International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2012 Issue 11 Volume 4 Number 2 Pages 76-80

INSTANTANEOUS DIRECT CONTROL OF BOTH MAGNETIC FLUX AND OUTPUT POWER OF INDUCTION MOTORS USING FUZZY LOGIC CONTROLLER

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Abstract- Recently, numerous researches are dedicated to Direct Power Control (DPC) which is adopted in both rectifiers and grid-connected inverters to improve the power quality indices. In this paper, the possibility of using direct power control method for three-phase induction motors via voltage source converters is surveyed. A mechanism is proposed to control the instantaneous output active power as well as the magnetic flux directly. The reference active power is determined through the fuzzy logic controller. Simulations in different situations verify the performance of controller.

Keywords: Direct Flux Control, Direct Power Control, Induction Motor, Fuzzy Logic Controller (FLC).

I. INTRODUCTION

Induction motors, particularly squirrel cage types, possess many advantages such as economical price, satisfying performance, long life, and simple structure which make them ideal for industrial applications. Therefore, in practice, the major portion of electric motors used in various industries is of this sort.

In recent years, direct power control has been widely introduced as a new method to control voltage source converters. Numerous publications are dedicated to applications of DPC on control of rectifiers, grid connected inverters, active filters, multilevel converters, and HVDC [1-5].

However, in the all above mentioned cases, the aim is to control both active and reactive power instantaneous values transferred between sources and loads. Meanwhile, in electrical motors fed by power electronic converters the controlled parameter is torque. In other words, the aim is to control position or speed of shaft and it is obtained by the direct applied torque. On the other hand, the torque and magnetic flux depend on active and reactive powers respectively [6-14]. In fact, this point was the gist idea of DPC in induction motors control.

The noticeable point here is that in both FOC and DTC methods the controlled parameter is torque but the direct. A novel direct power control of three-phase PWM rectifiers with constant switching frequency using fuzzy logic controller for space-vector modulation (fuzzy DPC-SVM) is proposed in [15].

In order to regulate the instantaneous active and reactive powers of the rectifier in an optimized approach, a novel fuzzy-based and voltage-oriented direct power control strategy (FVO-DPC) is proposed in [16]. The proposed strategy is based on the principle of the direct power control (DPC) strategy in three-phase voltage source pulse width modulations (PWM) rectifier. In the proposed FVO-DPC system, the active and reactive powers are controlled by a fuzzy logic controller and a fuzzy-based switching table.

The fuzzy logic controller is run through introducing the errors between command and estimate values of the instantaneous active and reactive power. The switching loss, the control precision and the dynamic characteristics are taken into consideration simultaneously in the process of setting the switching states of the fuzzy-based switching table.

The measurement is impossible therefore the estimated values are used. The accuracy of this estimation depends on several parameters such as operating conditions, machine's parameters, etc. As a result, estimation error is always inevitable. Conversely, both produced and consumed energies can be measured precisely. All in all, in this paper, the possibility of three phase induction motors power control via voltage source converters is discussed. In addition, reference values of the controlled variables and also the estimation techniques are evaluated. Moreover, a closed loop speed control system is simulated in Matlab/Simulink environment for different loading conditions. Finally, the simulation results confirm the satisfactory performance of proposed method.

II. MAGNETIC FLUX CONTROL OF SQUIRREL CAGE INDUCTION MOTORS

Undoubtedly, linkage flux is vital in induction motors. Indeed, sustaining the amplitude of linkage flux in the nominal value not only provides maximum electromagnetic torque but also prevents saturation. Hence, almost in all direct torque and flux control methods and also the proposed direct power and flux control techniques the magnetic flux is kept constant. Accordingly, the following equations are defined in the stationary stator reference frame for squirrel cage induction motors:

$$\vec{v}_s = R_s . \vec{i}_s + \frac{d\vec{\lambda}_s}{dt} \tag{1}$$

$$0 = R_r \vec{i}_r + \frac{d\vec{\lambda}_r}{dt} - j\omega_r \vec{\lambda}_r \tag{2}$$

where R_s, R_r, $\vec{v}_s$, and ω_r are stator and rotor winding's resistances, terminal voltage vector of motor, and the rotational speed of shaft respectively. Additionally, flux equations are as follows

$$\vec{\lambda}_s = L_s \vec{i}_s + L_m (\vec{i}_s + \vec{i}_r) \tag{3}$$

$$\vec{\lambda}_r = L_r \vec{i}_r + L_m (\vec{i}_s + \vec{i}_r) \tag{4}$$

where L_s, L_r are stator, rotor winding's self inductances and L_m is the magnetizing inductance. If the voltage drop on stator resistance is neglected, Equation (1) is obtained. Then time discrete format is like Equation (6).

$$\vec{v}_s = \frac{d\vec{\lambda}_s}{dt} \tag{5}$$

$$\Delta\vec{\lambda}_s = \vec{v}_s \Delta t \tag{6}$$

where Δt is switching period. Therefore, during a switching interval, alterations in stator flux are proportional to the stator voltage space vector.

III. INSTANTANEOUS DIRECT CONTROL OF OUTPUT POWER AND MAGNETIC FLUX VALUES

As a matter of fact, electromagnetic torque, controlled variable here, stems from the output active power (P_{out}):

$$P_{out} = T_e \omega_m = T_e \frac{\omega_r}{P} \tag{7}$$

where ω_m and P are the rotational speed of shaft and the number of pole pairs respectively. Regarding the stationary stator reference frame, the following equation for the electromagnetic torque is defined

$$P_{out} = \left(\frac{2}{3} P \,\mathrm{Im}\left[\vec{i}_s \vec{\lambda}_s^{\,*} \right] \right) \omega_m \tag{8}$$

Similarly, the stator flux vector is determined by Equation (3). Fortunately, the above equation is suitable for the output active power estimation. Hence, Equation (9), extracted from (3), (4), and (8), is adopted to define the switching pattern.

$$P_{out} = \frac{2}{3} \frac{L_m}{L^2} \omega_r I_m \left(\vec{\lambda}_s \vec{\lambda}_r^{\,*} \right) = \frac{2}{3} \frac{L_m}{L^2} \omega_r \lambda_s \lambda_r \sin(\theta_s - \theta_r) \tag{9}$$

where $L^2 = L_s L_r + L_m (L_s + L_r)$.

Here the stator flux amplitude is kept constant. The rotor flux, speed, and subsequently the angle of the rotor have little changes during a sampling period. These ignorable alterations are because of mechanical inertia which is sluggish in comparison with the electrical changes. Therefore, Equation (9) shows that the output active power is solely dependent on the stator flux angle.

Figure 1 illustrates how θ_s and the output power afterwards can be adjusted via appropriate stator voltage vector selection. Additionally, this figure depicts principles of stator flux amplitude control by selecting the proper stator voltage vector. Therefore, considering the precise stator flux space vector position and also the normalized active power and stator flux errors, the switching table is composed. For instance, for the θ_s given in Figure 1, choosing $\vec{V_2}$, $\vec{V_3}$, or $\vec{V_6}$ increases θ_s and the output power afterwards. Meanwhile, having $\vec{V_1}$, $\vec{V_4}$, or $\vec{V_5}$ decreases the output power. On the other hand, if $\vec{V_1}$ or $\vec{V_3}$ is selected the flux amplitude reduces. Conversely, choosing other active vectors results in flux amplitude growth.

Figure 2 shows how to determine the reference output active power with regard to the reference rotational shaft speed ($\omega_{m,ref}$). Here a proportional-integral controller is adopted to control the machine's speed.

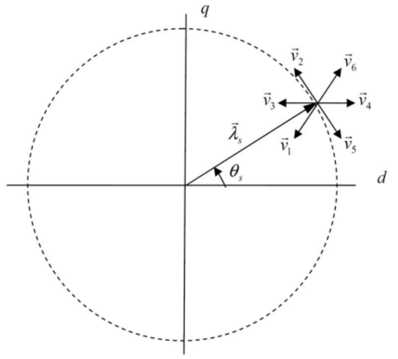

Figure 1. The relation of active power and flux control with the stator voltage vector in the stationary reference frame

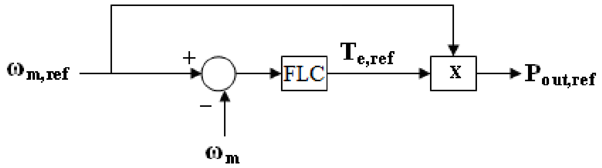

Figure 2. Active power reference value determined by the speed control loop

The complete direct control block diagram of the instantaneous output power and magnetic flux for an induction motor is illustrated in Figure 3. The reference active power is determined through the speed control loop (Figure 2). The transforming matrix is defined as follows

$$T = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad (8)$$

The scheme shown in Figure 3 is simulated in Matlab/Simulink. The corresponding specifications are listed in Table 1.

IV. FUZZY LOGIC CONTROLLER

The fuzzy control strategy is realized in the inference engine that is a rule base containing all possible combination of inputs and proper outputs for each of them [15]. The linguistic terms chosen for this controller are seven. The fuzzy control strategy is realized in the inference engine that is a rule base containing all possible combination of inputs and proper outputs for each of them [16-18].

Table 1. Specifications system

rated power	50 hp
Rated voltage	440 V
Frequency	50 Hz
Rated speed	1188 rpm
Sampling frequency	50 kHz

It should be noted that in all simulations the reference speed is assumed less than the nominal value to avoid field weakening phenomenon. Simulations are developed for both full and half load (the nominal torque is 180 Nm The flux amplitude is kept constant and equal to 1.2 wb. The simulation results are displayed in Figures 4 and 5. Contemplating the above figures, precise speed control with a fast transient state is vivid. Furthermore, both stability and efficiency of the proposed method over low velocity range is confirmed. Besides, the torque ripple is negligible for all conditions including different loads and speeds. Additionally, the starting torque experiences acceptable overshoot, rise time, and settling time.

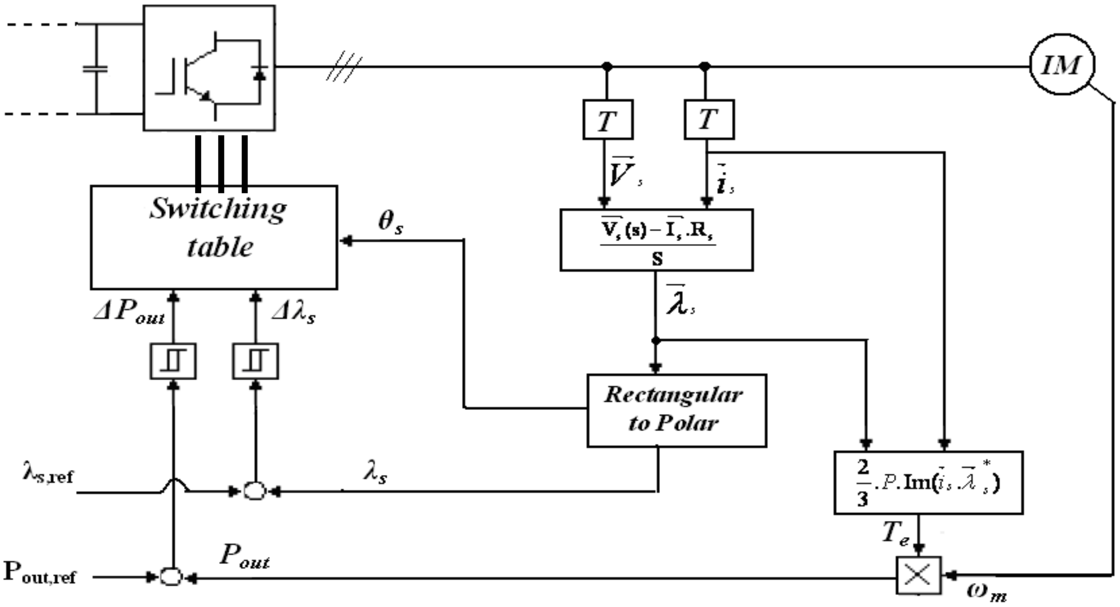

Figure 3. The direct control block diagram of the instantaneous output power and magnetic flux for an induction motor

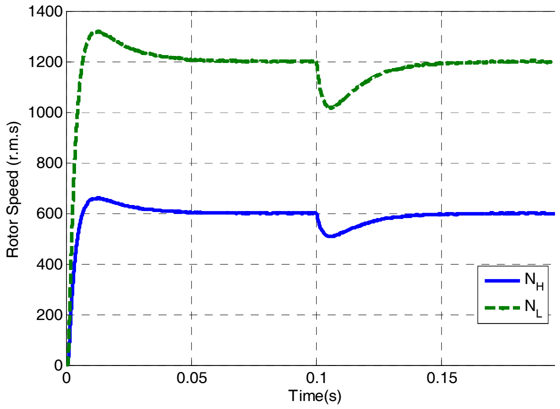

Figure 4. Speed responses under half-load condition and full-load condition

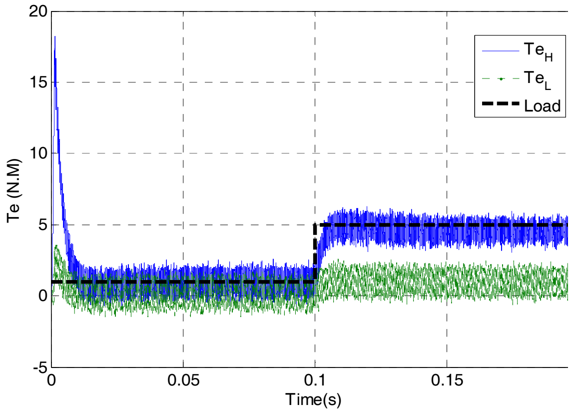

Figure 5. Torque responses under half-load condition and full-load condition

V. CONCLUSIONS

In this paper, the feasibility of three-phase induction motors via voltage source converters is discussed. In addition, reference values and the estimation ways of the control variables are addressed. In order to verify the efficiency, the proposed method is simulated in Matlab/Simulink environment. Simulations are developed for different operating conditions including varied loadings and speeds. The results of the closed loop speed controller confirm the satisfactory performance.

Advantages of fuzzy control are that it is parameter insensitive, provides fast convergence, and accepts noisy and inaccurate signals. The fuzzy algorithms are universal and can be applied retroactively in any system. System performance, both in steady state and dynamic conditions, was found to be excellent.

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