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ROBUST FIELD ORIENTED INDUCTION MACHINE CONTROL USING SMC

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Abstract: *The aim in this paper is to design a sliding mode speed and flux controller in order to make the system robust to external disturbances, noise, and unmodeled dynamics. The transient response of the system is also improved. The sliding mode control technique is justified for its robust nonlinear control to model uncertainty. Simulation results under load disturbances, parameter variations are obtained to verify the consistency of the SMC over PI controller.*

Key Words: ***Field oriented control of Induction Motor, SMC, and Advantages over PI controller***

1. INTRODUCTION

Induction machine is widely used in industries due to its low cost and reliability. It is a high order nonlinear system and coupling exists between the control variables. Also, from the practical point of view, the machine parameters may vary with temperature. The aim here is to make the speed and flux control robust to parameter variations by the use of a sliding mode controller which is an advantage over a PI controller. In case of a PI controller, the variation of motor parameters (such as stator and rotor résistance) degrades the performance of the controller and the machine becomes unstable.

Here, a 5HP induction motor is simulated with a sliding mode speed and flux controller and its responses are compared with that of a PI- controller. The PI controllers are commonly used, but the problem associated with it is the gains are subjected to continuous adjustment due to the noise and external perturbations. Also, due to sudden change in load and reference speed, the transient performance of the IM is not so admirable and there is a dip in the actual rotor speed and torque. Whereas, by designing the sliding mode controller for the same vector controlled induction machine, we observed better transient response in the performance of the IM. By taking parameter variations such as change in the rotor and stator resistances with temperature (up to 50% variation), load disturbance and speed variation up to 50%, with SMC, we get desired response. Hence, the robustness is verified.

2. INDUCTION MOTOR MODELLING

$$\begin{bmatrix} \dot{i}_{ds} \\ \dot{i}_{qs} \\ \dot{\psi}_{dr} \\ \dot{\psi}_{qr} \end{bmatrix} = \begin{bmatrix} -a_1 & \omega_e & a_2 & a_3\omega_r \\ -\omega_e & -a_1 & -a_3\omega_r & a_2 \\ a_5 & 0 & -a_4 & \omega_{sl} \\ 0 & a_5 & -\omega_{sl} & -a_4 \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ \psi_{dr} \\ \psi_{qr} \end{bmatrix} + \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} \tag{1}$$

The induction motor is modeled taking a rotor flux oriented synchronously rotating reference frame with stator current and rotor flux as the state-space variables.

3. FIELD ORIENTED INDUCTION MOTOR DRIVE

Vector or field oriented induction motor is achieved with a synchronously rotating reference frame (d-q) by aligning the flux component of stator current along the rotor flux and making the torque component of stator current perpendicular to it such that $\psi_{qr} = 0$ and $\psi_{dr} = \psi_r$.

The electromagnetic torque is given by;

$$T_e = \left(\frac{3p}{2}\right)\left(\frac{L_m}{L_r}\right)\psi_{dr} i_{qs}$$

(2)

The decoupling of torque and flux is verified by this vector control technique. This technique is simulated using both PI and sliding mode controller.

4. SMC DESIGN PRINCIPLE

A time varying surface **S(t)** is defined in the state space by the scalar equation S(x, t) = 0.

Where $S(x,t) = (\frac{d}{dt} + \lambda)e = \dot{e} + \lambda e$

(3)

λ = positive constant that determines the bandwidth of the system.

The sliding condition is;

$$\frac{1}{2}\frac{d}{dt}(s^2) \leq -\eta\,|s|\,. \tag{4}$$

η = positive constant that determines the degree to which the system state is attracted to the switching line. The control law for the sliding mode speed and flux control is derived and the gains of the controller are designed according to the control law. To reduce the chattering, a boundary layer of definite width on both sides of the switching line is introduced such as ;

$$sat\left(\frac{s}{\phi}\right) = \begin{cases} \frac{s}{\phi}; & |s| \leq \phi \\ sgn(s); & |s| > \phi \end{cases} \tag{5}$$

Where ϕ = width of the boundary layer on either side of the switching line.

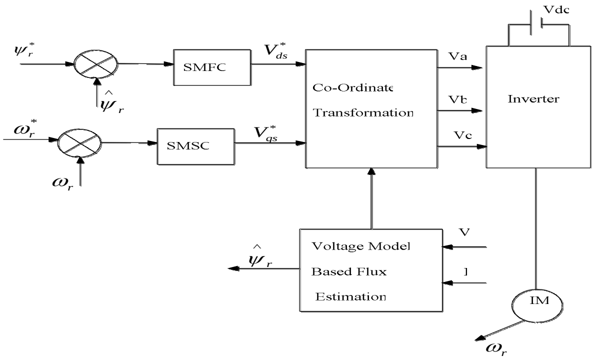

Fig. 1: Sliding Mode Speed and Flux Control of Vector Controlled Induction machine

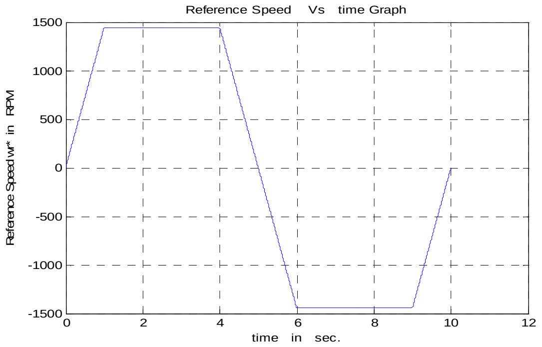

Fig. 2: Reference rotor speed trajectory Vs time

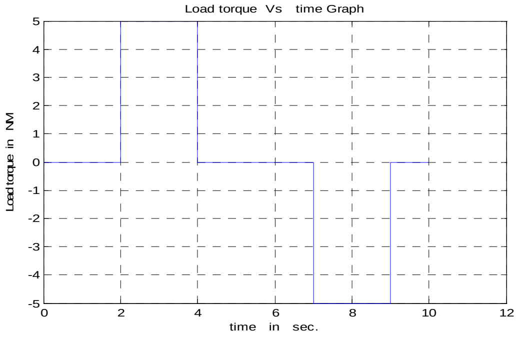

Fig. 3: Load Torque trajectory Vs time

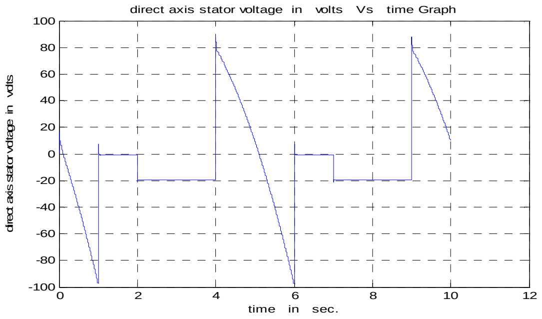

Fig. 4:d-axis controlled stator volatge with SMC

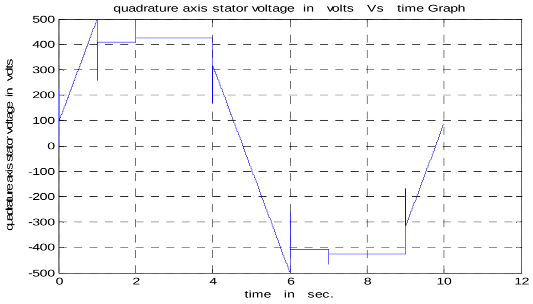

Fig. 5: q-axis controlled stator voltage with SMC

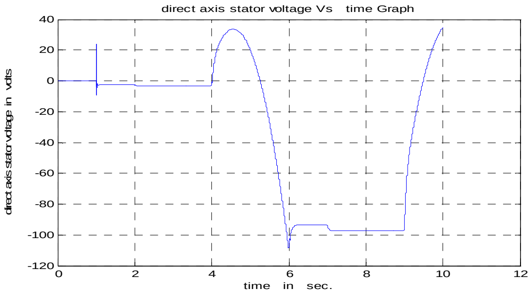

Fig. 6: d-axis controlled stator volatge with PI controller

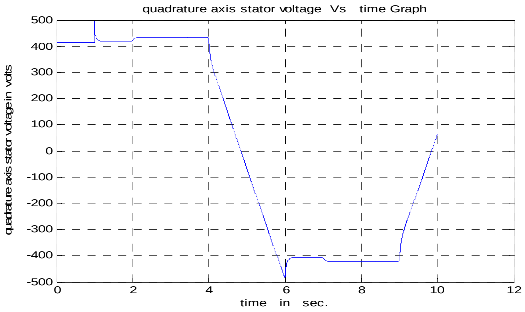

Fig. 7: q-axis controlled stator volatge with PI controller

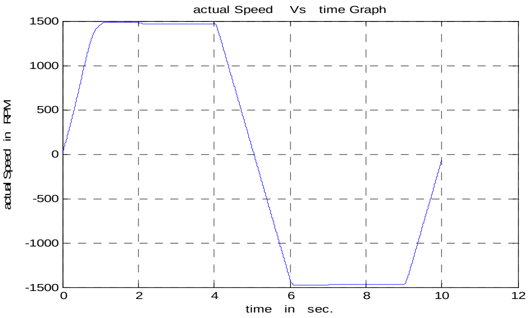

Fig. 8: Actual rotor peed Vs time with PI controller

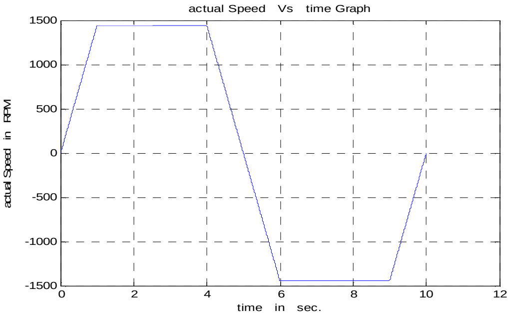

Fig. 9: Actual rotor speed Vs time with SMC

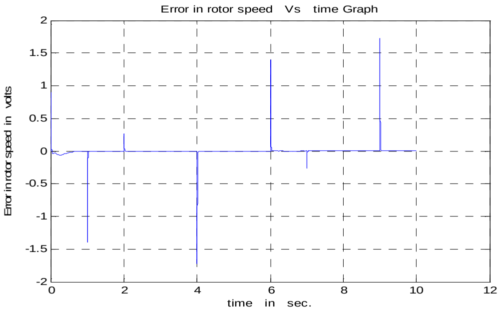

Fig. 10: Error in speed Vs time with SMC

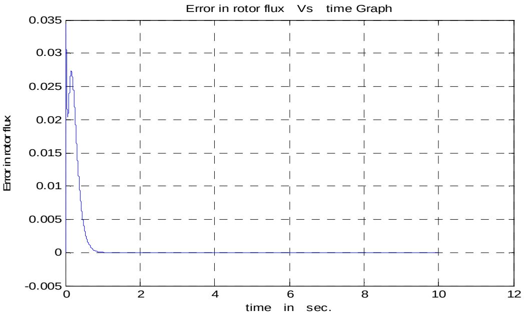

Fig. 11: Error in rotor flux Vs time with SMC

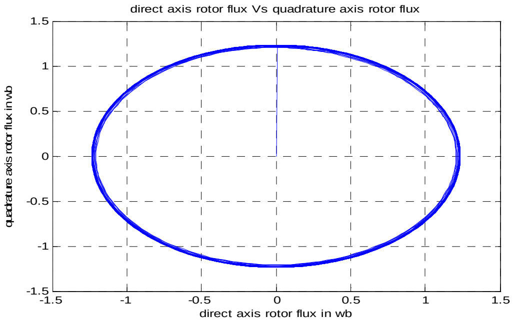

Fig. 12: Direct axis rotor flux Vs quadrature axis rotor flux with SMC

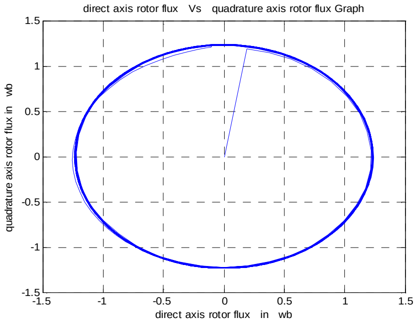

Fig. 13: Direct axis rotor flux Vs quadrature axis rotor flux with PI controller

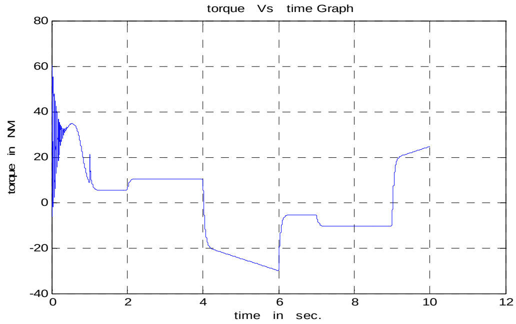

Fig. 14: Electromagnetic Torque Vs time with PI controller

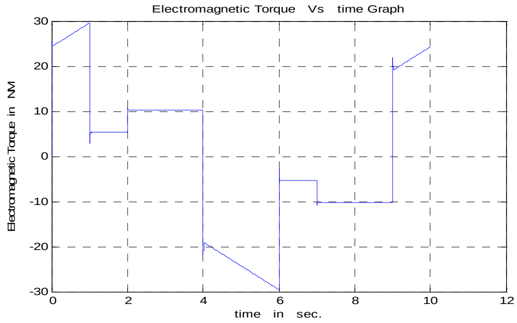

Fig. 15: Electromagnetic Torque Vs time with SMC

TABLE - 1

RATINGS and PARAMETERS OF THE INDUCTION MOTOR

Three phase, 50Hz, 5hp, 415volts, 1500RPM
Stator and Rotor Resistances: Rs = 7.34Ω, Rr = 5.46Ω
Stator and Rotor self inductances: Ls = Lr = 0.521H
Mutual inductance between stator and rotor:Lm=0.5H
Moment of inertia: J = 0.16kg . m^2
Coefficient of viscous friction: B = 0.035N. m .s/rad

5. ADVANTAGES OF SMC OVER PI CONTROLLER

In this scheme, with sliding mode speed and flux control, the machine parameters Rs and Rr are varied with temperature and the above responses were taken from which the system robustness is verified as the transient responses are smooth and better as compared to that of PI controller. Also with a step change in speed and load command, there is no change in actual rotor speed.With PI controller, the above responses were obtained with the variation of Rr. By varying Rs, it is observed that the system is getting unstable and it requires to reset the gain values of PI controller. The d- and q-axis controlled voltages are more accurate in case of SMC than that of PI controller. Also, with a step change in speed and load, the motor speed changes.The speed and flux error in SMC are very small, whereas for the PI controller it is larger than SMC.

6. CONCLUSION

The simulation is done by MATLAB M-file and from the result it is concluded that sliding mode control offers a robust control of field oriented induction motor drive as compared to that of PI controller.The induction motor is subjected to change in rotor and stator resistancec with temperature and the torque, speed and flux responses were observed.The transient behaviour of sliding mode control, such as change in speed, load torque shows better results than that of PI controller.Thus, the system is made robust to external disturbances, noise and unmodelled dynamics by the nonlinear controller such as sliding mode speed and flux control.

7. REFERENCES

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