Flexible Source Current Reference Generation for Predictive Current Control of Matrix Converter under Unbalanced Input Voltages

Thanh-Luan Nguyen, Hong-Hee Lee
School of Electrical Engineering, University of Ulsan

Abstract

This paper presents a new predictive current control (PCC) method to achieve the coordinate control of power and current of the matrix converter under unbalanced input voltages. In order to control the power fluctuation in the input side, the flexible source current reference is generated based on the positive-negative sequence components of the input voltage. The optimal switching state to adjust source and load currents is selected by minimization the cost function which is obtained from the sum of the absolute errors between the current references and their predictive values. Simulation results are given to validate the effectiveness of the proposed PCC method.

Keywords – Matrix converter (MC); predictive current control (PCC); unbalanced voltage; power fluctuation.

1. Introduction

Matrix converter (MC) is a direct AC-AC power converter, featuring no bulky capacitors on the dc bus. Compared with back-to-back voltage source converter, MC has many advantages such as sinusoidal input/output waveforms under normal conditions, controllable input power factor, regeneration capability and compact power circuit [1]. However, due to lack of dc-link capacitors for energy storage, the MC is highly sensitive to disturbance in the input voltage. In [2], when input voltage is unbalanced, input harmonic currents and instantaneous power ripple are generated. In order to reduce the effects of unbalanced input voltage, the predictive current control (PCC) method is recently proposed to control the MCs due to its advantages such as simplicity, fast dynamic response, and flexibility to control different variables. In [3], the PCC method to make the source currents in phase with their respective phase voltage is proposed by considering the output current regulation and the reactive power minimization on the source side. However, this method cannot ensure the current waveforms to be sinusoidal under unbalanced input voltage conditions. The PCC method which allows direct control of source and load currents has been presented in [4]. Even though the method in [4] can achieve the sinusoidal input current, it cannot control the power fluctuation that is caused by the input voltage imbalance.

In order to overcome these drawbacks, a new PCC method with flexible source current reference is proposed in this paper. The proposed PCC method can simultaneously control the input and output currents along with input power fluctuation. Furthermore, the unity input power factor operation for the MC is also achieved.

2. PCC of MC under Unbalanced Input Voltage

Fig. 1 shows the power circuit of the MC system. The PCC method uses a discrete-time model to predict the source and load currents for the 27 switching configurations (SCs) of the MC, and then the SC which minimizes a cost function is applied. Fig. 2 shows the PCC scheme to control MC under the unbalanced input voltage. A discrete model of the input side is employed to predictive the next value of the source current. The input side is represented by a following state-space model:

$$\begin{bmatrix} \dot{\mathbf{v}}_\mathbf{i} \\ \dot{\mathbf{i}}_\mathbf{s} \end{bmatrix} = \boldsymbol{A}\begin{bmatrix} \mathbf{v}_\mathbf{i} \\ \mathbf{i}_\mathbf{s} \end{bmatrix} + \boldsymbol{B}\begin{bmatrix} \mathbf{v}_\mathbf{s} \\ \mathbf{i}_\mathbf{i} \end{bmatrix}, \tag{1}$$

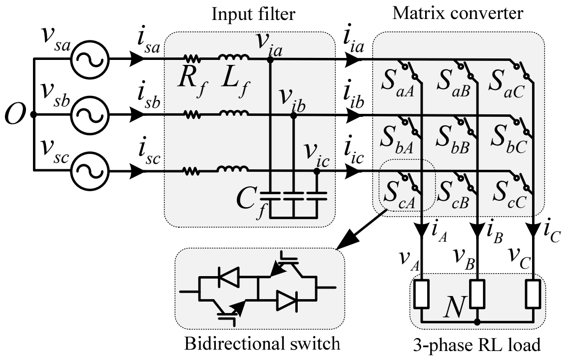

Fig. 1.Matrix converter topology.

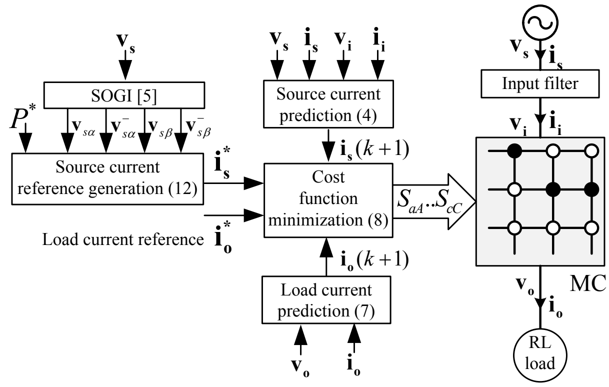

Fig. 2.Predictive current control scheme under unbalanced input voltages.

where $\boldsymbol{A} = \begin{bmatrix} 0 & 1/C_f \\ -1/L_f & -R_f/L_f \end{bmatrix}$, $\boldsymbol{B} = \begin{bmatrix} 0 & -1/C_f \\ 1/L_f & 0 \end{bmatrix}$. (2)

We assume that

$$\begin{aligned} \mathbf{v}_\mathbf{s} &= \mathbf{v}_\mathbf{s}(kT_s) = \mathbf{v}_\mathbf{s}(k), \\ \mathbf{i}_\mathbf{i} &= \mathbf{i}_\mathbf{i}(kT_s) = \mathbf{i}_\mathbf{i}(k) \quad for\ kT_s \le t \le (k+1)T_s, \end{aligned} \tag{3}$$

where T_s is the sampling time. Then, the discrete state-space model of the input side is determined as following:

$$\begin{bmatrix} \mathbf{v}_\mathbf{i}(k+1) \\ \mathbf{i}_\mathbf{s}(k+1) \end{bmatrix} = \Phi \begin{bmatrix} \mathbf{v}_\mathbf{i}(k) \\ \mathbf{i}_\mathbf{s}(k) \end{bmatrix} + \boldsymbol{\Gamma}\begin{bmatrix} \mathbf{v}_\mathbf{s}(k) \\ \mathbf{i}_\mathbf{i}(k) \end{bmatrix}, \tag{4}$$

where $\Phi = e^{AT_s}$, $\Gamma = \boldsymbol{A}^{-1}(\Phi - \mathrm{I}_{2?})\boldsymbol{B}$. (5)

On the load side, the dynamic model of the *RL* load is given as

$$\mathbf{v}_\mathbf{o} = R\mathbf{i}_\mathbf{o} + L\frac{d\mathbf{i}_\mathbf{o}}{dt}. \tag{6}$$

The output current prediction can be obtained by using a forward Euler approximation for (6):

$$\mathbf{i}_o(k+1) = \frac{T_s}{RT_s + L}\left[\frac{L}{T_s}\mathbf{i}_\mathbf{o}(k) + \mathbf{v}_\mathbf{o}(k)\right]. \tag{7}$$

In order to regulate both the source and load currents, the cost function is given as following:

$$g = \left(\left|i_{o\alpha}^* - i_{o\alpha}^p\right| + \left|i_{o\beta}^* - i_{o\beta}^p\right|\right) + \lambda\left(\left|i_{s\alpha}^* - i_{s\alpha}^p\right| + \left|i_{s\beta}^* - i_{s\beta}^p\right|\right) \tag{8}$$

The superscript “*” denotes reference values, while the predicted values are denote by the superscript “p”. The appropriate selection of the weighting factor λ allows optimal control of source and load currents.

3. Flexible Source Current Reference Generation

The load current reference $i_{o\alpha}^*, i_{o\beta}^*$ are imposed externally, while the source current reference $i_{s\alpha}^*, i_{s\beta}^*$ are generated by the control strategy. According to the instantaneous power theory, the source current references are derived as following:

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{2}{3}\frac{1}{v_{s\alpha}^2 + v_{s\beta}^2}\begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ v_{s\beta} & -v_{s\alpha} \end{bmatrix}\begin{bmatrix} P^* \\ Q^* \end{bmatrix}, \tag{9}$$

where P^* and Q^* are the input active and reactive power references, respectively. In case of unity power factor, Q^* is set to be zero. The source current references are rewritten based on the positive-negative sequence components of the input voltage:

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{2}{3}\frac{P^*}{v_{s\alpha}^{+2} + v_{s\alpha}^{-2} + 2v_{s\alpha}^{+}v_{s\alpha}^{-} + v_{s\beta}^{+2} + v_{s\beta}^{-2} + 2v_{s\beta}^{+}v_{s\beta}^{-}}\begin{bmatrix} v_{s\alpha}^{+} + v_{s\alpha}^{-} \\ v_{s\beta}^{+} + v_{s\beta}^{-} \end{bmatrix}. \tag{10}$$

From (10), the source current references are not sinusoidal because $v_{s\alpha}^{+}v_{s\alpha}^{-}$ and $v_{s\beta}^{+}v_{s\beta}^{-}$ terms provide a double frequency component in the denominator of (10). If these terms are removed by filtering, the sinusoidal input current can be obtained:

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{2}{3}\frac{P^*}{v_{s\alpha}^{+2} + v_{s\alpha}^{-2} + v_{s\beta}^{+2} + v_{s\beta}^{-2}}\begin{bmatrix} v_{s\alpha}^{+} + v_{s\alpha}^{-} \\ v_{s\beta}^{+} + v_{s\beta}^{-} \end{bmatrix}. \tag{11}$$

However, the input power appears fluctuation because of the unbalanced voltage. In order to achieve the coordinate control of the current and power, we introduce the flexible source current reference by combining both (10) and (11) with an adjustable coefficient k $(0 \le k \le 1)$. For simple description, the currents in (10) and (11) are assumed to be i_{s1}^* and i_{s2}^*, respectively. Then, the source current reference in the PCC method can be described as follows:

$$i_s^* = k i_{s1}^* + (1-k) i_{s2}^*. \tag{12}$$

From (12), for source current reference generation, the instantaneous source voltage sequence needs to be decomposed, and a second order generalized integrator (SOGI) [5] is used to extract positive-negative sequence components from unbalanced input voltages.

4. Simulated Results

In order to evaluate the performance of the proposed PCC method, the simulation is carried out by using MATLAB-Simulink software. An imbalance of 10% voltage amplitude is applied to both phase B and phase C of input voltages.

Fig. 3 shows the simulation results by decreasing k from 1 to 0. Figs. 3(b) and (c) show the good tracking of the source current i_s and load current i_o to their references i_s^* and i_o^*, respectively. Moreover, from Fig. 3(d), one can observe that the source current i_{sa} is in phase with the input voltage v_{sa}, i.e., a unity input power factor is achieved. Figs. 3(e) and (f) show that the power fluctuation increases and the source current harmonic reduces as the value of k decreases. In general, we cannot achieve the good current waveform and constant power without fluctuation under the unbalanced condition. Therefore, suitable coefficient k can be selected by making a tradeoff between the current harmonic and power fluctuation.

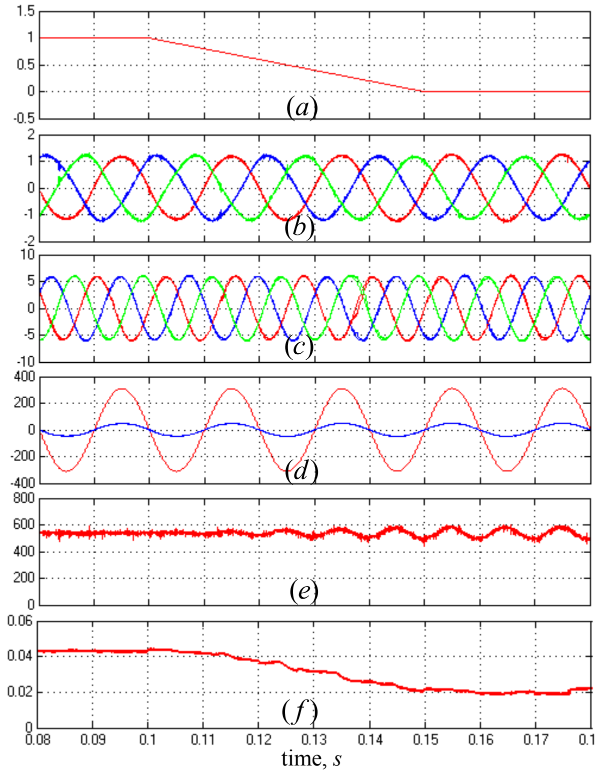

Fig. 3. Waveforms of (a) coefficient k; (b) source currents and their references [A];(c) load currents and their references [A]; (d) source current and voltage phase a; (e) input active power [W]; (f) THD of source current.

5. Conclusions

This paper presents a new PCC method that can simultaneously control the current and power of MC under the unbalanced input voltage condition. The source current reference is flexibly generated based on the positive-negative sequence components of the input voltage and an adjustable coefficient. The proposed PCC method achieves the good tracking of both source and load currents, and the unity power factor operation for the MC. The simulation results have demonstrated the effectiveness of the PCC method.

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References

[1] H. N. Nguyen and H. H. Lee, “A modulation scheme for matrix converters with perfect zero common-mode voltage,” *IEEE Trans. Power Electron*., vol. 31, no. 8, pp. 5411 - 5422, Aug. 2016.

[2] D. Casadei, G. Serra, and A. Tani, “A general approach for the analysis of the input power quality in matrix converters,” *IEEE Trans. Power Electron*., vol. 13, no. 5, pp. 852–891, Sep. 1998.

[3] R. Vargas, J. Rodriguez, U. Ammann, and P. Wheeler, “Predictive current control of an induction machine fed by a matrix converter with reactive power control,” *IEEE Trans. Ind. Electron*., vol. 55, no. 12, pp. 4362–4371, Dec. 2008.

[4] M. Rivera, J. Rodríguez, P. Wheeler, C. Rojas, A. Wilson, and J. Espinoza, “Control of a Matrix Converter With Imposed Sinusoidal Source Currents,” *IEEE Trans. Ind. Electron.*, vol. 59, no. 4, pp. 1939–1949, Apr. 2012.

[5] P. Rodriguez *et al.*, “A stationary reference frame grid synchronization system for three-phase grid-connected power converters under adverse grid conditions,” *IEEE Trans. Power Electron.*, vol. 27, no. 1, pp. 99–112, Jan. 2012.