of Deceleration block and output of this block was sliding surface S_3

Figure 3. 12 Deceleration segment MATLAB simulink Block

Position Control Segment S_4 :-

The Sliding surface for Position control,

$$S_4 = x_2 + cx_1 \quad (3.16)$$

Where, c is a positive constant[52-57,65]

The above Position control segment S_4 given by(3.16) implemented using MATLAB Simulink as

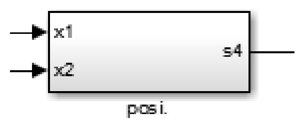

Figure 3. 13 Position control segment MATLAB simulink Block

The control law to ensure the sliding condition expressed in the following form[52-57,65]

$$T_e = K_1 v = K_1(h_1 + h_2 x_2) \quad (3.17)$$

The control law for Velocity control given by (3.17) implemented using MATLAB Simulink as

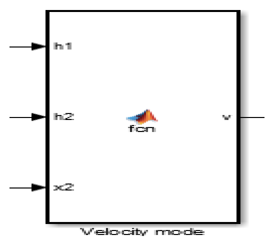

Figure 3. 14 velocity control segment MATLAB simulink Block

Inputs of Velocity control mode block were h_1, h_2, x_2 and output of this block was v. [52-57,65]

For Acceleration Segment,

$$h_1 = \begin{cases} \alpha_1, \ if \ \ s_1 x_2 > 0 \\ -\alpha_1, \ if \ \ s_1 x_2 < 0 \end{cases} \tag{3.18}$$

$$h_2 = \begin{cases} \beta_1, & if \quad s_1 > 0 \\ -\beta_1, & if \quad s_1 < 0 \end{cases} \tag{3.19}$$

Where, $\alpha_1 > \left|\frac{\alpha_{d1} J_m + T_L}{K_1}\right|$ $and\ \beta_1 > \left|\frac{B_m}{K_1}\right|$

For Run Segment,

$$h_1 = \begin{cases} -\alpha_2, \ if \ \ s_2 > 0 \\ \alpha_2, \ if \ \ s_2 < 0 \end{cases} \tag{3.20}$$

$$h_2 = \begin{cases} -\beta_2, & if \quad s_2 x_2 > 0 \\ \beta_2, & if \quad s_2 x_2 < 0 \end{cases} \tag{3.21}$$

Where, $\alpha_2 > \left|\frac{T_L}{K_1}\right|$ $and\ \beta_2 > \left|\frac{B_m}{K_1}\right|$

For Deceleration Segment,

$$h_1 = \begin{cases} -\alpha_3, & if \ \ s_3 x_2 > 0 \\ \alpha_3, & if \ \ s_3 x_2 < 0 \end{cases} \tag{3.22}$$

$$h_2 = \begin{cases} -\beta_3, & if \quad s_3 > 0 \\ \beta_3, & if \quad s_3 < 0 \end{cases} \tag{3.23}$$

Where $\alpha_3 > \left|\frac{T_L - \alpha_{d2} J_m}{K_1}\right|$ $and\ \beta_3 > \left|\frac{B_m}{K_1}\right|$

In velocity control mode MATLAB embedded function block named velocity controller programmed for Acceleration segment for gains defined in (3.18) and (3.19) for the time t=0 to t=t_1, run segment for gains defined in (3.20) and (3.21) for the time t=t_1 to t=t_2 and Deceleration Segment for gains defined in (3.22) and (3.23) for the time t=t_2 to t=t_3 [52-57,65]. Inputs for velocity controller block were $\alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3, t, x_2, s_1, s_2, s_3, \alpha_{d1}, \alpha_{d3}$ block and output of this block were h_1 , h_2

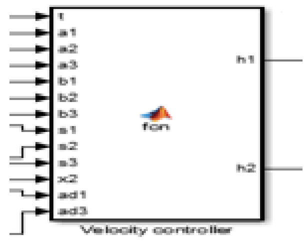

Figure 3. 15 Velocity controller MATLAB simulink Block

After the speed control mode is completed, the rotor has been moved to the desired position θ_d. The control law for position control mode [52-57,65]

$$v = k_1(h_1x_1 + h_2x_2 + v_0) \tag{3.24}$$

The control law for Position control given by(3.24) implemented using MATLAB Simulink as

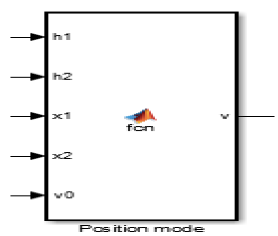

Figure 3. 16 Position mode MATLAB simulink Block

h_1, h_2, x_1, x_2, v_0 were inputs of Position control mode block and output of this block was v.

For Position control mode,

$$h_1 = \begin{cases} -\alpha_4, & if \quad s_4x_1 > 0 \\ \alpha_4, & if \quad s_4x_1 < 0 \end{cases} \tag{3.25}$$

$$h_2 = \begin{cases} -\beta_4, & if \quad s_4x_2 > 0 \\ \beta_4, & if \quad s_4x_2 < 0 \end{cases} \tag{3.26}$$

$$u_0 = \begin{cases} -T_0, & if \quad s_4 > 0 \\ T_0, & if \quad s_4 < 0 \end{cases} \tag{3.27}$$

With $\alpha_4 > 0, \beta_4 > \left|\frac{B_m - CJ_m}{K_1}\right|$ $and\ T_0 > \left|\frac{T_L}{K_1}\right|$

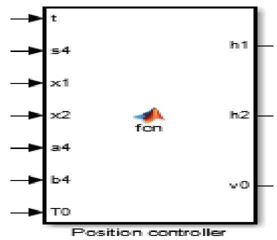

Figure 3. 17 Position controller MATLAB simulink Block

In position control mode MATLAB embedded function block programmed for gains defined in (3.25) and (3.26),(3.27). $\alpha_{4,}\beta_4, t, x_1, x_2$, s_4 , T_0 were inputs of Position controller block and output of this block were h_1 , $h_{2,}v_0$. All the MATLAB Simulink blocks (Fig.3.10-3.17) were combined to design Multi segment Sliding Mode controller (MSMC) as shown in Fig.3.18

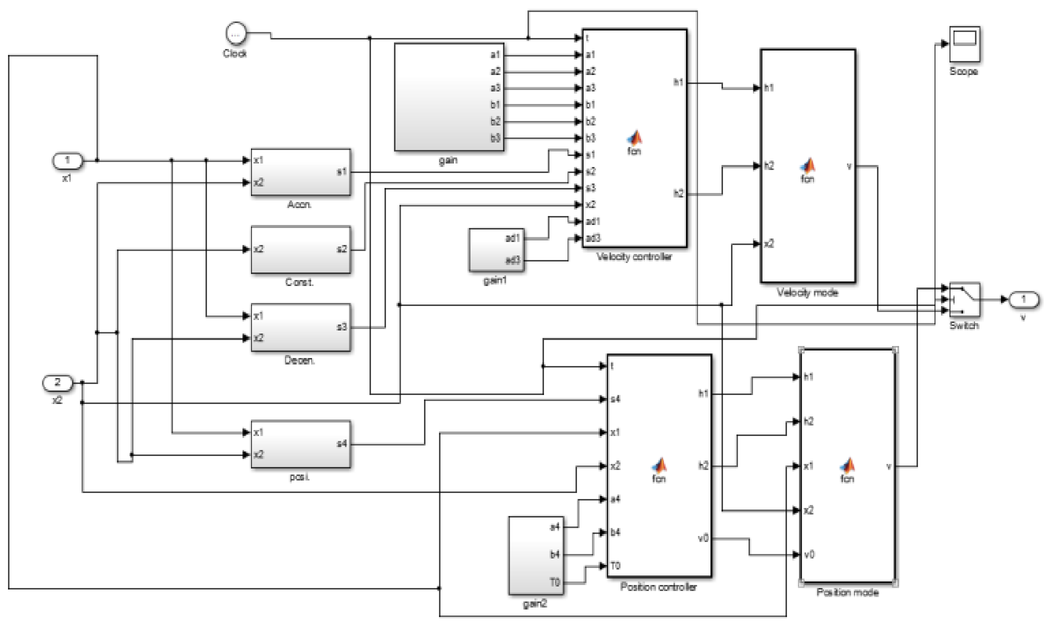

Figure 3. 18 Multi segment Sliding Mode controller MATLAB Simulink Block

3.4.4 Controller Implementation & Results

To demonstrate the effectiveness of designed multi segment sliding mode controller (MSMC), simulations carried out using MATLAB Software. This controller designed for speed and position control of Induction motor drive in accordance with trapezoidal velocity profile.

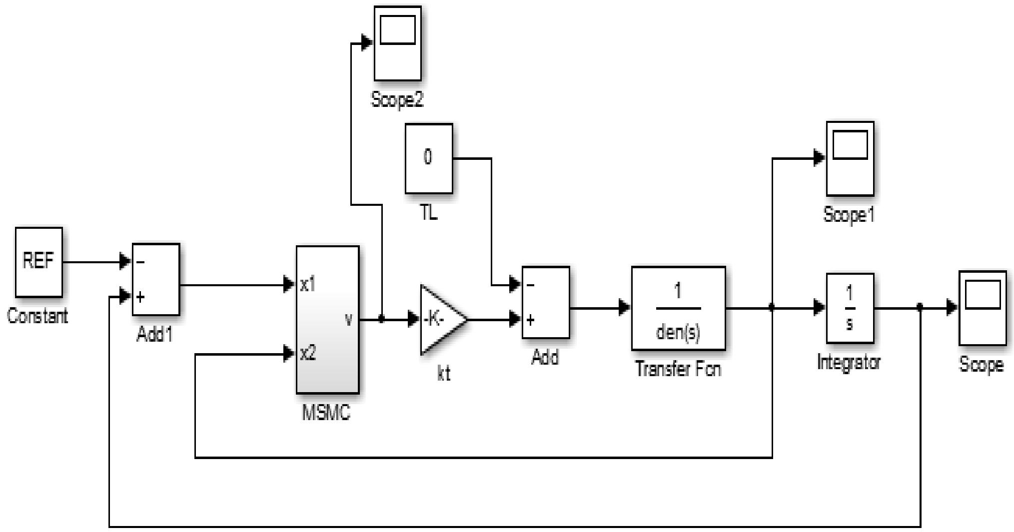

Figure 3. 19 MSMC based closed loop control of Induction motor drive

Controller configured to rotate the rotor of Induction motor drive 6π rad in 0.6sec with parameters and control gains for the trapezoidal velocity profile given in [53,65] as

$\alpha_1 = 15, \alpha_2 = 12, \alpha_3 = 15, \alpha_4 = 300, \beta_1 = 10, \beta_2 = 10,$
$\beta_3 = 10, \beta_4 = 200, c = 4, t_1 = 0.02sec, t_2 = 0.4189sec$
$t_3 = 0.6sec, \alpha_{d1} = 43.1\ rad/sec^2,\ \alpha_{d3} = -43.1rad/sec^2$

$T_0 = 12, \omega_r^* = 10.78\, rad/\ sec^2$

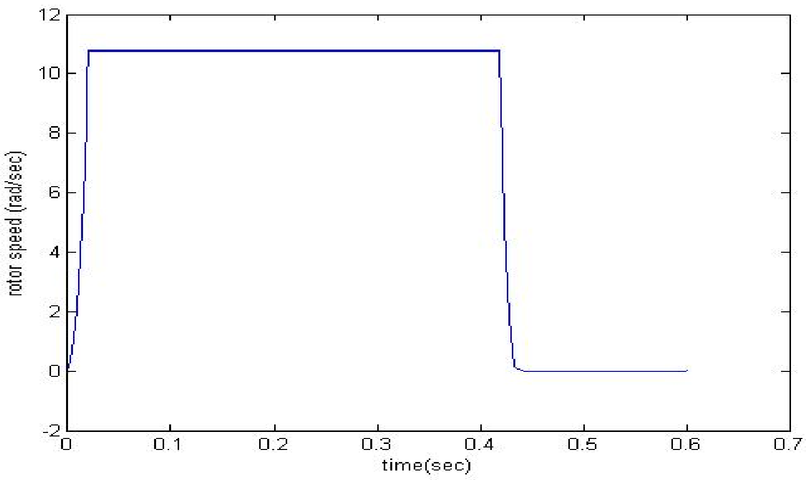

Figure 3. 20 Response of a MSMC based rotor velocity controller

The simulation results of the MATLAB based designed MSMC controller for Velocity control and position control of Induction motor drive was given in Fig.3.20 and Fig.3.21 respectively. In velocity control mode rotor rotates with different speed for acceleration, constant speed segment and for deceleration segment.

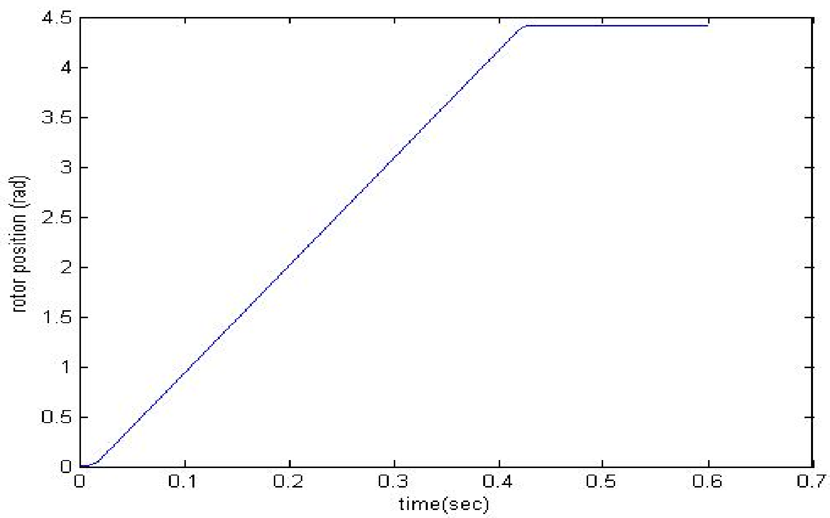

Figure 3. 21 Response of a MSMC based rotor position controller

Multi segment Sliding Mode controller was designed and implemented using MATLAB simulink software packages to satisfy the trapezoidal velocity profile requirements for increment motion control system. In comparison with conventional sliding mode controller design in MSMC design different sliding surfaces were selected for acceleration, run segment, deceleration segment for velocity control and also for position control system.

Paper presented on "Design and Implementation of Multisegment SMC for Induction Motor drive using MATLAB", International Conference on Computing, Communication, Electrical, Electronics, Devices and Signal Processing (CCEEDS) -2015 , Tamil Nadu ,India (28th-30th March 2015).

3.4.5 GA optimized Fuzzy Logic based MSMC

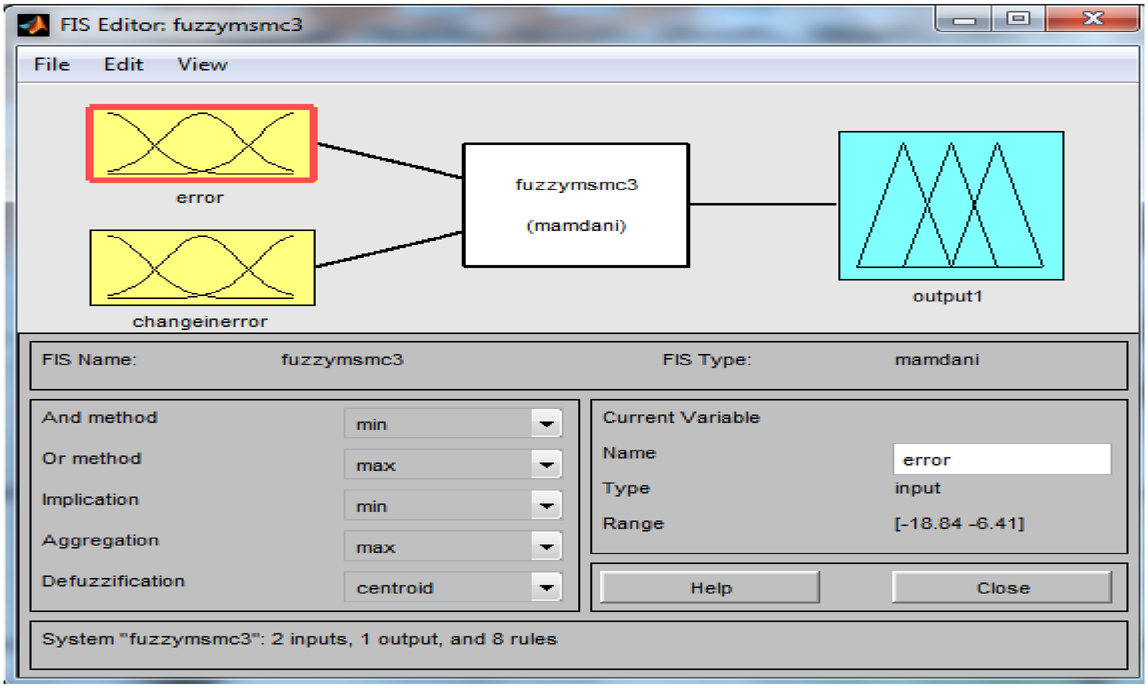

Figure 3. 22 FIS Editor for MSMC

Membership functions

Triangular membership functions were selected for the error ,change in error and output signals. Following table gives ranges for two inputs and output.

Table 3. 2 Membership Function for Error

Input Variable-1	Type of Membership Functions	Name of Membership Functions	Range
Error	Triangular	eNB	-18.849 to -16.774
		eNS	-16.650 to -14.699
		eZ	-14.670 to -12.629
		ePS	-12.600 to -10.559
		ePB	-10.530 to -6.4191

Table 3. 3 Membership Function for Change in Error

Input Variable-2	Type of Membership Functions	Name of Membership Functions	Range
Change in Error	Triangular	NB	-188.49 to -167.74
		NS	-166.50 to -146.99
		Z	-146.70 to -126.29
		PS	-126.00 to -105.59
		PB	-105.30 to -64.191

Table 3. 4 Membership Function For Output Variable Error

Output Variable	Type of Membership Functions	Name of Membership Functions	Range
Error	Triangular	oNB	5679.9 to 4737.41
		oNS	4730.0 to 3794.93
		oZ	3764.93to 2852.10
		oPS	2822.10 to 1910.00
		oPB	1930.00 to 25.00

Table 3. 5 Fuzzy rule base

Change in Error	Error				
	eNB	eNS	eZ	ePS	ePB
NB	oPS	oPS	oNB	oPS	oNB
NS	oPZ	oPS	oNS	oPS	oNS
Z	oPZ	oPZ	oZ	oZ	oZ
PS	oPZ	oPZ	oPS	oPS	oPS
PB	oPZ	oPS	oPB	oPB	oPB

Following 8 rules were utilized from the 25 rules as shown in above Fuzzy rule base Table.

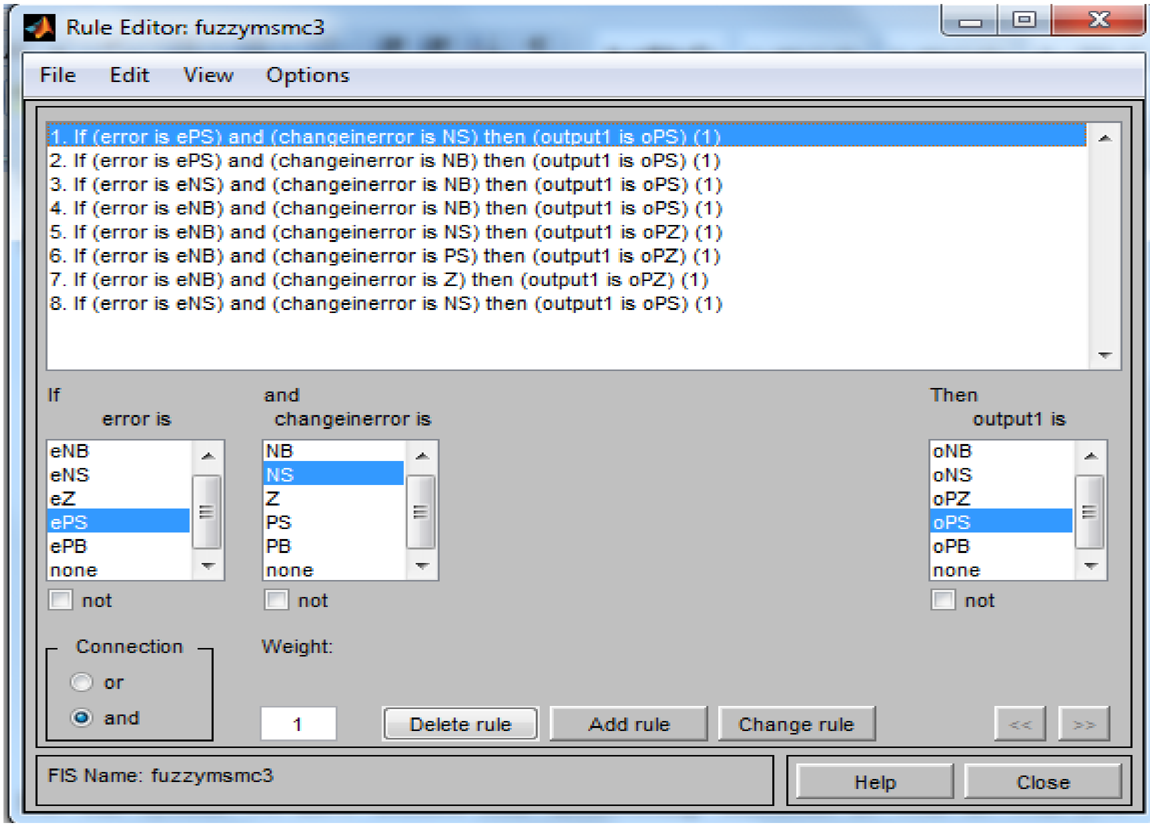

Figure 3. 23 Rule Editor for MSMC

The above fuzzy based MSMC controller is designed for the control of induction motor using indirect field oriented control approach. The values of Input parameters for velocity controller block $\alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3$ were optimized using Genetic Algorithm GUI tool of MATLAB. The Fitness function is defines as [53,65]. The upper and lower bounds of the parameters were $\alpha_1 \in [10,25], \alpha_2 \in [5,25], \alpha_3 \in [10,25]$ $\beta_1 \in [5,15], \beta_2 \in [5,20], \beta_3 \in [5,15]$. Population type double vector, population size=20, Initial range = [0;1],Scaling function=rank, selection function= stochastic uniform, Reproduction Elite count=2,crossover function=0.8,Mutation function= constrained dependent and other default values were selected for the optimization.

$$Fitness\ Function = 1 - 50 * S_i * \dot{S}_i + \frac{0.25}{1 + |i_{qs}^*|} \quad (3.28)$$

Where $i = 1,2,3$

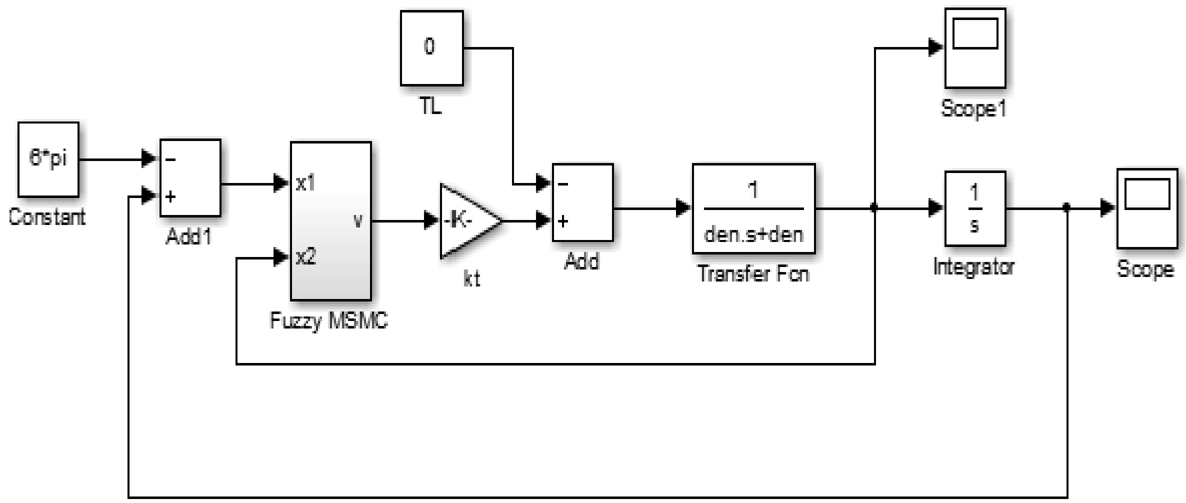

Figure 3. 24 GA-Fuzzy based MSMC

Simulation results of GA based Fuzzy MSMC controller and conventional controller is as shown

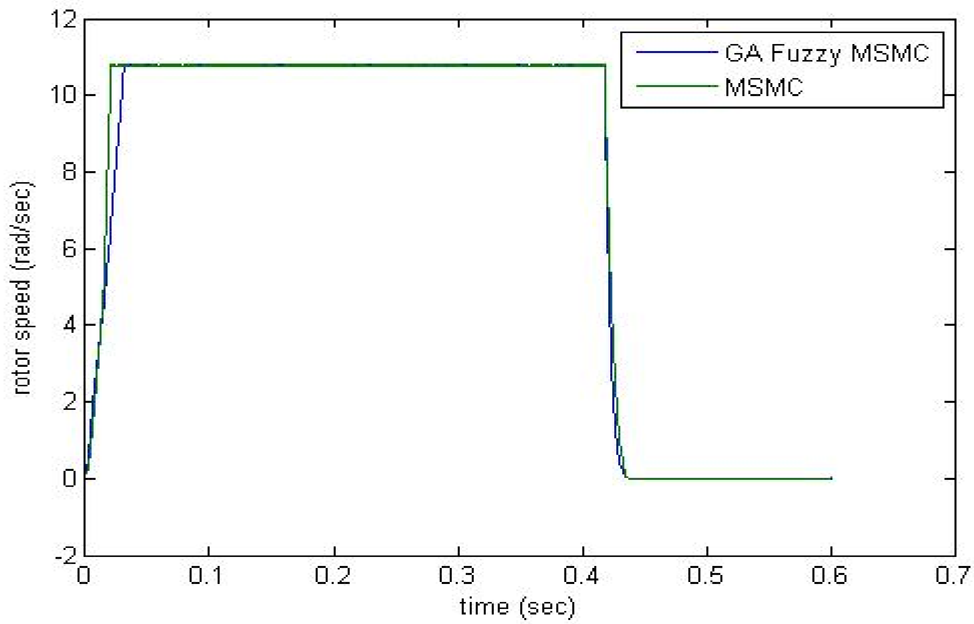

Figure 3. 25 Comparison of rotor velocity controller outputs

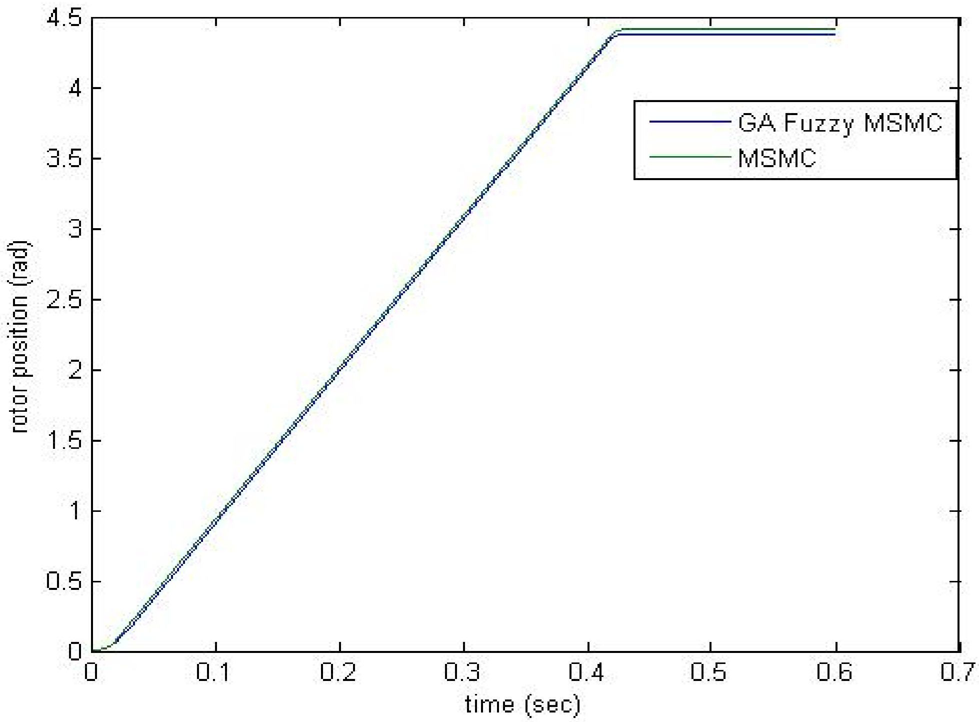

Figure 3. 26 Comparison of rotor position controller outputs

3.5 Summary

Sliding mode approach based controller gives superior performance for the system where parameter variations, load variations, modelling uncertainties, unknown disturbances are present compare to the other controller design approaches for Induction Motor speed control. In this chapter different sliding surfaces and switching signals are presented for induction motor speed control, based on the speed control requirements sliding surface and switching signal may be selected with or without modifications. Chattering effect is the disadvantage of the sliding mode control approach, with the proper selection of the control parameters and the smoothing of the discontinuity control the chattering effects can be reduced. Artificial Intelligence Techniques are also useful for the controller design with sliding mode control to reduce the chattering effect.Multi segment Sliding Mode controller is designed for speed and position control of Induction motor drive using field oriented control approach. Simulation results verify the effectiveness of controller. The results presented also encourage the real time design and implementation of Multi Segment Sliding mode controller using advance controllers and soft techniques to reduce chattering.