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# Hybrid Controller for Induction Motor

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**ABSTRACT**: Induction motor is a high performing electrical drive system now a day's squirrel cage induction motor has widely use in industries. The conventional PID controller shows steady state error or sluggish response during load variation. This paper presents a hybrid controller for controlling the induction motor by using Sliding mode controller and PID controller. The sliding mode controller controls the rotor flux and the motor torque where as the PID controller using to control the rotor speed of the motor. The robustness of the controller is carried out by change in motor parameters. Simulation results are given for illustration.

**KEYWORDS:** Induction Motors (IM); Sliding Mode Controller (SMC); Proportional Integral Control (PID).

## I.INTRODUCTION

Induction Motors (IM) are most widely used as a industrial drives, however the control of IM due to the higher order and nonlinearity become a challenging problem for the researchers. There are two types of IM wound rotor type or squirrel-cage type. Squirrel-cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. In the field of electric drives the control of IM, many controllers have been developed like field-oriented control (FOC) approach [1], direct torque control (DTC) approach [2], input-output linearization approach [3], some artificial intelligence based controller [4-5]. Now control by without mechanical sensors is receiving a wide attention. The SMC is one of the nonlinear controllers for the IM the attractive superior properties of SMC such as good performance in the case of nonlinear systems, robustness, insensitive to parameter variations and external disturbance is the main reason of the popularity [6-8].

The aim of this paper is to present a hybrid controller for controlling the induction motor, it is a combination of two controller, the controllers are operated in two loops. In one of the loop sliding mode controller regulates the motor torque and the rotor flux where as in other loop the PID controller regulates the motor speed.

This paper presents a combinational control scheme. A modelling of induction motor is introduced in section II, SMC is discussed in section III, to regulate the motor toque and the rotor flux. The outer loop with PID controller is discussed in section IV. Simulink model of the system and simulation results are presented in section V, and some concluding remarks are stated in section VI.

## II. MATHEMATICAL MODEL OF INDUCTION MOTOR

Synchronously rotating d-q reference frame is considered in this paper. The state space model of the induction motor can be described by a set of the first order non linear differential equations are given by [9,10]:

$$\frac{di_{sd}}{dt} = -a_1 i_{sd} + \omega_s i_{sq} + a_2 \psi_{rd} + a_3 \omega \psi_{rq} + a_4 u_{sd} \quad (1)$$

$$\frac{di_{sq}}{dt} = -a_1 i_{sq} + -\omega_s i_{sd} + a_2 \psi_{rq} + -a_3 \omega \psi_{rd} + a_4 u_{sq} \quad (2)$$

$$\frac{d\psi_{rd}}{dt} = a_5 i_{sd} - a_5\psi_{rd} + (\omega_s - \omega)\psi_{rq} \quad (3)$$

$$\frac{d\psi_{rq}}{dt} = a_5 i_{sq} - a_5\psi_{rq} - (\omega_s - \omega)\psi_{rd} \quad (4)$$

$$T_e = a_6\left[\psi_{rd} i_{sq} - \psi_{rq} i_{sd}\right] \quad (5)$$

$$\frac{dw}{dt} = a_7[T_e - T_L] \quad (6)$$

$$a_1 = \left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_r}\right), a_2 = \left(\frac{1-\sigma}{\sigma T_r}\right), a_3 = \left(\frac{1-\sigma}{\sigma}\right) \quad (7)$$

$$a_4 = \frac{1}{\sigma L_s}, a_5 = \frac{1}{T_r}, a_6 = \frac{3pL_m^2}{2L_r}, a_7 = \frac{pa_6}{J} \quad (8)$$

$$\sigma = 1 - \frac{L_m^2}{L_s L_r}, T_s = \frac{L_s}{R_s},\ T_r = \frac{L_r}{R_r} \quad (9)$$

here $i_{sd}, i_{sq}$ – the stator currents in ampere , $u_{sd}, u_{sq}$ – stator voltages in volts, and $\psi_{rd}, \psi_{rq}$ – rotor flux, ω is the rotor speed (rad/s), Te is the motor torque (Nm), $T_L$ is the load torque (Nm), $\omega_s$ is the angular frequency of the stator current (rad/s), σ is the leakage factor and p – the number of pole pairs. $R_s$ and $R_r$ is the stator and rotor resistances, $L_s$ and $L_r$ denote stator and rotor inductance, whereas $L_m$ is the mutual inductance, J is the moment of inertia of the IM.
The control objective is to regulate the rotor flux and rotor speed to the reference point.

## III. SLIDING MODE CONTROL

Sliding-mode control is one of the effective control methodologies for induction motor drive control. This technique adjust feedback by previously defining a surface, so that the system which is controlled will be forced to that surface, then the behaviour of the system slides to the desired equilibrium point. The main feature of this control is that we only need to drive the error to a switching surface. When the system is in the sliding mode, the system behaviour is not affected by any modelling uncertainties and/or disturbance [11-12].

The objective of SMC is to converge the rotor flux and torque to their reference values $\Phi_{ref}$ and $T_{ref}$ respectively, the rotor flux is defined as:

$$\Phi = \Psi_{rd}^2 + \Psi_{rq}^2$$
(10)

The error between the actual value and the reference value is defined as:

$$e_\Phi = \Phi_{ref} - \Phi \quad (11)$$

and

$$e_T = T_{ref} - T_e \quad (12)$$

Equation (5) and (10) shows that the relative degrees of the system with output signal Φ and Te are, respectively, 2 and 1, so the sliding surface is defined as follows

$$S_1 = \tau_\Phi \dot{e}_\Phi + e_\Phi$$

$$= \tau_\Phi\left(\dot{\Phi}_{ref} - \dot{\Phi}\right) + \left(\Phi_{ref} - \Phi\right) \tag{13}$$

$$S_2 = e_T = T_{ref} - T_e \tag{14}$$

where $\tau_\Phi > 0$ is the time constant of the sliding mode of $\Phi$. Since $\Phi_{ref}$ is a constant.

The control function will satisfy reaching conditions in the following form:

$$u = u_e + u_i \tag{15}$$

Here u is the control vector; $u_e$ is the equivalent control vector. In order that S1→0 and S2→0 in finite time, the control law is designed such that

$$\begin{bmatrix}\dot{S}_1\\ \dot{S}_2\end{bmatrix} = -\begin{bmatrix}k_1 \mathrm{sign}(S_1)\\ k_2 \mathrm{sign}(S_2)\end{bmatrix} \tag{16}$$

Where k1 and k2 are positive constants, sign (.) is the signum function

$$\mathrm{Sign}(S) = \begin{cases} 1 \text{ if } S > 1 \\ -1 \text{if } S < -1 \\ 0 \text{ if } S = 0 \end{cases} \tag{17}$$

From above equations the control voltage vector find out as:

$$u_{sd} = h'_{12}[h_{11} + k_1 \mathrm{sign}(S_1)] + h'_{13}\left[\dot{T}_{ref} + h_{21} + k_2 \mathrm{sign}(S_2)\right] \tag{18}$$

$$u_{sq} = h'_{22}[h_{11} + k_1 \mathrm{sign}(S_1)] + h'_{23}\left[\dot{T}_{ref} + h_{21} + k_2 \mathrm{sign}(S_2)\right] \tag{19}$$

Where,

$$\begin{aligned} h_{11} = -2\tau_\Phi \Big[&\left[a_5^2\left(i_{sd}^2 + i_{sq}^2 - i_{sd} - i_{sq}\right)\right] + a_5(\omega_s - \omega)\left(i_{sq} - i_{sd} + 2\psi_{rd} - 2\psi_{rq}\right) + \left(a_5^2 + a_2 a_5 + (\psi_s - \omega)^2\right)\psi_r^2 - \\ &2a_5(a_1 + a_5)\left(i_{sd}\psi_{rd} + i_{sq}\psi_{rq}\right) + a_5(\psi_s - 2\omega)\left(i_{sd}\psi_{rq} - i_{sq}\psi_{rd}\right) + \left(a_5^2 - (\omega_s - \omega)^2\right)\left(\psi_{rd} - \psi_{rq}\right)\Big] - \\ &2\left[a_5 i_{sd}\psi_{rq} + a_5 i_{sq}\psi_{rq} - a_5\psi_r^2\right] \end{aligned} \tag{20}$$

$$h_{12} = -2\tau_\Phi a_4 a_5 \psi_{rd} \quad ; \quad h_{13} = -2\tau_\Phi a_4 a_5 \psi_{rq} \tag{21}$$

$$h_{21} = -a_6\left[(a_1 - a_5) i_{sq}\psi_{rd} + (a_1 - a_5) i_{sd}\psi_{rq} - \omega\left(i_{sq}\psi_{rq} + i_{sd}\psi_{rd}\right) - a_3\omega\psi_r^2\right] \tag{22}$$

$$h_{22} = a_4 a_6 \psi_{rq} \quad ; \quad h_{23} = -a_4 a_6 \psi_{rd} \tag{23}$$

$$h'_{12} = \frac{\psi_{rd}}{2\tau_\Phi a_4 a_5 \psi_r^2} \quad ; \quad h'_{13} = \frac{-\psi_{rq}}{\tau_\Phi a_4 a_6 \psi_r^2} \tag{24}$$

$$h'_{22} = \frac{\psi_{rq}}{2\tau_\Phi a_4 a_5 \psi_r^2} \quad ; \quad h'_{23} = \frac{\psi_{rd}}{\tau_\Phi a_4 a_6 \psi_r^2} \tag{25}$$

## IV.PID CONTROLLER

A proportional-integral-derivative (PID) controller is a common feedback loop component in industrial control systems. The controller takes a measured value from a process or other apparatus and compares it with a reference set point value. The difference (or “error” signal) is then used to adjust some input to the process in order to bring the process measured value to its desired set point. Unlike simpler controllers, the PID can adjust process outputs based on the history and rate of change of the error signal, which gives more accurate and stable control. In contrast to more complex algorithms such as optimal control theory, PID controller can often be adjusted without advanced mathematics [13,14].

The equation of the PID controller is:

$$G(s) = K_P + K_D s + \frac{K_I}{s} \tag{26}$$

The constant of the PID controller is chooses as the best transient response.

The control system as shown in fig.1, it has two loops, one loop regulate the rotor flux and torque by using the SMC controller and the other loop is the speed controller by using the PID. The PID controller set the reference value of torque for the sliding mode torque controller.

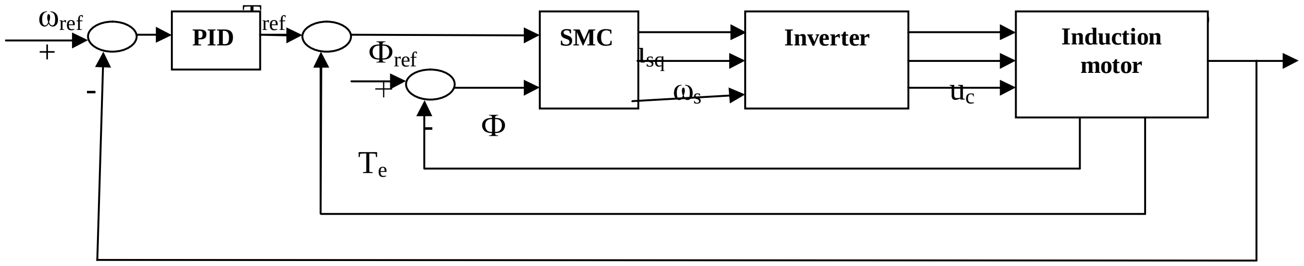

Fig.1.The control system

## V. SIMULATION RESULT

The 3-phase induction motor drive system, whose rating and parameters are given in Table-I, is subjected to test with the hybrid (PID and SMC) controller.

TABLE I
INDUCTION MOTOR PARAMETERS

| Parameter | Notation | Value |
|---|---|---|
| Rotor resistance | $R_r$ | 4.3047 Ω |
| Stator resistance | $R_s$ | 9.65 Ω |
| Mutual inductance | $L_m$ | 0.4475 H |
| Stator inductance | $L_s$ | 0.4718 H |
| Rotor inductance | $L_r$ | 0.4718 H |
| Rotor inertia | J | 0.0293 kg/$m^2$ |
| Pole pair | p | 2 |

The simulation model is shown in figure.2

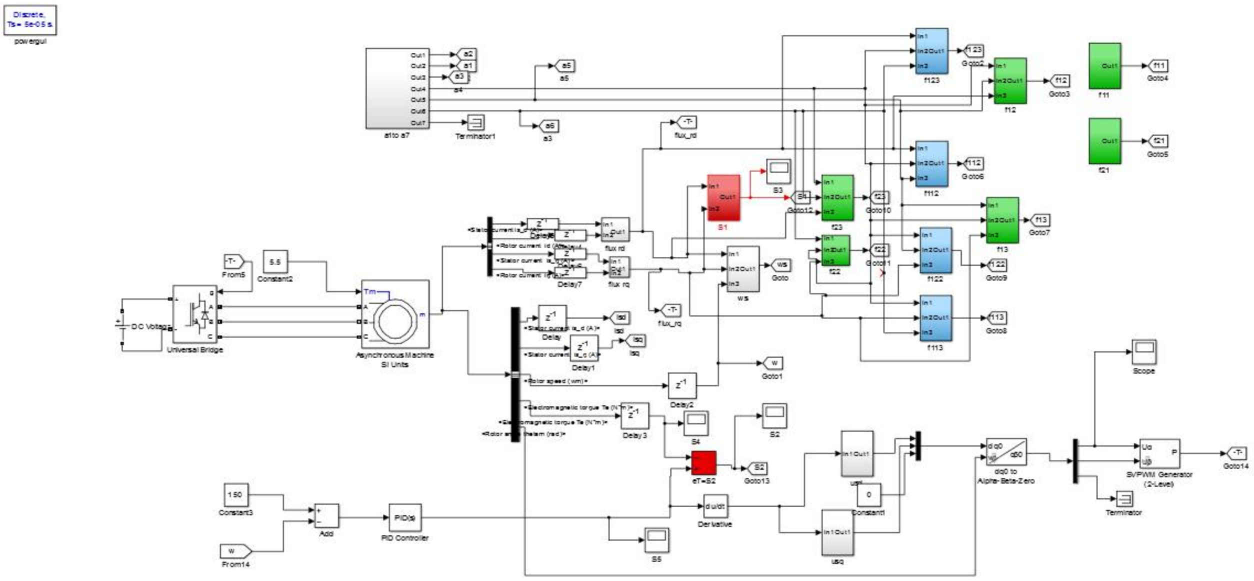

Fig.2. Simulation model of control system

The motor is started at time t=0s to speed ω=150 rad/s without load. At time t= 0.3s the load torque $T_L$=5.5 Nm is applied. The simulation results are given in figure 3 to figure 6.

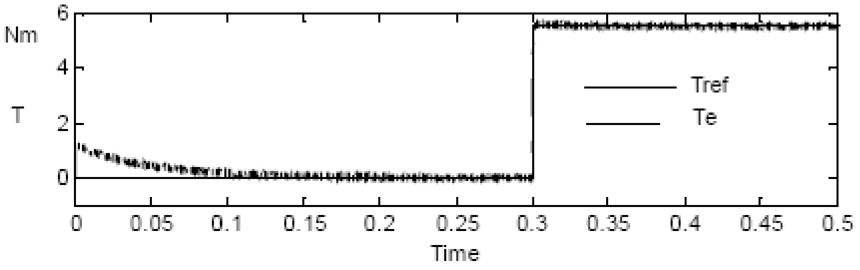

Fig.3. Torque Response

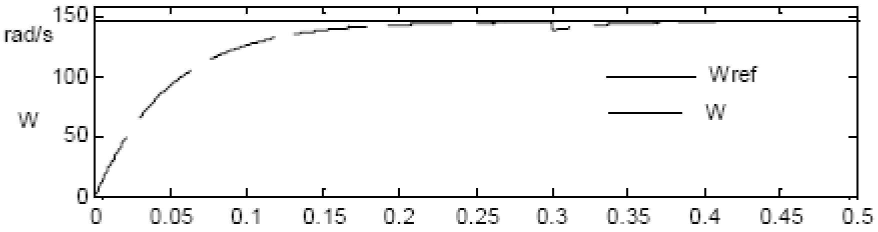

Fig.4. Speed Response

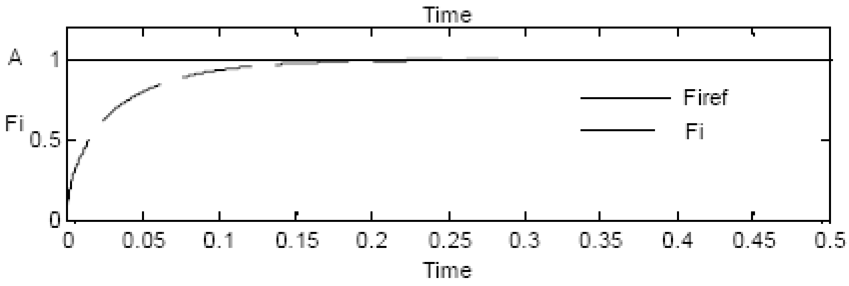

Fig.5 Flux Response

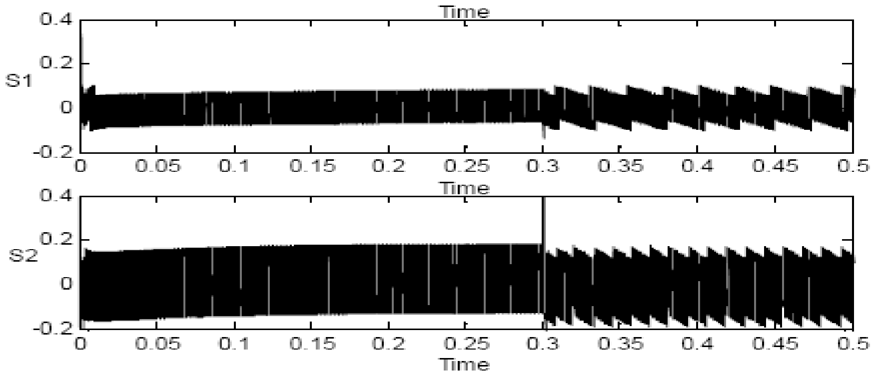

Fig.6. $S_1$ and $S_2$ sliding surfaces

Now vary the motor parameter the resistance and inductance of the motor that is different from the motor model, let $R_r'$= 1.2R$_r$; $R_s'$= 1.2R$_r$; $L_r'$= 0.5L$_r$; $L_s'$=0 .5L$_{s;}$ $L_m'$= 0.5L$_m$ , the simulation results are shown below:

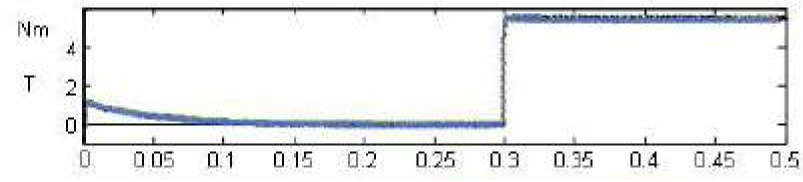

Fig.7. Torque Response

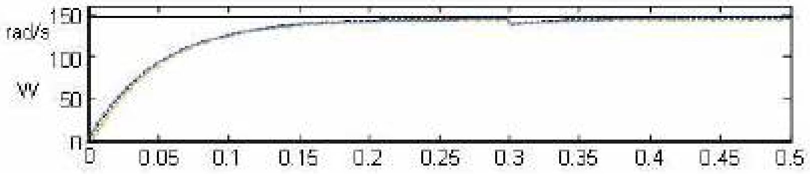

Fig.8. Speed Response

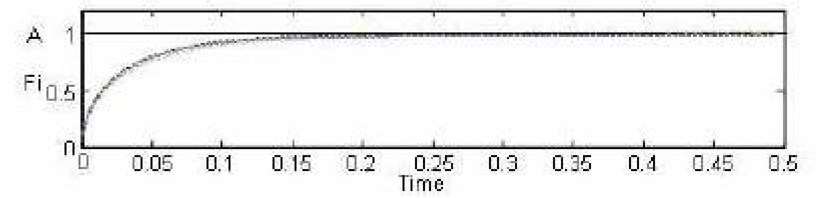

Fig.9 Flux Response

Observe from the simulation results from figure 3 to 5 and figure 7 to 9 that the response of the system is invariant from the parameter variation of the motor.

## VI.CONCLUSION

In this paper the hybrid controller combination of PID and sliding mode controller for induction motor control has been presented. From the simulation results we observed that the static errors of the rotor flux and the rotor speed are null and the influence of the load torque on the rotor flux and the rotor speed is negligible. A result shows that this scheme is robust to the parameter variation and shows a good performance. Sliding mode controller shows the torque ripples which are not completely eliminated, as in future work we use higher order sliding mode controller that eliminates the chattering problem in SMC.

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