An Investigation on Input Filter Design for Matrix Converters

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***Abstract*—Input filter is an essential component in a practical matrix converter (MC) system to generate the sinusoidal input currents. However, the input filter causes a displacement angle between the input current of MC and the source current. In this paper, we investigate the input filter design for MCs by considering the displacement angles of the input current and the input voltage to guarantee high input power factor (IPF) operation as well as low input current harmonic contents. Simulation results are provided to validate the input filter design with near unity input power factor and low total harmonic distortion (THD) of the input current.**

I. INTRODUCTION

In the past two decades, the matrix converter (MC) has gained more and more attention due to its advantageous features such as bidirectional power flow, sinusoidal input/output currents, controllable input power factor, compact design, and long life [1]. In the last decade, many researchers have focused on the input filter, commutation techniques, switching losses, stability, and common-mode voltage [2].

Among them, the input filter in MCs produces a phase shift ϕ between input line current and input line-to-neutral voltage at the main power supply [3]. It can significantly degrade the input power factor (IPF = cosϕ) under some operating conditions, especially at the light load. Consequently, the IPF at the power supply becomes far from the desired power factor of unity, which may cause a power factor penalty to the electric utility. Therefore, it is important to consider the IPF in MC systems.

This paper investigates the input filter design for MCs. The investigation is based on the displacement angles of the input current and the input voltage to guarantee high IPF operation and high performance for the input current. The paper also presents a comparison between the 2 strategies in terms of input current THD, power losses in the input filter, and the IPF. Finally, numerical simulations are carried out to verify the theoretical analysis.

II. INPUT FILTER ANALYSIS

In balanced operation, the instantaneous source voltages are as follows:

$$\mathbf{v}_s = \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = V_s \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t - 2\pi/3) \\ \cos(\omega_i t + 2\pi/3) \end{bmatrix} \quad (1)$$

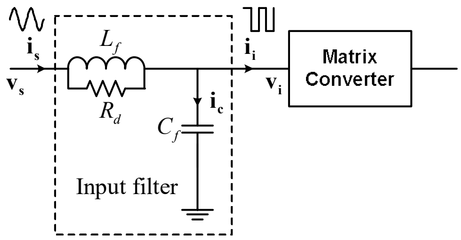

Fig. 1. Equivalent circuit of input filter.

where V_s and ω_i are the amplitude and the angular frequency of the source voltage, respectively.

A typical input filter configuration for MCs is illustrated in Fig. 1 [4]. It consists of a second-order LC filter with a damping resistor in parallel with the inductor. From Fig. 1, the input voltage and current vectors, $\vec{v}_i$ and $\vec{i}_i$, of the MC are functions of the source voltage and current vectors, $\vec{v}_s$ and $\vec{i}_s$:

$$\vec{i}_i = \frac{j\omega_i L_f + R_d - \omega_i^2 R_d L_f C_f}{j\omega_i L_f + R_d}\vec{i}_s - j\omega C_f \vec{v}_s \quad (2)$$

$$\vec{v}_i = \vec{v}_s - \frac{j\omega_i L_f R_d}{j\omega_i L_f + R_d}\vec{i}_s . \quad (3)$$

From (2), the cut-off frequency is

$$f_c = \frac{1}{2\pi\sqrt{L_f C_f}} \quad (4)$$

If the switching frequency is nearly 10 kHz, the cut-off frequency should not be lower than 500 Hz and higher than 2 kHz [5].

As can be seen from (2) and (3), capacitance C and inductance L affect displacement angles of the input current $\Delta\beta_i$ and the input voltage $\Delta\alpha_i$, respectively, as shown in Fig. 2. From the vector diagram in Fig. 2, the input filter can be designed by considering displacement angles of the input current and the input voltage as follows:

1) Strategy 1:

- $\Delta\beta_i = 1^0 \Rightarrow C_f = 2.2\ \mu\text{F}$
- $f_c \approx 750\ \text{Hz} \Rightarrow L_f = 20\ \text{mH}$

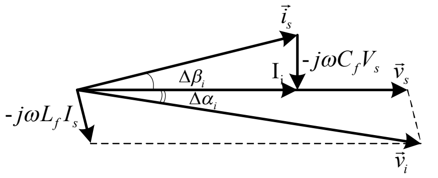

Fig. 2. Vector diagram for input filter.

- $\begin{cases} R_d \ ? \ \omega_i L_f \\ 0.01 < \xi = \dfrac{1}{2R_d}\sqrt{\dfrac{L_f}{C_f}} < 0.707 \end{cases} \Rightarrow R_d = 300\ \Omega$

2) Strategy 2:

- $\Delta\alpha_i = 2^0 \Rightarrow L_f = 2$ mH
- $f_c \approx 750$ Hz $\Rightarrow C_f \approx 22\ \mu$F
- $\begin{cases} R_d \ ? \ \omega_i L_f \\ 0.01 < \xi = \dfrac{1}{2R_d}\sqrt{\dfrac{L_f}{C_f}} < 0.707 \end{cases} \Rightarrow R_f = 30\ \Omega$

III. SIMULATION RESULTS

In order to verify the theoretical analysis, numerical simulations are carried out with a three-phase *RL* load using PSIM 9.0 software. The simulation parameters are shown in Table I.

Fig. 3 and 4 show the source phase voltage and current with the input filter parameters in strategy 1 and 2, respectively. As can be seen, the input currents are sinusoidal with both strategies. The filtered input current is characterized by leading the supply phase voltage with a phase angle that depends on the characteristics of the input filter.

Table II presents a comparison between the 2 strategies in terms of input current THD, power losses in the input filter, and the IPF. As can be seen, the MC achieves a higher IPF with the input filter parameters in strategy 1 than that in the strategy 2. However, it incurs a higher input current THD and power losses in the input filter with strategy 1.

IV. CONCLUSION

This paper has investigated the input filter design for MCs. Depending the displacement angles of the input current and the input voltage, we have designed 2 suitable sets of parameters for the input filter. The first strategy can guarantee small displacement angle of the input voltage, leading high IPF. The second strategy can achieve a lower power losses in the input filter and a lower input current THD. The performance of the 2 strategies is demonstrated by the simulation results

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TABLE I
SIMULATION PARAMETERS

Power supply	Output load	Strategy 1	Strategy 2
$V_s = 100V$	$R = 10\ \Omega$	$L_f = 20$ mH	$L_f = 2$ mH
$f_i = 60$ Hz	$L = 20$ mH	$C_f = 2.2\ \mu$F	$C_f = 22\ \mu$F
	$f_o = 50$ Hz	$R_d = 300\ \Omega$	$R_d = 30\ \Omega$

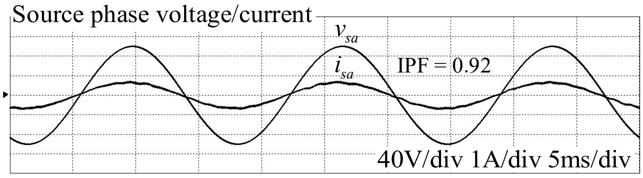

Fig. 3. Source phase voltage and current with the input filter parameters in strategy 1.

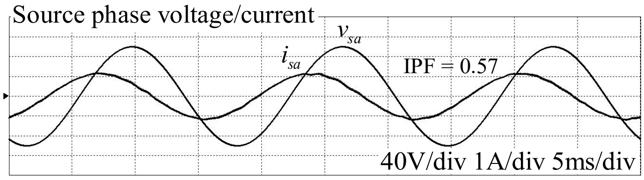

Fig. 4. Source phase voltage and current with the input filter parameters in strategy 2.

TABLE II
COMPARISON BETWEEN 2 STRATEGIES

	Strategy 1	Strategy 2
THD	4.2%	2.2%
Power losses	318 mW	52 mW
IPF	0.92	0.57

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