A Control Strategy to Obtain Sinusoidal Input Currents of Matrix Converter under Unbalanced Input Voltages

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***Abstract*— This paper presents a control strategy to achieve the balanced sinusoidal output currents, as well as sinusoidal input currents for the matrix converter (MC) under unbalanced input voltages. By regulating the modulation index of the converter according to the instantaneous input voltages, the output currents are kept balanced and sinusoidal. In order to obtain sinusoidal input currents, the input power factor angle should be dynamically calculated based on the positive and negative sequence components of the input voltages. This paper proposes a simple method to construct the expected input power factor angle without the complicated sequence component extraction of input voltages. Simulation results are given to validate the effectiveness of the proposed control strategy.**

Keywords—Matrix converter, input current distortion, unbalanced input voltages.

I. INTRODUCTION

Matrix converter (MC) is a single-stage direct AC-AC power converter without bulky capacitors on the dc bus. Compared with back-to-back voltage source converters, MC has many advantages such as sinusoidal input/output waveforms under normal conditions, controllable input power factor, regeneration capability and compact power circuit [1].

Owing to the lack of dc-link capacitors for energy storage, the MC is highly sensitive to disturbance in the input voltage. In [2], when the input voltages are unbalanced, the low-order harmonics are induced in the output voltages and input currents. In order to reduce the effects of unbalanced input voltage on the output performance, the most commonly used control strategy is the feed-forward compensation method based on the instantaneous value of input [3]. This method is effective to provide balanced output voltages and sinusoidal output currents. But, it leads to severe harmonics in the input currents when the input voltages are unbalanced. In [4] and [5], the improved methods are proposed to eliminate the undesirable harmonics in the input currents by modifying the input power factor angle as a function of positive and negative sequence components of input voltage.. In [6], the proportional integral resonant controller is designed in rotating *dq* reference frame to achieve a near unity input power factor and sinusoidal input current. However, all of these methods in [3]-[6] require the sequence component extraction of the input voltage, which is usually complicated and a large storage-consuming.

In order to overcome these drawbacks, this paper presents a simple control strategy to achieve the balanced and sinusoidal output currents and sinusoidal input currents of the MC under the unbalanced input voltages. The modulation index of MC is calculated based on the instantaneous input voltage to generate the balanced sinusoidal output currents. To avoid the complication to extract the input voltage sequence component, this paper proposes a method to construct an expected input power factor based on the input voltages in αβ stationary frame and their 90° lagging signals. Thus, the proposed control strategy can easily achieve the sinusoidal input currents since no sequence extraction algorithm is required. The proposed control strategy is verified by the simulation.

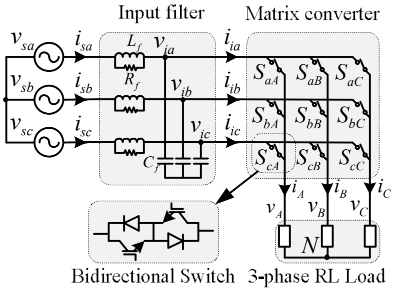


Fig. 1: Matrix converter topology.

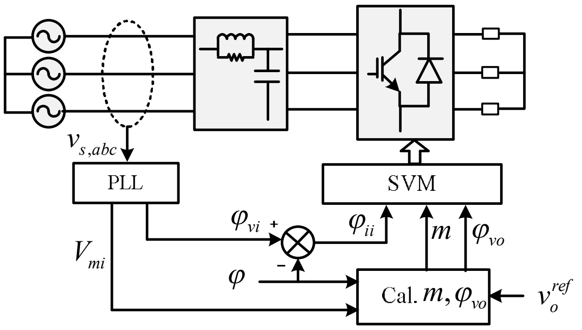


Fig. 2. Conventional control scheme with SVM.

II. THE PROPOSED CONTROL STRATEGY

A. Conventional Control Scheme with SVM

Fig. 1 shows the topology of MC. The classical space vector modulation (SVM) strategy is used to control the MC, as shown in Fig. 2. The instantaneous amplitude of input voltage V_{mi} is calculated based on the measured input voltages. The phase angle φ_{vi} of input voltage vector is obtained by using a three-phase phase-locked loop (PLL). The input current vector angle φ_{ii} is calculated by subtracting the input power factor angle φ from φ_{vi} .The amplitude V_{mo} and phase

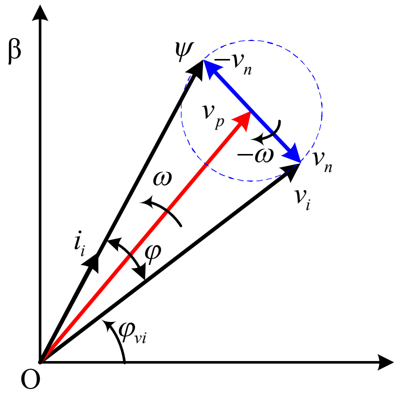


Fig. 3. Space-vector representation of method in [4]

angle φ_{vo} of output voltage reference are generated by output controller. The modulation index m is calculated based on V_{mi}, V_{mo}, and φ as (1). After m, φ_{ii} and φ_{vo} are obtained, the SVM algorithm can be implemented.

$$m = \frac{2}{3}\frac{V_{mo}}{V_{mi}\cos\varphi}. \tag{1}$$

The conventional control scheme with the instantaneous calculation of modulation index of MC can achieve the balanced sinusoidal output currents. The input power factor angle φ is set to zero for unity input power factor operation at any time. But, it causes severe harmonics in the input currents when the input voltages are unbalanced. Under the unbalanced input operation, the input voltage vector of the MC is expressed as

$$\mathbf{v}_\mathbf{i} = v_p + v_n = \mathbf{V}_\mathbf{p}\, e^{j\omega t} + \mathbf{V}_\mathbf{n}\, e^{-j\omega t} \tag{2}$$

where $\mathbf{V}_\mathbf{p}, \mathbf{V}_\mathbf{n}$ are the time phasors of positive and negative sequence components of the input voltage, respectively, and ω_i is the input angular frequency.

According to [4], in order to obtain sinusoidal input currents, the input power factor angle should be calculated based on the positive and negative sequence components of the input voltages. As shown in Fig. 3, the input current vector is modulated along a space vector ψ , which is defined as following:

$$\psi = v_p - v_n = \mathbf{V}_\mathbf{p}\, e^{j\omega t} - \mathbf{V}_\mathbf{n}\, e^{-j\omega t} \tag{3}$$

B. Proposed Construction Method of the Expected Input Power Factor Angle

To avoid the complication to extract the input voltage sequence component, this paper proposes a method to construct the expected input power factor based on the input voltages in αβ stationary frame and their 90° lagging signals. In the following discussions, x' denotes the signal that lags x by 90 electrical degrees. The lagging signal of the input voltage can be expressed as following:

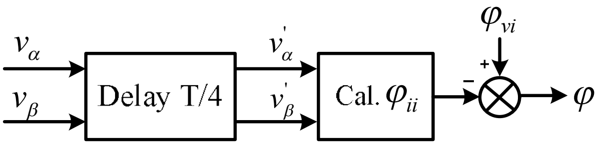


Fig. 4. Proposed method to construct expected input power factor angle.

TABLE I. SYSTEM PARAMETERS

Variables	Description	Value
V_s	Input phase voltage (RMS)	100V
f_s	Input frequency	60Hz
L_f	Input filter inductance	1.4mH
C_f	Input filter capacitance	22μC
R_f	Damping resistance	30Ω
R	Load resistance	26 Ω
L	Output inductance	12mH
T_s	Sampling time	100μs

$$\mathbf{v}_\mathbf{i}' = \mathbf{V}_\mathbf{p}\, e^{j(\omega t - \frac{\pi}{2})} + \mathbf{V}_\mathbf{n}\, e^{-j(\omega t - \frac{\pi}{2})} = -j\mathbf{V}_\mathbf{p}\, e^{j\omega t} + j\mathbf{V}_\mathbf{n}\, e^{-j\omega t} \tag{4}$$

From (4), $j\mathbf{v}_\mathbf{i}'$ can be expressed as

$$j\mathbf{v}_\mathbf{i}' = j(-j\mathbf{V}_\mathbf{p}\, e^{j\omega t} + j\mathbf{V}_\mathbf{n}\, e^{-j\omega t}) = \mathbf{V}_\mathbf{p}\, e^{j\omega t} - \mathbf{V}_\mathbf{n}\, e^{-j\omega t} \tag{5}$$

From (3) and (5), the modulated space vector ψ is rewritten as follows:

$$\psi = jv_i' = j(v_{i\alpha}' + jv_{i\beta}') = -v_{i\beta}' + jv_{i\alpha}', \tag{6}$$

where $v_{i\alpha}'$, and $v_{i\beta}'$ are 90° lagging signals of the αβ components of input voltage $v_{i\alpha}$, and $v_{i\beta}$, respectively. The input current vector angle φ_{ii} is calculated as

$$\varphi_{ii} = \arctan\left(-\frac{v_\alpha'}{v_\beta'}\right). \tag{7}$$

Then, the expected input power factor is calculated as

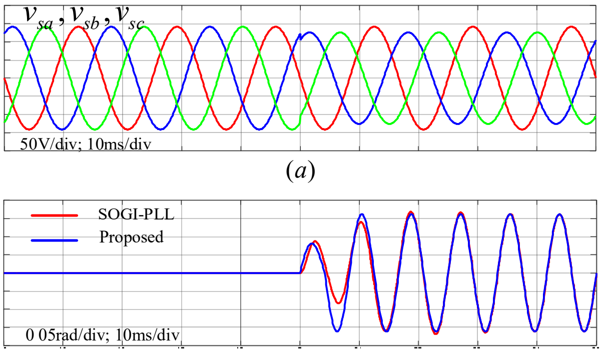
$$\varphi = \varphi_{vi} - \varphi_{ii}. \tag{8}$$

Fig. 4 shows the constructive realization of the expected input power factor.

III. SIMULATION RESULTS

In order to verify the effectiveness of the proposed control strategy, the simulation is carried out by using MATLAB-Simulink software. The system parameters are listed in Table I. A 15% decreased phase voltage is applied to both phases B and C of the input voltages. The output frequency is 80Hz and the amplitude of output voltage reference is fixed as 60V (RMS).

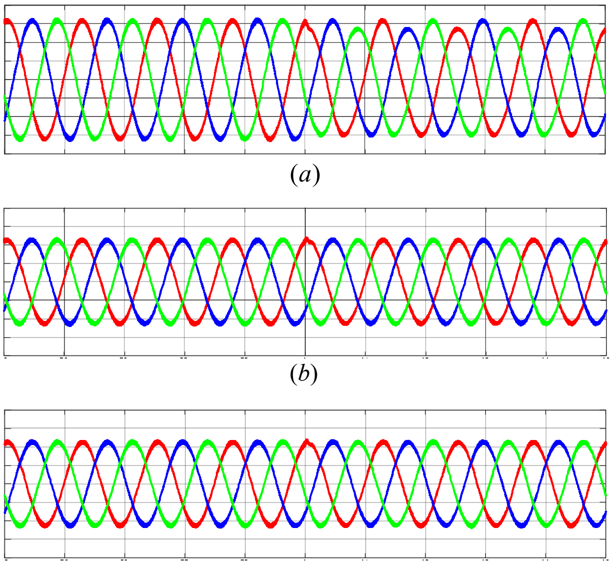
Fig. 5 shows the comparison of the expected input power factor angle with the proposed method and the second-order generalized integrator phase-locked loop (SOGI-PLL)-based



(*a*)

(*b*)

Fig. 5. (a) Three-phase input voltages change from balanced to unbalanced at 0.5s, (b) The expected input power factor.



(*a*)

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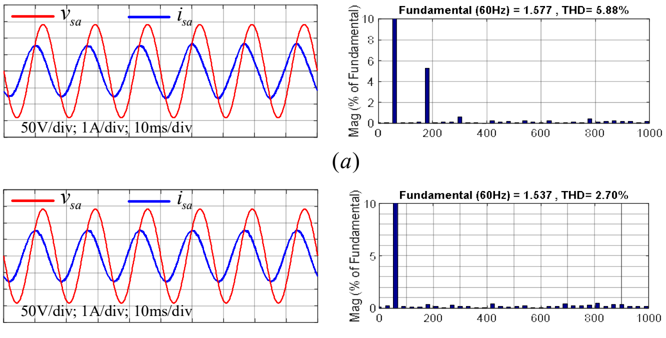
Fig. 6. Output currents of MC when phase input voltages change from balanced to unbalanced at 0.5s (current, 1A/div, time, 10ms/div): (a) Method 1, (b) Method 2, (c) Method 3.

input voltage sequence component extraction. As shown in Fig. 5, when the input voltages become unbalanced, the proposed method can construct the expected input power factor angle faster. Fig. 6 shows the output currents with three methods: method 1 with the conventional SVM, method 2 with the instantaneous modulation index calculation, and method 3 with the proposed method. Fig. 6(a) shows that the output current in method 1 is distorted and unbalanced when the input voltages become unbalanced. Figs. 6(b) and 6(c) show that the output currents with method 2 and 3 are all sinusoidal and balanced no matter whether the input voltages are balanced or not. Fig. 7 shows the performance of input currents with two improved methods. As shown in Fig. 7(a), the third- and fifth-order harmonics appear clearly in the input current with method 2. However, by using method 3, the third- and fifth-order harmonics of input current are effectively suppressed, as shown in Fig. 7(b).



(*a*)

(*b*)

Fig. 7. Input performance of MC under unbalanced input voltages: (a) Method 2, (b) Method 3.

IV. CONCLUSION

This paper presents an effective control strategy for the MC under the unbalanced input voltage conditions. In this strategy, the modulation index is calculated based on the instantaneous value of the input voltages. Thus, the output currents are kept balanced and sinusoidal. The expected input power factor angle for input current harmonics elimination is constructed based on the input voltages in αβ stationary frame and their 90° lagging signals. Therefore, the proposed control scheme can achieve the sinusoidal input currents without the complicated sequence extraction of input voltages. The feasibility of the proposed control strategy has been demonstrated by the simulated results.

ACKNOWLEDGMENT

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