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Terminal Sliding Mode Based Model Predictive Control Strategies for the Torque Control of Induction Machine

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Abstract**—**The Model Predictive Torque Control is used as a control strategy for induction machine due its quick dynamic reaction, intuitive nature, and flexibility to integrate limitations. Model predictive torque control (MPTC), an upgraded form of Direct Torque Control (DTC), is a frequently used control method for induction motor drives. To reduce torque ripples, PI-based MPTC was traditionally used. It does not, however, solve the reliable and accurate tracking of speed. In this paper, a TSMC-based MPTC scheme is developed, which combines the features of TSMC and Model Predictive Control (MPC) to produce a robust and adaptable system that enhances tracking performance while minimizing torque ripple. The MPTC chooses the best switching states to minimize the cost function; the motor parameter behavior changes with time, and the variation in motor parameter affects the motor's performance. To successfully suppress variation, a modified MPTC having torque variation updating mechanism is employed. The purpose of terminal sliding mode control is to soften the speed's approach to the reference value. The result is demonstrated in Matlab/Simulink. The use of a TSMC-based Model Predictive Controller for rapid and quick dynamic torque response of an IM motor has been demonstrated through simulation results (MPC). For parameter uncertainties and speed variation, the proposed control strategy has a higher performance validity than conventionally tuned PI, SMC control schemes.

Keywords**—** Induction Machine, Direct Torque Control DTC, Terminal Sliding Mode Control TSMC, Model Predictive Torque Control MPTC

I. INTRODUCTION

The IM i.e (induction machine) is a non-linear and complicated system. The researchers were inspired by the growing number of industrial and residential applications to create a new, resilient, a flexible and dynamic system capable of meeting the demands of today's industry requirements to eliminate torque ripples over a large speed range, a combination of MPTC and a PI-controller is widely used. For the propulsion motors in EV, I-M are the popular choice due to its high-performance efficiency, simple construction, reliability, low maintenance cost, etc. the increase in popularity also increases the requirement precise control of dynamic behavior of I-M. in literature numerous control strategies for I-M are available [1]. MPTC uses machine equations to generate voltage vectors for direct torque control DTC. The drive system's lack of durability is the primary disadvantage of PI-based MPTC. Despite the fact that MPTC decreases torque ripples, the PI does not ensure the system's endurance or disturbance rejection capability.

The traditional PI-based MPTC is shown in Figure 1 below. It operates in two loops: (a) the inner loop and (b) the outer loop. The PI is a part of the inner loop, whereas the MPTC is part of the outer loop [2-4] J. Rodriguez and colleagues. provided predictive control with the PI controller as the outer loop (Rodriguez 2004) [4]. Changes in motor parameters (stator and rotor resistance) as well as external disturbances such as a sudden change in load torque impact IM's regular operation [5]. Fengxiang Wang.etal [6] presented the various strategies to control torque and flux in induction motor. The IM fails to follow the reference speed when subjected to external disturbances and parameter fluctuations. Md. Habibullah also presented a finite state method based on the PI control mechanism [7]. In the inner loop, AA. Ahmad employed a proposed control strategy based on state monitoring cost index and PI control [8].

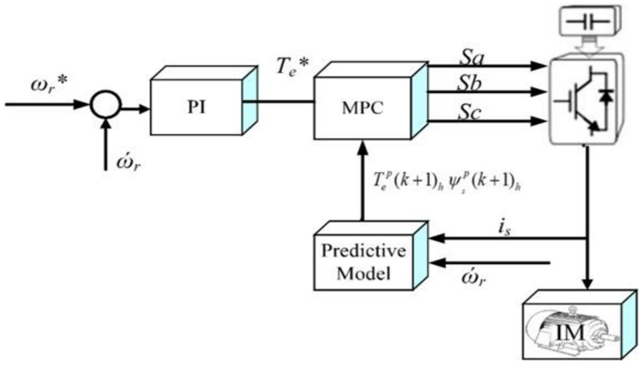

Figure 1. *Conventional PI based MPTC.*

This paper offers an IM MPTC based on Terminal Sliding Mode Control (TSMC), which addresses the drawbacks of PI-based MPTC. TSMC is a useful technique for designing a reliable controller for a nonlinear system. By decoupling and simplifying the nonlinear system into smaller dimensional partial components, terminal sliding mode control reduces the complexity of the feedback system's design. The TSMC is less sensitive to matching disturbances, therefore a precise model isn't required. When compared to PI-based MPTC, the steady state performance would be improved. Simulations in MATLAB/Simulink will ensure the stability and robustness of the proposed control system. paper.

II. LITERATURE REVIEW

First Induction machine controllers employ a variety of strategies which is based on initial and maintenance cost, reliability, simplicity, simple structures, efficiency and having low losses [13]. The important ones to mention are Voltage/Frequency Control, Vector Control, Field Accelerated Method, and Direct Torque Control (DTC). One of the most suitable approaches for driving induction machines is Direct Torque Control (DTC). DTC allows direct control of stator flux and torque by selecting the proper inverter state, as the name implies [14]. Its key feature is better performance, which comes with a number of benefits thanks to its simplified structure and control architecture. The DTC provides a number of advantages, including almost sinusoidal stator currents and fluxes; high dynamic performance even when the rotor is locked; and the lack of co-ordinate transformations, mechanical transducers, voltage modulators, and PID controllers. It also has a simple control system and a short computation time, as well as reduced parameter sensitivity and enhanced dynamic properties.

Traditional DTC, on the other hand, has a number of flaws. For example, issues with starting and low-speed operation, as well as changing switching frequency. Many research attempts have been conducted for improvement as a result of these issues, and various solutions have been presented. They Include Non- Artificial methods mainly “Sophisticated Tables”, Model Predictive Control schemes and Fuzzy Logic based approach. Among these, Model Predictive control method is a promising approach.

A. *Model Predictive Technique*

The essential idea behind the model predictive control method, or in our scenario, Model Predictive Torque Control (MPTC) involves calculating the relevant control signals in advance. The future behavior in the sense of a state variable which is projected over a period of time based on the system model. The MPTC is essentially a more advanced version of DTC. To regulate the flux and torque of IM, the MPTC uses vector selection, which substitutes the look-up table with an online optimization of a pre-defined cost function. The DTC method is fails to remove torque ripples and flux because the voltage vectors picked from the switching table are insufficient to eliminate ripples.

The MPTC swiftly analyses and selects the most optimum voltage vectors from the 8 space vectors. A least cost function is chosen as a result of the chosen voltage vector, and the flux and torque follow the reference as closely as possible. Using a suitable mathematical model of the induction machine, the electromagnetic torque is estimated for each sampling period for all conceivable inverter modes. The switching states of the inverter are then chosen by the predictive algorithm to ensure that the anticipated electromagnetic torque and the reference torque are as close as possible. Using an optimization cost function, the MPTC technique analyses all potential voltage vectors within one sample interval and selects the best one.

B. *TSMC Based Design of MPTC for IM Systems*

To address the problems mentioned by the PI-Based MPTC approach, we provide Terminal Sliding Mode Control (TSMC) with a nonlinear sliding variable. During the sliding phase, a nonlinear fractional power item will be incorporated into the sliding variable to give better attributes such as finite time convergence of state variables, as well as rapid and precise tracking. External disturbances are quite sensitive to PI-based MPTCs, affecting the system's robustness. The Terminal Sliding Mode Controller (TSMC) is less sensitive to matching disturbances and parameter changes, which increases the system's robustness and eliminates the requirement for a precise model.

By providing a discontinuous regulating system that forces the system to arrive to a steady state, terminal sliding mode management changes the dynamics of the non-linear system. The overall system will be decoupled and simplified into smaller, more dimensional subpart components, lowering the feedback system's complexity. The main purpose of the TSMC-based MPTC scheme is to achieve reliable torque and speed control, adequate dynamic performance, and acceptable robustness to internally and externally disturbances.

C. *Equivalent Model and Vector Representation of Induction Motor*

The equivalent circuit of IM also called Steinmetz or T-equivalent circuit. The equivalent circuit diagram of IM is presented in Figure 2, where Xs is the stator reactance and Xr is the rotor reactance, and Rs shows stator resistances and Rr shows rotor resistances, while Xm shows mutual reactance of motor model. The equivalent circuit is similar to the voltage transformer circuit. The only difference is that of secondary side resistance due the short circuit of the rotor winding. In this thesis, the parasitic effects such as eddy currents and magnetic field saturation are assumed to be neglected.

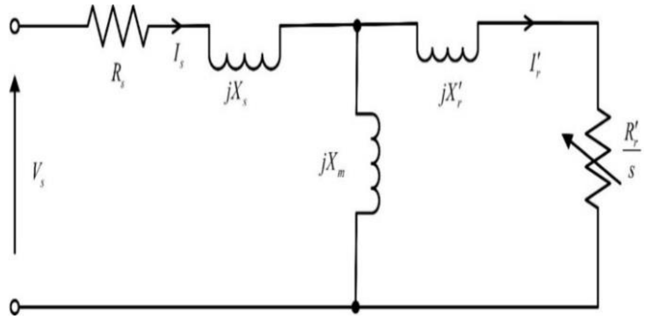

Figure 2. *Induction motor equivalent circuit diagram.*

The stator and rotor voltage equations with respect to their own winding system are presented in equations (1) and (2). These equations are necessary for vector representation of the induction motor equation.

$$\overrightarrow{U_s^s} = R_s\overrightarrow{I_s^s} + \frac{d\overrightarrow{\varphi_s^s}}{dt} \tag{1}$$

$$\overrightarrow{U_r^r} = R_r\overrightarrow{I_r^r} + \frac{d\overrightarrow{\varphi_r^r}}{dt} = 0 \tag{2}$$

Here Rr and Rs are the rotor and stator resistances, respectively. The space vector of variables is represented by $\overrightarrow{(.)}$

D. Inverter Model

In this research work to ensure that the Induction Motor IM is properly fed, a two-level voltage source inverter is required. This inverter has eight switching states which is shown in below figure.2 and figure.3 has shown its three-axis graph. And the below table.1 presents the voltage vectors with their voltage's states. The vector v1 to v6 are active vectors and the remaining v0 and v7 are null vectors.

$$U_{Sabc} = [U_{Sa}\ U_{Sb}\ U_{Sc}]^T \tag{3}$$

$$I_{Sabc} = [I_{Sa}\ I_{Sb}\ I_{Sc}]^T \tag{4}$$

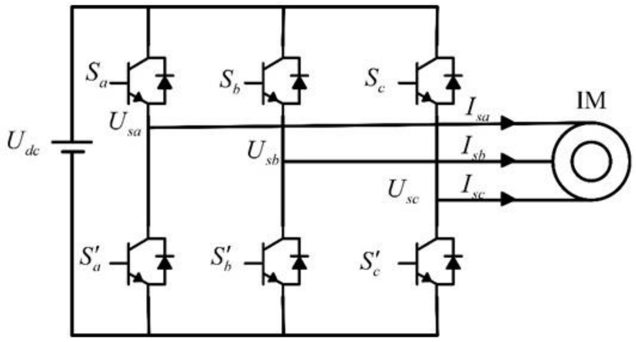

Figure 3. *Circuit of 2L-VSI of Induction Motor.*

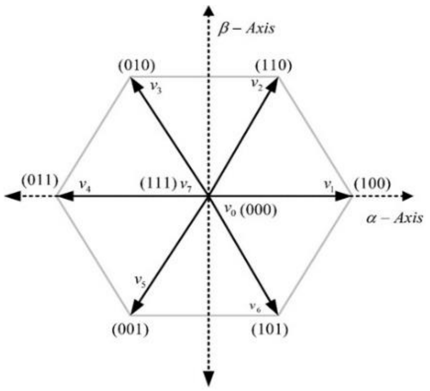

Figure 4. *Three axis representation.*

TABLE *1. Switching States at Selected Voltages $2L - VSI$ of Induction Motor.*

$Voltage\ vectors$	Voltage frame $\alpha\beta$		$Switching\ states$		
	S_α	$U_{S\beta}$	Sa	Sb	Sc
Vo	0	0	0	0	0
$V1$	$\frac{2}{3}U_{dc}$	0	1	0	0
$V2$	$\frac{1}{3}U_{dc}$	$\frac{1}{\sqrt{3}}U_{dc}$	1	1	0
$V3$	$-\frac{1}{3}U_{dc}$	$\frac{1}{\sqrt{3}}U_{dc}$	0	1	0
$V4$	$-\frac{2}{3}U_{dc}$	0	0	1	1
$V5$	$-\frac{1}{3}U_{dc}$	$-\frac{1}{\sqrt{3}}U_{dc}$	0	0	1
$V6$	$\frac{1}{3}U_{dc}$	$\frac{1}{\sqrt{3}}U_{dc}$	1	0	1
$V7$	0	0	1	1	1

Equation(3) and (4) define three phase voltage and currents. The switching functions $Sa, Sb, and\ Sc$ is in equation 5. In contrast, equation 6 shows the stator voltage in a two-dimensional stationary frame.

$$U_{Sabc} = [S_a\ S_b\ S_c]^T \frac{U_{dc}}{2} \tag{5}$$

$$\mathrm{U}_{\alpha\beta} = \begin{bmatrix} \mathrm{U}_{s\alpha} \\ \mathrm{U}_{s\beta} \end{bmatrix} = \begin{bmatrix} \frac{3}{2} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \end{bmatrix} \begin{bmatrix} \mathrm{U}_{sa} \\ \mathrm{U}_{sb} \\ \mathrm{U}_{sc} \end{bmatrix} \tag{6}$$

III. CONTROL STRATEGIES AND PROPOSED DESIGN

A. Conventional DTC

The decoupling issue of the stator current in FOC framework is settled by DTC in a powerful manner. This strategy was proposed by Takahashi and [10] M. Depenbrock [11] for IM drives in the mid of 1980s. EL Ounajili Najib.etal [15] presented direct Torque Control is one of the amazing system that can control the power of the enlistment machine (IM). In DTC the stator voltage vectors are straightforwardly chosen by the distinction between genuine force and stator transition linkage values. There is no requirement for inward current guideline circle and the intricate field direction block in DTC. DTC can give exact and a quick reaction to force, because of this explanation, DTC can function admirably in immersed voltage. For quick and fast prompt control, the decoupled motion and force control is executed. The 2-level hysteresis comparators are utilized to control the electromagnetic force and the stator transition. The stator motion and force are controlled at the same time through the voltages chose by the query table. The look into table purposes the stator motion data and the result of the comparators as a list to choose these voltages. DTC execution fundamentally relies on the assessment of the stator transition and force. The electromagnetic force and stator motion assessment is done by the situations from equation(7) to (14). The stator current in directions can be changed as;

$$I\alpha = Ia \tag{7}$$

$$I_\beta = \frac{\sqrt{3}}{3}(I_{a+}I_b) \tag{8}$$

Ia and Ib are the current in the stator. (Sa, Sb, Sc) the voltages of the stator may be calculated from the switching states in which we get equation(5) and (6).

$$V_\alpha = \frac{V_{dc}}{3}(2S_a - S_b - S_c) \tag{9}$$

$$V_\beta = \frac{\sqrt{3}}{3}V_{dc}(S_b - S_c) \tag{10}$$

From the above equations the voltages can be calculated as,

$$\varphi_\alpha = \varphi_{\alpha_{old}}(V_a - R_s I_\alpha - S_c)T_s \tag{11}$$

$$\varphi_\beta = \varphi_{\beta_{old}}(V_\beta - R_s I_\beta - S_c)T_s \tag{12}$$

The stator flux magnitude is expressed as

$$\varphi_s = \sqrt{\varphi^2{}_\alpha + \varphi^2{}_\beta} \tag{13}$$

The electromagnetic torque is formulated as

$$T_e = \frac{3}{4}p(I_\beta\varphi_\alpha - I_\alpha\varphi_\beta) \tag{14}$$

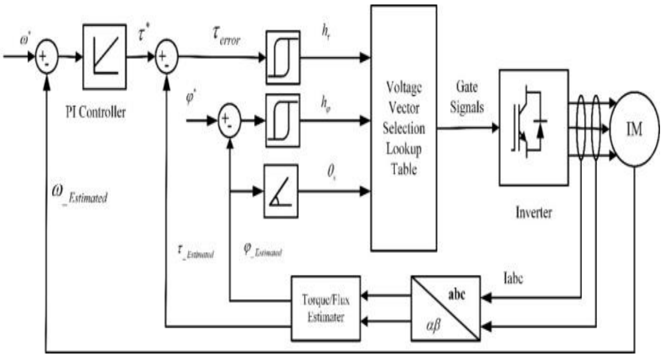

Figure 5. *Conventional DTC block diagram.*

B. Standard PTC

The estimation, prediction, and optimization of the cost function are the three fundamental aspects of PTC The IM model estimate the rotor flux φ_r^p from the stator measured current I_s^p. Using these estimated values of current we can also estimate the stator flux φ_s^p. The estimation equations are given below.

Stator flux estimation:

$$\overrightarrow{\varphi_s^p} = \overrightarrow{\varphi_s^{p-1}} + T_s * (v^{p-1} - R_s * I_s^{p-1}) \tag{15}$$

Rotor flux is given as

$$\overrightarrow{\varphi_r^p} = \frac{L_r}{L_m}\overrightarrow{\varphi_s^p} + I_s^{p-1} * (L_m - \frac{L_r * L_s}{L_m}) \tag{16}$$

The prediction of the stator current $\overrightarrow{I_s^p}$ and stator flux $\overrightarrow{\varphi_s^{p+1}}$ for the next sampling time can be predicted for the same model of IM Model.

Stator Flux prediction:

$$\overrightarrow{\varphi_s^{p+1}} = \overrightarrow{\varphi_s^p} + T_s * (v_i - R_s * \overrightarrow{I_s^p}) \tag{17}$$

$$I_s^p = (1 + \frac{T_s}{\tau_\sigma}) * I_s^{p-1} + \frac{T_s}{\tau_\sigma + T_s}\left(\frac{1}{r_\sigma} * \frac{k_r * \varphi_r}{\tau_\sigma - k_r * jw_m}\right) + v_i \tag{18}$$

Stator Current prediction:

The predicted torque can be calculated as:

$$T^p = \frac{3}{2} * P * (\varphi_s^{P+1} * I_s^{P+1}) \tag{19}$$

The cost function for the optimization can be written in the form of reference and predicted torque, reference and predicted flux as:

$$F = |T^*| - T^{p+1} + \lambda\left|(\varphi_s^* - \varphi_s^{p+1})\right| \tag{20}$$

whereas,

The Reference Torque is by T^*;

The Prediction Torque is shown by T^{p+1};

The Reference Flux is shown by φ_s^*;

λ is the weighting factor for flux error calculated as:

$$\lambda = \frac{\tau_{nom}}{\varphi_{nom}}$$

Cost work F is created for each accessible stator voltage vector. Through enhancing the expense work, the voltage vector for which the expense work has the base worth is applied to the engine terminals through inverter. The square outline of the ordinary PTC is introduced in Figure 5 and the means continued in PTC are summed up in the stream graph chart in figure.6.

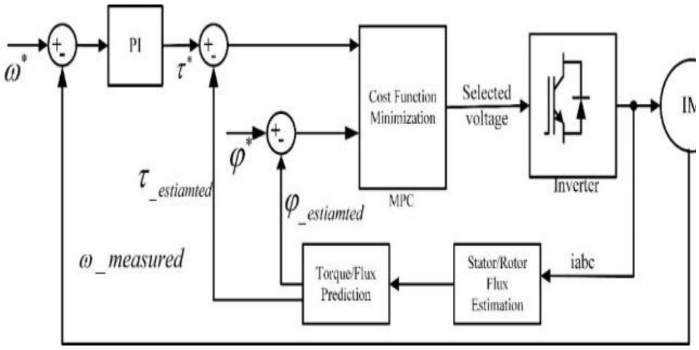

Figure 6. *Block diagram of standard PTC.*

The PTC activity can be summed up in the accompanying advances:

A. Rotor speed and stator current estimations
B. Apply the stator voltage vector
C. Stator transition and electromagnetic force expectation, for the seven-voltage vector chose from the table
D. Cost work is created for every one of the seven voltages
E. The ideal voltage vector is chosen by minimization of the expense work applied to the IM through inverter

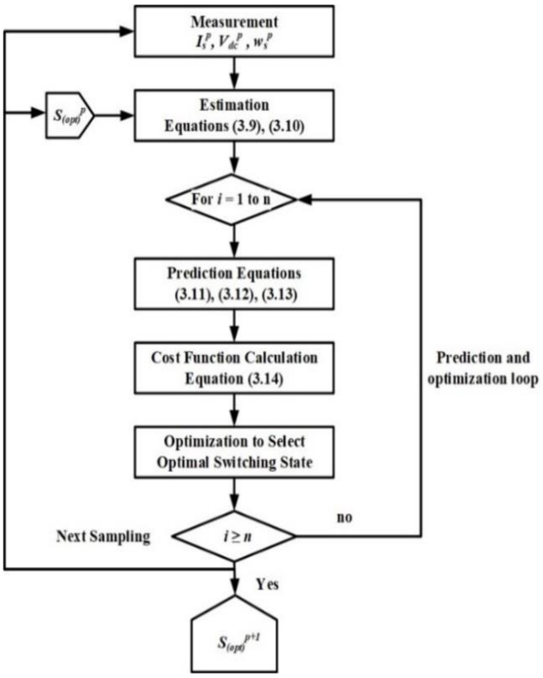

Figure 7. *Flow diagram of standard MPC.*

C. Design of SMC for Proposed Method

SMC method despite the fact that non-direct in nature, can be used for both straight as well as non-straight frameworks. SMC offers different highlights that would be useful some of which incorporates (i) a robust control structure, (ii) ease of implementation and (iii) control precision. Unsettling influence dismissal and boundary variety have little impact on SMC. The SMC block outline for the proposed model is portrayed in Figure 8.

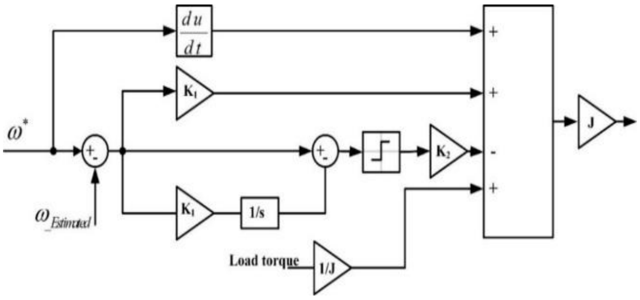

Figure 8. *Block diagram of SMC for the proposed model.*

The load torque in this figure exists in the equivalent control part of the final control law of SMC. Therefore, it is also considered as external disturbance.

To explain the design of SMC mathematically, we may use the disturbance acting on IM having disturbances can be expressed;

$$bT_e = \omega_m + a\omega_m^* + f \tag{21}$$

Whereas, $b = \frac{1}{J}, a = \frac{B}{J}, f = \frac{T_L}{J}$

Applying uncertainties $Da, Db, and\ f$ in terms of $a, b\ and\ f$ respectively, and got equation(22) below;

$$\omega_m = (b + \Delta b)T_e + (a + \Delta a)\omega_m^* + (f + \Delta f) \tag{22}$$

The speed reference error is as follow:

$$e(t) = \omega_m^t(t) - \omega_m(t) \tag{23}$$

where, $\omega_m^*(t)$ shows the reference speed of the rotor. By taking derivative with time of equation(19) we get

$$e^{\bullet}(t) = -ae(t) + u(t) + d(t) \tag{24}$$

Whereas,

$$u(t) = bT_e - a\omega_m^*(t) - f(t) - \frac{d}{dt}\omega_m^*(t) \tag{25}$$

The uncertainty for the above equation(25) is given as;

$$d(t) = \Delta bT_e + \Delta a\omega_m^{\bullet} + \Delta f \tag{26}$$

The sliding surface chosen for the proposed controller is given in equation(27) as;

$$S(t) = e(t) - \int_0^t (k-a)e(\tau)d\tau \quad (27)$$

With $\frac{d}{dt}S(x) = S(x) = 0$.

The SMC controller was created to relocate the error closer to the sliding surface. At the sliding surface, the derivatives and integrals of the errors tend to zero. The trajectories are compelled to go towards the sliding surface by the devised control system, which employs the SMC technique. The sliding surface and the control design law are combined in the SMC approach. The control system behavior can describe as;

$$e^{\bullet}(t) - (k-a)e(t) = 0 \quad (28)$$

The variable control structure can also be represented as;

$$u(t) = ke(t) - \beta\ sgn(S) \quad (29)$$

where, β refers to the switching gain, sliding surface is represented by S while the sign function is referred by *sgn(S)* that can be represented mathematically through:

$$sgn(S(t)) = \begin{cases} 1\ if\ S(t) > 0 \\ -1\ if\ S(t) < 0 \end{cases} \quad (30)$$

The reference torque was derived by putting equation(25) into the equation(29) as;

$$T_e^* = \frac{1}{b}\left[ke - \beta sgn + a\omega_m^*(t) + \omega_m^{*\bullet}(t) + f\right] \quad (31)$$

Lyapunov function is used to verify the stability of SMC equation that is given in equation(28), as;

$$V = \frac{1}{2}S(X)^T S(X) \quad (32)$$

SMC stability conditions are:

$$\frac{d}{dt}V = S(X)^T \frac{dt}{dt}S(X) \le 0 \quad (33)$$

The sliding surface chosen is that of equation(27) and its derivative is as:

$$S^{\bullet}(t) = u(t) - ke(t) + d(t) \quad (34)$$

Now put the value of $S^{\bullet}(t)$ in equation(32), we get equation(35).

$$V^{\bullet} = -\beta\|S\| + S\ dt \quad (35)$$

Henceforth, from condition of equation(29), obviously the condition for security is accomplished when $\beta \gg \|dt\|$.

D. Terminal Sliding Mode Control Design

The surface to be used in designing terminal SMC is as follows:

$$S = e + \lambda \int |e|^{\frac{q}{p}} sign(e) \quad (36)$$

The surface derivative is calculated as follows:

$$\dot{S} = \dot{e} + \lambda|e|^{\frac{q}{p}} sign(e) \quad (37)$$

By changing the value of $\dot{e}$ in the previous equation, we get:

$$\dot{S} = -ae(t) + d(t) + \lambda|e|^{\frac{q}{p}} sign(e) \quad (38)$$

Using (S=0), the following new control law is obtained:

$$i_q^* = \left[ke - \beta sgn(S) - \lambda|e|^{\frac{q}{p}} sign(e) + a\omega_m^* + \dot{\omega}_m^* + f\right] \quad (39)$$

acknowledgement section may be presented after the conclusion, if desired.

IV. SIMULATION RESULT

This part presents the near investigation of the projected controller with different controller. In this fragment, we approve the proposed speed control techniques utilizing reenacted information. The point of this part is the confirmation of adequacy of TSMC (Terminal Sliding Mode Control) and MPTC (Model Predictive Torque Control) for torque control of three stage IM. Besides, relative appraisal is additionally done in this part.

The basic contribution of this paper is to evaluate the performance of the SMC and it enhance scheme for induction machine. The inverter switching and other system dynamics considered in this paper are conventional and based on published books. Therefore, only those results are presented, that evaluated and justifies the superior performance of the proposed controllers. Moreover, the simulated parameters are given as follows:

A. SIMULATION RESULTS OF PROPOSED CONTROLLER AND ITS COMPARISON

Figure 9 shows a speed range from (0 to 150) in radians per second is used in primary test to confirm the PI (Proportional Integral), SMC (Sliding Mode Control), and proposed regulator's speed following. Figure 9 shows how PI regulator completely connects at 0.5 sec. The overrun of the PI regulator speed waveform is 8 rad/sec. The SMC joins at a rate of 0.44 seconds. The SMC has a 0.2 rad/sec overshoot. At 0.43 seconds, the proposed regulator approves the rapid intermingling. The suggested regulator's overshoot has been completely eliminated. The proposed improved regulator completely eliminates the IM's speed overshoot, allowing the SMC to be upgraded using a TSMC computation, as shown in figure.9.

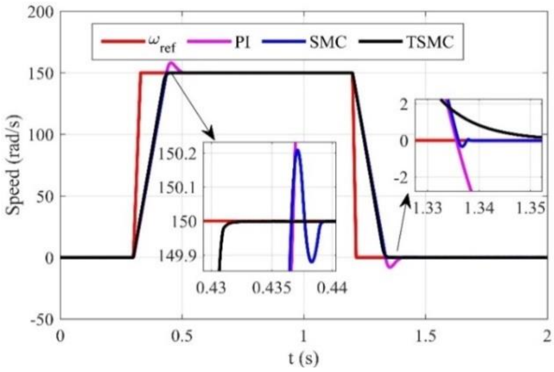

Figure 9. *PI, SMC, and Proposed TSMC Speed Response.*

Figure.10 shows the stator current for the PI, SMC, and TSMC regulators. It also indicates that the suggested regulator has eliminated some of the initial current waves. By reducing the current beginning waves, the proposed regulator has eliminated the overshoot in the traditional SMC.

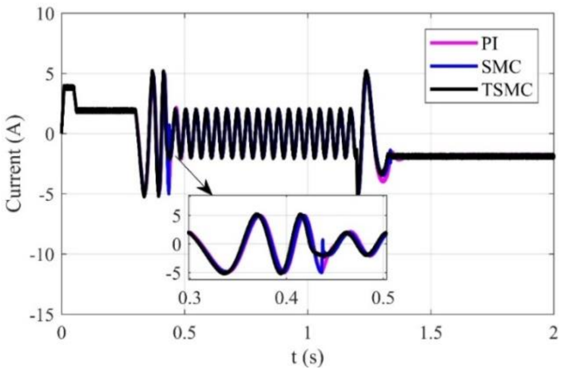

Figure 10. *Shows stator current of Proposed TSMC.*

Figure.11 show the individual speed responses of the TSMC controller.

With the reference speed ωref, the red line shows the reference speed and the black line shows the TSMC.

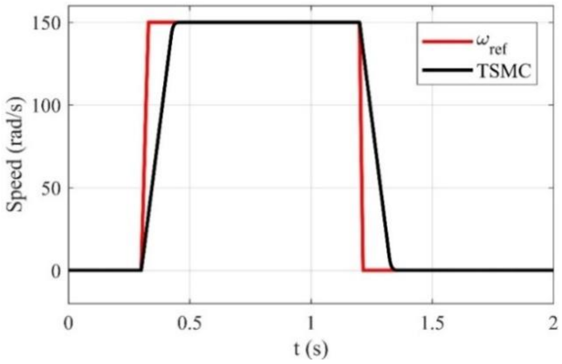

Figure 11. *Shows TSMC's speed response.*

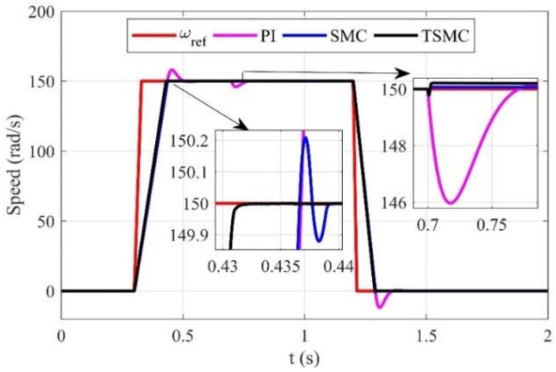

Figure 12. *The Figure Shows the Speed responses of the Proposed TSMC, SMC and PI in the presence of external load.*

Figure.12 shows a speed range from (0 to 150) in radians per second in which at 0.7 second a torque of 8 Nm was applied. In figure.12 the pink line shows the PI which is 4 (rad/s) undershoot and the blue line shows the SMC is 0.2 (rad/s) undershoot and the back line shows the TSMC which is 0.17 (rad/s) undershoot that's all at the applied load at 0.7s. Also, the convergence time for PI (0.7s) is more than SMC which is (2.5ms) and more than TSMC which is 1.5ms.

The below figure.13 depicts the current response of all three controllers as a function of load variation.

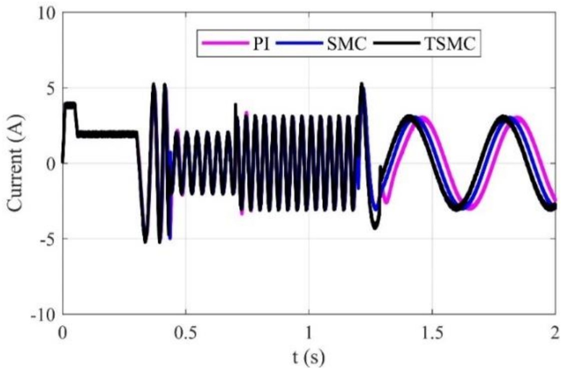

Figure 13. *Proposed TSMC Stator Current Under External Load.*

CONCLUSION

The sliding mode-based model predictive torque control technique improves the control strategy for Direct Torque Control (DTC) in induction motors. In Matlab/Simulink, various control techniques are analyzed and compared to the proposed control approach. A Terminal sliding mode-based MPTC for IM was presented in this thesis. Various control approaches for IM are implemented and critically examined, including PI, SMC, and TSMC controller-based model predictive control. The use of a TSMC-based Model Predictive Controller for rapid and quick dynamic torque response of an IM motor has been demonstrated through simulation results (MPC).

The PI controller, which is used for speed regulation and reference torque generation, is simple to implement and has less chattering, while the sliding mode controller offers the advantages of parameter change resilience and disturbance rejection. For parameter uncertainties and speed variation, the proposed control strategy has a higher performance validity than conventionally tuned PI control schemes. As a result, in the suggested control scheme, the PI controller is replaced by TSMC. In this thesis, the results of both controllers are analyzed and compared.

FUTURE WORKS

The suggested control approach will be used for transition, current, position, speed control, and vector control of the induction machine in the not-too-distant future. Furthermore, this strategy will be approved by a DSPACE test arrangement. Furthermore, the recommended robust control plans for the three-stage induction machine will be seriously considered.

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