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Reducing Moment and Current Fluctuations of Induction Motor System of Electrical Vehicles by using Adaptive Field Oriented Control

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Abstract—**This paper presents an adaptive field oriented control (FOC) method for induction motor systems (IMSs). After the details of the method are presented, the conventional FOC is applied to control the moment of the system in order to observe current and moment fluctuations. And then, the adaptive FOC method is applied to the IMS to change the switching condition of the voltage vectors. In terms of current, moment and electromagnetic flux, the conventional FOC and the adaptive FOC methods are compared. The proposed method gives better results at the IMS output. Simulation results show that current and moment fluctuations can be reduced by using the proposed approach.**

Index Terms—**Field oriented control, induction motors, moment and current fluctuations.**

I. INTRODUCTION

Field Oriented Control (FOC) is the first vector control method developed for induction motors where it is mostly used to control the speed of the motor. FOC is often not preferred to control moment (torque) due to its low level sensitivity. The aim of a control system is to minimize output error or let the output parameter of the system to reach its predefined value. Hence, in a speed control system, the reference parameter is rotor mechanical speed, electrical angular speed or mechanical angular value. All these parameters are related to each other.

FOC draws the attention of research communities. In [1]–[4], speed control using FOC is investigated. The study on adaptive FOC in [5] focuses on inverter losses rather than moment control. In [6], FOC is compared with direct torque control (DTC). In [6], it is shown that DTC gives slightly better results than FOC at the expense of higher current and torque ripples at high dynamics. [4] analyses the parameter influences on FOC via model reference adaptive system where the study point outs the adaptive approach to estimate them. [7] emphasizes on torque control and torque ripples via FOC method; however, it is applied to permanent magnet motors.

Since the control parameter of this study is moment, our reference value is moment. For the given system to be controlled, a three phase induction motor, our reference signal is the voltage vector which leads the motor to reach its reference value. In case of the conventional FOC, in the Δt time slot (safety parameter) which depends on the mechanical angular value of rotor, control signal changes its vector position. Any magnitude or angular errors at the changes of the vectors lead to additional electrical and mechanical oscillations. The main goal of this study is to improve the conventional FOC by an adaptive structure from the line control to a bandwidth control to reduce the electrical and mechanical oscillations. In this adaptive structure, when the desired moment value enters in a bandwidth, adaptive controller checks the system in time-slots and introduce the former voltage vector again to the system in the duration of Δt as long as the moment stays within its desired bandwidth values. The voltage vector is only calculated again and introduced to the system when the moment value stays out of the bandwidth. Here, Δt is the time slot where we apply the next voltage vector to the induction motor system (IMS). It can also be defined as the time in which the motor parameters settle in. This parameter is the negative inverse of the dominant pole of the motor mathematical equation.

II. ANALYSIS OF THE ADAPTIVE FOC

The voltage vector needed for the FOC algorithm is as [8]–[11]

$$\bar{U}_1 = R_1\bar{i}_1 + \frac{L_o}{1+\sigma_2\tau_2}\left[\bar{i}_1 - (1 - jw_e\tau_2)i_\mu\right] + \sigma(1+\sigma_1)L_o\frac{d\bar{i}_1}{dt}, \quad (1)$$

where $\bar{U}_1$ is the voltage vector which is applied to the motor system in a former time slot; R_1 is equivalent stator resistance; L_o is magnetising inductance; $\sigma, \sigma_2, \tau_2, w_e, i_\mu$ are the main parameters of the induction motor; $\bar{i}_1$ is the stator

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current.

The current vector of the sum of all stator currents is given as

$$\overline{i}_1 = i_A e^{j\alpha} + i_B e^{j(-\frac{2\pi}{3}+\alpha)} + i_C e^{j(\frac{2\pi}{3}+\alpha)}. \tag{2}$$

Here, the calculation of the two parameters is needed. The former is the complex current $\overline{i}_\mu$ belongs to the d-q axes systems. This can be calculated using (3) and (4):

$$\begin{cases} \dfrac{d\overline{\psi}_{1m1}}{dt} = \overline{U}_1 - R_1\overline{i}_1, \\ \overline{\psi}_{1m2} = L_o\overline{i}_\mu = (1+\sigma_2)\overline{\psi}_{1m1} - \dfrac{\sigma}{1-\sigma}L_o\overline{i}_1. \end{cases} \tag{3}$$

The latter is the derivation of the stator current

$$\frac{d\overline{i}_1}{dt} = \left(\frac{di_{1d}}{dt} - \frac{di_{1q}}{dt}\right)e^{j\lambda_\mu} + j\left(w + \frac{i_{1q}}{i_\mu \tau_2}\right)\overline{i}_1, \tag{4}$$

where λ_μ is the angular value at d-q axis system and describes the angular value of the $\overline{i}_\mu$. (5) clarifies the calculation of the parameters in (4):

$$\begin{cases} \dfrac{di_{1d}}{dt} \cong \dfrac{i_{1dref} - i_{1d}}{\Delta t}, \\ \dfrac{di_{1q}}{dt} \cong \dfrac{i_{1qref} - i_{1q}}{\Delta t}, \\ i_{1dref} = \sqrt{3W_{ref} / L_o}, \\ i_{1qref} = \dfrac{3}{2}T_{ref}\dfrac{1+\sigma_2}{pL_o i_{1dref}}, \\ \Delta t = 5\tau_{em}, \end{cases} \tag{5}$$

$$\begin{cases} \sigma\tau_1\tau_2 s^2 + (\tau_1 + \tau_2 - jw\sigma\tau_1\tau_2)s + (1 - jw\tau_2) = 0, \\ \tau_{em} = -1/s. \end{cases} \tag{6}$$

(6) gives us the dependence of Δt to τ_{em}. In (6), the only parameter which changes the dominant pole is w. If this equation is further analysed, it can be seen that w (w_e) is depended on the w_m, w respectively. Now, the relationship between w (rpm) and Δt can easily be seen. Thus, Δt takes the form of a varying parameter which is depended on the rpm of the motor.

This study basically does not change the math of the conventional FOC. Here, we rather concern on the application to the system. As we pointed out before, the adaptive controlled system is checked at the beginning of the all $\Delta t = 5\tau_{em}$ times as long as the moment stays within its desired values. The moment value is checked at the end of safety parameter and if it is noticed that the moment stays in the bandwidth, then the controller goes with the former voltage vector and reapplies it to the system again. When a change occurs and the moment value stays outside its borders, then new calculations for the voltage and angular value are made and the new voltage vector is applied to the system.

Fig. 1 describes how the vector information is processed. Later, this vector information is converted to the electrical signal, and then applied to the inverter. Using the data obtained from 1-2-4 terminals, active vectors and their timing process in a Δt time is determined. In order to determine active vectors, Δt is needed to be known since it changes up to the mechanical speed. Once Δt is obtained, using the components of stator current in d-q axis system, active and passive vectors are defined. Fig. 2 focuses on the control scheme of the IMS. Reference moment, mechanical angular value and time combined with the stator current determine the voltage vector in d-q axis system and the angular value. Thus, torque reference is used since we consider the control in this study based on torque control of the system. When we integrate the angular value and the phase, we obtain the angle needed. After the math operations and the axes transformations, we obtain the voltage vectors which will be used to control the system. Fig. 3 illustrates the IMS used in this study.

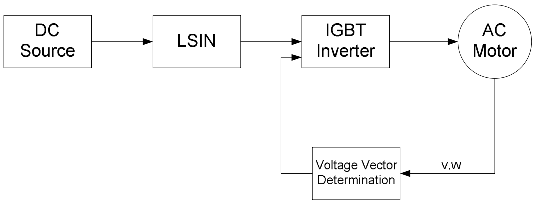

Fig. 1. Determination of vectors and the conversion of vector information to the electrical signal.

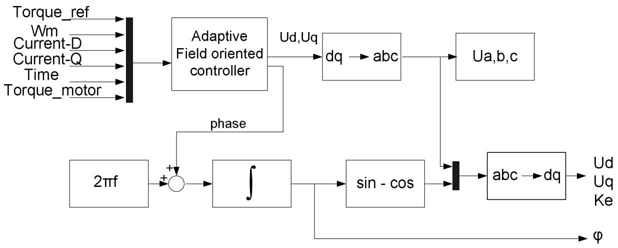

Fig. 2. Controller scheme of the IMS.

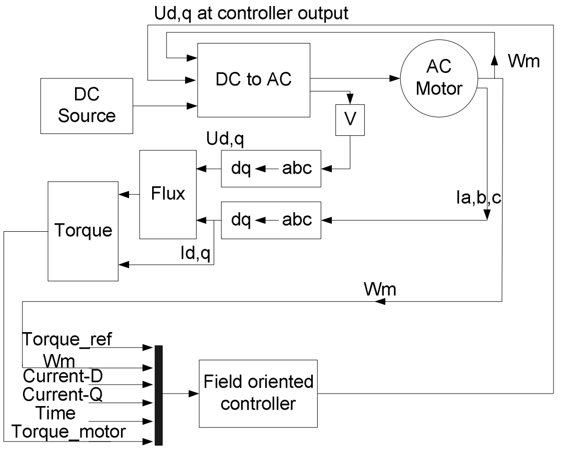

Fig. 3. Induction motor system.

Basically, using transformed voltage and current samples at the inverter and motor output, the flux value is determined. By having flux and transformed current sample, torque is obtained. With the other reference parameters, the controller gives the decision for the voltage vector which will be applied to the AC motor through inverter.

III. SIMULATION RESULTS OF THE IMS

This part of the study interprets the simulation results of the proposed adaptive FOC control algorithm. Fig. 4 and Fig. 5 are related to the stator flux variation.

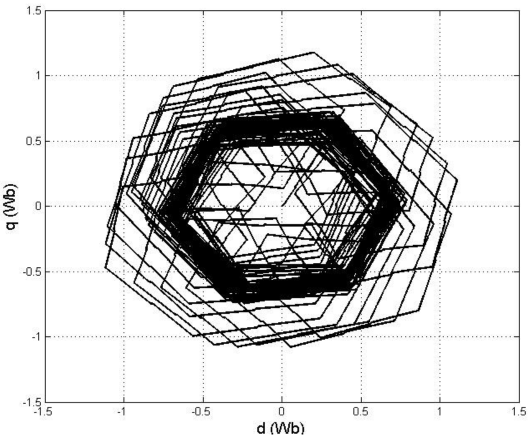

Fig. 4. Stator flux variation of the conventional FOC algorithm.

In Fig. 4, the stator flux changes rapidly. Fig. 5 illustrates the better performance of the proposed adaptive FOC algorithm in terms of stator flux. Since this study basically aims and points out the calculation of the voltage vectors where the control parameter, *moment*, is out of its predefined value. Only then the calculation of the voltage vectors where the control parameter is it is out of range results in better performance in terms of stator flux variation in Fig 5.

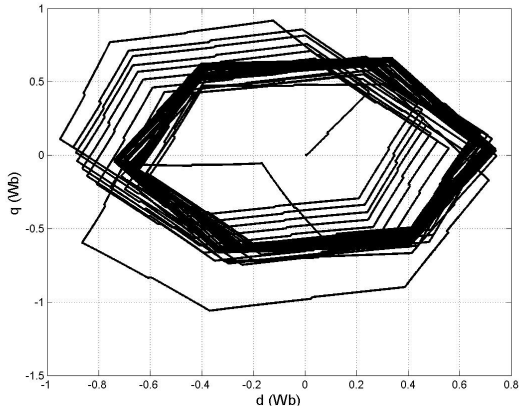

Fig. 5. Stator flux variation of the proposed FOC algorithm.

Fig. 6 shows the change of the stator phase current of the conventional one, and Fig. 7 shows the change of the stator phase current of the proposed FOC algorithm. Here, the calculation of the voltage vectors when made only in the sampling time where the control parameter is out of its predefined value results in better output of the stator current driven from the supply.

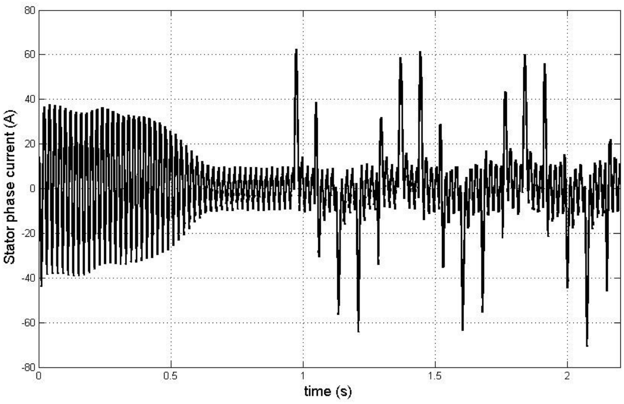

Fig. 6. Stator phase current variation of conventional FOC algorithm.

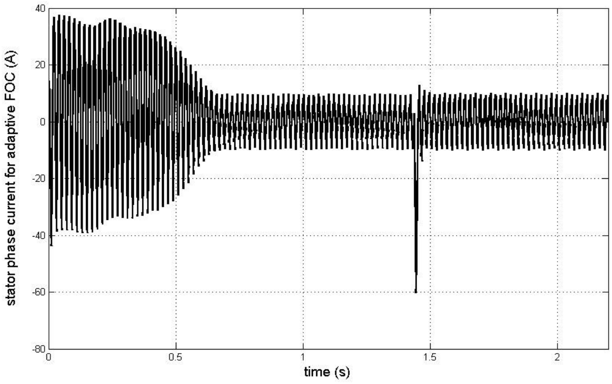

Fig. 7. Stator phase current variation of the proposed adaptive FOC algorithm.

In Fig. 8 and Fig. 9, rpm variation of the both algorithms can be seen. From Fig. 9, it is seen that the proposed algorithm gives better speed performance than the conventional one. The adaptive structure we used in this study leads less calculation and less interruption of the field oriented vector control, since we consider the moment control in a bandwidth rather than a single desired value. In terms of moment comparison of the both algorithms, the proposed algorithm gives better results as expected.

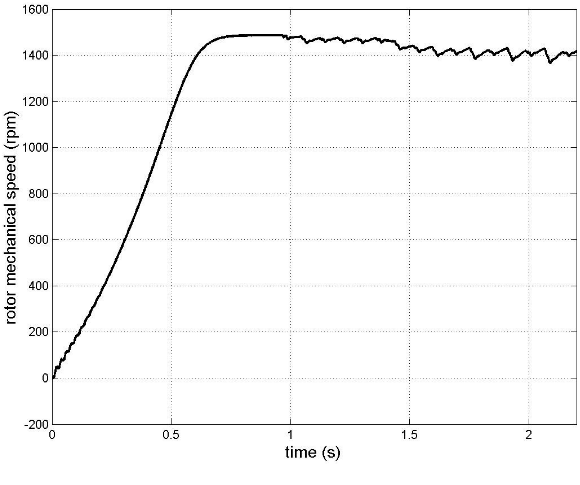

Fig. 8. The rotor mechanical speed variation of the conventional FOC algorithm.

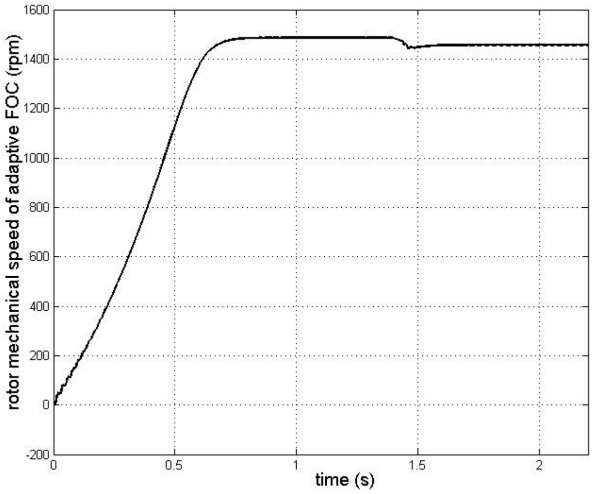

Fig. 9. The rotor mechanical speed variation of the proposed adaptive FOC algorithm.

In Fig. 10 the rapid variation of the moment is seen; however, in Fig. 11, the moment parameter of the systems behaves in a more stable manner. In this study, the adaptive controlled system is checked at $\Delta t = 5\tau_{em}$ times and the value of the safety parameter decrease where the system enters in its steady state response.

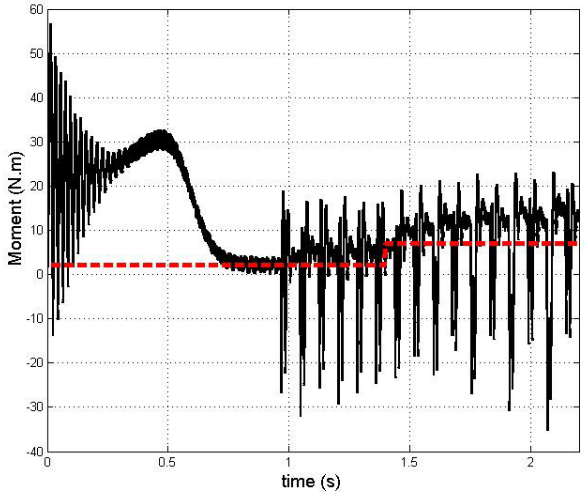

Fig. 10. The moment variation of the conventional FOC algorithm.

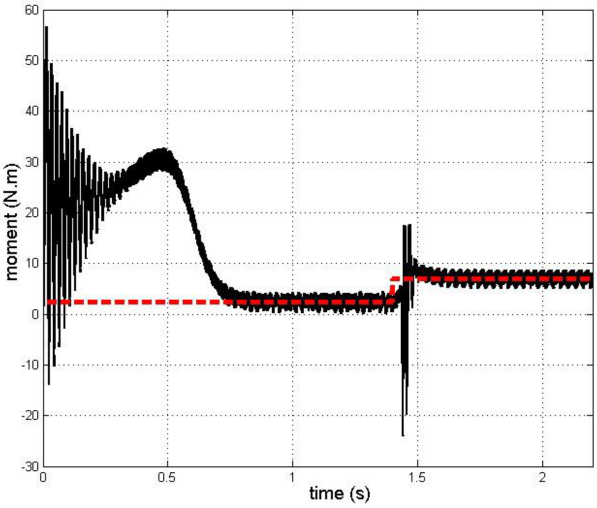

Fig. 11. The moment variation of the proposed adaptive FOC algorithm.

IV. CONCLUSIONS

In this study, an adaptive field oriented control for the moment parameter is proposed. This adaptive structure basically aims to control the induction motor system if the moment stays outside its predefined value. By calculating and applying a new voltage vector to the system, the moment of the system is set again within predefined values. The effectiveness of the proposed method is shown with the results of the simulations in MATLAB.

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