

CONTROL OF PWM INVERTER-FED INDUCTION MOTORS

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ABSTRACT

This paper to review of control methods for high performance PWM inverter-fed induction motor drives is presented. Starting from the description of an induction motor by the space vectors, the basic control are discussed. As first, the most popular field oriented control (FOC) is described. Secondly, the direct torque and flux vector control (DTC) method is briefly characterized.

1 INTRODUCTION

The induction motor thanks to its well known advantage as simple construction, reliability, ruggedness and low cost has found very wide industrial appellations. Furthermore, in contrast to the commutation Dc motor, it can be used in aggressive or volatile environments since there are no problems with spark and corrosion. These advantages, however, are occupied by control problems when using induction motor in speed regulated industrial drives.

The most popular high performance induction motor control method as field oriented control (FOC) or vector control. The motor equation are (rewritten) transformed in a coordinate system that rotates with rotor (stator) flux vector. These new coordinate are called field coordinate. In field coordinate-for the constant rotor flux amplitude- there is a linear relationship between control variables and speed. Moreover, as in separately excited DC motor, the reference for the flux amplitude can be reduced in field weakening region in order to limit the stator voltage at high speed.

Transformation of the induction motor equation in the field has a good physical basis because it corresponds to the decoupled torque production in separately DC motor. However, from the theoretical point of view other type of coordinate can be selected to achieve decoupling and linearization of the induction motor equation. The speed and rotor flux amplitude are decoupled by feedback.

2 MATHEMATICAL MODEL OF THE MOTOR

Mathematical description of the induction motor is based on complex space vectors,

which are defined in a coordinate system rotating with angular speed w_K . In per unit and real-time representation the following vectorial equation describe behavior of the squirrel-cage motor.

$$U_s = r_s i_s + T_N (d\psi_s / dt) + jw_K \psi_s \quad (1)$$

$$0 = r_r i_r + T_N (d\psi_r / dt) + j(w_K - w_m) \psi_s \quad (2)$$

$$\psi_s = x_s i_s + x_M i_r \quad (3)$$

$$\psi_r = x_r i_r + x_M i_s \quad (4)$$

$$\frac{dw_m}{dt} = \frac{1}{T_M} (m - m_l) \quad (5)$$

The electromagnetic torque m can be expressed as

$$m = \frac{x_M}{x_R} \text{Im}[\psi_r i_s^*] \quad (6)$$

If a current controlled PWM inverter is used, the stator voltage (1) can be neglected because it does not affect the control dynamics of the drive.

3 FIELD ORIENTED CONTROL (FOC)

3.1 ROTOR FLUX ORIENTED (RFOC)

In the case of FOC, it is very convenient to select the angular speed of the coordinate system w_K equal w_s . Under this assumption the rotor current vector from the rotor voltage (2) by (4) we obtain a differential equation for the rotor flux vector:

$$d\psi_r / dt = -(\psi_r / T_r) - j(w_s - w_m)(\psi_r / T_N) + (x_M / T_r) i_s \quad (7)$$

Where: $T_r = \frac{x_r}{r_r} T_N$ - is the rotor time constant. For the rotor field oriented coordinate

$x - y$ (fig. 1) we have

$$\psi_{rx} = \psi_r ; \psi_{ry} = 0 \quad (8)$$

And (7) can be rewritten as follows

$$d\psi_r / dt = -(\psi_r / T_r) + (x_M / T_r) i_{sx} \quad (9)$$

$$0 = -(w_s - w_m)(\psi_r / T_N) + (x_M / T_N) i_{sy} \quad (10)$$

Equation (10) describes the influence of the stator current components i_{sx} on the rotor flux. The motor torque, according to (6), can be expressed as following:

$$m = (x_M / x_r) i_{sy} \psi_r \quad (11)$$

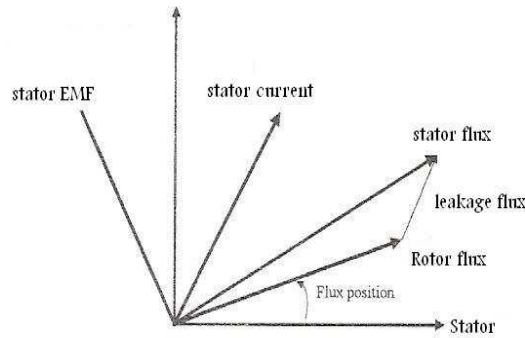


Fig. 1: Vector diagram illustrating rotor and stator fluxes as well as stator EMF vectors

3.2 STATOR FLUX ORIENTED CONTROL (SFOC)

Substituting the rotor current vector from the rotor voltage (2) by (3) we obtain a differential equation for the stator flux vector:

$$\begin{aligned}
 d\psi_s / dt = & -(\psi_s / T_r) - j\omega_r(\psi_s / T_N) + \dots\dots\dots \\
 & \dots\dots\dots + \sigma x_s (di_s / dt) + (x_s / T_r)i_s + j\omega_r(\sigma x_s / T_N)i_s
 \end{aligned}
 \tag{12}$$

Where: $\sigma = 1 - (x_M / x_s x_r)$ – is the total leakage factor:

For the stator field oriented coordinate x - y (fig. 1) we have

$$\psi_{sx} = \psi_s ; \psi_{sy} = 0
 \tag{13}$$

And (12) can be rewritten as follows:

$$\begin{aligned}
 d\psi_s / dt = & -(\psi_s / T_r) + \sigma x_s (di_{sx} / dt) + \dots\dots\dots\dots\dots\dots \\
 & \dots\dots\dots\dots\dots\dots + (x_s / T_r)i_{sx} - j\omega_r(\sigma x_s / T_N)i_{sy}
 \end{aligned}
 \tag{14}$$

$$(\omega_r / T_N)(\psi_s - \sigma x_s i_{sx}) = \sigma x_s (di_{sy} / dt) + (x_s / T_r)i_{sy}
 \tag{15}$$

The motor torque, according to (6) using (3), can be expressed as follows

$$m = i_{sy}\psi_s
 \tag{16}$$

Equation (14) shows that there exist a coupling between the torque producing stator current component i_{sy} and stator flux ψ_s (fig. 2b). Therefore, for current controlled PWM inverters (SFOC) required decoupling network resulting in more complicated structure as (RFOC). Systems.

4 DIRECT TORQUE CONTROL (DTC)

4.1 BASIC PRINCIPLE

In FOC schemes, the control quantity is the torque current component which, for constant flux, adjusts the torque directly:

$$m_e = \frac{x_M}{x_r} \psi_r i_{sy} = \frac{x_M}{x_r} \psi_r i_s \sin \delta \quad (17)$$

This makes the CSI or current controlled (CC)-PWM inverter very convenient for the implementation of this control method. In the case of VSI PWM-fed drives, however, not only the stator current but also the stator flux may be used as the torque control quantity:

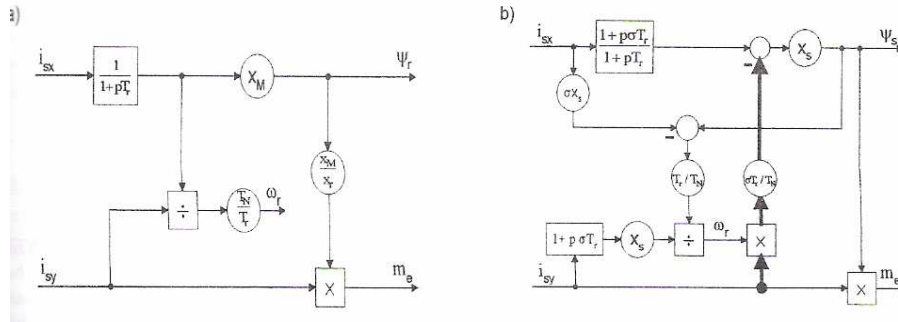


Fig. 2: Torque production in current controlled FOC

$$m_e = \frac{x_m}{x_r} \psi_r \frac{1}{x_\sigma} \psi_s \sin \delta_\psi \quad (18)$$

Note that the stator flux is a state variable which can be adjusted by stator voltage.

From the stator voltage (1), for $r_s = 0$, we may write

$$T_N \frac{d\psi_s}{dt} = u_s = u_v, \quad (19)$$

Where u_v is the inverter output voltage vector (fig. 3) described by the following equation.

$$\underline{u}_v = \begin{cases} (2/3)u_d e^{j(v-1)\pi/3} & \text{For } v = 1, \dots, 6 \\ 0 & \end{cases} \quad (20)$$

Which assumes six non-zero values (active vector) and two zero values (zero vectors or zero states). It follows from (3) that

$$\psi_s = \frac{1}{T_N} \int_0^t u_v dt. \quad (21)$$

For six-step operation, the inverter output voltage constitutes a cyclic and symmetric sequence of active vectors, so that, in accordance with (21), the stator flux moves along a hexagonal path. The introduction of zero vector stops the flux, an effect known as a step pulse, but it does not change its path. For sinusoidal PWM, which constitute a suitable

sequence of active and zero vectors, the stator flux moves along a track resembling a circle. The rotor flux rotates continuously with the actual synchronous speed along a near-circular path, because its components are sinusoidal. Stator and rotor flux vectors are related by equation:

$$\psi_s = \frac{x_M}{x_r} \psi_r + x_\sigma i_s \quad (22)$$

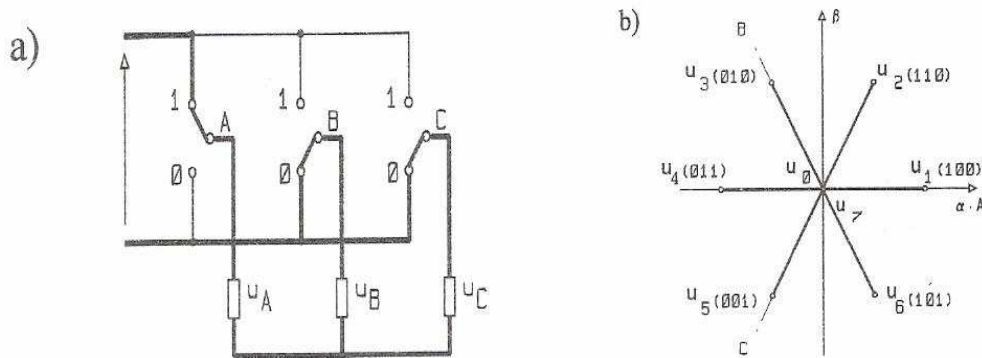


Fig. 3: Simplified diagram of the VSI feeding an induction motor

5 CONCLUSION

In constant to FOC where flux and torque is controlled by acting on (field oriented) current vector components, DTC regulates flux and torque directly while currents are controlled indirectly. Therefore, the properties of this control can be summarized as follows:

1. There is no separate voltage PWM block,
2. There are no current regulation loops,
3. Coordinate transformation is not required,
4. There is no need for a voltage decoupling network,
5. Flux vector and torque or estimation is required, as in direct FOC system.

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