Stability Analysis of Multiple Input Multiple Output System Using Sliding Mode Controller

Uthra Devi. S, Sahana. K, T.V. Narmadha

Abstract - This paper depicts the design and implementation of nonlinear control approach called sliding mode control for Multiple Input Multiple Output (MIMO) system. In order to provide a good regulation of output in this system it is mandatory to make them operate in the closed loop mode using conventional controllers such as P, PI and PID controller. But the use of conventional controllers have failed to provide the desired regulation of output voltage under large variation of system parameters. Due to these disadvantages of conventional controllers a nonlinear controller called sliding mode controller (SMC) is proposed here. Sliding mode controller is used to regulate the system against disturbances. Sliding mode controllers is designed for Induction motor having Multiple Input Multiple Output (MIMO) system. The design of the controller is done with an aim to regulate the output against disturbances. The main advantage of SMC over the non conventional control is its stability and good response variations with respect to the input.

Keywords: Induction motor, DC motor, Sliding mode control, output regulation

I. INTRODUCTION

One of the major challenges faced during the control of dynamic systems is the disturbances and uncertainties present in real plants. These disturbances play a vital role in influencing the stability of the system as they have the ability to degrade the performance of the system or even cause instability. Hence, the control of dynamical systems in presence of uncertainty conditions has become an important subject of research in recent years. There are several methodologies available to regulate and stabilize the system against parameter uncertainties present in the controlled plant. Among all the existing techniques, the Sliding Mode Control (SMC) technique is found to be the most simplest and robust control technique[1].

The basic idea of SMC is the usage of a specific surface in state space called sliding surface that are designed using discontinuous control laws. The trajectory of the system in state space is driven onto the sliding surface so that the system attains stability against disturbance. In the Sliding mode controller design, the control input has the ability to overcome the effects of uncertainties and disturbances acting on the system. SMC has several advantages. Among them ,two main advantages have made the sliding mode controller as an effective nonlinear control approach in terms of simplicity and in overcoming the effects of uncertainties .Firstly, When the system trajectory is on the sliding manifold in state space it behaves as a reduced order system with respect to the original plant. Secondly, the stability and dynamics of the system is insensitive to uncertainties when the system trajectory is on the sliding surface. These two features of SMC have made it suitable for linear and nonlinear system control [6]-[10]. Design of controller using sliding mode control can be done by a conventional method insuring stability of the system dynamics.

This paper proposes the development of Sliding Mode control for MIMO system. Sliding mode control is capable of providing good stability and elimination of steady state error compared to controllers like P, PI, PID. There is always a discrepancy existing between the actual plant dynamics and its mathematical model used during the design of controller. External disturbances, unknown plant parameters, and unmodeled dynamics are the main causes for these discrepancies in controller design. The major challenge in controller design is to provide the desired closed-loop system performance in the presence of these uncertainties using appropriate control laws[3]. This has led to the development of many robust control techniques that are far superior than conventional controllers like PID controllers which are sensitive to unmodeled dynamics and external disturbances.

II. SLIDING MODE CONTROL

A. Principle of Sliding Mode Control

Sliding mode control (SMC), is one of the effective nonlinear robust control approaches since it provides system dynamics with an invariance property to uncertainties when the system trajectory is along the sliding. The first step of SMC design is to design a sliding surface using suitable control laws. The sliding surface is designed such that it models the desired closed-loop performance in state space. Second step involves the design of control algorithm which forces the system state trajectories toward the sliding surface and make them to stay on it.

The time period before the system trajectory reaches the sliding surface is called the reaching phase. After the reaching phase, the time period during which the system trajectory reaches the sliding surface and slides to the origin along the sliding surface is known as the sliding phase. The system is insensitive to uncertainties when it is in the sliding phase, but not during the reaching phase. Thus the system dynamics is affected by uncertainties in the reaching phase[2].

In an ideal system the state trajectory slides smoothly on the sliding surface as the switching frequency is very high. However, In real systems the switching frequency is limited. Hence the system state chatters around the sliding surface and the limit cycle occurs even in the steady state.

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SMC is insensitive to both matched internal and external disturbances.SMC techniques is suitable to any systems. SMC is even applicable to any minimum phase systems with relative degree smaller than the order of the system. The control algorithm is designed based on the model of the system to be controlled.

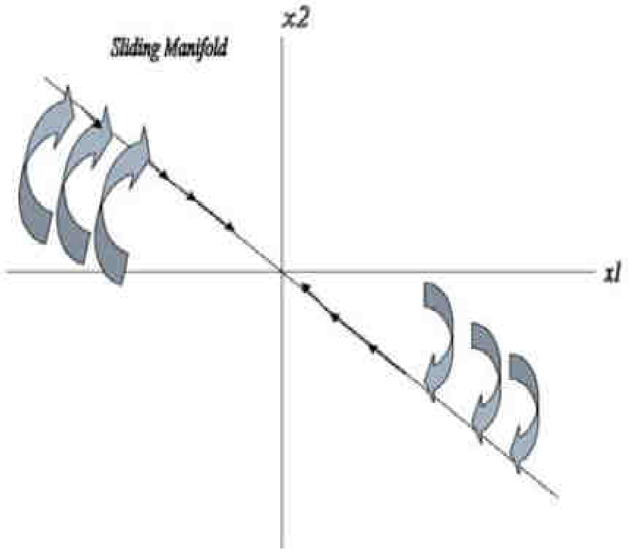

Figure.1 Sliding surface in state space

B. Design Procedure of Sliding Mode Controller

A sliding mode controller can be designed using two steps.

- Initially a sliding surface is designed in state space such that the desired closed loop performance is achieved when the system state trajectories are on the sliding surface.
- Then a control algorithm is designed using discontinuous control laws available such that the system state reaches the sliding surface and continues to stay on the sliding mode.

C. Control laws

There are three control laws available to design the sliding mode controller.

- Constant rate reaching law:
  $\dot{s} = -\, k \, \mathrm{sign}(s) + d$, where $k > d_{max}$
- Constant plus proportional rate reaching law:
  $\dot{s} = -\, k\, s - \in \mathrm{sign}(s) + d$, where $\in > d_{max}$
- Super twisting law:
  $\dot{s} = -\, k_1 \, |s|^{\frac{1}{2}} \, \mathrm{sign}(s) + z$
  $\dot{z} = -k_2 \mathrm{sign}(s) + d$, where $k_2 > d_{max}$

In this paper,sliding mode controller is designed using constant rate reaching law as this law is simple to implement for complex systems.

III. MATHEMATICAL MODELING OF INDUCTION MOTOR

A. Introduction

Induction motors are the commonly used motor for industrial applications due to their simple design, low cost, reliability and broad choice of sizes and specifications. Hence, Induction Motors have begun to replace DC Motors as they suffer from the problem of spark during commutation and requirement of DC source. In contrast, Induction Motor are rugged , easy to maintain and cheap. Hence they are widely used in domestic applications. Due to the availability of wide range in rating of industrial sectors they are quite popular among the industrial sector.The major challenge involved in the control of Induction motor is the nonlinear dynamics of the system [4]. The power efficiency of Induction motor is directly related to the square of rotor flux. So to obtain high dynamic performance the squared rotor flux must be accurately controlled with the speed and torque of the motor[5]. In this paper, the flux of Induction motor having single input single output system is controlled varying the stator voltages.

B. State Space Model

The stator and rotor current components are considered as state variables where as the stator voltage components are considered as inputs and stator current components are considered as outputs.

$$X = [\quad I_{ds} \quad I_{qs} \quad I_{dr} \quad I_{qr} \quad]^T$$

$$U = [\quad V_{ds} \quad V_{qs} \quad]^T$$

The state space representation is given by

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

$$A = \frac{1}{L_r L_s \; - L_m^2} \begin{pmatrix} -R_s L_r & \omega_r L_m^2 & L_m R_r & \omega_r L_m L_r \\ -\omega_r L_m^2 & -\, L_r R_s & -\omega_r L_m L_s & L_m R_r \\ -L_m R_s & -\, \omega_r L_m L_s & -L_s R_r & -\omega_r L_r L_s \\ \omega_r L_r L_s & L_m R_s & -\omega_r L_r L_s & -\, L_m R_r \end{pmatrix} \quad B = \frac{1}{L_r L_s \; - L_m^2} \begin{bmatrix} L_r & 0 \\ 0 & L_r \\ -L_m & 0 \\ 0 & -L_m \end{bmatrix}$$

C. Ratings

PARAMETER	VALUE
POWER(P)	0.37KW
CURRENT (I)	1.8 A
VOLTAGE(V)	220 V
NUMBER OF POLES(p)	4
FREQUENCY (f)	50 Hz
SPEED (rpm)	1420 rpm
STATOR RESISTANCE (Rs)	20.13 ohm
ROTOR RESISTANCE (Rr)	13 ohm
STATOR INDUCTANCE (Ls)	1.05 H
ROTOR INDUCTANCE (Lr)	1.33 H
MUTUAL NDUCTANCE(Lm)	0.957 H
MOMENT OF INERTIA (J)	0.0005 kg N/m2

D. Simulation

The uncertainities and disturbances such as external disturbances, unknown plant parameters, and unmodeled dynamics are assumed together as a square wave in the signal builder block in figure.3 and applied to the state variables. The disturbances cause the state variables to be displaced from stability position. The sliding mode controller regulates the state variables against these uncertainities by varying the control input direct component of stator voltage V_{ds}. The simulink block diagram shown in figure 2 gives the overall block diagram of the system. The simulink block diagram in figure 3 gives the sliding surface designed using constant rate reaching law.

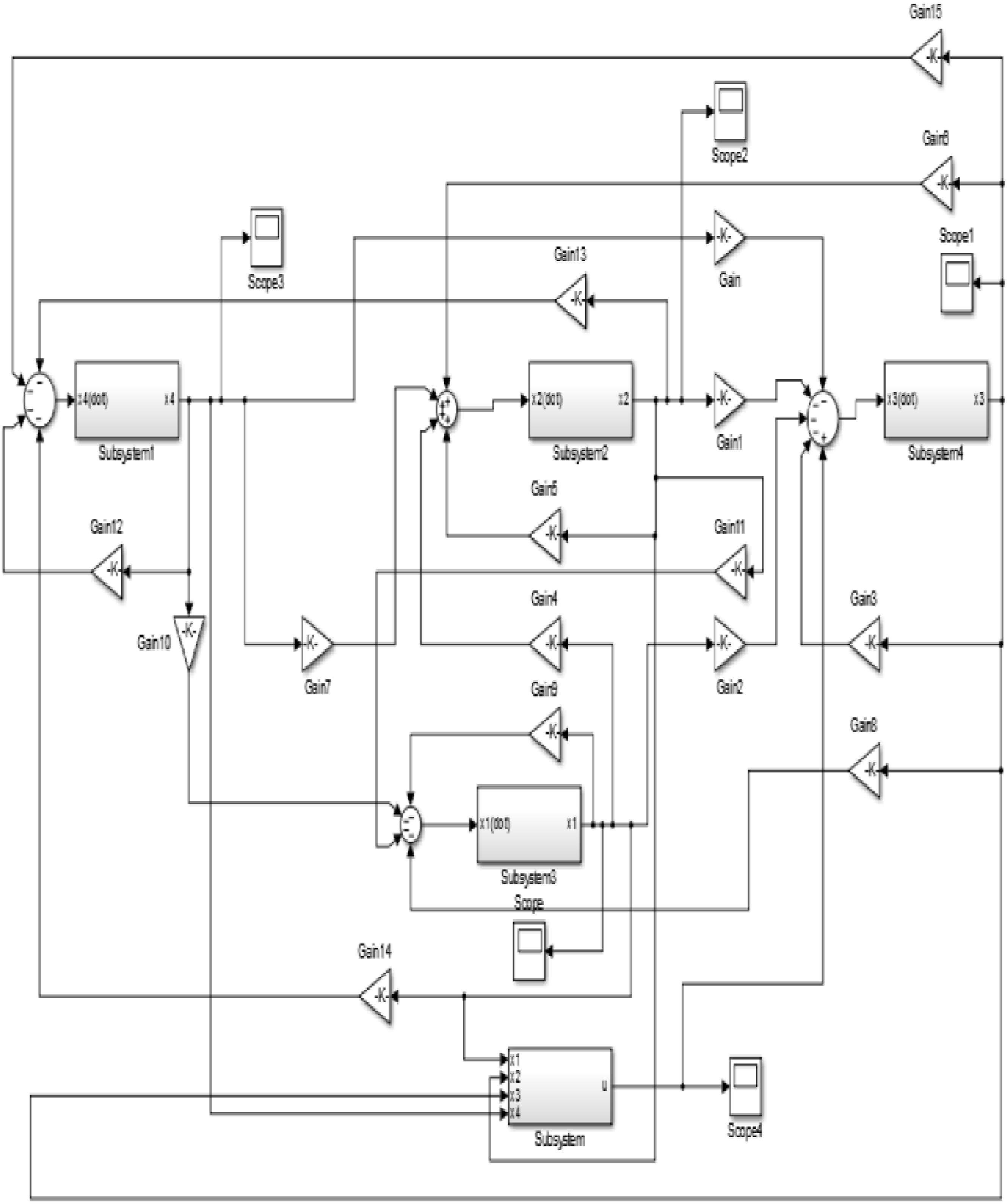

Figure.2 Simulink block of Induction motor

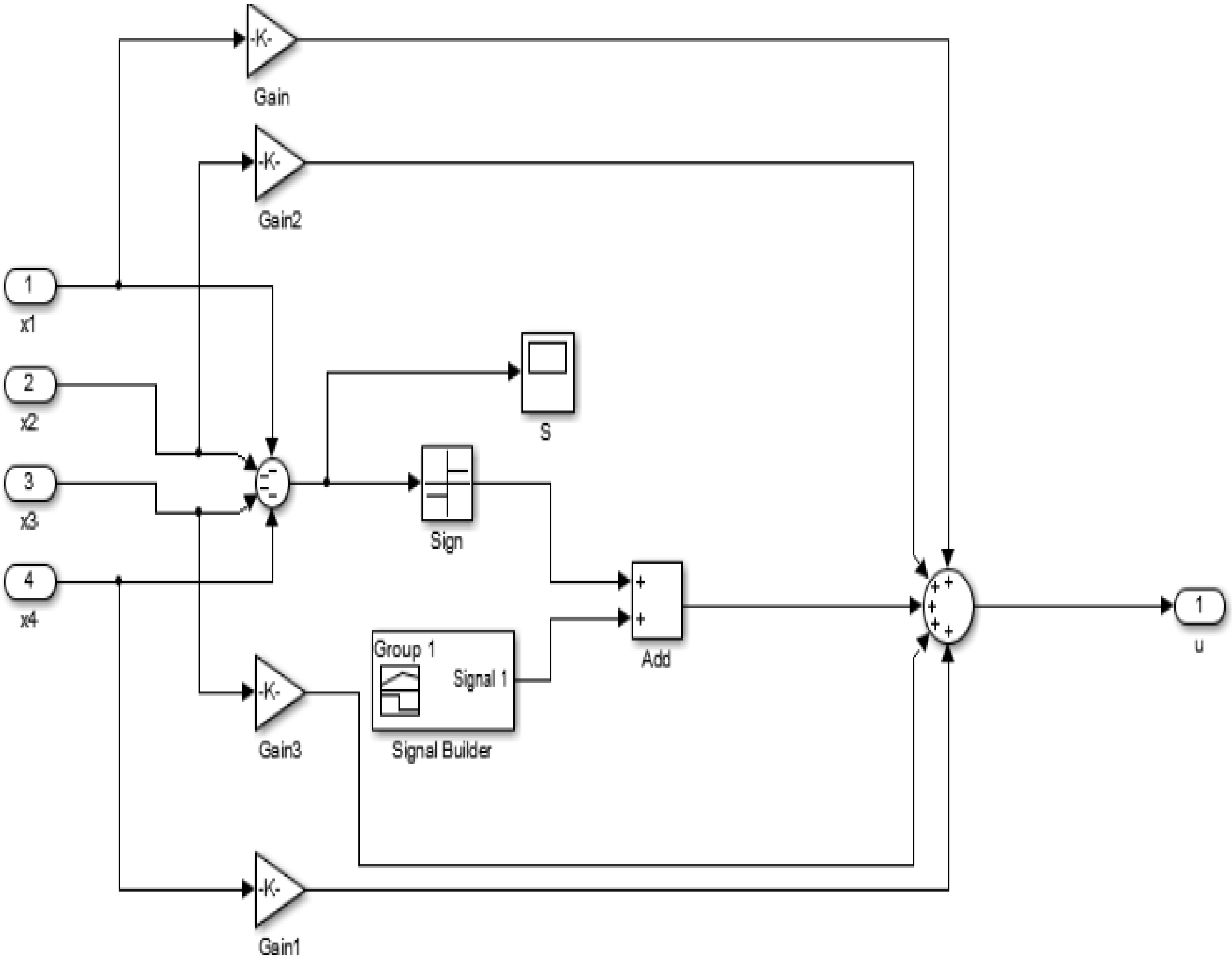

Figure 3. Simulink block of sliding surface

E. Simulation Output

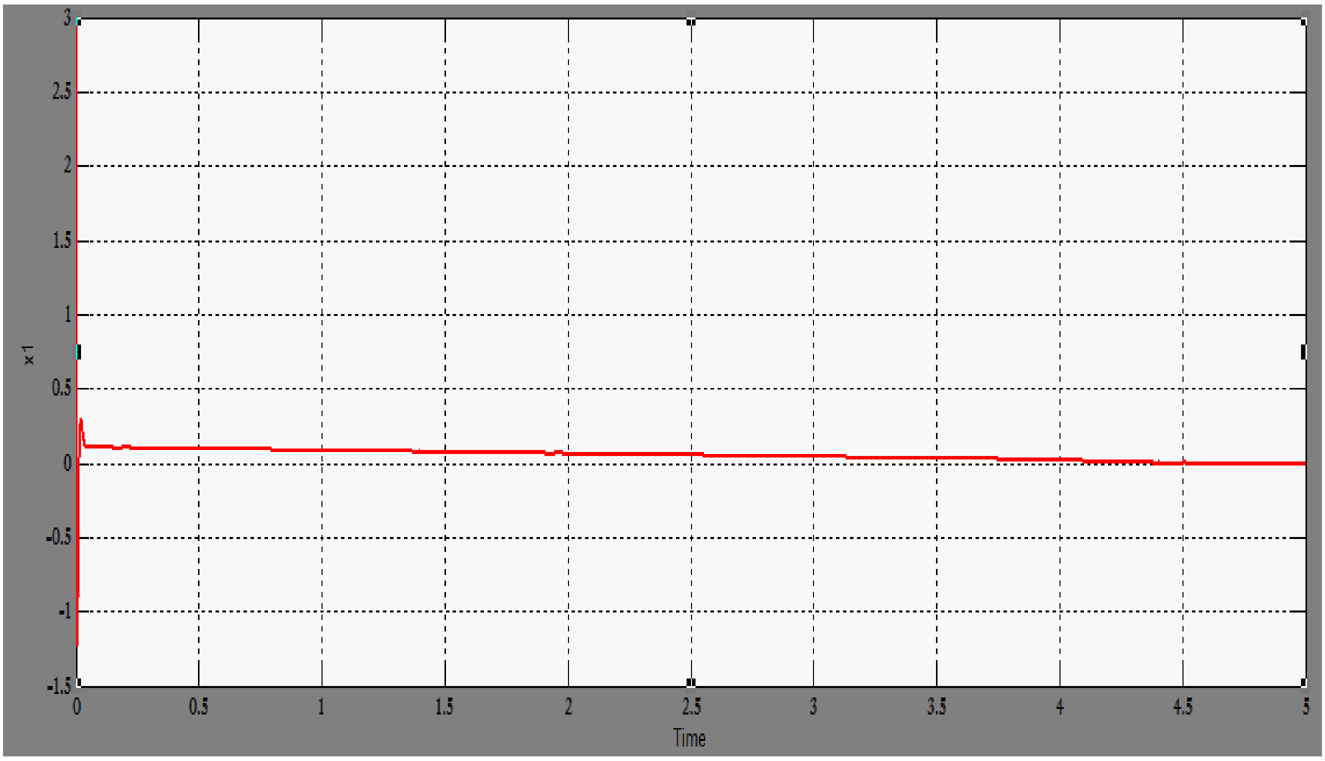

Figure.4 Regulation of x1

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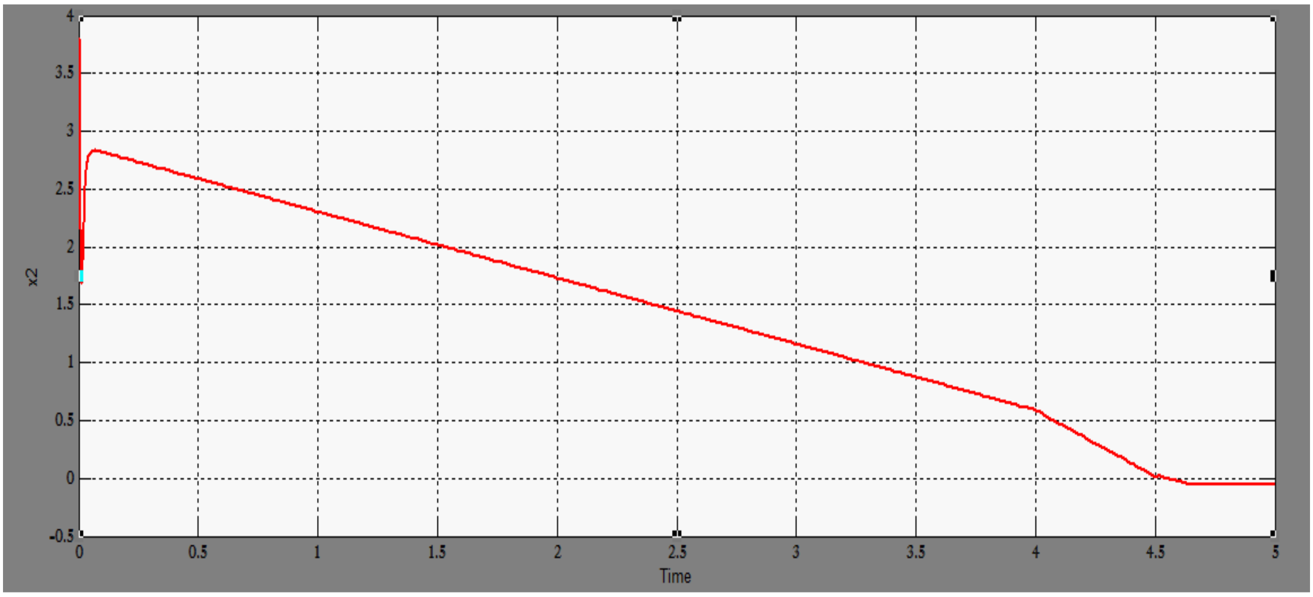

Figure.5 Regulation of x2

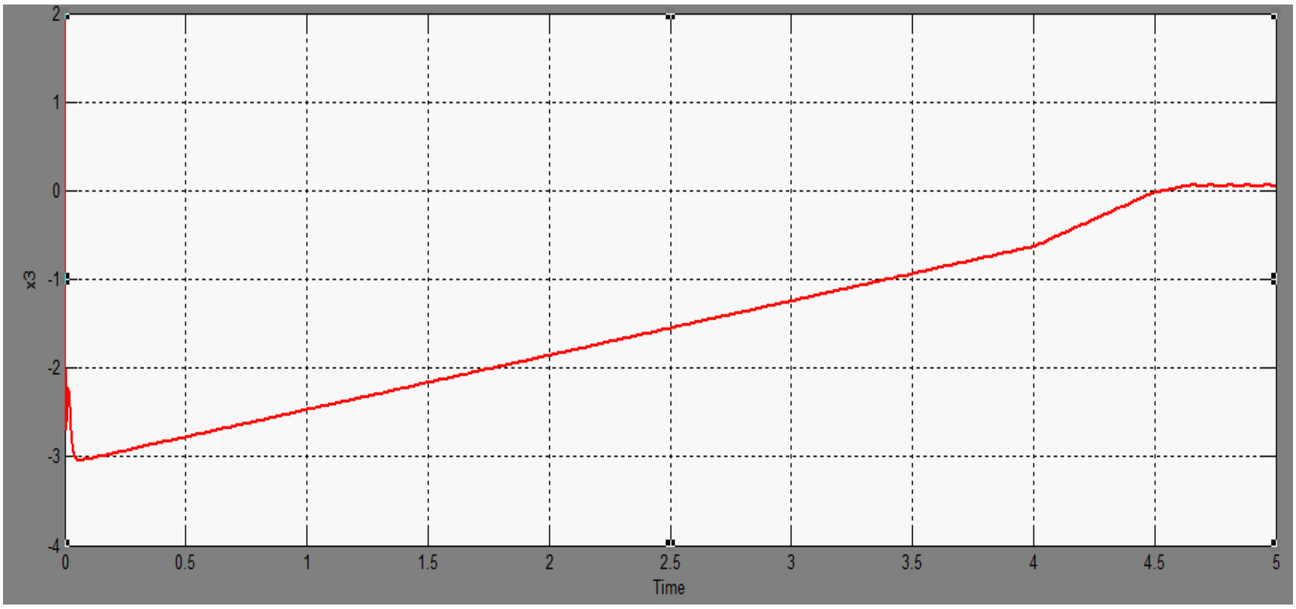

Figure.6 Regulation of x3

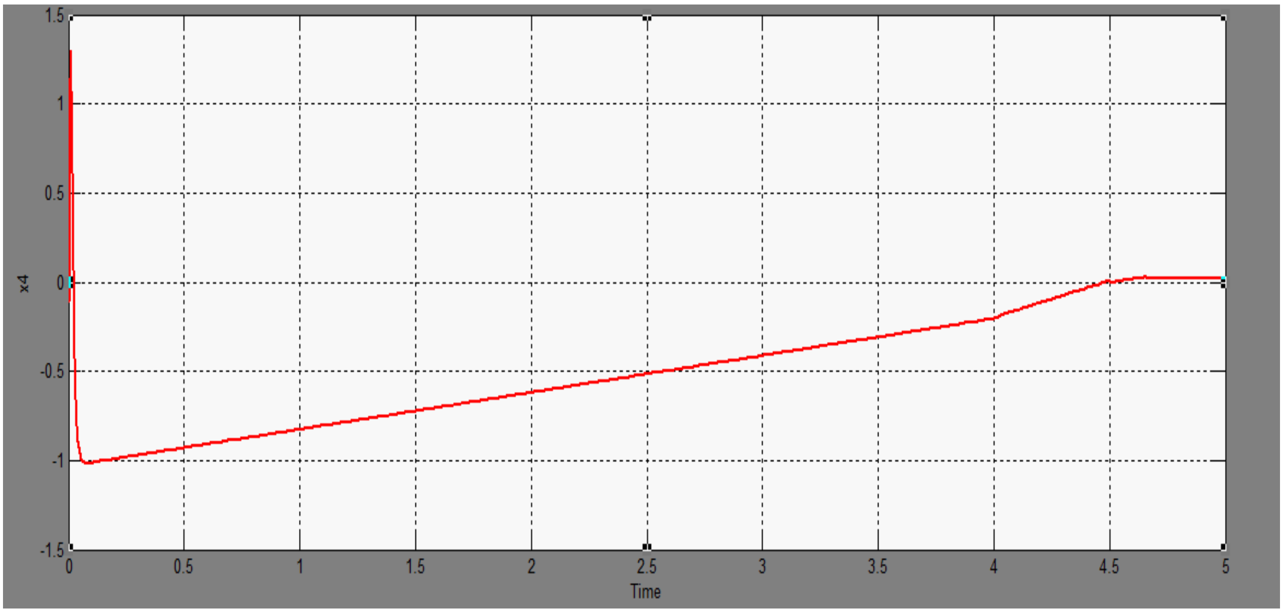

Figure.7 Regulation of x4

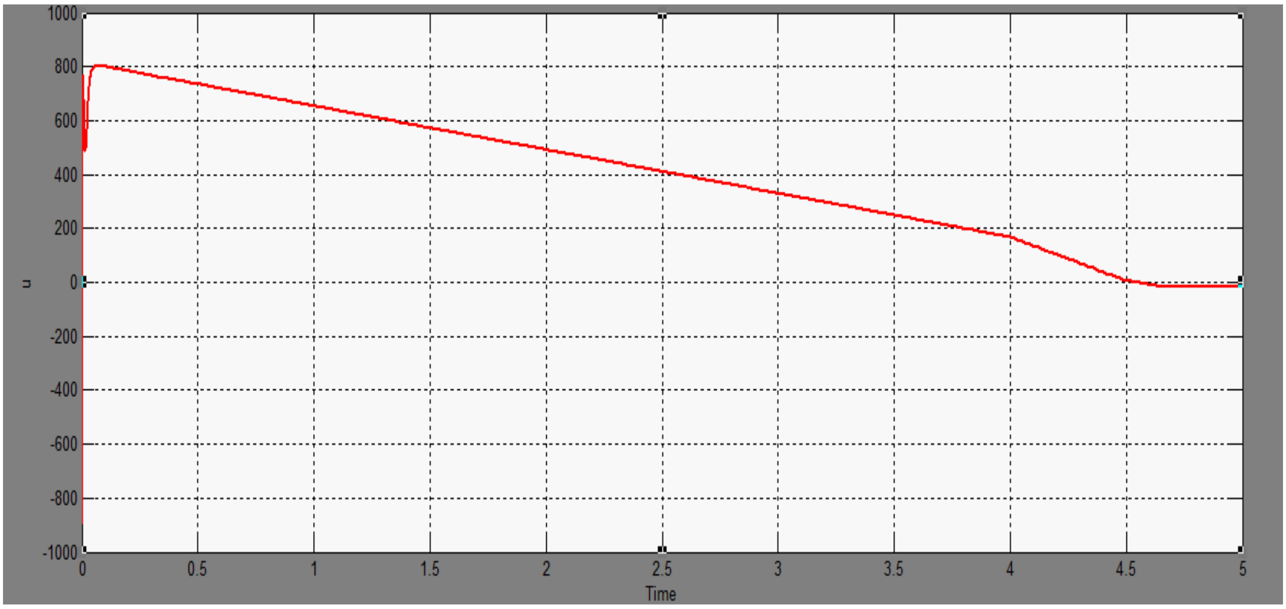

Figure.8 Control input

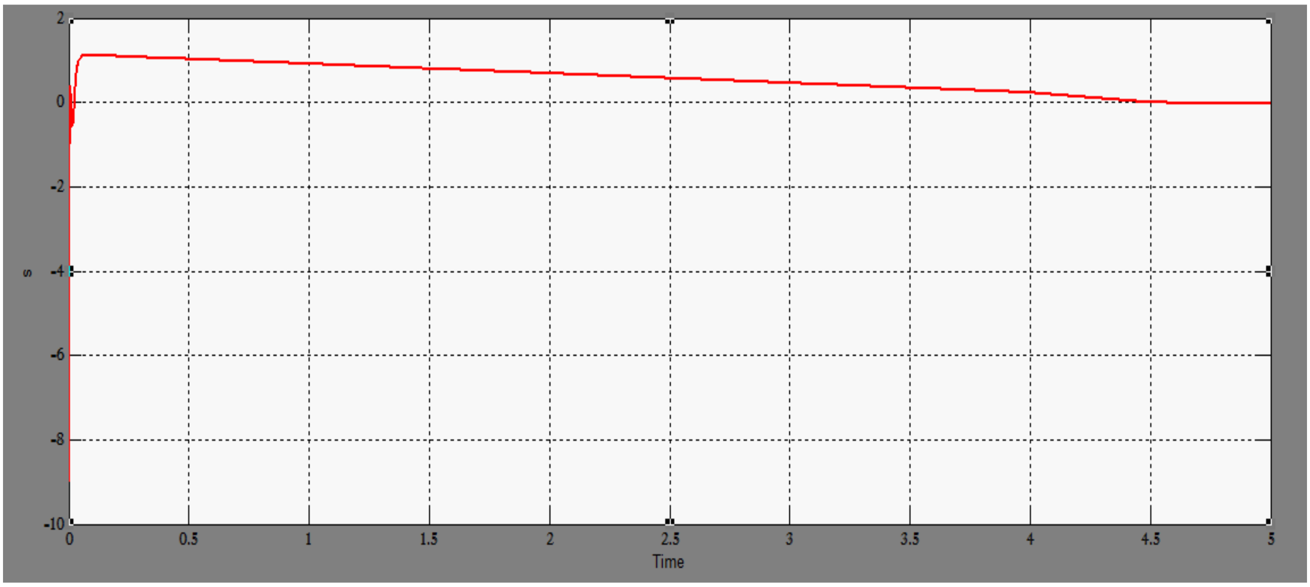

Figure. 9 Sliding surface

IV. CONCLUSION

Thus the regulation of Induction motor MIMO system is performed using sliding mode control using constant rate law. The sliding mode controller has overcome the effects of disturbances and unmodeled dynamics and the parameters are regulation with less value of control input.

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