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Compensation strategy of matrix converter fed induction motor drive under input voltage and load disturbances using internal model control

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A B S T R A C T

The Matrix Converter (MC) is well known for its diverse advantages and applications but the output characteristics are adversely affected by the input voltage disturbances because there is no energy storage elements present in the dc link. Hence the matrix converter fed drive performance is affected. In this paper, Internal Model Control (IMC) based controller which is capable of achieving perfect set point tracking and disturbance rejection is proposed for compensating the voltage disturbances and load disturbances of matrix converter fed vector controlled Induction Motor (IM) drives. Modeling of matrix converter with input voltage disturbances and parameter estimation of IMC based speed and current controllers for vector controlled induction motor drive are described in this paper. The simulation results validate the input voltage disturbance rejection and improved dynamic performance of matrix converter fed induction motor drive obtained using IMC based controller.

1. Introduction

Matrix converters have number of advantages such as regenerative power flow and sinusoidal input current. A review of three phase PWM AC–AC converter topologies which includes voltage and current dc link converters, Indirect matrix converter, Direct matrix converter and some extended MC topologies was presented in [1]. A four leg matrix converter topology with vector control technique to variable speed diesel driven permanent magnet generator was presented in [2]. Matrix-reactance frequency converters, a different topology of matrix converter is presented in [3]. In [4] the authors presented a review of the most popular control and modulation strategies for matrix converters in the last decade and concluded that the control strategy has a significant impact on the resonance of the MC input filter. In [5–7] the authors presented the performance of MC fed drives under input voltage disturbances. The analysis of input voltage disturbances with popular modulation strategies of MC are presented in [8–10]. Some of the compensation methods were proposed by different researchers in [11–16]. A new fault tolerant matrix converter is proposed in [17]. PSCAD simulation on THD analysis of single phase to single phase matrix converter is presented in [18]. A simulation study on matrix converter fed doubly fed induction generator for wind energy conversion system is presented in [19]. The goal of control system design is fast and accurate set point tracking. IMC based current and speed controller can cancel the influence of disturbances because the feedback signal is equal to this influence and modifies the controller set point accordingly. IMC based speed controller was presented in [20,21] for BLDC motor. IMC based controllers for PMSM as working model was proposed in [22–24]. IMC based *v*/*f* control of induction motor was described in [25]. In this paper IMC based speed and current controller was designed and tested for input voltage disturbance rejection and load disturbance rejection of MC fed vector controlled induction motor drive.

2. Mathematical modeling

The important contribution of this paper is the mathematical modeling and analysis of matrix converter fed vector controlled induction motor drive performance and compensating the effects of input voltage and load disturbances. Mathematical model based system analysis requires less computation time [28]. The whole system comprises of a power supply, a second-order input L–C filter and a matrix converter feeding rotor flux oriented controlled induction motor is represented in Fig. 1. In the following, design and parameter estimation of IMC based controllers are given. Analytical developments are carried by neglecting the effects of switching harmonics, considering the output voltages and input currents and their values over a switching interval. The higher the switching frequency, the more this assumption holds, because the input L–C filter and the load act as low pass filters. The system equations, in terms of space vectors, can be written for convenience in different reference frames.

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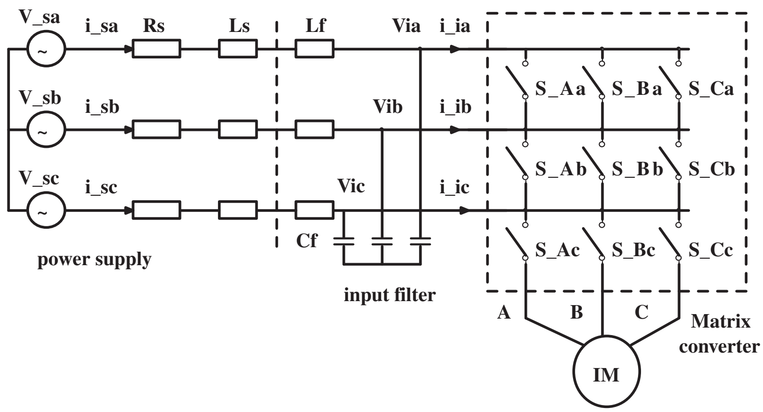

Fig. 1. Matrix converter fed IM drive.

2.1. Dynamic d–q model of induction motor

The dynamic d–q model of induction motor is used here to implement field orientated control method. The stator and rotor leakage inductances and the magnetizing inductance of induction motor are represented as,

L_{ls}, L_{lr} and L_m, respectively. Then, $L_s = L_{ls} + L_m$, and $L_r = L_{lr} + L_m$ are the stator and rotor inductances. Using Park's transformation in d–q model the stator variables are transformed to a synchronously rotating reference frame fixed in the rotor. Using space vectors the voltage and current equations of induction motor is written as

$$\frac{di}{dx} = Av + Bi \tag{1}$$

where $i = [\,i_{ds} \quad i_{qs} \quad i_{dr} \quad i_{qr}\,]^T$

$$v = [\,v_{ds} \quad v_{qs} \quad v_{dr} \quad v_{qr}\,]^T$$

$$A = \frac{1}{L_\sigma^2}\begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ -L_m & 0 & L_s & 0 \\ 0 & -L_m & 0 & L_s \end{bmatrix}$$

$$B = B(\omega_0) = \frac{1}{L_\sigma^2}\begin{bmatrix} -R_sL_r & \omega_0 L_m^2 & R_rL_m & \omega_0 L_rL_m \\ -\omega_0 L_m^2 & -R_sL_r & \omega_0 L_rL_m & R_sL_m \\ R_sL_m & -\omega_0 L_sL_m & -R_rL_s & \omega_0 L_sL_r \\ \omega_0 L_sL_m & R_sL_m & -\omega_0 L_sL_r & R_rL_s \end{bmatrix}$$

where $\mathrm{L}_\sigma^2 = \mathrm{L}_s\mathrm{L}_r - \mathrm{L}_\mathrm{m}^2$

Stator and rotor d and q axis components of currents are represented as i_{ds}, i_{dr}, i_{qs} and i_{qr} respectively [27]. The d and q axis components of rotor voltage v_{dr} and v_{qr} are zero because the rotor windings are shorted. The stator and rotor fluxes are related to the stator and rotor current, as

$$\begin{bmatrix} \lambda_r \\ \lambda_s \end{bmatrix} = \begin{bmatrix} L_s & L_m \\ L_m & L_r \end{bmatrix}\begin{bmatrix} i_s \\ i_r \end{bmatrix} \tag{2}$$

The stator flux can also be obtained from the stator voltage and current, as

$$\frac{d\lambda_s}{dx} = v_s - R_s i_s \tag{3}$$

$$\text{or} \quad \lambda_s = \int_0^t (v_s - R_s i_s)dt + \lambda_s(0) \tag{4}$$

while the rotor flux in the squirrel-cage motor satisfies the equation

$$\frac{d\lambda_r}{dx} = j\omega_0\lambda_r - R_r i_r \tag{5}$$

Finally, the motor developed torque is expressed as $T_m = \frac{2}{3}P_p I_m(i_s\lambda_T^*)$

$$= \frac{2}{3}P_p(i_{qs}\lambda_{qr} - i_{ds}\lambda_{qr}) \tag{6}$$

2.2. Matrix converter switching algorithm

The input/output quantities are represented by their average values over a cycle period of T_c. The input/output relationships of voltages and currents are related to the states of the nine switches and can be written in matrix form [24].

$$\begin{bmatrix} v_{o1} \\ v_{o2} \\ v_{o3} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}\begin{bmatrix} v_{i1} \\ v_{i2} \\ v_{i3} \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} i_{i1} \\ i_{i2} \\ i_{i3} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}\begin{bmatrix} i_{o1} \\ i_{o2} \\ i_{o3} \end{bmatrix} \tag{8}$$

with $0 \leqslant m_{hk} \leqslant 1$; $h = 1, 2, 3$; $k = 1, 2, 3$.The variables m_{hk} are the duty cycles of the nine switches s_{hk} and can be represented by the duty-cycle matrix m. Implementing the duty cycles and the co-ordinate transformation, the input–output relationships of the matrix converter can be written as

$$\overline{v_o} = \frac{3}{2}(\overline{v_i}\overline{m_i^*} + \overline{v_i^*}\overline{m_d}) \tag{9}$$

$$\overline{i_i} = \frac{3}{2}(\overline{i_o}\overline{m_i} + \overline{i_o^*}\overline{m_d}) \tag{10}$$

where the duty cycle space vectors $\mathrm{m_d}$ and $\mathrm{m_i}$ is defined in the reference frames rotating at the angular speed $\omega_i + p\omega_r$ and $\omega_i - p\omega_r$ respectively. v_o, v_i, i_o, i_i are the voltage and current space vectors for input and output sides of matrix converters. The symbol * denotes the complex conjugate. The modulation of the input current vector that basically differ in the direction along with the current vector is modulated. This direction can be represented introducing an arbitrary vector ψ, here called the modulation vector. Any modulation strategy is completely defined once the modulation vector is assigned. For any strategy it is, $\bar{i} \cdot j\psi = 0$. The problem of determining a modulation strategy is completely defined by solving the following equations with respect to m_d and m_i

$$\overline{m_d} = \frac{\overline{v_o}\overline{\psi}}{3(\overline{v_i}.\overline{\psi})} + \frac{\lambda}{\overline{v_i^*}\overline{i_o^*}} \tag{11}$$