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Predictive Speed And Flux Control Based Sensorless Sliding Mode Observer For Induction Motor Used In Electric Vehicle

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Abstract--- Electric vehicles are replacing popular conventional IC engine vehicles since they are having higher energy efficiency, maintenance free operation for customer and providing pollution free environment. Electric vehicle manufacturers are having many control strategies to overcome the limitations of traditional vehicles with recent advancements. The static and dynamic performance using Sliding Mode Observer for an induction motor in electric vehicle provides efficient torque to run the vehicle and its is discussed in this paper. To achieve efficient torque control and greater efficiency Direct Torque Control (DTC) based sensor less estimation technique of flux, torque, theta and speed with space vector pulse width modulation is proposed in this paper. This main aim of this work is the sensor less estimation design and simulation of a direct torque controlled induction motor drive system for torque ripple minimization and starting current minimization. The performance analysis of induction motor used in electric vehicle is simulated with MATLAB SIMULINK. The simulations are evaluated for dynamic speed variation conditions to validate the performance of the proposed approach.

Keywords--- Electric Vehicles, Induction Motor, Sliding Mode observer, Space Vector Pulse Width Modulation, torque ripple, sensor less estimation

1. INTRODUCTION

Electric vehicles are gaining its importance due to the reduction of greenhouse gas emissions. Electric vehicles, unlike regular vehicles, use an electric motor that is powered by electricity from batteries or a fuel cell. Hybrid Electric vehicles are propelled by an internal combustion engine and battery-powered electric motors have a better fuel economy and lower emissions. Plug-in electric vehicles are powered use the grid for power and store it in batteries [1, 2, 3].The electric vehicle's efficiency, affordability, maximum speed, and dependability are all influenced by the motors used. Electric motors used in electric vehicle applications include

DC, induction, permanent magnet synchronous, switching reluctance, and brushless DC motors [4]. Among the several technologies used, the induction motor is the most mature for EV applications. For greater efficiency and economy, energy optimization is a crucial factor to consider in electric vehicles [5][6]. On an electric vehicle, the various estimator techniques are used to evaluate the effects of speed fluctuations on motor properties such as stator resistance and inductance, as well as the magnet used in the rotor, especially at high speeds when the motor temperature is raised [7]. To make flux and speed estimation resilient to parameter changes, the m two sliding-mode current observers technique is employed. The stability theory based on current and flux observers are used to generate adaptive speed estimation [8]. The main drawbacks with traditional direct torque management of induction motor drives are excessive torque ripple and poor transient response to dynamic speed and torque changes during start-up [9]. The sliding mode observer is useful for estimating flux, torque, and speed. Sliding mode control reduces the initial current [10].

Sliding Mode Observer Design

Sliding mode observers have been developed to assess rotor speed of the induction motor used in the electric vehicle applications. The sliding mode observer appears to be a successful tool because of its successful results against simulated dynamics, insensitivity to variable modifications, ambient transient response, and quick dynamic reaction [11]. The three-phase stator currents are transformed from the three-phase reference frame to a diphase reference frame, and then to the rotating field frame (d-q) using the following method:

$$\begin{cases} \mathrm{i_{direct}} = \sqrt{\frac{2}{3}}\left(\cos(\hat{\theta})\mathrm{i_a} + \cos\left(\hat{\theta} - \frac{2}{3}\pi\right)\mathrm{i_b} + \cos\left(\hat{\theta} + \frac{2}{3}\pi\right)\mathrm{i_c}\right) \\ \mathrm{i_{quadrature}} = \sqrt{\frac{2}{3}}\left(-\sin(\hat{\theta})\mathrm{i_a} - \sin\left(\hat{\theta} - \frac{2}{3}\pi\right)\mathrm{i_b} - \sin\left(\hat{\theta} + \frac{2}{3}\pi\right)\mathrm{i_c}\right) \end{cases} \quad (1)$$

where i_a, i_b, and $i_c$signifies the three-phase stator currents, correspondingly, and $\hat{\theta}$represents the estimated flux angle. The feedback process of $\hat{\theta}$ is illustrated in Figure 6.1. As illustrated in the figure, V_d and V_q are engaged as feedback to the sliding mode observer.

(1) and (2), respectively, can be used to calculate the reference frame vector$\Psi_{estimated}$ and the torque generated by the machine, $\mathrm{T}_{estimated}$

The stator flux vector $\Psi_{estimated}$ and the torque generated by the machine $\mathrm{T}_{estimated}$ can be estimated with the help of (1) and (2), correspondingly.

$$\Psi_{\mathrm{sd}} = \int(\mathrm{V_{stad}} - \mathrm{R_{sta}}.\,i_{\mathrm{stad}})\,.\,\mathrm{dt} \quad (2)$$

Only the stator resistance $\mathrm{R_{sta}}$ and the number of motor poles p are required in the preceding formulae.

The magnitude of the supply winding flux is determined by

$$\Psi_{\mathrm{estimated}} = \sqrt{\left(\Psi_{\mathrm{stad}}{}^2 + \Psi_{\mathrm{staq}}{}^2\right)} \quad (3)$$

At this moment, with the stator flux and the diphase reference frame from the stator currents, together with the motor poles P, Torque is estimated depending on the equation below.

$$\mathrm{T_{est}} = \frac{3}{2}\,\mathrm{P}(\Psi_{\mathrm{stad}}.\,i_{\mathrm{staq}} - \Psi_{\mathrm{staq}}.\,i_{\mathrm{stad}}) \qquad (4)$$

where, Ψ_{stad}andΨ_{staq} represents the stator flux ; i_{stad} and i_{staq} represents the stator currents

Estimated Flux angle can be computed from the Equation given in (5).

$$\theta = \tan^{-1}\left(\frac{\Psi_{\mathrm{staq}}}{\Psi_{\mathrm{stad}}}\right) \qquad (5)$$

Sensor less Speed Estimation

The estimated stator flux must be translated into rotor flux based on the magnetising inductance as well as the auxiliary inductance per phase in order to determine the sensor less speed.

$$\Psi_{\mathrm{rotord}} = \frac{L_m}{L_r}\Psi_{\mathrm{stad}}; \qquad \Psi_{\mathrm{rotord}} = \frac{L_m}{L_r}\Psi_{\mathrm{staq}} \qquad (6)$$

Square of rotor flux,

$$\Psi_{\mathrm{rotor}} = \sqrt{{\Psi_{\mathrm{rotord}}}^2 + {\Psi_{\mathrm{rotorq}}}^2} \qquad (7)$$

The acquired rotor flux must be translated into, α_r, β_r coordinates, by use of the transfer function in order to determine the speed of the rotor field.

The rotor field's speed = $(\Psi_{\mathrm{rotord}} \times \Psi_{\mathrm{rotor}\beta r}) - (\Psi_{\mathrm{rotorq}} \times \Psi_{\mathrm{rotor}\alpha r})$ (8)

In addition, the above determined factor, with the intention of estimating the speed of rotor field, slip is essential in addition [12]. Slip is determined from the previously recognized torque and rotor resistance R_{rotor}in accordance with the equation,

$$slip = T_{estimated}\left(\frac{R_{rotor}}{2}\right) \qquad (9)$$

Sensorless electrical speed estimation

$$\omega_{estimated}{}^{(electrical)} = \frac{Speed\ of\ rotor\ field - slip}{(squre\ of\ rotor\ flux)}$$

At this instant, the electrical speed is transformed into the mechanical speed by using the following equation

$$\omega_{estimated}(electrical) = \frac{\omega_{estinated}(mechanical)P}{2}$$

(10)

Where P indicates the number of poles per phase.

Speed of rotor field is deducted from the slip and the result is divided by the square of the rotor flux. Therefore, in this paper, speed is approximated not including the speed position sensors which are the most fundamental contribution of this current research work. This paper exploits only the phase current dimensions to perform the sensor less speed evaluation [12]. As a result, in the paper, the sliding mode observer module decides the complete electrical (stator, rotor and mechanical) constraints of the motor, for instance, stator flux, magnitude of stator flux, theta, torque and electrical speed.

Speed and Torque Control

The discrepancy occurs between the estimated and set speeds; as a result, the necessary torque T_{ref} must be designed based on the speed PI adjuster, i.e.,

$$T_{ref} = (\omega_{set} - \omega_{est})\left(K_{p\omega} + \frac{K_{i\omega}}{S}\right) \qquad (11)$$

The PI adjuster's role is to perfect the speed across a limited range in order to ensure speed tracking accuracy and a stable state error.

Similarly, the derived reference torque and the predicted torque from the sliding mode observer are regulated using the torque PI regulator to accomplish the zero torque error for attaining the desired Vstaq.

$$V_{staq} = \left(T_{ref} - T_{estimated}\right)\left(K_{pT} + \frac{K_{iT}}{s}\right) \qquad (12)$$

Stator Flux Reference

$$\Psi_{ref} = \frac{\varphi ref * \omega b}{\omega_{estimated}} \qquad (13)$$

where $\omega b = 157\ rad/s$ denotes base speed; $\varphi ref = 0.95$. $\omega_{est}$is acquired from the sliding mode observer.

$$V_{stad} = \left(\Psi_{ref} - \Psi_{estimated}\right)\left(K_{p\varphi} + \frac{K_{i\varphi}}{s}\right) \qquad (14)$$

Similarly, to accomplish the required Vstad, the torque PI regulator manages the observed stator flux standard as well as the estimated stator flux from the sliding mode observer to obtain the zero flux error.

The acquired direct-quadrature frame voltages V stad and V staq are then recycled back to the sliding mode observer to estimate the induction motor's required electrical limitations [13, 14, 15].This test is carried out by measuring the current in the stator. The voltages V stad and V staq are transformed into a three phase voltage using the inverse park transformation, which is then fed into the Space Vector Pulse Width Modulation (SVPWM) [16, 17].

2. SIMULATION RESULTS

The proposed work is implemented in MATLAB/Simulink platform. The proposed system model shown in Figure 6.1 is evaluated for various dynamic conditions to measure the performance of the system.

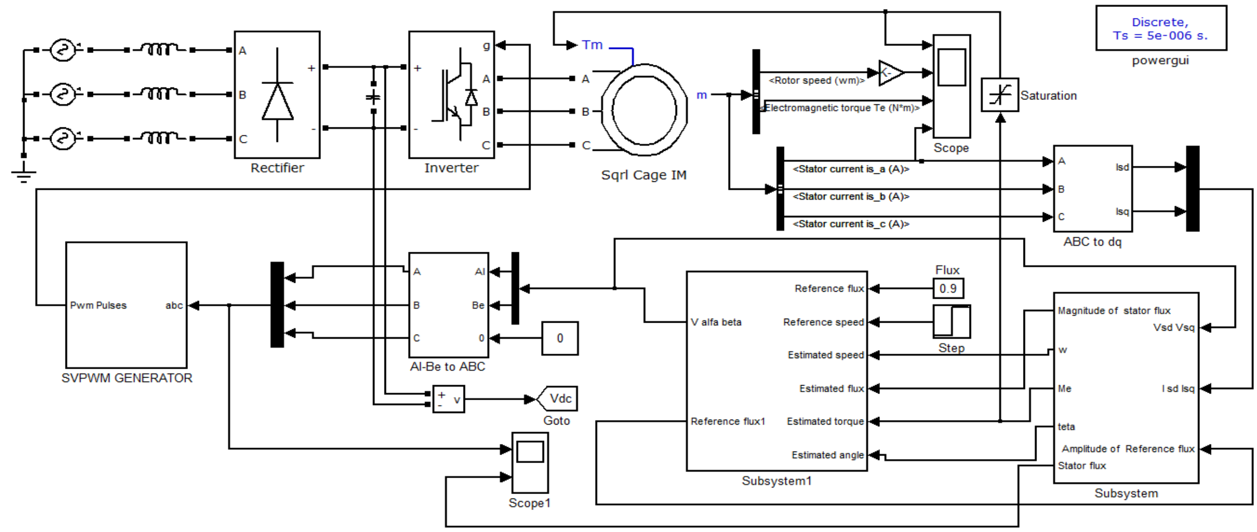


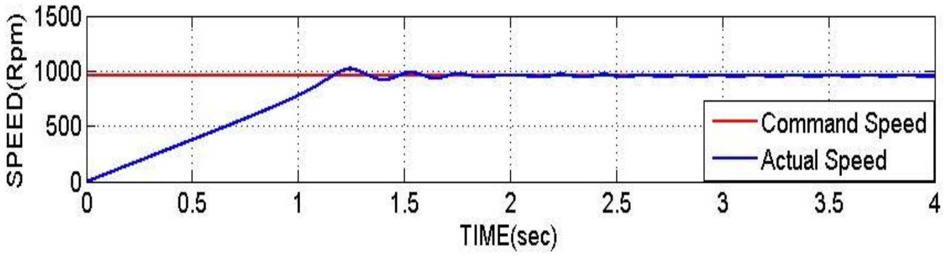
Figure 1 Simulation Circuit-DTC of Induction Motor with Sliding Mode Control

The proposed analysis is based on the normal speed and torque control of induction motor, sudden change in speed variation, Minimizing the starting current and torque ripple minimization. The simulation parameters are shown in Table 1.

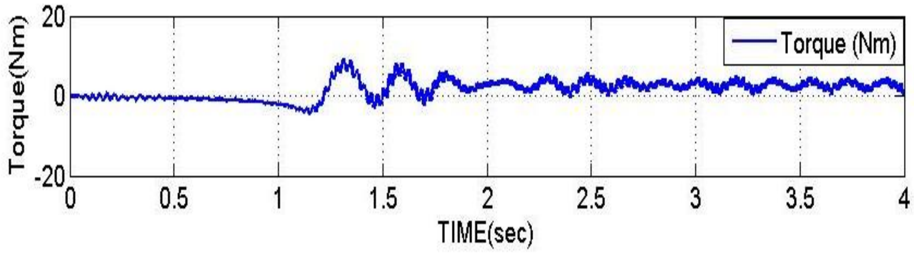
Table 1 Induction motor design parameters for DTC using slide mode NPC

Parameters	**Rating**
Input Supply	50Hz,4 kW, 400 V, 155 rad/s
Poles	2
Rating of the motor	5
Stator Rsta and Rotor resistances Rrotor	Rs = 0.5 ohms, Rr = 0.25 ohms
Stator Lsta and rotor Lrotor self inductances	Ls = 0.0415; Lr = 0.0412 H
Mutual Inductance between stator and rotor Lm	Lm = 0.0403 H

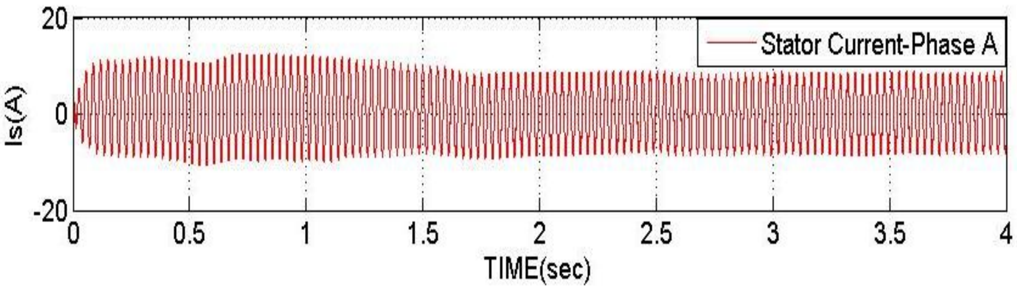
Figure 6.2 shows the proposed system response for a set speed of 100 rad/s speed condition. It is clearly observed from the figure that, at 1.25 seconds, the speed gets settled after the acceleration from 0 to 1.24 seconds.



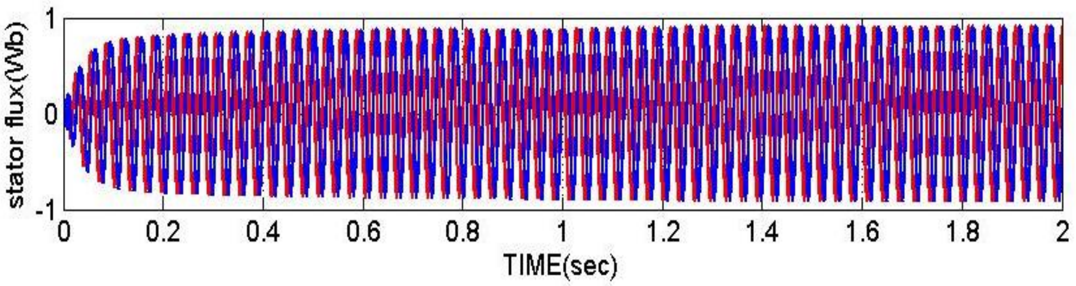
(a) Speed



(b) Torque



(c) Stator Current



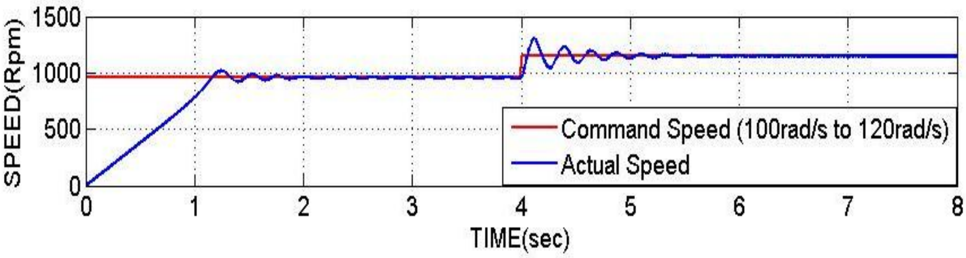
(d) Stator Flux

Figure 2 Proposed System Response for 100 rad/s speed condition

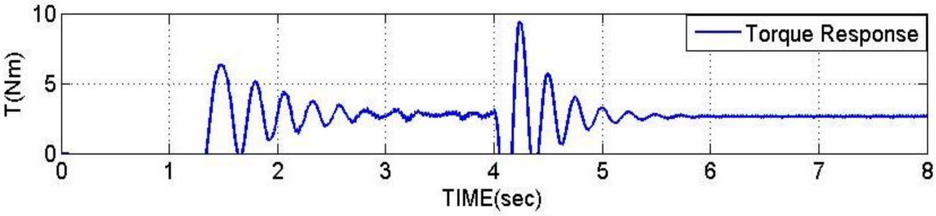
Figure 2 (a) shows the command and the actual speed response. At this instant, the corresponding torque response is shown in Figure 2(b) wherein the torque gets settled at 1.25 seconds after the gradual acceleration. The stator current is shown in Figure 2(c) with 10 Amps current. Similarly, stator flux response estimated by the sliding mode observer is shown in the Figure 2(d) which is 0.9Wb.

Figure 3 shows the proposed system response under dynamic speed change condition. At, 4 seconds, the speed is increased from 100 rad/s to 120 rad/s. Figure 3 (a) shows the response of the proposed system at this sudden change in speed variation condition. The system settles at 120 rad/s after the sudden change at 4 seconds. Figure 3 (b) shows the torque response of the proposed system during sudden speed variation.

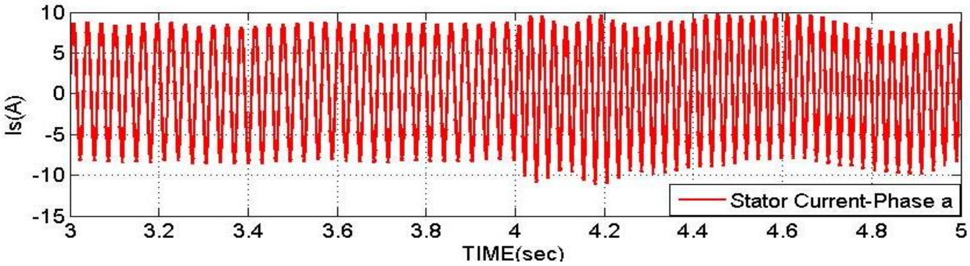
Initially, there is slight fluctuation in the torque response but, it settles after 5 seconds based on the speed variation. Figure 3 (c) shows the stator current the during sudden speed variation. Initially, the stator current is maintained at 9 Amps. During speed change at the instant 4 seconds, there is slight deviation in the speed variation, but the stator current gets controlled which is clearly shown. Figure 3 (d) shows the stator voltage response during sudden change in speed. At the time instant of 4 seconds, the stator voltage gets increased correspondingly due to the speed variation.



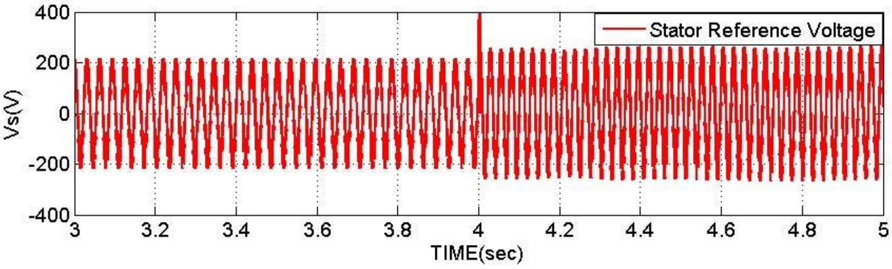
(a) Speed Response



(b) Torque



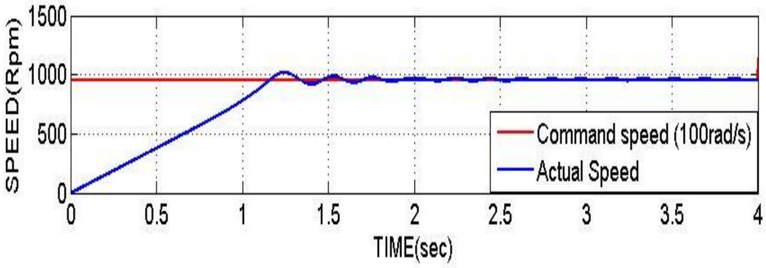
(c) Stator Current Response



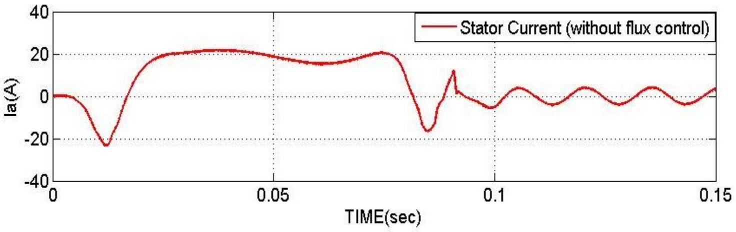
(d) Stator Voltage

Figure 3 Proposed System Response during speed change

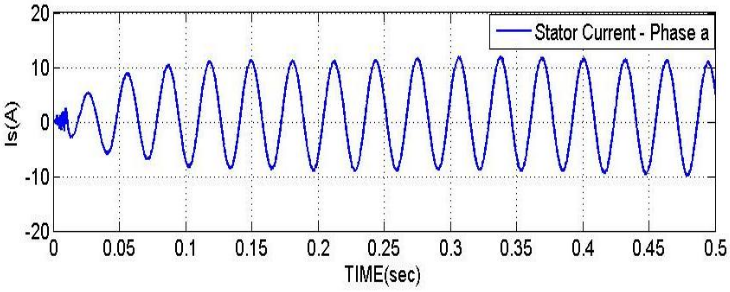
Figure 4 shows the drive response for starting current minimization. Figure 4 (a) shows the actual and command speed. Figure 4 (b) shows the stator current without the flux control. It is observed from the figure that, there are deviation and uncontrolled response till 1 second. Figure 4(c) shows the stator current with sliding mode control, wherein there is initial decreased current and then, there is gradual increase in the current. Figure 4 (d) shows the actual and the command flux. The command flux response is set at 0.9 Wb, it is observed that, with the gradual increase in the flux, the flux gets established after 1 second.



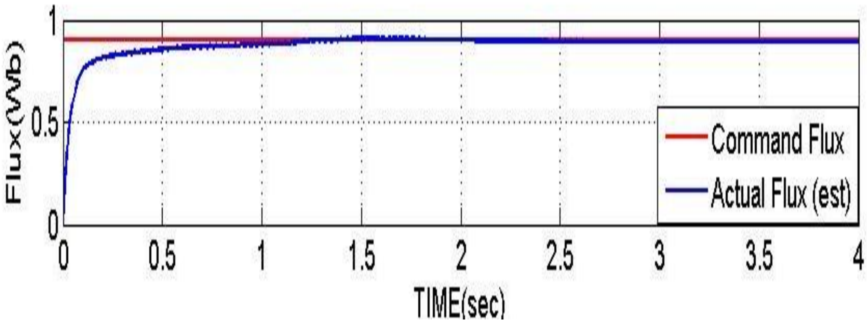
(a) Speed Response



(b) Stator Current without sliding mode control



(c) Stator Current with sliding mode control



(d) Stator Flux

Figure 4 Proposed System Responses for Starting Current Minimization

Figure 5 shows the torque response of the proposed system for minimizing the torque ripples. In The conventional approach, torque response shows larger deviation whereas the proposed scheme the steady state toque error is reduced.

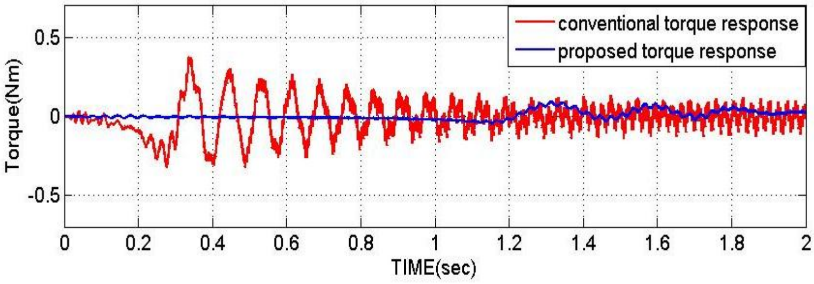


Figure 5 Proposed System Torque Response

3. CONCLUSION

A predictive speed and flux control with Sensorless estimation of speed, torque, theta and flux using sliding mode observer was proposed. The limitations of the conventional DTC methods are overcome in this work through Sensorless estimation with SVPWM technique. The result shows that the proposed system attains lesser torque ripple for various dynamic speed conditions. The proposed system provides significant results for starting current minimization wherein there is gradual increase in the stator current.

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