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Sliding Mode Control for Speed of an Induction Motor with Backlash

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ABSTRACT
One of the most problem of nonlinear mechanical system that limit the performance of the position and speed control is backlash, a controller used in this paper is applied to an induction motor includes a gear, the main purpose of this paper is to study the effect of backlash on the performance of the motor and the goal is tracking speed trajectory , the paper described a comparison of controlling three phase induction motor using PI controller and sliding mode control under the effect of backlash and load torque variations , the simulation is implemented using MATLAB/ SIMULINK, the performance of the system is illustrated via simulation

Keywords
induction motor- backlash-variable structure system

1. INTRODUCTION
Induction motor is widely used in industries due to robustness, simple maintance and low cost

Induction motor is more difficulty to control than DC motors that is because nonlinearity, complex and multivariable of mathematical model [1, 2]. There is several methods have been proposed to control induction motor in the absence of backlash [3], [4], [5], [6].

The study of control systems with backlash began in 1940 [7], until now there is more attention around control system with backlash .One of the mechanical elements is gear; the behavior of the system is changed when gear is attached to induction motor, the movement's speed, direction and torque can be changed, the error occurs in the motion when gears change direction is known as backlash when the motor is not connected to the load ,the effect of backlash can disturb the motor system ,and high torque impulses can occur, the life time of the system can be reduced, the backlash is present in most mechanical and hydraulic systems ,it is bad for control performance [8].

The sliding mode control methodology has become the principle operational mode for the control systems based on variable structure system [9].The main idea of sliding mode control is to enforce the motion of the sliding mode in predefined switching surfaces in the system state space using discontinuous control [10].

In this paper a sliding mode controller is applied to induction motor, the effect of backlash is considered and the result is compered by using PI controller these results are examined using simulations in Simulink.

2. BACKLASH
A nonlinear behavior that effect on the set up of the system is backlash which effect on the stability and the performance of the mechanical system depending on the machine's operating conditions and mechanical surroundings, gears and transmissions is the major part of systems with backlash [11] .

Backlash is a problem especially occurred in gear systems, it considered a drawback when constant angular velocity is desired. There are several solutions are done but it can't completely reduce backlash. Controlling the movement is a solution to deal with backlash

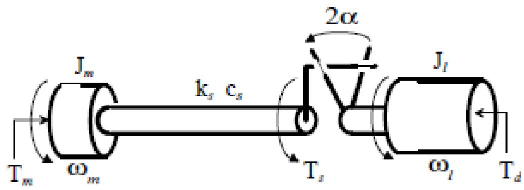


Fig (1) Two mass system with backlash

$$J_m \dot{\omega}_m = -c_m \omega_m - T_s + T_m \quad (1)$$

$$J_1 \dot{\omega}_1 = -c_1 \omega_1 + T_s - T_d \quad (2)$$

$$\omega_d = \omega_m - \omega_1 \quad (3)$$

$$T_s = K_s \theta_d + c_s \omega_d \quad (4)$$

where Jm (kg/ m2) is the motor moment of inertia,cm (Nm/(radl/s)) is the viscous motor friction, Ts (Nm) is the transmitted shaft torque, Tm (Nm) is the motor torque,J_l (kg/ m2) is the load moment of inertia, c_l (Nm/(rad/s))is theviscous load friction, Td (Nm) is the load torquedisturbance, k_s(Nm/rad) is the shaft elasticity, and c_s(Nm/(rad/s)) is the inner damping coefficient of the shaft.
Control engineers was avoided the problem of backlash .the common way is to control the system with backlash such as the system without backlash, no problem happened when backlash is small, but when high performance is desired, this way is not good, till now there are several approaches to tackle the problem of backlash [12].

3. MATHEMATICAL MODEL OF AN INDUCTION MOTOR
A fifth order nonlinear differential equations of an induction motor is represented using a rotating field reference frame (d,q) as below [13]

$$\dot{I}_{ds} = \frac{\alpha}{\tau_I L_I}\varphi_{dr} + \frac{\alpha}{L_I}\omega_m \varphi_{qr} - \frac{1}{\tau_I} I_{ds} + \omega_s I_{qs} + \frac{1}{L_I} u_{ds}$$

$$\dot{I}_{qs} = -\frac{\alpha}{L_I}\omega_m \varphi_{dr} + \frac{\alpha}{\tau_I L_I}\varphi_{qr} - \omega_s I_{ds} + \frac{1}{\tau_I} I_{qs} + \frac{1}{L_I} u_{qs} \quad (5)$$

$$\dot{\varphi}_{dr} = -\frac{1}{\tau_r}\varphi_{dr} + \omega_r \varphi_{qr} + \frac{L_m}{\tau_r} I_{ds}$$

$$\dot{\varphi}_{qr} = -\omega_r \varphi_{dr} - \frac{1}{\tau_r}\varphi_{qr} + \frac{L_m}{\tau_r} I_{qs}$$

$$\dot{\omega}_m = \frac{1}{J}(T_e - T_m)$$

Where (u_{ds} ,u_{qs}) are the stator voltage components,

(I_{ds} , I_{qs}) are the stator current components, φ_{qr} and φ_{dr} are the rotor flux components. $R_I = R_s + \alpha^2 R_r$, where R_s and R_r are stator and rotor resistances, $L_I = L_s - \alpha L_m$, $\tau_I = L_I / R_I$,

L_s *and* L_r are the stator and rotor cyclic inductances, L_m is the mutual inductance, ω_m is rotor pulsating, J represents the moment of inertia. T_e is the electromagnetic torque equation [3,5] the above equations are nonlinear model and complicated

4. BACKLASH MODEL

There are different mathematical models of backlash are used such as [7]

1-Physical Model for Backlash

2-Modeling with Describing Functions

3-Deadzone Model

in practice ,the most common model used is dead zone model , in this paper a dead zone is the model that used to describe backlash ,the shaft torque T_s is proportional to the shaft twist θ_s

$$T_s = K_s \theta_s = K_s D_\alpha(\theta_d) \quad (6)$$

Where θ_s is a static function of the displacement

The dead zone function can be defined as [14, 15]

$$D_\alpha(x) = \begin{cases} x - \alpha & \text{if } x \succ \alpha \\ 0 & \text{if } |x| \prec \alpha \\ x + \alpha & \text{if } x \prec -\alpha \end{cases} \quad (7)$$

The shaft is modeled as a spring having no inertia and no internal damping and shaft damping is zero, without backlash, $\theta_s = \theta_d$

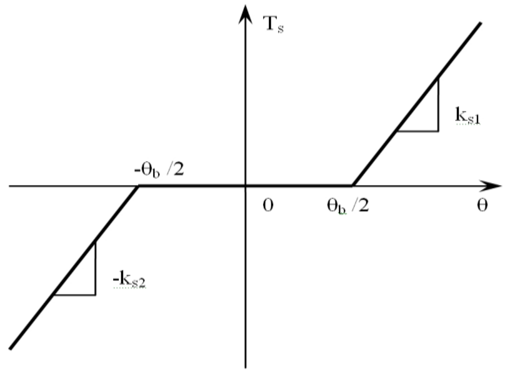


Fig (2) Dead zone model

There are lots of effort done to solve the backlash control problem, various control strategies used such as linear controllers, describing functions, adaptive and non-linear control from the motor side, adaptive control and non-linear control state feedback

As shown in fig .2 a dead zone element is used to model backlash. There is no torque transferred by the shaft in backlash mode[16,17].

5. SLIDING MODE CONTROL

There are many algorithms interested in sliding mode control because simplicity of design, robustness and control of independent motion .A consequence of discontinuous control is sliding mode control; there are two steps in sliding mode control, in the first a switching surface is constructed to produce a desired behavior.

The second switching control is designed; the state converges to the sliding surface and stayed on sliding manifold

The dynamics of error *e(t)* and its derivative $\dot{e}(t)$ are driven to the origin along the sliding line [9].

$s_i(x) = 0$ is called a sliding surface, $s_i(x)$ is an (n-1) dimensional switching function .and is called switching surface or switching hyperplane as in figure (3)

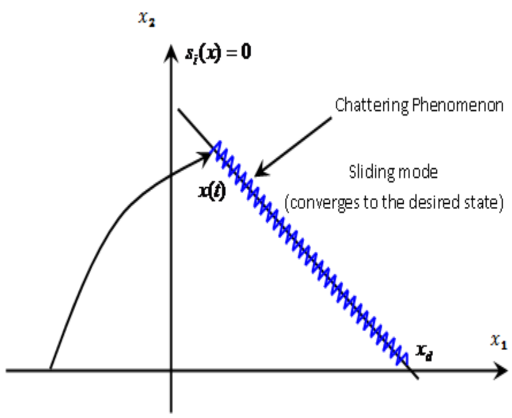


Fig.3 .The chattering Phenomenon near a sliding surface

The controlled input $u_i(x,t)$ is applied to the system to obtain the desired output. The inputs of induction motor is (u_d, u_q), and the currents of induction motor (i_d, i_q) are required to calculate to obtain the desired speed ω

Sliding surface can be defined as

$$s_i(x) = ce + e^{\bullet} \quad (8)$$

Where

$$e = \omega_m^* - \omega_m \quad (9)$$

Where ω_m^* is the speed reference and c is a parameter designing and c $\succ$ 0that defined the error dynamics once the state reached to the sliding surface

The controller $u_i(x,t)$ is divided to hitting control input and equivalent control

$$u_i(x,t) = u_{eq} - ksign(s) \quad (10)$$

Where k is positive constant

6. SIMULATION AND DISCUSSION

The simulations of the system are performed using the parameters as shown in table (1).MATLAB/SIMULINK

are used to carry out the simulation. Three phase induction motor with gear are used and is runed at sampling period T = 2e- 6 s.

The performance of the torque and speed is

compered under variations of load torque by using sliding mode control and the PI controller, when the load torque is zero the backlash gap is opened and the stability controller is used. Fig (5-7) indicates the simulation results for a three phase induction motor, the oscillations of shaft torque are significantly higher than without backlash. The difference between motor speed and load speed increases.

It is noted that the states of the system is forced to move towards the sliding surfaces by SMC, and then the states are sliding on the surfaces and achieving the required performance. Fig (4) shows speed, torque and current using PI controller without load, fig (5) shows speed, torque and current using the PI controller with load .these results can be showed as the following:

The speed set point is 500rpm at time t = 0 s, . As shown in the fig (4-b), the speed follows precisely the acceleration ramp. The

speed of motor is ramping to final value when the load torque is applied to the motor at t = 0.5 s,

The speed decreased to zero at t=1s, and the mechanical load decreased to -1200 N.m at 1=1.5s

The motor current is high beginning by 1500A after that it decreased when load torque is decreased

Fig (6) shows speed, torque and current using SMC controller without load, fig (7) shows speed, torque and current using the SMC controller with load, the speed response of Fig. (6-a) indicates there is no changed in the rotor speed at these ranges, and the applied torque is rejected by the sliding mode controller and the rotor speed is riding over the sliding surface and the controller is robust against change of the load torque.

7. RESULTS

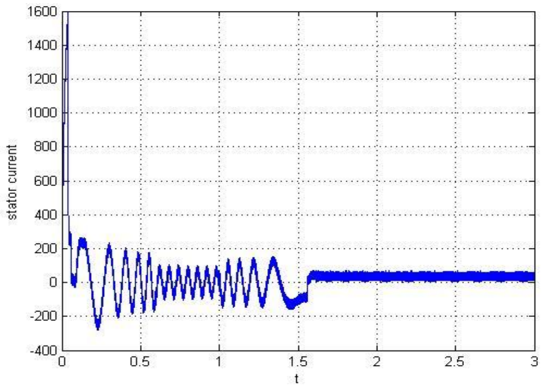


Fig (4-a)

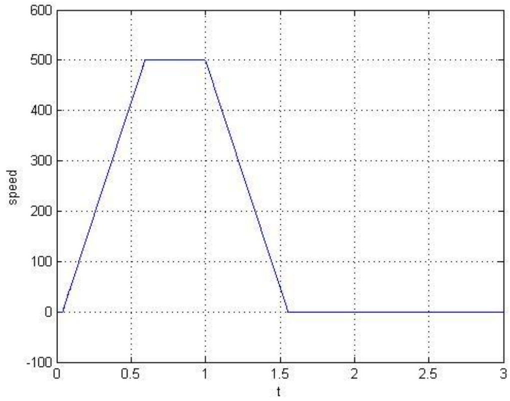


Fig (4-b)

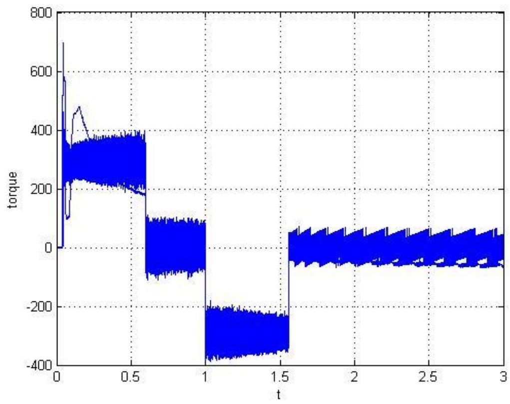


Fig (4-c)

Figures 4 simulation results with PI controller with no load system

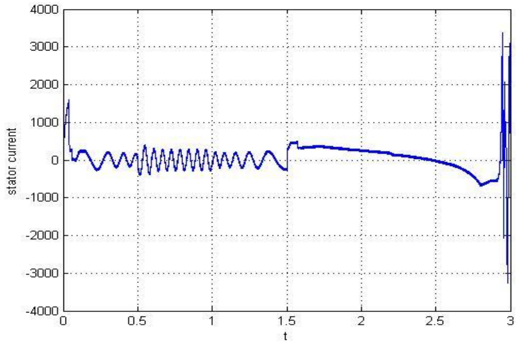


Fig (5-a)

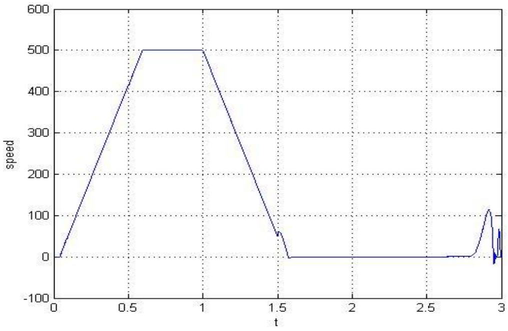
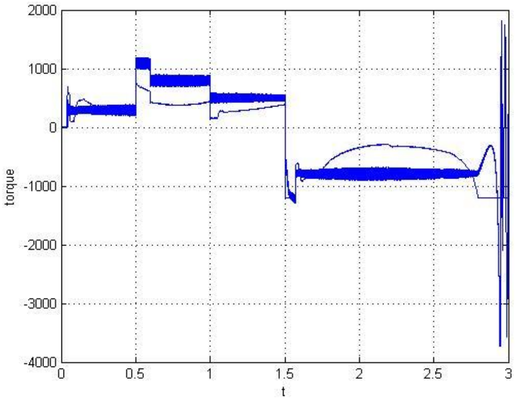


Fig (5-b)



Fig(5-c)

Figures 5 Simulation results with PI controller with load and under the effect of backlash

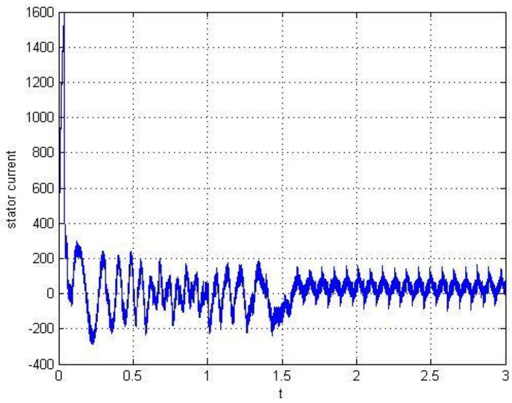


Fig (6-a)

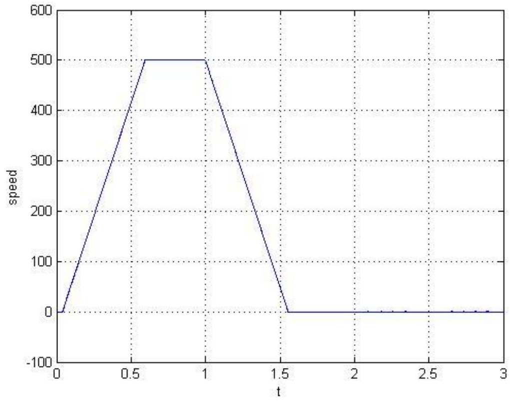


Fig (6-b)

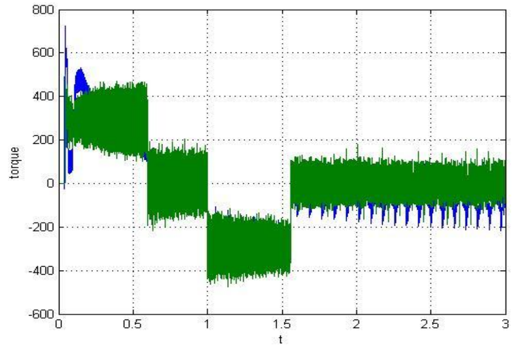


Fig (6-c)

Figures 5 Simulation results with SMC controller with no load and under the effect of backlash

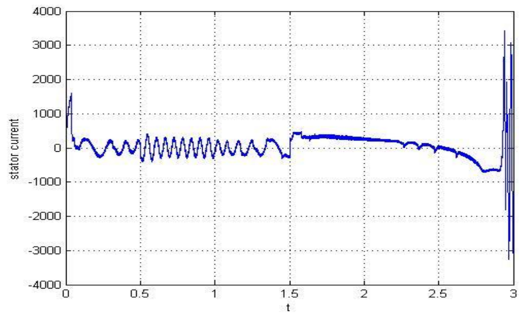


Fig (7-a)

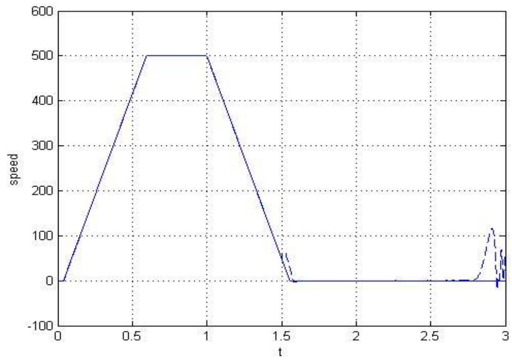


Fig (7-b)

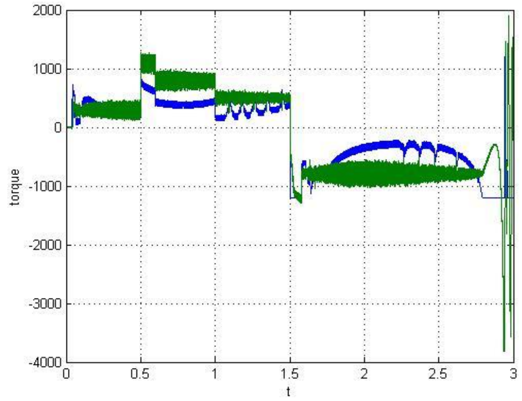


Fig (7-c)

Figures 7 Simulation results with SMC controller with load and under the effect of backlash

8. CONCLUSION

This paper represents the design of a control system for the controlling speed of three phase induction motor includes a gear and under the effect of backlash, the paper described a comparison of controlling three phase induction motor using PI controller and sliding mode control under the effect of backlash ,the paper show a better response of the motor can be obtained by using the proposed controller and the stability controller is used when load torque is zero, the oscillations of shaft torque are significantly higher than without backlash.

Table1. Parameters of the Induction motor

Self-inductance of stator and rotor	Ls = Lr =0.3mH
Resistance of stator and rotor	Rs = 0.0149 Ω , Rr = 0.0093Ω
Mutual inductance between stator and rotor	Lm=10.46mH
Viscous friction Coefficient	B =0.08N. m .s/rad

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