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DESIGN AND ANALYSIS OF FUZZY LOGIC BASED SLIDING MODE CONTROLLER INDUCTION MOTOR

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ABSTRACT

In comparison to PID controller, the PI controller is simpler but exhibits slower response and also provides some steady state error in speed. Perhaps PI controller can be easily implemented with simple operational amplifier circuits. Nonlinear control systems are affected by inaccuracies in the plant model. SMC is considered as an important control technique for such sort of control problems. A transfer function, a feedback control law and some models representing the uncertainty are the typical components of a robust controller. The SMC is robust but slow and suffers from the problem of chattering apart from being more difficult to realize. Adaptive Sliding Mode Controller (ASMC), on the other hand, is fast, more robust, and free from problem of chattering. However, it requires a larger memory for real time implementation and is difficult to realize. Hence Fuzzy Sliding Mode Controller (FSMC) is proposed and it is found to perform well as compared to ASMC, in terms of robustness and learning capability

KEYWORDS: *Induction Motor, FLC Based Sliding Mode Controller, PI Controller, Indirect Vector Control*

Article History

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INTRODUCTION

About 50% of total electrical energy produced is consumed by industries all over the globe. An economical and more practical means to limit energy usage is the energy conservation. Because of its benefits like reliability, robustness, maintenance free operation and low cost, the Induction Motor (IM) is one of the bulk consumers ofelectrical energy. The IM occupies a major part of the total electrical load [1]. A

Small increment in efficiency of these motors by providing enhanced control or optimal design can result in a significant drop in energy cost. Nonlinear, complex and time varying dynamics are the important

Characteristics of IMs. Many of the IM problems related to control have been solved by means of vector control techniques. Blaschke was the pioneer

To work on the principle of vector control and this was followed by several researchers in their research papers on the aspects of vector control. In scalar control, the IM may exhibit an excellent response during steady-state condition.

However, its dynamic behaviour is not satisfactory. The prime reason for this limitation is due to the fact that the controlof torque and flux are not delinked from each other as with the case of DC motor. The IMs are sensitive to drive parameter variations due to temperature andflux measurements or speed estimation deviations.

For easy computation, the order reduction is done to simplify the nonlinear plants. Imprecision occurs due to model simplification and uncertainties existing in the plant. Industrial Plants with less parameter variations and disturbances make use of the robust controllers to solve the uncertainties. Among the robust control techniques suitable for IM, Sliding Mode Controller (SMC) was studied by many investigators. A Russian Scientist in 1950s developed SMC which is a variable structured controller. The SMC method is used inthe cage motor applications requiring faster dynamic response from both during start and speed reversal. In the SMC, many continuous functions are defined to map the state of the system to a specific control surface. There are many trajectories which slide along the boundaries of the control structure. The problem found in the SMC is chattering, which occurs because of its fast switching of control signals.

Normally switched controllers have many imperfections that limit switching frequency in real-time systems. Around the sliding surface, unwanted oscillations of the trajectories occur. These are referred to as chattering effect. Chattering problems also exist when a processor samples the signals.Chattering problem in digital circuits occurs between any two sampling instances because the plant operates in open loop system. To avoid the chattering effects, intelligent controllers are preferred. Perhaps, methods like Fuzzy Inference Systems (FISs) are the right choice for the design of motor controllers in industries to replace the PID controllers. Fuzzy SMC (FSMC) provides an alternative solution to PID controller, especially for nonlinear control problems like the control of IM. FSMC with closed loop operation in vector control mode is also presented in this research work.

Indirect Vector Controller

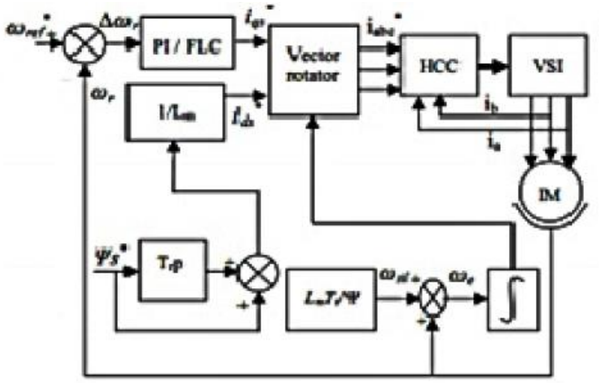

Figure 1: Speed Control of IM Using Indirect Vector Control.

Speed control of indirect vector controlled induction motor using PI controller failed to achieve accurate speed response when external parameters such as load torque, moment of inertia and viscous friction varied with known bounds. In this chapter the sliding mode control is introduced in place of PI controller to achieve good and accurate response if limits on the external controller variations are known. Sliding mode control technique is a non linear control technique applicable to system of order n, but presented here only for a first-order system.

A switching surface is defined and the control law is designed to drive the system state onto the switching surface in such a way that if the state is on for once, the system is constrained to remain on the switching surface. The control law is designed by knowing the bounds of parameter variations on the basis of Lyapunov's stability. The responses of step command and impact due to internal controller variations, such as rotor resistance and inductance are studied. The block diagram for complete implementation of speed controller, based on sliding mode is shown in Fig-3 Sliding mode controller design is explained in detail to generate the q- axis synchronous frame current by processing the error produced by comparing the command speed and actual speed, which is sensed by the sensor. The slip speed command signal is generated from the flux command signal, and then added to the actual speed to generate the unit vector which is used to convert stator q-d axis currents command in synchronous reference to stator reference frame. The stator reference frame current commands are again converted into ab-c current command signals. The a-b-c current command signals is compared with corresponding actual current through a hysteresis band controller to generate the pulses for triggering the six switches of 3 phase inverter [3,4,5].

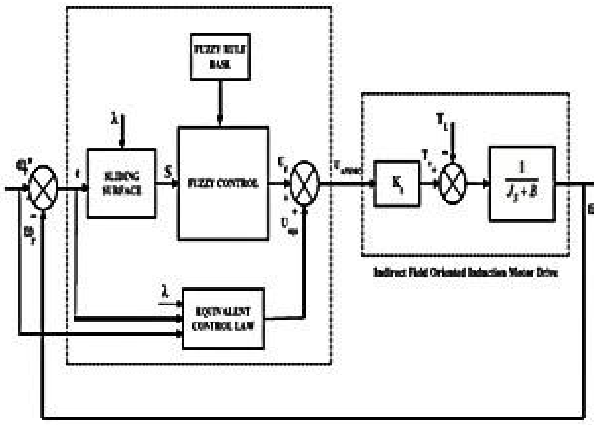

Figure 2: Schematic of Fuzzy Sliding Mode Controller.

Vector control of Induction motor drive shows quick reaction, smooth execution, and high powerful reaction with speed variation and transient circumstances. Concerning phasor chart of Indirect Vector Control strategy for enlistment engine, this is displayed in Figure 2

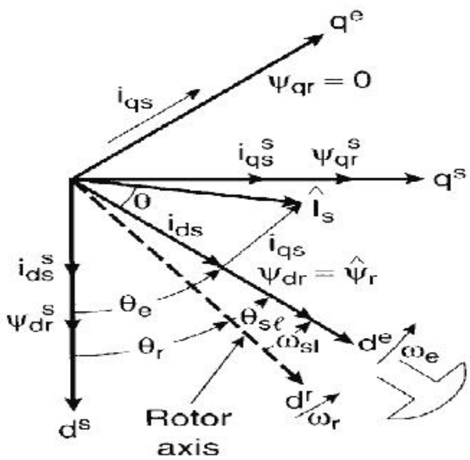

Figure 3: Phasor Representation of Indirect Vector Control IM.

$$\theta_e = \int \omega_e dt = \int(\omega_r + \omega_{st})dt = \theta_r + \theta_{st} \quad - \tag{1}$$

The rotor equations

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_R i_{ds} - \omega_{st}\psi_{qr} = 0 \quad - \tag{2}$$

For decoupling control fr = 0, So that the flux f_r

directs on the d-axis

Now from equations (1) and (2), we get

$$\frac{L_r d\psi_{dr}}{R_r dt} + \frac{R_r}{L_r} + \psi_r = \frac{L_m}{L_r} i_{ds} \quad - \tag{3}$$

Slip calculation of IM as

$$\omega_{st} = \frac{L_m R_r}{\psi_r L_r} i_{qs} = \frac{R_r i_{qs}}{L_r i_{ds}} i_{qs} \quad - \tag{4}$$

$$K_s = \frac{\omega_{st}}{i_{qs}} = \frac{L_m R_r}{L_r \psi_r} \quad - \tag{5}$$

‘Therefore decoupling method performs better under slip angular speed for field orientation and fixed rotor flux control of IM

$$\psi_r = L_m i_{ds} \quad - \tag{6}$$

The electromagnetic torque is given by

$$K_s = \frac{3\, P\, L_m \psi_r i_{qs}}{2*2\, L_r} \quad - \tag{7}$$

and dr / dt = 0 can be switched to equation 4, so that the rotor flux is set as Figure 2 shows a diagram of the Fuzzy slider control valve for indirect vector control Induction motor you want ωr *. Fuzzy Logic controller in recent times, fuzzy logic control techniques are preferred in manyindustrial applications. Fuzzy Logic Controllers (FLCs) are rule-based systems whichcan easily represent the human knowledge. The ‘fuzzy sets’ were introduced by LotfiZadeh in the year 1965, as an extension of the conventional set theory. In conventionalset theory, an object is either a member or non-member of a set. The fuzzy concept isto introduce that partial membership function is possible. The most important part of the FLC system is the Fuzzy Control Rules associated through a fuzzy inference system. Technological advances in solid-state power electronics devices and high computing capability digital controllers have madeAC motor drive applications simpler. In this part of the thesis, the application of SMC for efficient three phase IM is investigated. The central focus of the proposed researchis to improve the SMC technique with a prime intent of chattering mitigation. The feasibility of the proposed design for industrial applications is highlighted withexperimental studies on prototype models and hardware-in-loop simulations. The hardware implementation of FSMC is done by using low cost hardware-in-loop structure using FPGAs for better dynamic response. The real-world applications of theFSMC are mentioned below:

- Energy preservation mode is necessary in recent drive units. Theincreasing current is kept low during rise in speed and so SMC achievesa smooth transition of speed. In textile industries, vector control of IM drive is used.
- It requires the AC motor to function at varying speeds and torque levels to suit variousloads. As in Figure 1.4 the basic fuzzy logic system consists of fuzzification, inference mechanism and

CONTROLLER DESIGN

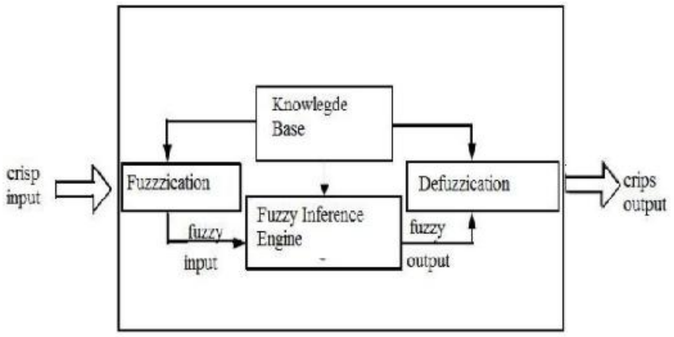

Figure 4: Shows a Block Diagram of a Fuzzy Interference System with Logical Controller Consists of Four Basic Major Components: Defuzzification Fuzzy, Fuzzy Inference Engine and Knowledge Base.

Figure. 4 Fuzzy Interference system

Output / Input

The design of the fuzzy system providing flexible input and output. The mainly important variables that come in handy are the default speed controller selected as the speed error

FUZZIFICATION

The input and output parameters are normalized to lie between 0 and 1. Fuzzification is the process of modifying the crisp variables to fuzzy variables. The input variables are represented by triangular representation of membership functions. Linguistic variables *PS (Positive Small), PM (Positive Medium) and PB (Positive Big), Z (zero), NB (Negative Big), NM (Negative Medium), NS (Negative Small),* are shown in Figures 5(a), 5(b) and 5(c). In order to obtain better control, the membership functions near the zero regions should be made narrower. Hence, the membership functions can be adjusted to some extent on a trial and error basis to improve dynamic performance. The input variables of FSMC are *Error* and *Change -in- Error*, and outcome variable is *Torque*. Here Error is the divergence between situation sliding line and actual representative point of the system on the phase plane

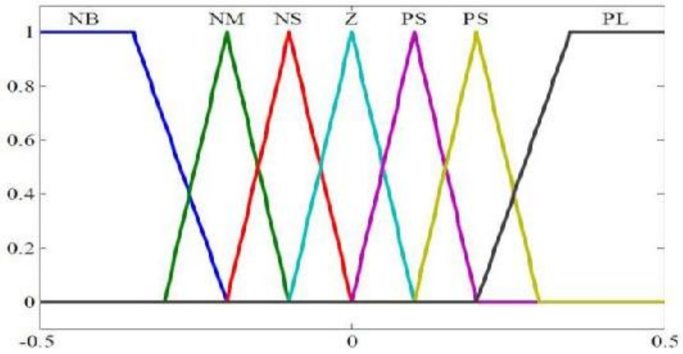

Figure 5: (A) Degree of Membership Vs. Error.

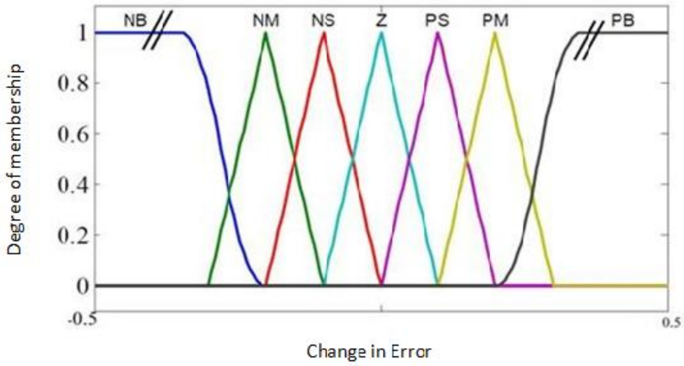

Figure 5: (B) Degree of Membership Vs. Change in Error.

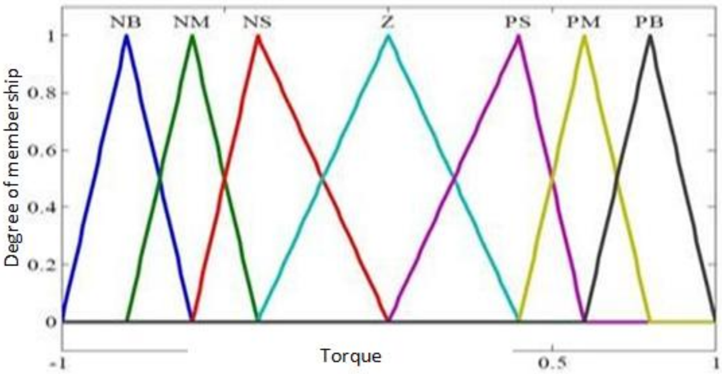

Figure 5: (C) Degree of Membership Vs. Torque.

Fuzzy Inference and Rule Base

The FIS is a set of a rule base data system. A sample rule is as given below.

If Error is NB and Change in Error is NB, Then T is NB

Where, *T* denotes *Torque*. Forty-nine rules are created using Fuzzy Logic. In the case of FSMC, the control rule is designed in such a way that the actual trajectory always turns towards the reference sliding line on the phase plane. The actual trajectory also does not cross the reference sliding line on the phase plane. Thereby the existence condition is satisfied. The formation of the rule base can be done based on the following,

- Experience and control knowledge derived from the users and operating manual,
- User control actions formulated in terms of input-output operating data,

- Fuzzy modelling of the control process and
- Applying Intelligent techniques like neural network,

Slide Mode Controller

A sliding mode control of IM with dynamic variations where in the system changes based on the current state of the structure. FSMC is a non linear control applied to both non linear and linear plants which is part of the adoptive techniques. FSMC can control larger speeds with great control of parameters variations and loads torques disturbance. FSMC is a variable structure of independent controls can be viewed as combined switching logic. A sliding surface is to be designed and with appropriate switching logic the drive response is forced to track or slide along the sliding surface or plane in a phase plane without load disturbance. A slippery surface is defined on a global scale by the scalar equation. [8] s (e, ė, t) = 0 When, a smooth variable, S is

$$s(t) = e(t) + \lambda_e(t) \quad - (8)$$

$$s(t) = \omega_r(t) - A_{pn}\omega_r(t) - B_{pn}U(t) - L(t) + \lambda_e(t) \quad - \quad (9)$$

Equation (8), indicates the control parameters determined as of s(t) = 0 disregarding the distributed vulnerability (L(t)=0) is achieved the ideal presentation under ostensible model and it is implemented to as comparable parameters as follows

$$.U_{eq}(t) = B_{pn}[\omega_r(t) - A_{pn}\omega_r(t) + \lambda_e(t) - \quad (10)$$

Not with stand, the vector control is exceptionally boundary delicate. Erratic boundary varieties, outside load unsettling influence, unmodelled and nonlinear elements unfavourably influence the control execution of the Induction motor drive. In this manner the control exertion can't guarantee the traditional control execution. Subsequently FSMC to be intended to organize of the impact of the unappreciable aggravations

$$U_h(t) = g_h \, Sign\left(S(t)\right) \quad - \quad (11)$$

Where gh is a represents control gain concerned withupper limits of uncontrolled variables, and denoted with sgn(.) is a sign function.

$$U_{SMC}(t) = U_{eq}(t) + U_h(t) \quad - \quad (12)$$

Now, the sliding mode control rule based controller provides extraordinary performance due to the high control over plant and its operation functions, which leads to dynamic control dialog and system conditions. Reducing the discussion of the limits is usually introduced into the SMC controller, and then the regulatory Stability within the Limits cannot be guaranteed and insufficient selection of the threshold values may result in an unstable tracking response. It is therefore a system of controlling the sliding modes, in which an abstract thinking approach is used to follow the law of sliding control.

Fuzzy Logic Based Slide Mode Controller

The Fuzzy logic based SMC uses a set of fuzzy rules representing the decision making process to correct the impact of definite system motives. the purpose of using FSMC is to replace the controller with a competent method with an incomprehensible legal system. Incomprehensible input vectors system vehicle speed deviation Δω and acceleration Δώ. An incomprehensible set of input and outgoing membership functions is displayed in Fig. (3). Unexplained output is a change of reference torque (ΔTref {k}) added to the previous reference torque value (Tref {k-1}). Unintelligible output sets have the same language variables that are used for inputs except that an additional T to indicate Positive torque. The observation table, in which the correlation between input variables, Δω and Δώ, also described the output variables of the abstract mind control were developed and applied to simulations. A lookout table is provided in Table 1. The Advanced Small Mode Method has been used to obtain vague exit rules stage, as follows:

$$\frac{K_p s+K_i}{s} = K_p + \frac{K_i}{s} \tag{13}$$

$$\Delta T\{k\} = \frac{\int y \times \mu(y) \times dy}{\int \mu(y) \times dy} \tag{14}$$

Table -1 represents the look up table of fuzzy logic based Sliding mode controller which define the bond between output variable in a fuzzy variables. FSMC is used and modified to find out the expected torque (Tref) system indicator shown in Fig. (2). FSMC output is sum of previous reference torque Tref {k-1} and calculated current Tref {k} using equation (15).

$$Tref\,\{k\} = Tref\,\{k-1\} - \Delta\, T\,\{k\} \tag{15}$$

Speed Deviation (Δω)	Speed Deviation Chang (Δώ)						
	NL	NM	NS	Z	PS	PM	PL
NL	T-NL	T-NL	T-NL	T-NL	T-NM	T-NS	T-Z
NM	T-NL	T-NL	T-NL	T-NM	T-NS	T-NS	T-NS
NS	T-NL	T-NL	T-NM	T-NS	T-NS	T-NS	T-NS
Z	T-NM	T-NM	T-NS	T-Z	T-PS	T-PM	T-PL
PS	T-PM	T-PM	T-PM	T-PM	T-PM	T-PL	T-PL
PM	T-NS	T-Z	T-PS	T-PM	T-PL	T-PL	T-PL
PL	T-Z	T-PS	T-PM	T-PL	T-PL	T-PL	T-PL

Figure 6: Input and Output Fuzzy Memberships.

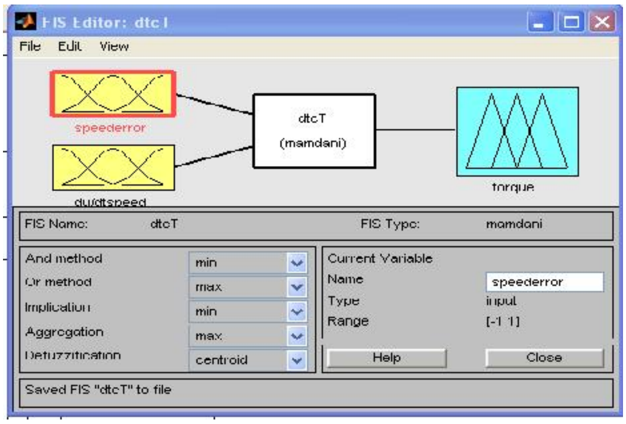

Figure 7: Input And Output Fuzzy Memberships.

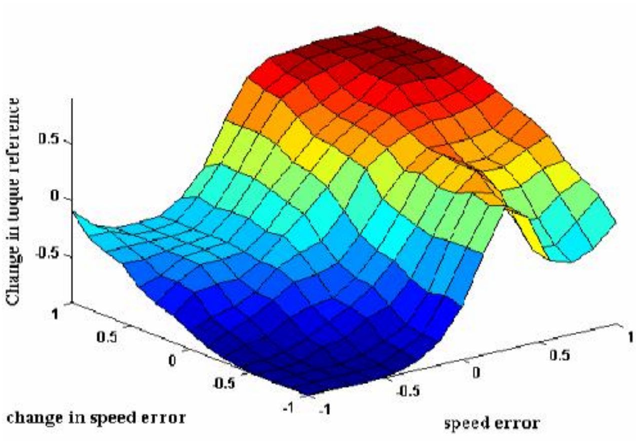

Figure 8: Output Surface of FLC.

RESULTS AND DISCUSSIONS

Various distractions were modelled to test vehicle performance using DTC under PI and FLC based sliding mode controls. Figure 9 represents a comparative of the flexible response of a vehicle installed outside the current limit and without ωref load equal to 300, 750 and 1500 rpm. The proposed FSMC speed control provided a more flexible response, in terms of shooting and rotation percentage, compared to the standard traditional controls with Kp = 20 and Ki = 0.1. The figure numbers 10 - 12 represent the performance of the DTC using the PI the controller and figure numbers 14-16 represent the SMC-FLC based DTC by comparing the variable vehicle response when initiated at the current limit against loading and full load, respectively, at ωref equals 750, 1500 and 500 rpm. The best performance in speed control of IM as achieved by FSMC especially in the case of full load. Fig. 13 represents the simulink model of fuzzy logic based sliding mode control on three phase induction motor which achieved better performance as compared to the traditional controller Simulink Implementation of PI based Sliding mode controller for IM

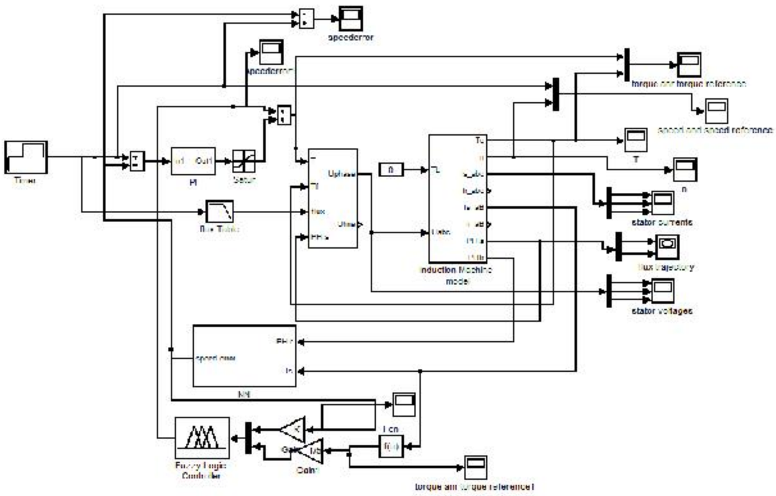

Figure 9: Simulink Implementation of Dtc Pi Circuit.

RESULTS

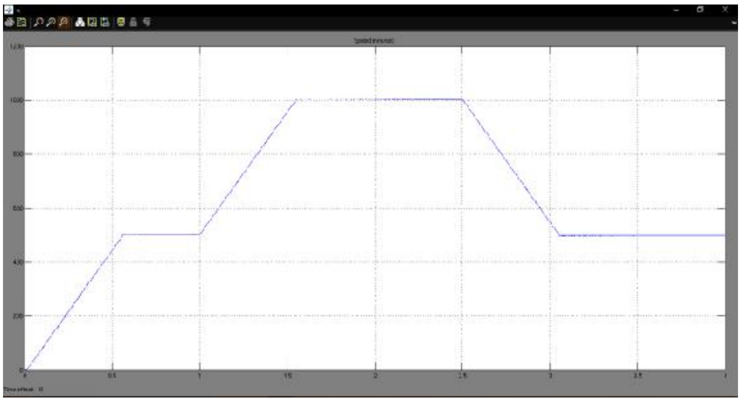

Figure 10: Speed in m/s.

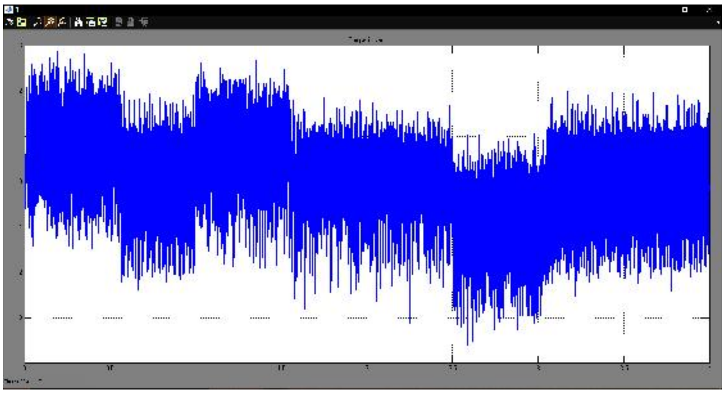

Figure 11: Torque in M/S.

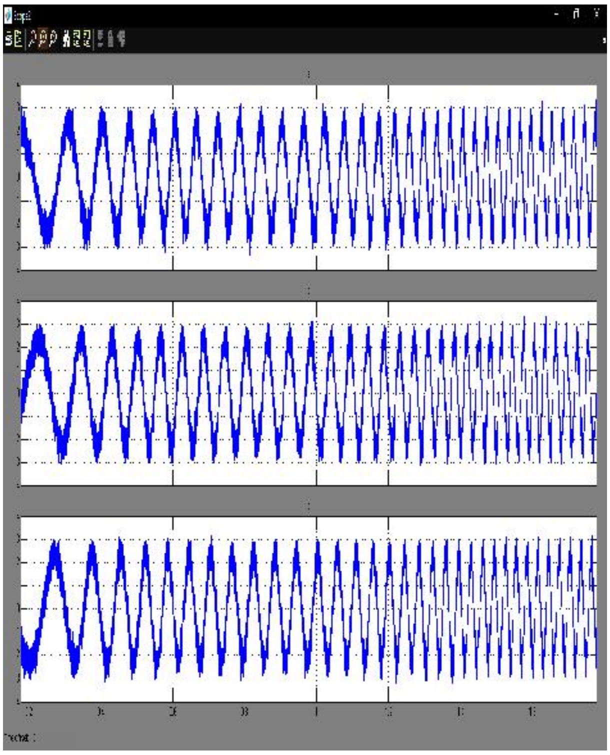

Figure 12: Stator Currents.

Simulink Implementation of FLC based Sliding mode controller for IM

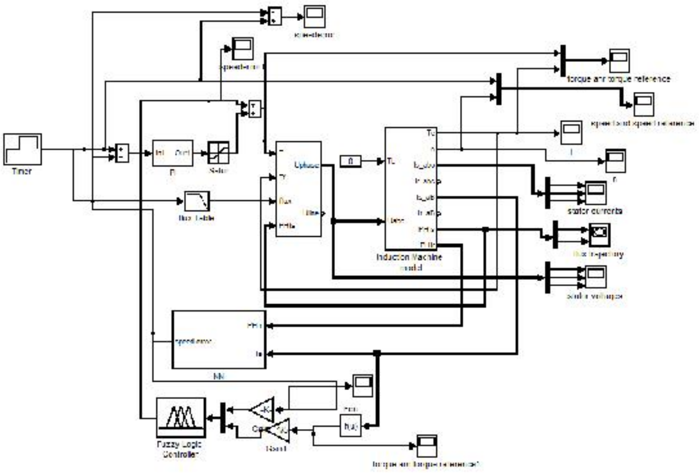

Figure 13: Simulink Implementation of Dtc Fuzzy Circuit.

RESULTS

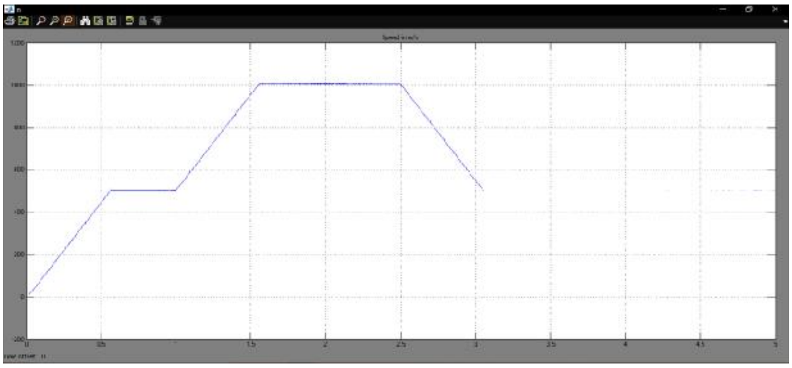

Figure 14: Speed in M/S.

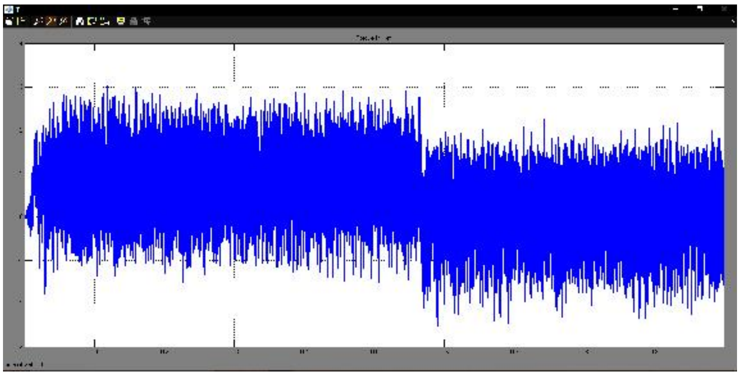

Figure 15: Torque in M/S.

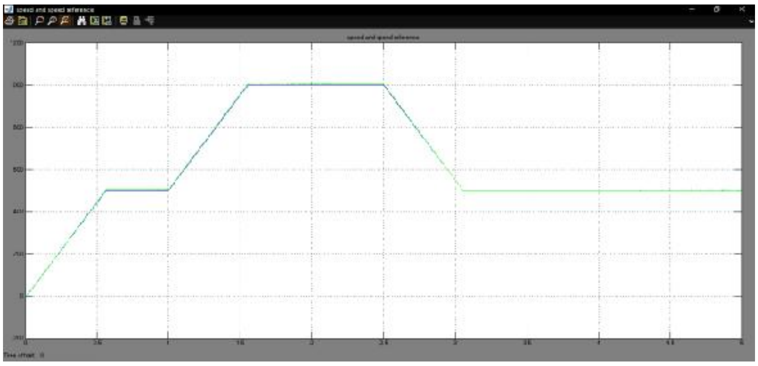

Figure 16: Stator Currents.

CONCLUSION

This paper has successfully demonstrated the use of an indirect sliding mode control system for induction drive focused on indirect location tracking commands from time to time. The design and description of the classic sliding mode (SMC) controller is presented in detail. Then, a blurring mind control is used to tune the controller to remove oscillations and improve system performance. However, advanced logical control analysis, design and speed regulation of the vector controlled IM using various controllers demonstrated through the computer simulation using MATLAB/Simulink. Many results are presented to show the capability of FLC based SMC as compared to other control techniques. simulation results are presented to illustrate the effectiveness of designed controller for the vector controlled IM

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