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Reduction of torque ripples using the DTC-SVM method in PMSM with extended Kalman filter

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ABSTRACT

A detailed analysis has been conducted on two motor control algorithms: direct torque control (DTC) and field-oriented control (FOC). There are two ways that a voltage source inverter (VSI) can regulate a permanent magnet synchronous motor (PMSM). When using the PMSM and voltage source inverter (VSI), dead time is employed to turn off both the upper and lower switches to prevent short circuits. However, by supplying the PMSM with unexpected polarity voltages at the VSI output voltage, this switching technique reduces distortion. It is challenging to utilize the sensor to directly detect the fault voltage that results in an open circuit. This work examines the nonlinearity of the electric power controller during dead time during PMSM operation using the DTC algorithm to increase control stability. The stress distribution is estimated using an extended Kalman filter (EKF). Ultimately, the model presented in this study verified the increase in stator current and torque output through simulations and testing.

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1. INTRODUCTION

In motor control, the two most talked-about topics are direct torque control (DTC) and field-oriented control (FOC). Since the 1980s, DTC algorithms have been developed. In the early years of the asynchronous motor business, DTC algorithms were commonly utilized. Synchronous motors started to operate using DTC algorithms as high speed and performance became more and more important in the automobile sector. The DTC algorithm is a technique to manage the motor torque and flux that makes use of a hysteresis controller as the switch and a look-up table (LUT) of the stator flux command with the torque command value [1]-[3]. The torque curve of the conventional DTC method, however, is unable to maintain the angle between the stator and rotor fluxes when the hysteresis controller and LUT are employed. There are numerous control solutions employed to address the issue of the device's continual rotation. Among these is the integrated direct torque control space vector modulation (DTC-SVM) technique, which maintains the load angle directly with the stator flux [4]-[9]. The purpose of a DTC-SVM control approach is to regulate torque by improving the accuracy of the stator current. To achieve accurate control, DTC-SVM needs a precise estimation of the stator flux's amount and state. The majority of DTC-SVM algorithms estimate the stator flux and state based on the motor and current characteristics. Lastly, the inverter voltage source (VSI) sensor is installed to monitor the motor's three-phase current value and calculate the stator flux magnitude. By including noise and measurement, it is impossible to determine the precise location and value of the stator current, which can lead to torque drift or inadequate control [10]-[12]. When opening and closing VSI switching points, different techniques have been employed to shorten the time needed to avoid short circuits [13]-[18]. While employing the FOC algorithm, the majority of these techniques modify the time difference according to the current orientation. Furthermore, the voltage produced by the current transformer's diodes which includes the inverter's MOSFETs and IGBTs does not enter the associated charging process. The circuit breakers diode voltage loss was also measured in a subsequent investigation, although the precise figure was not immediately known [19]. Lastly, the extended Kalman filter, or extended Kalman filter (EKF), is not a reliable way to detect voltage current. This DTC control probe corrects for this issue. The Kalman filter technique has been the focus of constant research since it was first applied to synchronous motors in 1983 [20]. Numerous permanent magnet synchronous motor (PMSM) algorithmic domains have been the subject of an ongoing investigation into the Kalman filter [21]-[23]. Furthermore, research is being conducted on the Kalman filter approach [24]-[26]. Using the FOC algorithm, physical therapy has been the subject of the majority of investigations. This work proposes a method of calculation utilizing a continuous Kalman filter and investigates the regression produced by the DTC algorithm. The usefulness of the suggested method has been demonstrated by comparison, and the controller's performance has improved.

2. DTC–SVM method implementation in PMSM

An alternating current (AC) synchronous motor excited by a sinusoidal electromagnetic field (EMF) wave and a permanent magnet is known as a permanent magnet synchronous motor (PMSM). A hybrid form of an induction motor and a brushless DC motor is the PMSM. Its permanent magnet rotor and stator winding are similar to those of a DC brushless motor. Nonetheless, the coil arrangement in the stator creates a sinusoidal current density in various air currents, and the stator construction is comparable to a synchronous motor. The energy density of the stator is larger than that of comparable-priced induction motors because the energy is not dispersed to produce a magnetic field. PMSM generates energy at zero speed using permanent magnets; however, it needs a digital device to function. High-performance devices frequently have PMSM installed. The characteristics of a high-performance engine include acceleration from zero speed, torque control across the engine speed range, and acceleration from zero speed. PMSM provides this control through the use of vector control technology. Another word that's frequently used to characterize vector control techniques is field-oriented control (FOC). The vector control algorithm's basic concept is to split the stator into two halves, one of which produces torque and the other of which produces magnetism. When separated, each object can be controlled separately.

The power control value and stator flux control value are given to the control module in a manner as in to the standard DTC procedure. The DTC-SVM controller, however, does not utilize a proportional integral (PI) controller but instead a hysteresis controller to output the erroneous torque value based on the command angle δ^*. Furthermore, by estimating the motor current and stator current, the stator flux controller generates an angle instruction that permits the output of the stator current. Using the current angle and voltage command angle from the stator flux controller, the SVM receives the stator voltage vector command value and angle command value. The difference between the stator's current position produced by the DTC-SVM algorithm and the DTC-SVM control block diagram created by the conventional DTC approach is depicted in Figure 1.

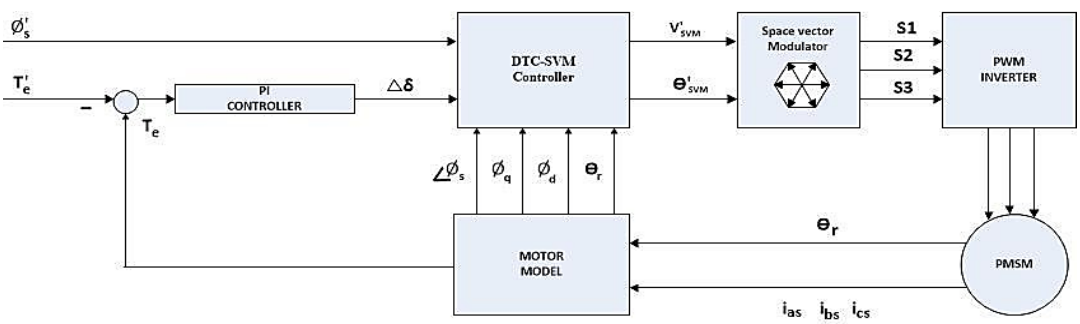

Figure 1. Block diagram of the DTC-SVM control technique

The vector load angle, denoted by δ, might stay unchanged. If the stator current is over estimated due to the δ* error, torque divergence will arise from an incorrect assessment. The DTC-SVM approach maintains a constant angle θ and enables the stator flux to be positioned in a position vector by alternating the states of the six switches in a single cycle.

3. APPLICATION OF EXTENDED KALMAN FILTER IN PMSM CONTROL

R. E. Kalman created the Kalman filter in 1960. The Kalman filter has been the subject of extensive study and useful applications as a result of developments in digital computing. Kalman filters are used in many ways, including in weather, manufacturing, and navigation. The Kalman filter is a technique used to remove missing data from indirect (and noisy) measurements. It creates an ideal dynamic system for understanding the statistics of both linear and discrete (minimum variance) audio components. Figure 2 depicts the Kalman filter's construction. EKF is a great iteration technique for estimating the state of dynamic, nonlinear systems and is based on the least squares method. Put otherwise, it is a cumulative approximation of the state probability distribution of a stochastic system with measurement noise and a random Gaussian process. Since the state model is nonlinear, EKF can be used to predict the state transition. In this case, the back EMF is treated as a transition state. A discrete nonlinear model with noise given as (1).

$$\begin{cases} x(k+1) = F(x(k), u(k)) + w(k) \\ y(k) = h(x(k) + v(k) \end{cases} \quad (1)$$

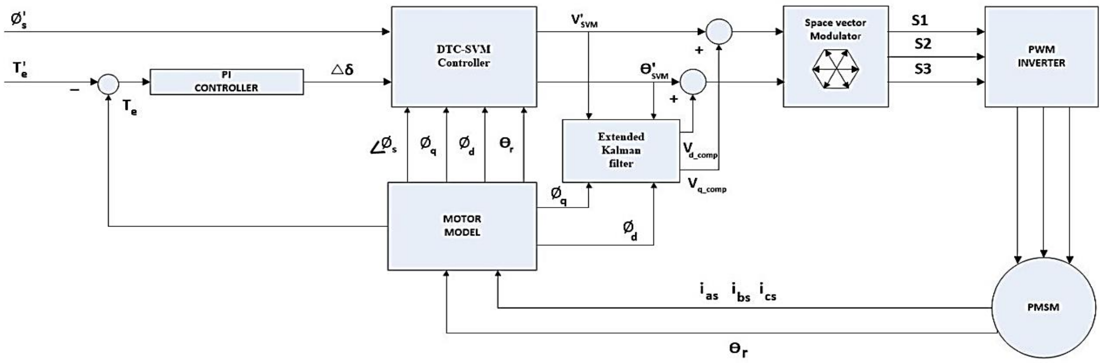

Figure 2. Block diagram of DTC-SVM control using Kalman filter-based extended fault observer design

4. RESULTS AND DISCUSSION

The simulation results illustrate that the motor cannot be made to change speed when the load varies once it reaches a fixed value. The space vector pulse width modulation (SVPWM) method also increases the PMSM settling time. The speed characteristics of the machine are as shown in Figure 3. Before additional torque occurs, a 30N-M torque is applied to the motor after 0.2 seconds, followed by a delay of 0.01 seconds and 10% ripples as shown in Figure 4. Firstly, the motor draws approximately 20A of peak overshoot current as shown in Figure 5. After applying Kalman filter algorithm, with a delay of 0.001 after 0.2 seconds, which yields 3% ripples as shown in Figure 6 and with delay of 0.25 seconds, when the motor is stable, it uses approximately 7 A of overshoot current. So, after 0.25 seconds, PMSM will consume about 7 A of current as shown in Figure 7.

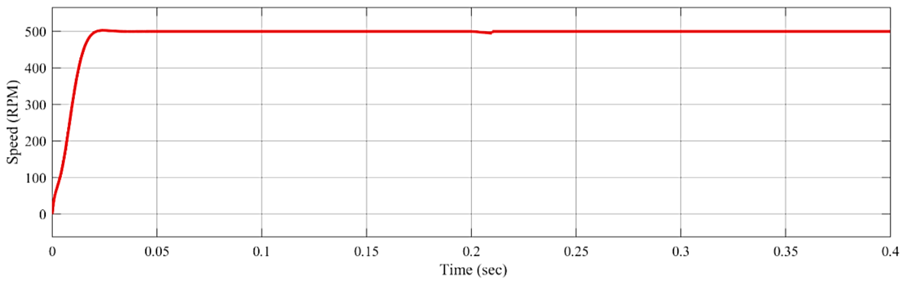

Figure 3. Speed of PMSM without Kalman filter

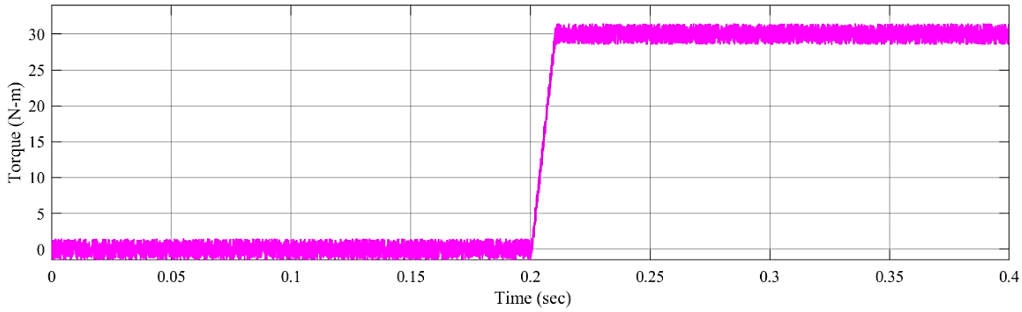

Figure 4. Torque without using Kalman filter

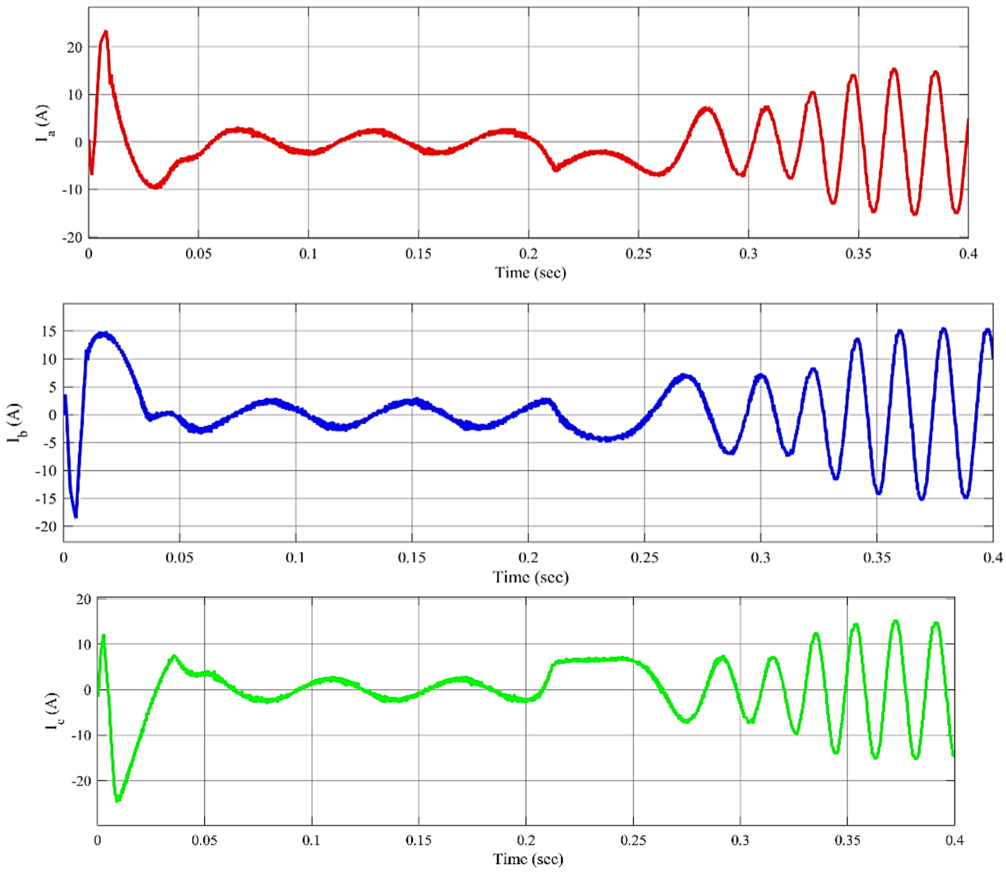

Figure 5. 3-phase stator current without using Kalman filter

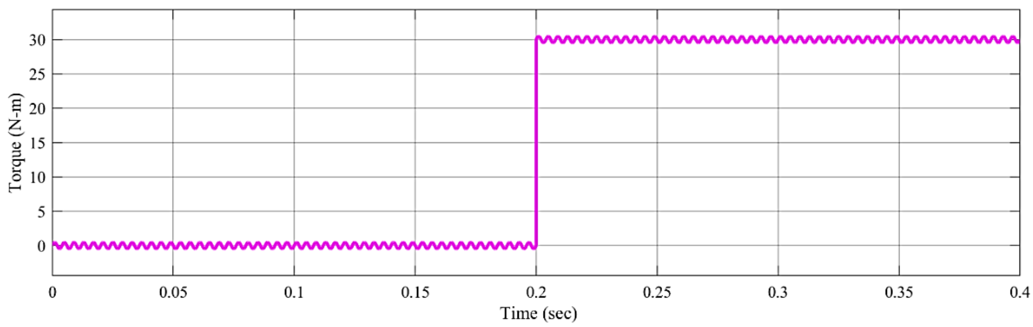

Figure 6. Torque characteristics with Kalman filter

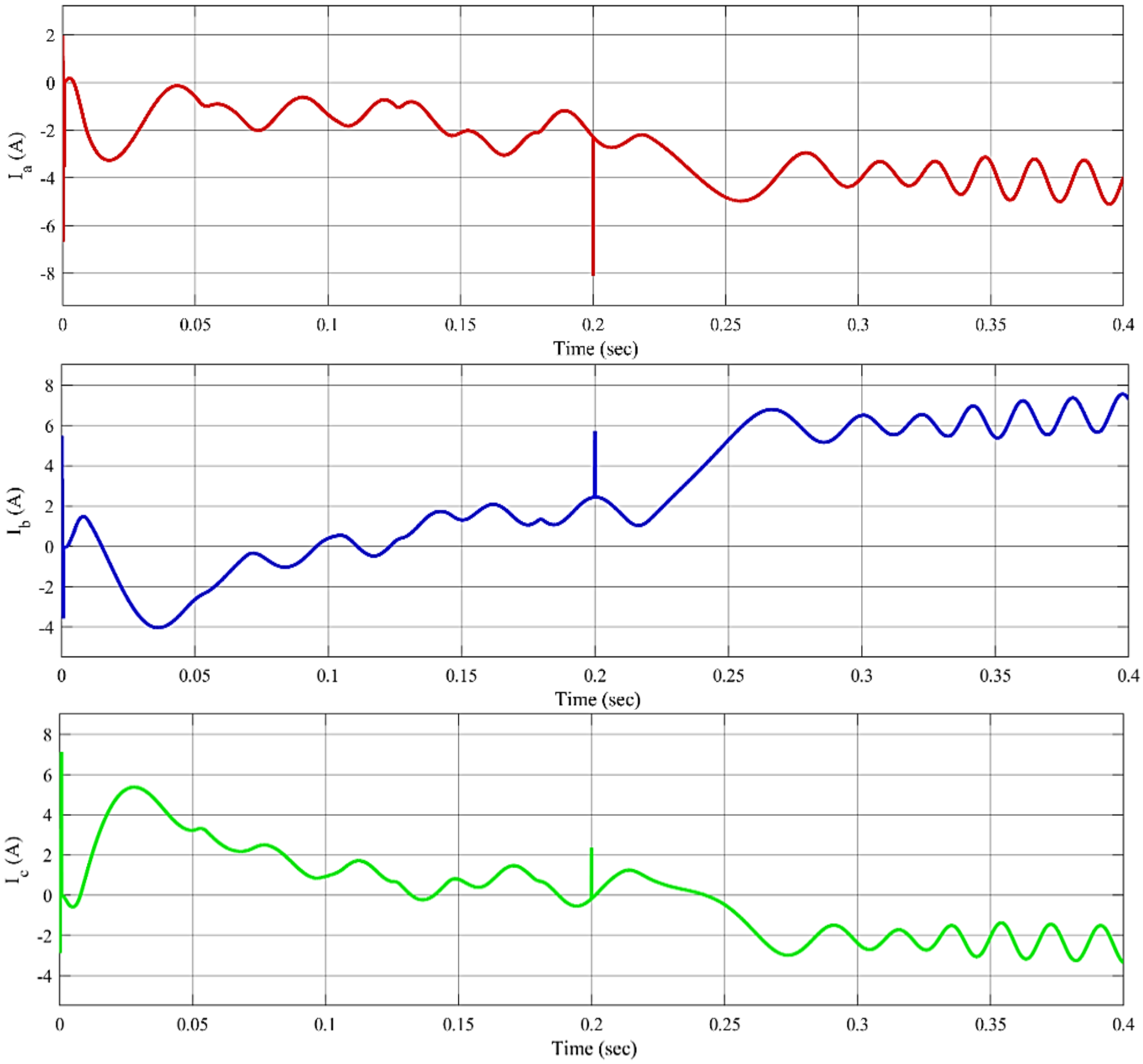

Figure 7. 3-phase stator current using Kalman filter

From the results obtained as shown in Table 1, the torque ripple can be decreased by 7% and the peak over shoot of the stator current can be reduced to 7A. The peak-to-peak ripple value of the stator current can be reduced up to 40% by applying a Kalman filter. The comparison of different parameters before and after the implementation of the Kalman filter is shown in Table 1.

Table 1. Parameters of PMSM with and without using Kalman filter algorithm

Parameters	Without Kalman filter	With Kalman filter
Torque ripples	10%	3%
Peak overshoot of stator current	20 A	7 A
Stator current ripple	2.4	0.6

5. CONCLUSION

This function introduces EKF's speed sensor for speed control (DTC) to estimate rotor position and speed. The algorithm works at various speeds. The results of the Simulink model of DTC–SVM speed control-based PMSM are verified. Various parameters like speed, stator current, and torque characteristics of PMSM are analyzed both with and without the Kalman filter. There is a significant improvement in various parameters like reduction in torque ripple, decreased magnitude of peak overshoot stator current, and reduced ripple in the stator current by implementing the Kalman filter. This improves the performance of PMSM and hence further can be extended by using various intelligent controllers like neural and fuzzy controllers.

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