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Total Sliding Mode Control of Servo Induction Motor Using Simulation Approach

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ABSTRACT : This paper is demonstrates that invariant regulator and superior servo performance can be obtained, through an total sliding mode control system, which is insensitive to uncertainties including parameter variations and external disturbance in the whole control process. The simulation result of the control schemes for a given servo Induction Motor is discussed below.

Keywords: Field oriented induction servo motor, computed torque controller, total sliding mode controller, PID controller.

I. INTRODUCTION

The induction machine is largely used in industry, mainly due to its reliability and relatively low cost. The control of the induction machine (IM) must take into account machine specificities: the high order of the model, the nonlinear functioning as well as the coupling between the different variables of control. Furthermore, the machine parameters depend generally on the operating point and vary either on the temperature (resistance), or with the magnetic state of the induction machine, without taking into account the variation. These parametric variations modify the performances of the control system when we use a regulator or a control law with fixed parameters. The new industrial applications necessitate speed variations having high dynamic performances, a good precision in permanent regime, and a high capacity of overload on all the range of speed and a robustness to the different perturbations. Conventional Proportional-Integral (PI) controllers, designed using the classical control theory, are well suited to the control of linear processes whose exact model is known. However, the majority of physical systems usually contain non-linear relations that are difficult to model. On the other hand, to use a self-tuning PI controller, an adequate drive model must be known. As it is well known by linear control theory, the design PI con-stroller procedure consists in tuning their parameters in order to achieve the required bandwidth and disturbance rejection. A quite precise knowledge of motor and load parameters is thus required. This condition cannot be always satisfied because some parameters are not exactly known and/or are subject to variations during operation. As a consequence of this phenomenon a degradation of the drive performance occurs. To avoid these problems, different non-linear control strategies have been proposed in the literature. Control structure based on artificial intelligence, such as artificial neural network, fuzzy logic, and variable structure controller (VSC) appears to be an advantageous solution for control of such processes Thus, the recourse to robust control algorithms is desirable in stabilization and in tracking trajectories. The variable structure control (VSC) possesses this robustness using the sliding mode control that can offer many good properties such as good performance against un demodled dynamics, insensitivity to parameter variation, external disturbance rejection and fast dynamic. These advantages of sliding mode control can be employed in the position and speed control of an alternative current servo system. A proportional-integral-derivative controller (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 controllers can often be adjusted without advanced mathematics. However, pushing robustness and performance to the limits requires a good understanding of the theory and controlled process [1-7].

II. FEEDBACK LINEARIZATION

In the case of linearization methods some plants, especially robots, have provided very interesting applications, but unfortunately the same is not true for most commonly encountered nonlinear plants which usually do not fulfill the conditions for linearisability and are further more so complex that the corresponding nonlinear controller would never be implement able. Using feedback linearization, moreover, introduces an intermediate step into the design of the control system. The plant is first linear zed and then a linear controller is added to the feedback linearized system to achieve the desired control goals [8, 9]. It is evident that this two-step approach may have a price in terms of optimality if compared, e.g., with the approximate solution of the corresponding Hamilton-Jacobin-Bellman equation for the original nonlinear system, even if the linear controller is optimal for the feedback linearized system.

A. Control of Induction Motor by feedback Linearization

The control of Induction Motor constitutes a theoretically challenging problem since its dynamical system is nonlinear, the electric rotor variables are not measurable, and the physical parameters are most often imprecisely known. The control of the induction motor has attracted much attention in the last decade. One of the most significant developments in this area has been the field oriented control. Partial feedback linearization together with a proportional-integral (PI) controller is used to regulate the motor states. This technique is very useful except that it is very sensitive to parameter variation. To improve the field-oriented control, full linear zing state feedback control, based on differential geometric theory has been proposed. These methods require relatively complicated and nonlinear calculation in the control algorithm. To entirely linearize and to decouple the Induction Motor, nonlinear control techniques can be used.

B. Drawbacks of Feedback Linearization

Although the theory of feedback linearization is well known, its application to the control of Induction Motors raises a number of specific implementation problems which have to be solved.

- An observer to be used since a part of the state, the rotor flux, is not measurable in industrial applications.
- The nonlinear controller is developed in continuous time. It is implemented in discrete time, and the delay introduced has to be taken into account.
- The power inverter must be protected by limiting the stator current. This is taken into account in the development of control algorithm.

III. CONTROL OF INDUCTION MOTOR BY COMPUTED TORQUE CONTROLLER

Computed torque is a special application of feedback linearization of nonlinear systems. Computed torque controllers appear in robust control, adaptive control, learning control etc, torque control allows us to conveniently derive very effective controllers, while providing a framework to provide independent position control for complex applications. It does not need a priori information about the bounds on the uncertain or time varying parameters and operates if the changes are within the given bounds.

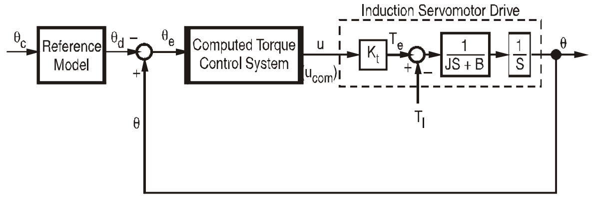

Fig. 1. Block diagram of computed torque control.

Proposed controller leads to performance improvements despite its simple Structure and. Conventional Relatively Lowest control effort, High performance if no uncertainties.

A. Need for Sliding Mode Control Scheme

Computed torque or inverse dynamics technique is a special application of feedback linearization of nonlinear systems. The computed torque controller is utilized to linearize the nonlinear equation of robot motion by cancellation of some, or all, nonlinear terms. Then, a linear feedback controller is designed to achieve the desired closed-loop performance. Consequently, large control gains are often required to achieve robustness and ensure local stability. Thus, it is natural to explore other nonlinear controls that can circumvent the problem of uncertainties in the computed torque approach and to achieve better compensation and global stability.

IV. CONTROL PRINCIPLE OF SLIDING MODE CONTROL

Sliding Mode Control does not require a disturbance waveform characterization to implement the control law. The main advantage of Sliding Mode Control (SMC) is the robustness to unknown disturbances. Required knowledge of the disturbance is limited to the disturbance boundary. Traditional SMC was, however, limited by a discontinuous control law. Depending on the plant dynamics, high frequency switching may or may not be an issue to contend with. There are techniques to limit and eliminate the high-frequency switching associated with traditional SMC. It is the intent of this paper to look at several SMC techniques utilizing an model with bounded external disturbances. The effective gains of the error compensator can be increased by using a sliding mode controller to tune the observer for both speed adaptation and for rotor flux estimation. It provides robust performance for a drive with respect to variations in motor parameters as well as rapid changes in load torque. This control approach is nonlinear where the drive response is forced to "slide" along a predefined trajectory in a phase plane by a switching algorithm despite parameter variations or load disturbances [10-11].

SMC Graphical lustration

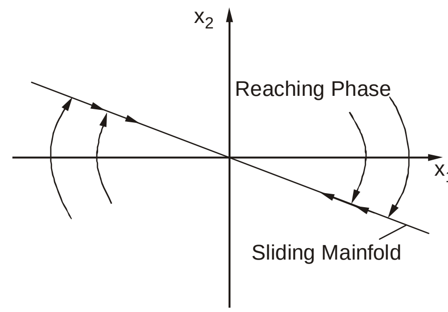

Fig. 2. Graphical illustration of SMC.

Consider a sliding mode controller (SMC) for a simple second-order undamped linear system with a variable plant gain, K. The SMC controller comprises two switches with the option of positive or negative feedback as shown in the figure below.

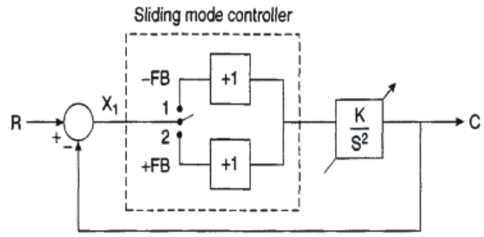

Fig. 3. Variable structure control of second order system.

In either the positive or negative feedback case, the system can be shown to be unstable. However, when switched between the two states, not only can stability be achieved but the system can be made robust against variations in K.

Consider first the case of negative feedback, i.e. switch 1 closed. In this case,

$$X_1 = R - C$$

or $\quad R - X_1 = C$

where X_1 = loop error

Differentiating this expression gives:

$$\frac{d}{dt}(R - X_1) = \frac{dC}{dt} = -X_2$$

$$\frac{dX_1}{dt} = X_2$$

To satisfy the loop relation, we can also write:

$$\frac{dX_2}{dt} = KX_1$$

Combining these equations gives:

$$\frac{d^2X_1}{dt} + KX_1 = 0$$

The general solution to this equation is:

$$X_1 = A\sin\left(\sqrt{K}t + \theta\right)$$

$$X_2 = \frac{dX_1}{dt} = \sqrt{K}A\cos\left(\sqrt{K}t + \theta\right)$$

Combining these equations gives

$$\frac{X_1^2}{A^2} + \frac{X_2^2}{(\sqrt{K}A)^2} = 1$$

This is the equation of an ellipse as shown below:

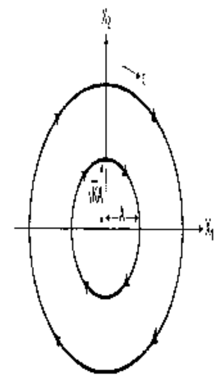

Fig. 4. Ellipse graph.

Similarly, in the positive feedback mode, (switch 2 closed) the equations become:

$$\frac{dX_1}{dt} = X_2$$

$$\frac{dX_2}{dt} = KX_1$$

Combining these equations gives:

$$\frac{d^2X_1}{dt^2} - KX_1 = 0$$

The general solution to this equation is:

$$X_1 = B_1e^{\sqrt{Kt}} + B_2e^{-\sqrt{Kt}}$$

$$X_2 = \frac{dX_1}{dt} = \sqrt{K}B_1e^{\sqrt{Kt}} - \sqrt{K}B_2e^{-\sqrt{Kt}}$$

Squaring and combining these equations gives:

$$\frac{X_1^2}{4B_1B_2} - \frac{X_2^2}{4B_1B_2} = 1$$

This equation describes a set of hyperbolas as shown in the Fig.

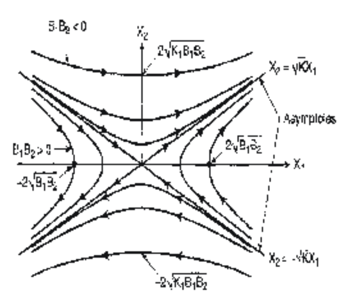

Fig. 5. Two phase plane diagram.

The straight line asymptote equations are obtained by setting B_1B_2 = 0 which gives:

$$KX_1^2 - X_2^2 = 4KB_1B_2 = 0$$

The system can be switched back and forth between these two modes. The superposition of the two phase plane diagrams results in the figure shown below:

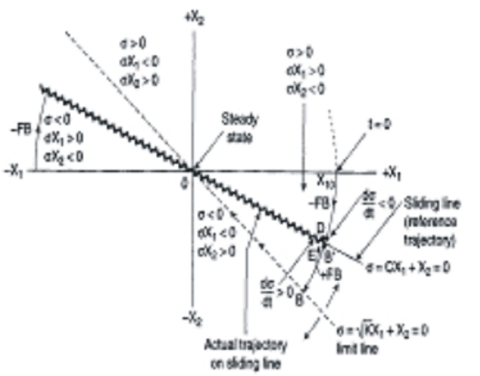

Fig. 6. Sliding line control in phase plane X_1 – X_2.

$$\sigma = \sqrt{K}X_1 + X_2$$

Assume that system at t = 0 is in –ve feedback mode at point X_{10}. It moves along the ellipse until the +ve feedback mode is invoked at point B. It will then (ideally) move along B_0 to settle at 0 at steady state, where X_1 and X_1 are zero. Let us define a straight line reference trajectory by the equation:

where $C < \sqrt{K}$ so that the line slope is lower than and beyond the range of the variation in K.

$$\sigma = CX_1 + X_2 = 0$$

Notice that the +ve and –ve feedback ellipses and hyperbolas cross the reference trajectory in opposite directions. This results in a zig-zag variation about the reference trajectory until steady state is reached (as the operating condition is switched back and forth between +ve and –ve feedback).

V. TOTAL SLIDING MODE CONTROL SYSTEM

Total Sliding mode controller is the combination of the computed torque controller and sliding mode controller, it is one of the effective nonlinear robust control approaches since it provides system dynamics with an invariance property to uncertainties once the system dynamics are controlled in the sliding mode.The control system block diagram of an induction servo motor drive with the implementation of field-oriented control can be simplified as shown in Fig. 7.

$T_e = K_t\ iqs*$

$K_t = (3np/2)(L_m^{\ 2}/Lr)\ i_{ds*}$

$Hp(s) = 1/(Js + B)$

where T_e is the electric torque, K_t is the torque constant, i_{qs*} is the torque current command, i_{ds*} is the flux current command is the number of pole pairs, Lm is the magnetizing inductance per phase, L_r is the rotor inductance per phase is the moment of inertia is the damping coefficient and s is laplace operator.

The mechanical equation of the induction servomotor drive can be represented as:

$$\ddot{\theta}(t) = A_n\dot{\theta}(t) + B_n u(t)$$

where θ is the motor position; $U(t)$ is the control effort. A_n, B_n are given:

A_n = –B/J = –1.1172 (s*rad) – 1;

B_n = Kt/J = 101.4854 (A*s2) – 1;

B, J, Kt are constant for servo motor.

Kt = 0.4851 Nm/A; J =0.00478 Nms

B = 0.00534 Nms/rad

- Total sliding mode law

$u_{sm}(t) = u_{eq}(t) + u_{vs}(t)$

- Control law for U_{eq}:

$$u_{eq}(t) = B_n^{-1}[-A_n\dot{\theta}(t) + \ddot{\theta}_d(t) - k_1\dot{\theta}_e(t) - k_2\theta_e(t)]$$

- Control law for U_{vs}:

$$u_{vs}(t) = -B_n^{-1}W\,\mathrm{sgn}[s(t)]$$

where $s(t)$ is the output of sliding surface, which is defined as follow:

$$s(t) = \dot{\theta}_e(t) + k_1\theta_e(t) + k_2\int_0^t \theta_e(\tau)d\tau$$

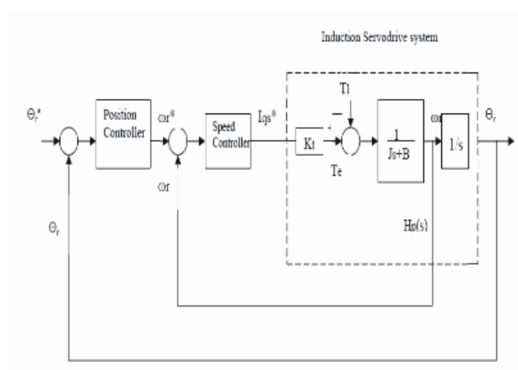

Fig. 7. Simplified block diagram of an induction servomotor drive.

The proposed total sliding mode control system is depicted in Fig. 7. The presentation of total sliding-mode control for the uncertain induction servomotor drive system is divided into two main parts.

- Base Line Model Design
- Curbing Controller Design

The first part addresses performance design. The objective is to specify the desired performance in terms of the nominal model, and it is referred to as base line model design Fig. 8.

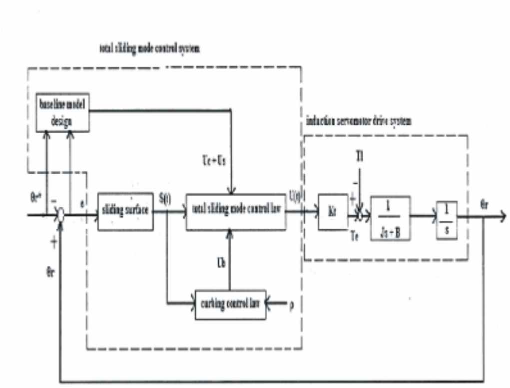

Fig. 8. Block diagram of Total Sliding Mode Control system.

A. Baseline Model Design

In base line model design, two controllers are designed in the control effort. The first controller which is a computed toque controller is used to compensate for the nonlinear effects and attempts to cancel the nonlinear terms in the model. After the nonlinear model is linearized, the second controller is used to specify the desired the system performance. Moreover, the stability of the controlled system may be destroyed. To ensure the system performance as desired, despite the existence of the uncertain system dynamics, a new sliding-mode controller is proposed.

B. Curbing Controller Design

In the curbing controller design an additional controller is designed using a new sliding surface to ensure the sliding motion through the entire state trajectory, which totally eliminates the unpredictable perturbations effect from the parameter variations and external load disturbances. Therefore, in the total sliding-mode control system the Controlled system has a total sliding motion without a reaching phase. The objectives of the curbing controller are twofold. The first is to keep the controlled system dynamics on the sliding surface. That is, curb the system dynamics on to the sliding surface for all time. Thus it is called a curbing controller. Accordingly, the second objective is to guarantee that the closed loop perturbed system has the same performance as the base line model design.

VI. SIMULATION RESULTS

The parameters of the proposed control system are given as, $\rho = 5$, $\lambda = 0.1$. All the parameters in the proposed control system are chosen to achieve the best transient control performance in the simulation and also considering the requirement of stability. It should be noted that the fixed bound of lumped uncertainty ρ can be determined roughly owing to the limitation of control effort, and to the possible perturbed range of parameter variation and external load disturbance.

A. Simulation results for Case 1

Without controller-on no load

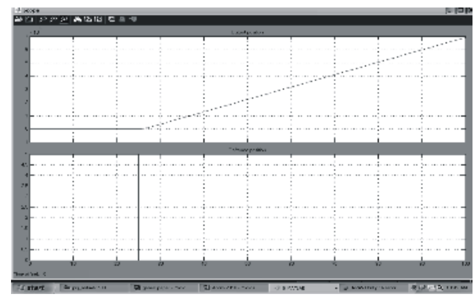

Fig. 9. Simulation Results showing output, Input, of servo induction motor Design in Simulink for no load..

B. Simulation results for Case 1.1

Without controller-on load

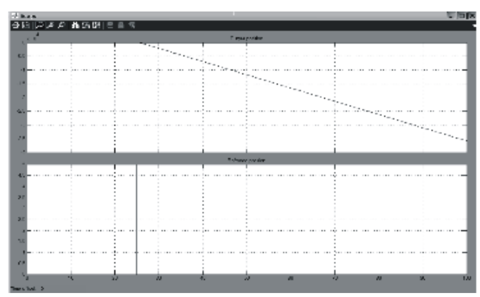

Fig. 10. Simulation Results showing output, Input of servo induction motor Design in Simulink for no load.

C. Simulation results for Case 2

Using PID controller

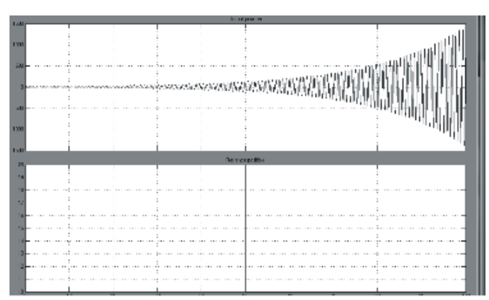

Fig. 11. Simulation Results showing output, Input of PID controller design in Simulink.

D. Simulation results for Case 3

Using sliding mode controller-on no load

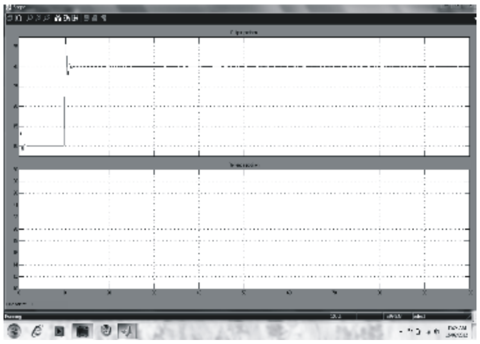

Fig.12. Simulation Results showing output, input using SMC design in Simulink for no load.

E. Simulation results for Case 3.1

Using sliding mode controller-on load

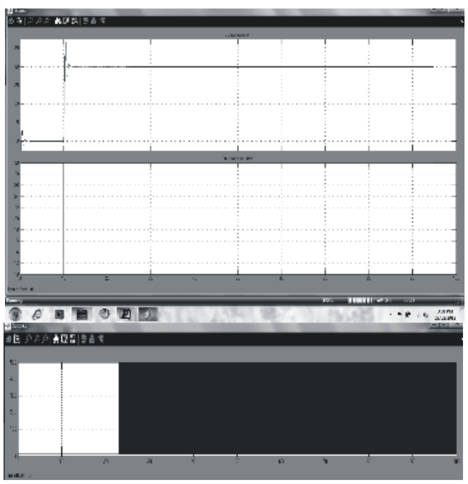

Fig. 13. Simulation Results shows output, input and control effort of SMC design in Simulink for on load.

F. Simulation results for Case 4

Using Computed torque controller-on no load

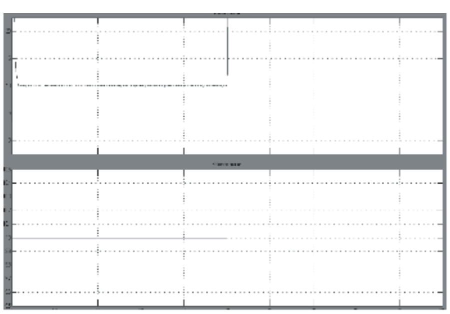

Fig. 14. Simulation results showing output, input of Computed torque controller design in Simulink for no load system.

G. Simulation results for Case 4.1

Using Computed torque controller-on load

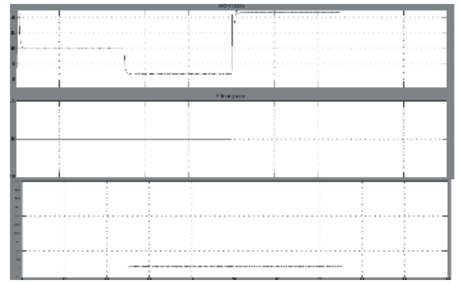

Fig. 15. Simulation results for output, input of rotor position, load torque and control effort of CTC design in Simulink for on load system.

H. Simulation results for Case 5

Using Total sliding mode (SMC + CTC) controller-no load

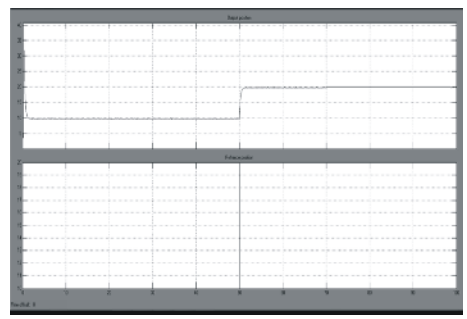

Fig. 16. Simulation results showing output, input of TSMC design in Simulink for no load system in Case-5 the source we have taken in step form.

I. Simulation results for Case-5.1

Using TSMC for no load

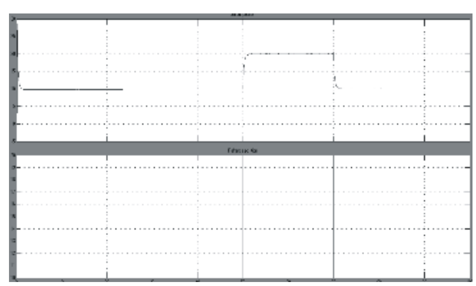

Fig. 17. Simulation Results showing output, Input.

For TSMC design in Simulink in Case-5.1 source we have taken in combination of pulse generator and constant form for no load

J. Simulation results for Case-5.2

Using TSMC for on load

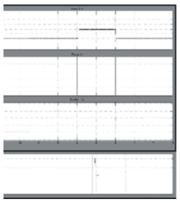

Fig. 18. Simulation results showing output, input, load torque and control effort for case-5.2 source we have taken in combination of pulse generator and constant form for on load.

K. Simulation results for Case

Using TSMC for no load Case-5.3

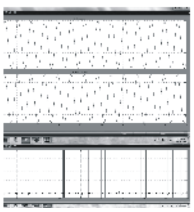

Fig. 19. Simulation Results showing output, Input, control effort for Case-5.3 source we have taken in sine wave form for no load.

VII. CONCLUSION

The position of a field oriented induction servomotor drive for a given reference input signal was controlled using the PID controller, computed torque controller, sliding mode controller and total Sliding-Mode Control Schemes and by comparing the all, it is concluded that the total sliding mode control scheme is more robust and efficient.

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