A DSP-Based Torque Monitor for Induction Motors

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I. INTRODUCTION

Induction motors dominate industrial drives and their domestic, vehicular, and military applications are on the rise. Induction machines are robust, simple, and inexpensive, requiring only minimum maintenance. Although most induction motors still run uncontrolled, adjustable speed induction motor drives enjoy rapid growth. A torque feedback signal is needed in most of these drives. Direct torque sensors are impractical and an estimate of the developed torque must be derived from voltage and current measurements. Estimation of torque in uncontrolled motors is valuable too, providing important information about operating conditions and degree of utilization of the motor. Torque estimation algorithms require substantial signal processing, best performed by DSPs [1]-[4].

This paper presents a torque monitor for both controlled and uncontrolled induction motors, based on the TMS320F24x DSP platform. The algorithm of estimation of stator flux and developed torque is described. Details of implementation and test results for a fractional-power motor are given.

II. OPERATING ALGORITHM

The torque monitor is based on the well-known equations of the induction motor, some of which are shown directly in the subsequent block diagrams. First, the actual phase voltages, v_a and v_b, and currents, i_a and i_b, are converted into the d and q components of the voltage and current vectors, $\underline{v}_s$ and $\underline{i}_s$, as illustrated in Fig. 1.

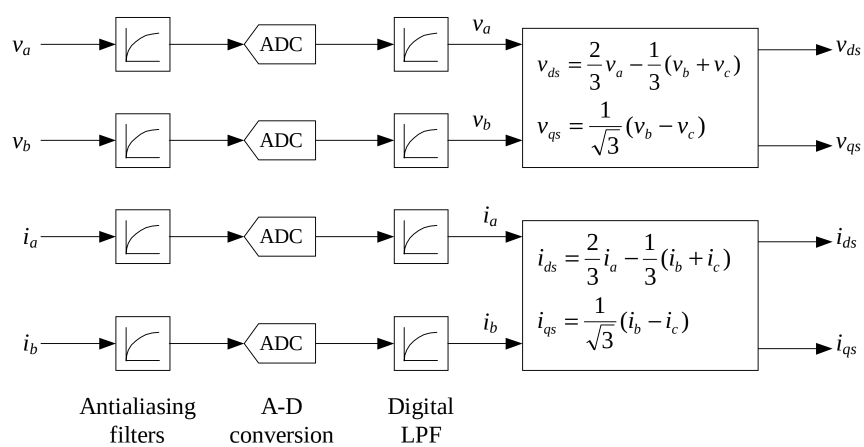

Fig. 1. Voltage and current measurement and pre-processing.

The electromagnetic torque, T_e, developed in the induction motor can be calculated using space vectors, $\underline{i}_s$ and $\underline{\psi}_s$, of the stator current and flux, as shown in Fig. 2, where p denotes the number of poles of the motor.

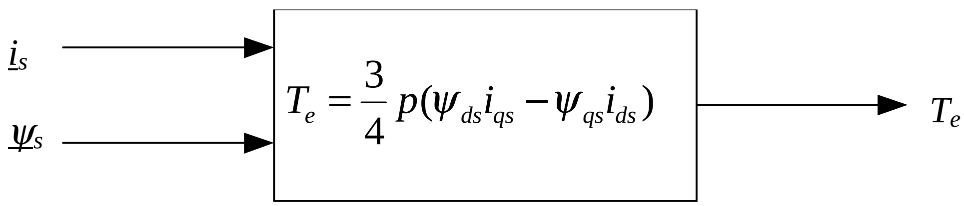

Fig. 2. Electromagnetic torque calculation.

The major difficulty consists in accurate estimation of the stator flux, which is a time integral of the stator EMF, calculated by subtracting the voltage drop across stator resistance, R_s, from the stator voltage vector, $\underline{v}_s$. Direct integration is impractical because of the offset and initial condition problems [5].

The flux estimator, shown in Fig. 3, is a full-order MRAS observer [6]. It allows accurate estimation of vectors of both the stator flux, $\underline{\psi}_s$, and rotor flux, $\underline{\psi}_r$ (knowledge of the latter vector can be used in estimation of speed of the motor).

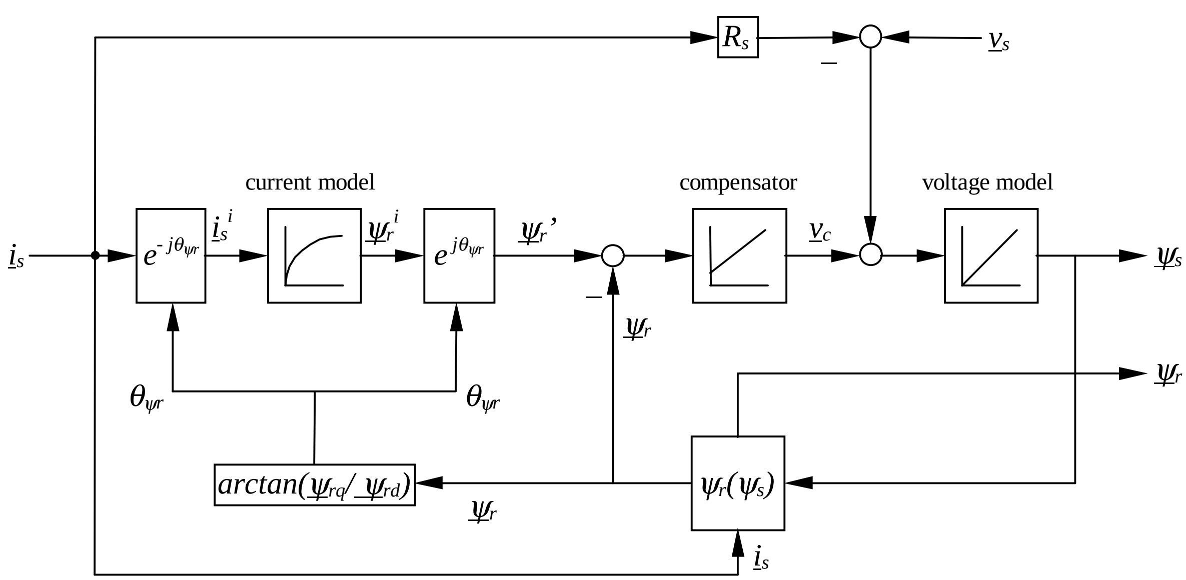

Fig. 3. Stator and rotor flux estimation.

The "current model" block is described by equations

$$\psi_{dr}^{i} = \frac{L_m}{(1 + sT_r)} i_{ds}^{i} \qquad (1)$$

$$\psi_{qr}^{i} = 0 \qquad (2)$$

and the "voltage model" block performs integration of the input signal. The rotor flux vector is obtained from the stator flux, $\underline{\psi}_s$ and stator current, $\underline{i}_s$, vectors as

$$\underline{\psi}_r = \frac{L_r}{L_m} \underline{\psi}_s - \frac{L_s L_r - L_m^2}{L_m} \underline{i}_s \, . \qquad (3)$$

The adaptation mechanism in the compensator uses the rotor flux, $\underline{\psi}_r$', generated in the current model and the rotor flux, $\underline{\psi}_r$, produced by the voltage model. The output signal, v_c, of the compensator is given by

$$\underline{v}_c = (K_P + K_I \frac{1}{s}) (\underline{\psi}_r - \underline{\psi}_r ') \qquad (4)$$

where 1/*s* denotes the integration operator, and

$$K_P = \omega_1 + \omega_2 \, , \quad K_I = \omega_1 \cdot \omega_2 \, . \qquad (5)$$

It has been found that the best performance of the flux estimator corresponds to $w_1 = 2 - 5$ rad/s and $w_2 = 20 - 30$ rad/s.

III. EXPERIMENTAL SETUP AND RESULTS

The experimental setup of the torque monitor is shown in Fig. 4. The flux and torque estimation algorithms are implemented in a TMC320F243 evaluation module (EVM). A 230-V, 0.75-hp induction motor, loaded with a dc generator, is supplied directly from the utility line. The setup is controlled from a personal computer and the input/output module allows reading selected motor variables at a digital display. The analog interface performs acquisition of the stator voltage and current signals.

Selected experimental results are illustrated in Figs. 5 to 9. The waveform of per-phase stator flux is shown in Fig. 5 and that of the rotor flux in Fig. 6. Time variations of magnitudes of these fluxes are shown in Fig. 7. Figures 8 and 9 show waveforms of estimated torque of the motor on no load and on full load, respectively. The low-frequency torque pulsation has a frequency equal that of rotation of the motor, which indicates a mechanical origin (e.g., misalignment of the motor and load shafts, or rotor imbalance/eccentricity) of this pulsation. The high-frequency torque ripple is mostly resulting from low quality of the supply voltage.

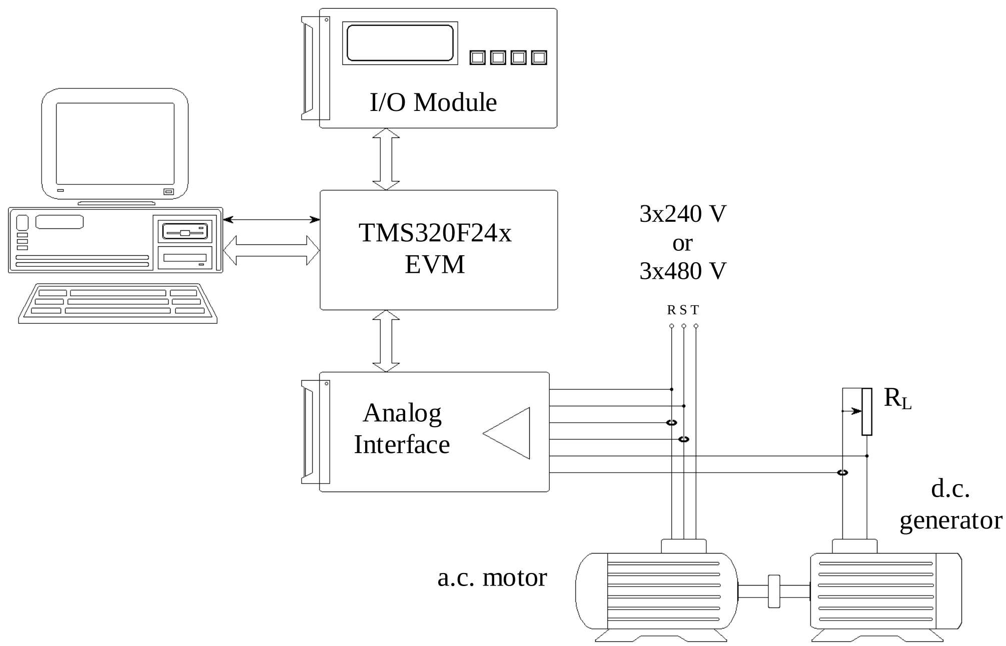

Fig. 4. Experimental setup.

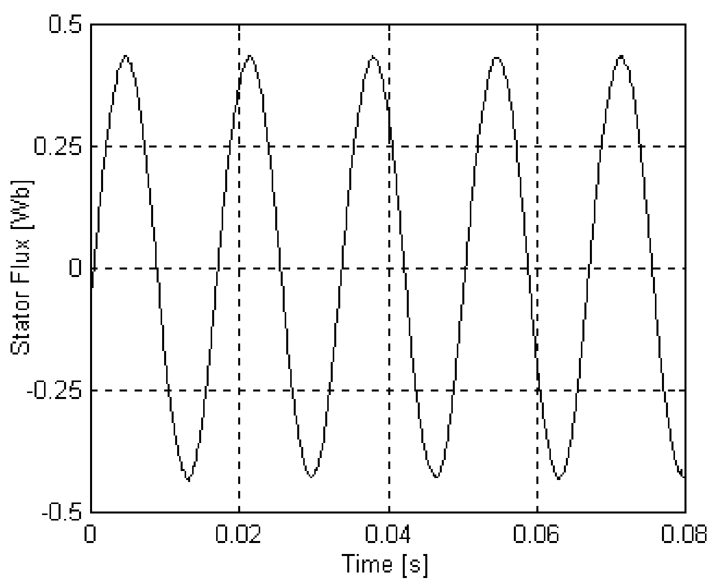

Fig. 5. Per-phase stator flux waveform.

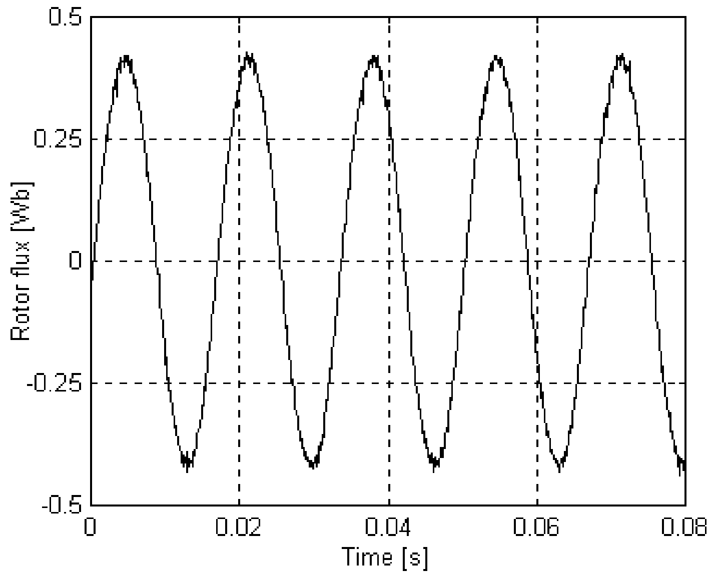

Fig. 6. Per-phase rotor flux waveform.

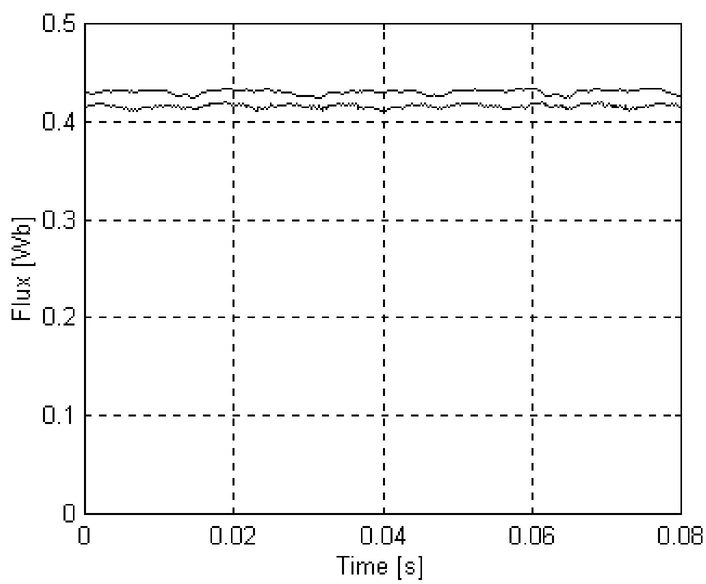

Fig. 7. Magnitudes of stator (top line) and rotor (bottom line) fluxes.

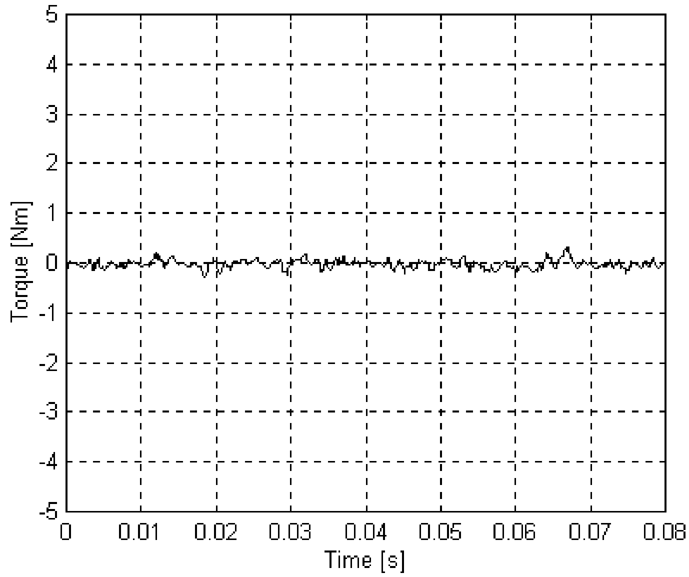

Fig. 8. Estimated torque of the motor on no load.

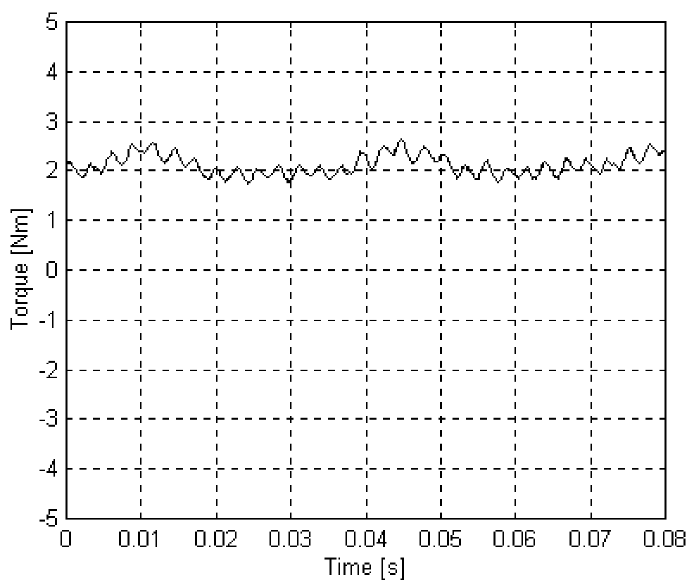

Fig. 9. Estimated torque of the motor on full load.

Thanks to the low price of the TMC320C24x DSP controllers, the torque monitor is inexpensive and, as such, it may find use in low-cost controlled and uncontrolled induction motor drives. In the latter case, the torque monitor can be used as a monitor of motor variables, such as the voltage, current, power, flux, and torque. Availability of the calculated rotor flux vector allows extending the operating algorithm on estimation of the motor speed.

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