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Permanent Magnet Synchronous Motor Flux Observer Implementation with TI F28335 DSP for Electric Vehicle System

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Abstract – This study represents a flux observer application for permanent magnet synchronous motor (PMSM) based electric vehicle (EV) system. Getting rid of speed sensors is very important for reducing EV cost. Firstly, motor control algorithm and observer algorithm are written on Simulink environment and download to TI F28335 DSP over USB by using Simulink Embedded Coder. Then the system is tested at variable speed which is changes every 10 seconds. The results show the performance of the flux observer estimation. It is seen that the flux observer successfully estimates the actual speed in most areas only expect for transients. The effectiveness of flux observer is proven via experimental results.

Keywords – PMSM, Flux observer, Simulink, DSP, Electric vehicle

I. INTRODUCTION

In an era of rapidly advancing technology and growing environmental concerns, the automotive industry has witnessed a transformative revolution with the advent of Electric Vehicles (EVs). Gone are the days when gasoline-powered engines solely ruled the roads, as EVs have emerged as a promising and sustainable alternative, paving the way towards a cleaner, greener future [1]. At its core, an Electric Vehicle is an automobile that relies on electricity as its primary source of propulsion. Unlike conventional internal combustion engine vehicles, which heavily rely on fossil fuels and emit harmful pollutants, EVs harness electric power to drive their wheels, producing zero tailpipe emissions. This fundamental shift from traditional energy sources to electricity has opened up new horizons for transportation and sustainability.

The PMSM is a type of electric motor that has gained widespread popularity in the EV domain due to its exceptional efficiency, high power density, and seamless control capabilities [2–4]. Unlike traditional internal combustion engines, PMSMs operate on the principles of electromagnetism, leveraging permanent magnets to generate a rotating magnetic field and produce motion without relying on direct physical contact [5,6]. One of the key features that distinguish PMSMs from other electric motor types is their synchronous operation, wherein the rotor and the rotating magnetic field of the stator move at the same speed. This synchronicity ensures optimal performance, minimized energy losses, and enhanced overall efficiency, making PMSMs an ideal choice for the demanding requirements of modern EV propulsion.

The PMSM speed observer, also referred to as a speed estimator or sensorless control system, is an advanced algorithmic approach designed to accurately determine the rotational speed of the motor's rotor without the need for physical speed sensors [7]. Traditionally, speed control in PMSMs relied on feedback from sensors, such as encoders or resolvers, which provided direct measurements of the rotor's speed. However, the integration of sensors adds complexity, cost, and potential points of failure to the system. In contrast, the speed observer offers an elegant and cost-effective alternative, ushering in a new era of sensorless control strategies. At its core, the PMSM speed observer leverages mathematical models, signal processing techniques, and advanced control algorithms to estimate the rotor speed based on available electrical signals and motor parameters. By analyzing the motor's electrical variables, such as voltages and currents, and comparing them with the expected behavior derived from the model, the observer can deduce the rotor speed with remarkable accuracy and precision.

The Flux Observer is a key component in the control and performance optimization of PMSMs. As the name suggests, it is an advanced algorithmic technique designed to estimate the magnetic flux within the motor without the need for physical sensors [8]. By analyzing the motor's electrical variables, such as voltages and currents, and incorporating mathematical models and control algorithms, the Flux Observer can accurately deduce the magnetic flux within the motor in real-time. This information is crucial for precise control of the motor's torque and speed, leading to improved efficiency and dynamic performance [9]. The Flux Observer's ability to operate in a sensorless manner reduces cost, complexity, and potential points of failure in PMSM control systems, making it an indispensable tool in the advancement of sensorless motor control strategies and contributing to the widespread adoption of electric propulsion systems.

The aim of this study is successfully implementing the flux observer algorithm to PMSM system with TI F28335 DSP by using Simulink.

II. System Description

dq axis currents of PMSM (i_d and i_q) can be expressed as below [10].

$$\dot{i}_d = -\frac{R_s}{L_d} i_d + \omega_e \frac{L_q}{L_d} i_q + \frac{1}{L_d} v_d \tag{1}$$

$$\dot{i}_q = -\omega_e \frac{L_d}{L_q} i_d - \frac{R_s}{L_q} i_q - \omega_e \frac{\lambda_f}{L_q} + \frac{1}{L_q} v_q \tag{2}$$

In Eq. (1) and (2), v_d and v_q are the dq axis voltages, R_s is the stator resistance, L_d and L_q are the dq axis inductances, λ_f is permanent magnet flux linkage, and ω_e is electrical angular speed. Electromagnetic torque equations can be written as follows.

$$T_e = K_t i_q \,, \quad \left(K_t = \frac{3p}{4} \lambda_f \right) \tag{3}$$

$$T_e = J\dot{\omega}_r + B\omega_r + T_L \tag{4}$$

Where p is the pole pairs, ω_r is the rotor speed, J is the inertia of rotor, B is the friction factor, and T_L is the load torque.

Block diagram of PMSM system is given in Fig. 1. and experimental setup is presented in Fig. 2.

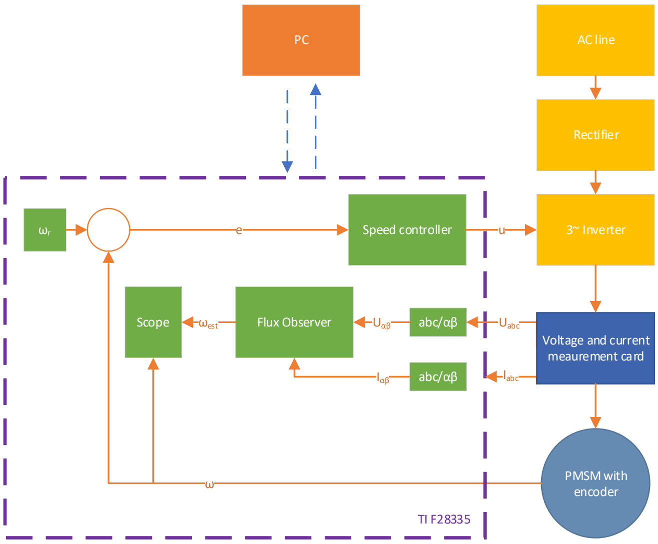

Fig. 1 Block diagram of PMSM system

Fig. 2 Experimental setup

The experimental setup consists of a 400 W PMSM, a rectifier, an inverter circuit, a voltage and current measurement card, TI F28335 DSP, and a PC. PMSM parameters are presented in Table 1.

Table 1. PMSM parameters

Parameter	Value
Rated voltage	200 V
Rated current	2.8 A
Frequency	200 Hz
Stator resistance	2.7 Ω
dq-axis inductances	8.5e-3 H
Permanent magnet flux	0.0615 Wb
Rotor inertia	31.69e-6 kg.m^2
Friction factor	52.79e-6 N.m.s/rad
Pole pairs	4

III. Flux Observer

In this study, PMSM speed is estimated with using Flux Observer (FO). In FO, voltage and current values are used in stationary αβ reference frame. Rotor flux equations in αβ frame are given below.

$$\psi_\alpha = \int\left(V_\alpha - I_\alpha R_s\right)dt - \left(L_s \cdot I_\alpha\right) \quad (5)$$

$$\psi_\beta = \int\left(V_\beta - I_\beta R_s\right)dt - \left(L_s \cdot I_\beta\right) \quad (6)$$

Here V_α and I_α are αβ axis components of voltage and current, respectively. R_s is the stator resistance, L_s is the stator inductance. Electromagnetic torque, electrical position equations are given in Eq. (7) and (8). Rotor speed is defined in Eq. (9).

$$T_e = \frac{3}{2} \cdot p \cdot \frac{L_m}{L_r}\left(\psi_\alpha I_\beta - \psi_\beta I_\alpha\right) \quad (7)$$

$$\theta_e = \tan^{-1}\frac{\psi_\beta}{\psi_\alpha} \quad (8)$$

$$n = \theta_e \frac{d}{dt} \cdot \frac{2\pi}{60} \quad (9)$$

Where p is the pole pairs, L_r and L_m are rotor and magnetizing inductances. n is the rotor speed as revolutions per minute (RPM).

IV. Experimental Results

All written algorithms are prepared on Simulink [11–13], compiled with using Simulink Embedded Coder [14,15], and downloaded to DSP over USB emulator. FO is tested on the experimental setup which is given in Fig. 2. Motor speed is changed every 10 seconds with PID speed controller [16,17]. Actual speed (Act) and FO speed estimation outputs are compared. The results are illustrated in Fig. 5.

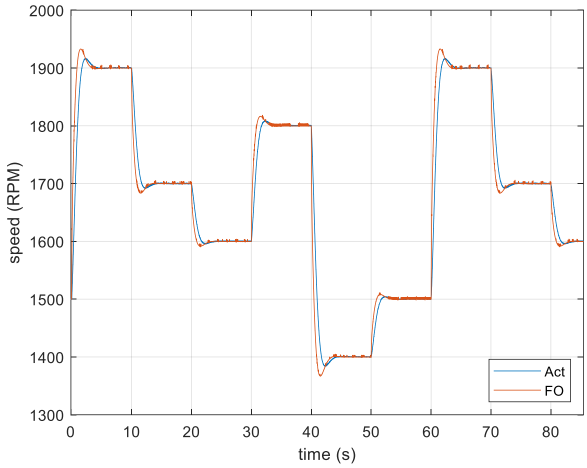

Fig. 5 Test results

In Fig. 5, FO successful estimates the speed in most areas, especially flat ones. Accuracy is lowers in transient areas because of suddenly changing currents.

V. Conclusion

In this study, a flux observer model is implemented for PMSM speed estimation in EV system. Speed controller and observer algorithms are prepared on Simulink environment and download to DSP via Simulink Embedded Coder. The system is tested with variable speed is changes every 10 seconds. Then the obtained data are examined. Flux observer estimates effectively almost all areas, except for transient areas which is cause by phase currents. As a result of the study, the idea that there is no obstacle to the use of flux observers in EVs to reduce costs emerges.

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