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# Direct Field Oriented Controller Applied to Observe Its Advantages over Scalar Control

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## Introduction

There are two widely used amplitude control methods: scalar and vector control [1–3]. Scalar drive allowed the induction machines to be used in variable speed applications conveniently. In fact, today it can still be preferred for some applications. The main reason for this is that it is easy to implement therefore cheap. However, the direct current (DC) machine was mainly used for variable speed applications in the past. Because its torque and flux are naturally decoupled and can be controlled independently by the torque producing current and the flux producing current [4].

Vector control of an induction machine has received significant attention over the years [4-10]. Blashke and Hasse have first developed the new technique called vector control [7–9]. Then, researchers such as Leonhard and Bose have helped improve the technique [10, 11]. Since then, the use of the induction machine for variable speed applications becomes more and more frequent. Because this control principle allows the same performance for IM as a separately excited DC machine, and can be adapted well to all type of electrical drives associated with induction machines [12]. The main advantages of IM over DC Machine for the same performance are cost, robustness and reliability. The reason the new technique is named as Vector Control is, it controls the phase of the stator current besides its amplitude and frequency [13]. As principle, since field flux vector is oriented along with one of the components of the stator current, this method is also called “Field Oriented Control” [14].

During the process of decoupling the torque and flux components of stator current, four different type vector control appears according to which rotating field the reference frame (d-q coordinate system) is fixed on: magnetizing flux oriented, rotor flux oriented and stator flux oriented [13]. The control type used in this work is a vector control linked to the rotor flux. If the reference frame is rotated synchronously with the rotor flux, the components of stator current can be controlled as DC values just as if it were a DC machine. In direct FOC studied here as well, the rotor flux is computed in magnitude and position by a flux estimator from the motor terminal quantities and from the mechanical speed.

## The induction machine model

State model is in the form of (1) as usual. Vectors and matrices that constructs the state model are seen in (2) and (3):

$$sX = AX + BU\,, \tag{1}$$

$$\mathbf{X}=\begin{bmatrix} I_{qs} \\ I_{ds} \\ I_{qr} \\ I_{dr} \end{bmatrix},\qquad \mathbf{U}=\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix},\qquad \mathbf{B}=1/\Delta\begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ -L_m & 0 & L_s & 0 \\ 0 & -L_m & 0 & L_s \end{bmatrix}, \tag{2}$$

$$\mathbf{A}=1/\Delta\begin{bmatrix} R_s L'_r & \omega_e L_s L'_r - \omega_r L_m^2 & -R_r L_m & \omega_o L_m L'_r \\ \omega_r L_m^2 - \omega_e L_s L'_r & R_s L'_r & -\omega_o L'_r L_m & -R_r L_m \\ -R_s L_m & -\omega_o L_s L_m & R_s L_s & \omega_r L_s L'_r - \omega_e L_m^2 \\ \omega_o L_s L_m & -R_s L_m & \omega_e L_m^2 - \omega_e L_s L'_r & R_s L_s \end{bmatrix}, \tag{3}$$

where $\Delta = L_s L'_r \quad L_m^2$.

In addition, torque and speed equations given in (4), (5) are required to complete state model. These are output states. Ψ components here are from flux estimator mentioned before:

$$T_{em} = \frac{3}{4}\frac{L_m}{L_r}(I_{qs}\psi_{dr} \quad I_{ds}\psi_{qr})\,, \tag{4}$$

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_{em} \quad F\omega_m \quad T_{mech})\,. \tag{5}$$

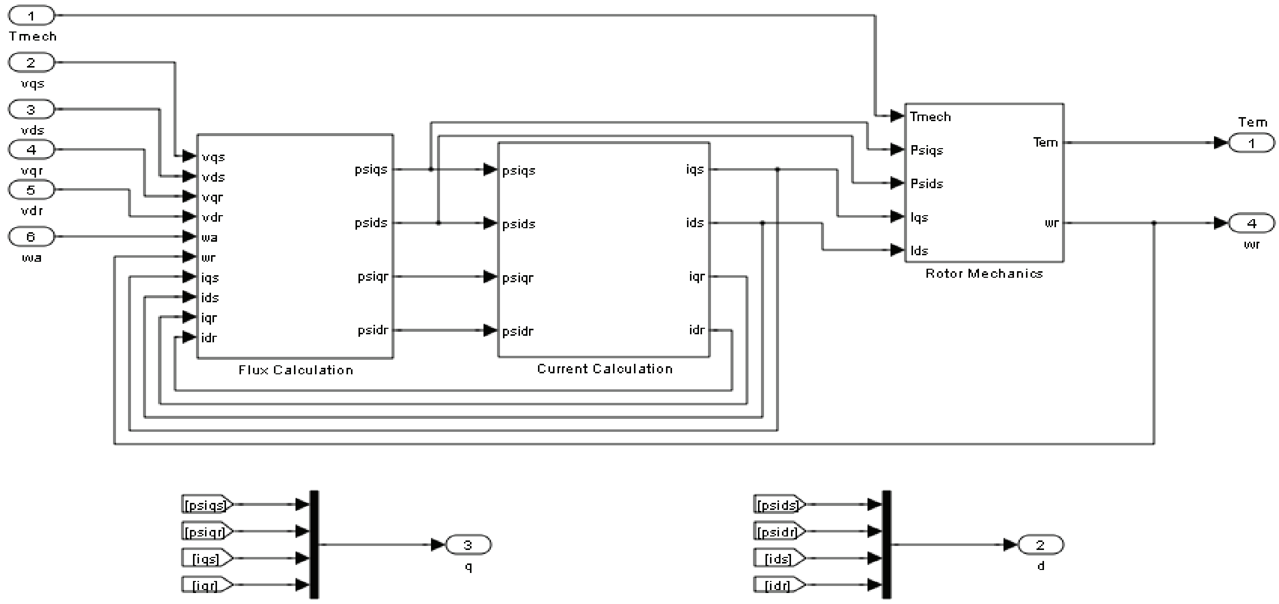


**Fig. 1.** Details of the induction machine subsystem

The implementation of mathematical model described above is carried out by using a subsystem and masking it after building the model parametrically in MATLAB/Simulink. And we can see the details of this subsystem in Fig. 1.

**Simulation results of scalar control**

The Simulink IM model we already developed is used for this very scalar control (Fig. 2). In practice, Scalar drives use a pulse-width-modulation scheme to create an output roughly approximating a sine wave of variable frequency, with its amplitude, or voltage, proportional to set point frequency.

However, in this simulation, since power is mainly carried by the fundamental component, only the fundamental component of the PWM outputs will be presented. Thus, the simulation can provide some understanding of the control principle involved without going into the details of the power electronics of the inverter, which can be difficult and time-consuming simulation because of the frequent discontinuities caused by the inverter switching.

The primary control variable in the simulation is the frequency $w^*_e$. The commanded phase voltage $V^*_s$ is generated by a gain to maintain a constant stator flux. In Fig. 3 can be seen how the model performs.

**Simulation Results of FOC Control**

In Fig. 4, the inputs of block are the reference speed shown as speed* and the load torque Tl, respectively. Furthermore we can see the rotor speed (wr) and the electromagnetic torque (Tem) as main outputs.

As shown in Fig. 5, FOC Drive uses the stator currents in abc frame [Is(abc)] and mechanical speed (wm) as feedback for some calculations. The stator voltages have been applied to the Induction Machine Block and the stator currents, electromagnetic torque and rotor speed under a load torque (Tl) have been calculated by machine model in Fig. 1. Although the stator currents are fed back to FOC Drive, they have not been used to calculate new stator currents.

These new stator currents have been obtained by using reference and rotor speed. It can be seen these currents as outputs of Inverse Park Transformation shown in Fig. 5.

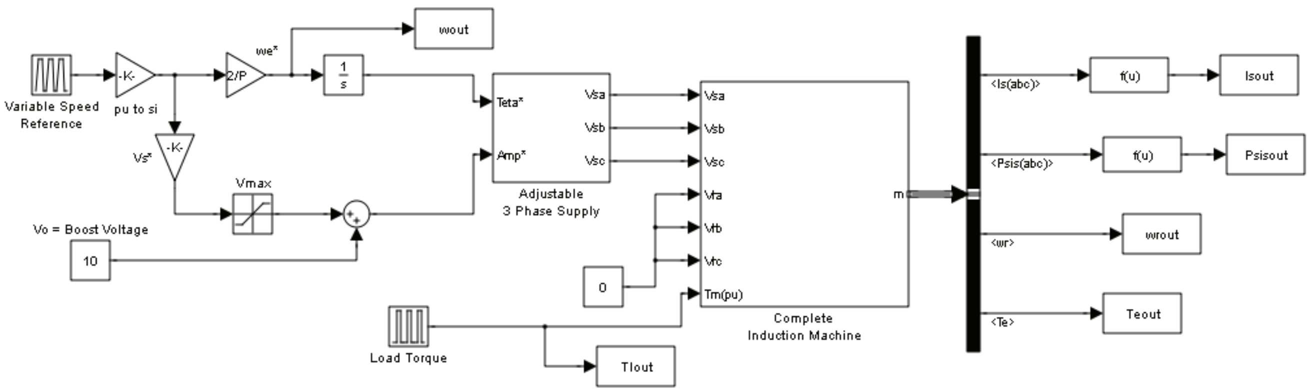


**Fig. 2.** Scalar drive for induction

Another point in simulation is 100 ms of dead time, which is enough time for flux to be imposed to the rotor. If speed reference or load torque is imposed to the system when the rotor flux values are less then 20%-30% of reference flux, it may cause stator and rotor currents to be produced over 10-15 times of nominal. This simulation shows effect of the load torque variance. If $K_p$ & $K_i$ values are well-chosen as we did here, load torque variance is not a considerable disturbance for the speed both in steady and transient state. But, when the slope of variance is increased, it is going to cause big current.

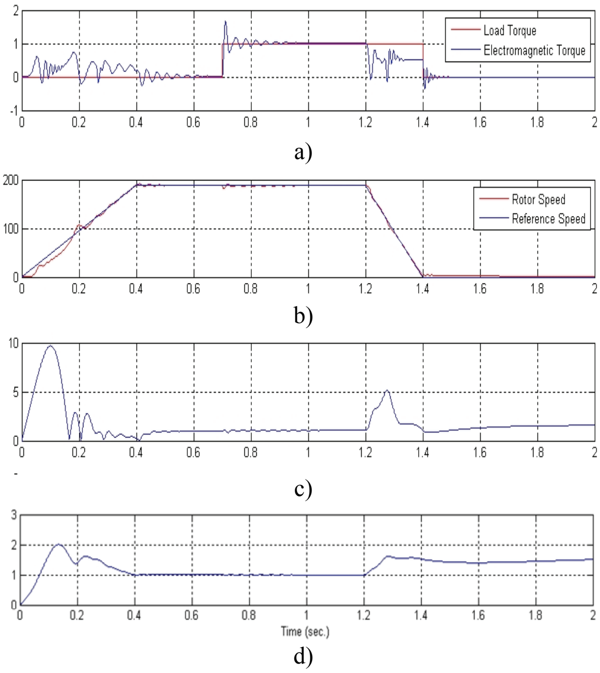


**Fig. 3.** Variable speed & variable load torque results of IM under the scalar drive: (a) Torque response in pu, (b) speed response (rad/sn), (c) Stator current amplitude in pu, (d) Stator flux amplitude in pu

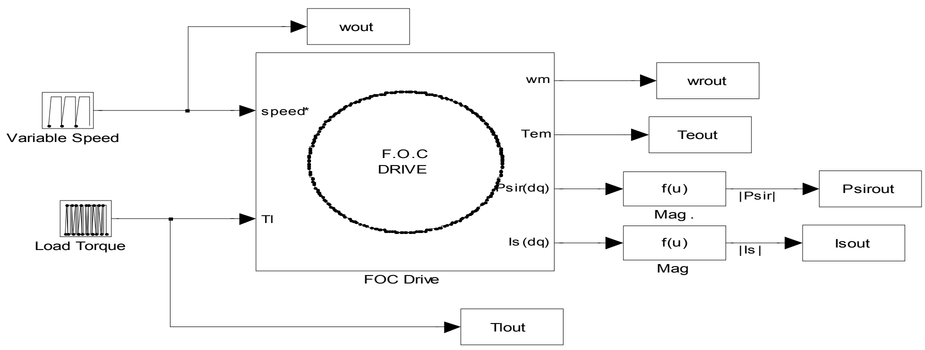


**Fig. 4.** FOC drive block

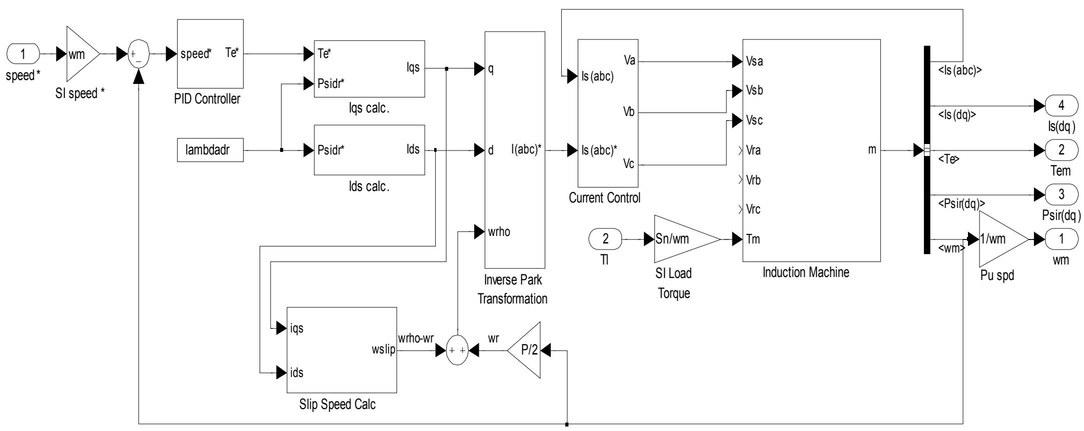


**Fig. 5.** FOC drive block diagram

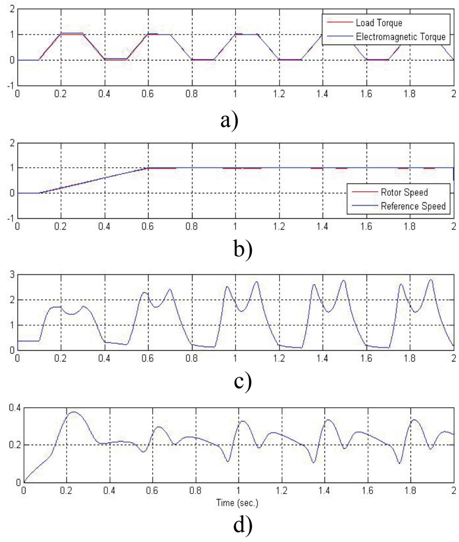


**Fig. 6.** Variable speed & variable load torque results of IM under the FOC drive: (a) torque response in pu, (b) speed response (rad/sn), (c) stator current amplitude in pu, (d) stator flux amplitude in pu

## Conclusions

For applications that do not require frequent speed or load variations, scalar drive method for controlling an IM works well. Also in the applications where a small variation of motor speed with loading is tolerable, a simple open loop system using a scalar control with low-frequency compensation may be satisfactory. In addition, it is relatively simple to implement. However, for applications that require fast dynamic response, the scalar control method will give sluggish response (Fig. 3). Furthermore, the motor currents will be high during start-up. Lastly, position control is not possible with this open loop system.

As for field oriented control, these are not the case. Even if dead time is unused, the deviations in speed during transient operation are small and also the recovery from the transients is very fast, which means fast dynamic response (Fig. 6). Also very accurate position control is achieved with field oriented control. This can be realized by adding an integrator just after the speed output of the machine block. With all these features, FOC drive allows induction motor to be available in servo applications.

In the models used above, the effect of magnetic saturation is not presented. But motor may go into the region of saturation during operation and this would cause changes in some parameters of the motor. So in further simulations, this effect can also be studied.

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A new squirrel cage induction motor (IM) model, which is based on the state model in d-q coordinate system, is proposed so that it is available for direct field oriented control (FOC), which is of rotor flux oriented type, or vector control. Then, using the IM model, field oriented and scalar speed controllers are designed in Simulink environment. MATLAB figures have been used to visualize the simulation results of either control principles. Ill. 6, bibl. 14 (in English; abstracts in English and Lithuanian).

**A. Cifci, Y. Uyaroglu, S. Birbas. Valdiklio, skirto tiesiogiai orientuotam laukui, pranašumų, palyginti su skaliariniu valdymu, nustatymas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 3(119). – P. 15–18.**

Pateikiamas naujas narvelinio indukcinio variklio modelis, pagrįstas būsenų modeliu d-q koordinačių sistemoje. Modelis pritaikytas tiesiogiai orientuoto lauko arba vektorių kontrolei. Naudojant indukcinio variklio modelį lauke orientuoti ir skaliarinio greičio valdikliai suprojektuoti „Simulink" terpėje. MATLAB paveikslai buvo panaudoti modeliavimo rezultatams vizualizuoti. Il. 6, bibl. 14 (anglų kalba; santraukos anglų ir lietuvių k.).