

## State-Space Modeling and Harmonic Analysis of Matrix Converter with RL Load and Passive LC Filter

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**ABSTRACT:** This study analyses the performance of a three-phase matrix converter supplying an R–L load with the addition of a simple LC filter to improve output power quality. The approach involves mathematical modelling based on matrix representation, development of a state-space model, and simulation using predefined system parameters. The system is evaluated under two conditions: without a filter and with an LC filter, to assess their impact on output voltage, load current, ripple, settling time, and Total Harmonic Distortion (THD). The results show that without filtering, the output voltage exhibits overshoot and high ripple, with voltage THD reaching 12.6%. After applying the LC filter, the output voltage becomes more stable and converges to the desired 400 V, with voltage ripple reduced to below 1.5 Vpp and THD decreased to 3.8%. Furthermore, the load current becomes smoother and more stable, with current ripple reduced by more than 80%. The settling time is also significantly improved. These findings demonstrate that a simple LC filter is effective in enhancing power quality and dynamic performance of matrix converters, offering a practical and cost-effective solution for modern power conversion systems.

**Keywords:** matrix converter; LC filter; R–L load; power quality; THD

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### I. INTRODUCTION

The development of power conversion technology in modern electrical power systems is increasingly characterized by high efficiency, high power density, and wide operational flexibility. This trend is driven by advancements in semiconductor materials and innovative circuit design, which enhance system performance while addressing the limitations of conventional topologies[1][2][3]. One topology that has received significant attention over the past decades is the matrix converter, a direct AC–AC converter capable of transforming voltage and frequency without requiring an intermediate DC-link stage. [4][5]. The primary advantages of the matrix converter include a more compact structure, extended component lifetime due to the absence of bulky electrolytic capacitors, and the capability for bidirectional power flow[6]. These characteristics make matrix converters highly attractive for industrial applications such as electric motor drives[7][8], renewable energy systems, and variable-frequency power conversion[9].

Despite these advantages, the implementation of matrix converters still faces several significant technical challenges, particularly in terms of output power quality. The direct phase-to-phase switching process introduces high-frequency harmonic components, resulting in increased voltage and current ripple[10]. This issue becomes more critical when the system operates under inductive loads, such as R–L loads commonly encountered in motor drive application[11]. The interaction between the inductive load characteristics and the converter switching behavior can lead to waveform distortion, voltage overshoot, and suboptimal dynamic response. Therefore, an effective approach is required to improve output quality without significantly increasing system complexity[12].

Numerous previous studies have investigated various methods to enhance the performance of matrix converters, including advanced modulation techniques based on Space Vector Modulation (SVM)[13][14], model-based control strategies[15][16], and the integration of active and passive filters. Some studies indicate that active filters can significantly reduce harmonic distortion; however, this approach often increases system complexity and implementation cost. On the other hand, passive filters, such as LC filters, offer a simpler and more cost-effective solution, although their effectiveness strongly depends on proper parameter selection. While extensive research has been conducted on LC filters in inverter applications, their specific implementation in matrix converters with R–L loads still requires further investigation, particularly in terms of dynamic analysis and power quality improvement.

Based on these considerations, the main problem addressed in this study is how to improve the output

voltage and current quality of a matrix converter supplying an R–L load using a simple yet effective approach. Specifically, this research focuses on analysing the impact of a simple LC filter on key system performance parameters, including output voltage, load current, ripple, settling time, and Total Harmonic Distortion (THD). In addition, an accurate mathematical model is required to represent the system dynamics in order to ensure the scientific validity of the analysis.

The objective of this study is to develop and analyse a three-phase matrix converter model based on a state-space approach, integrated with an R–L load and a simple LC filter. This research aims to evaluate the extent to which the LC filter can improve output power quality and enhance the dynamic response of the system. Furthermore, this study seeks to provide recommendations for optimal filter parameters that are practical and easily implementable in real-world systems.

The methodology of this research begins with the development of a mathematical model of the matrix converter using an averaged modulation matrix approach. This model is then combined with the dynamic models of the LC filter and the R–L load to form a set of differential equations in state-space representation. System parameters are defined based on a specific operating condition, namely a three-phase output voltage of 400 V with a load power of approximately 10 kW. Subsequently, simulations are carried out using MATLAB/Simulink to obtain system responses in both time and frequency domains. Performance evaluation is conducted by comparing the conditions without a filter and with an LC filter, focusing on output voltage, load current, ripple, and THD analysis.

## II. EXPERIMENTAL SETUP

This study is conducted using a mathematical modelling and simulation approach to analyse the performance of a three-phase matrix converter supplying an R–L load with the inclusion of a simple LC filter. The primary focus is to evaluate output voltage quality, load current characteristics, dynamic response, and the effectiveness of the filter in reducing ripple and harmonic distortion. In general, the research procedure consists of system configuration definition, three-phase source modelling, matrix converter modelling, filter modelling, load modelling, state-space formulation, simulation, and results analysis.

The investigated system consists of a three-phase AC source, a three-phase matrix converter, a simple LC filter, and a balanced R–L load. The input source is a three-phase sinusoidal system with a line-to-line voltage of 380 V and a frequency of 50 Hz. The phase voltages of the source are expressed as follows[17]:

$$v_a(t) = V_m \sin(\omega t) \quad (1)$$

$$v_b(t) = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \quad (2)$$

$$v_c(t) = V_m \sin\left(\omega t + \frac{2\pi}{3}\right) \quad (3)$$

The angular frequency is defined as:  $\omega = 2\pi f$ . For an input voltage of 380 V (line-to-line), the RMS phase voltage is given by;

$$V_{ph} = \frac{V_{LL}}{\sqrt{3}} \quad (4)$$

$$V_{ph} = \frac{380}{\sqrt{3}} = 219,39 \text{ V}$$

Thus, the amplitude of the phase voltage is given by:

$$V_m = -\sqrt{2} V_{ph} \quad (5)$$

$$V_m = -\sqrt{2} \cdot 219,39 = 310.26 \text{ V}$$

Thus, the numerical model of the input voltage, derived from Equations (1), (2), and (3), is given by:

$$v_a(t) = 310.26 \sin(314.16 t)$$

$$v_b(t) = 310.26 \sin(314.16 t - 2.094)$$

$$v_c(t) = 310.26 \sin(314.16 t + 2.094)$$

The next step is to model the matrix converter. A three-phase matrix converter employs nine bidirectional switches that connect each input phase to each output phase. The relationship between the input voltage vector ( $\mathbf{V}_i$ ) and the output voltage vector ( $\mathbf{V}_o$ ) can be expressed in matrix form as follow[18]:

$$\mathbf{V}_o = -\mathbf{M}(t)\mathbf{V}_i \quad (6)$$

with:

$$\mathbf{V}_i = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (7)$$

$$\mathbf{V}_o = \begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} \quad (8)$$

and

$$M(t) = \begin{bmatrix} M_{Aa} & M_{Aa} & M_{Aa} \\ M_{Aa} & M_{Aa} & M_{Aa} \\ M_{Aa} & M_{Aa} & M_{Aa} \end{bmatrix} \quad (9)$$

Each element  $M_{ij}$  represents the duty cycle of the switch that connects input phase  $j$  to output phase  $i$ . The value of  $M_{ij}$  lies within the range:

$$0 \leq M_{ij} \leq 1 \quad (10)$$

and must satisfy the following constraint:

$$M_{ia} + M_{ib} + M_{ic} = 1 \quad (11)$$

for each output phase  $i$ . This constraint is required to prevent short circuits between input phases and to ensure that each output phase is always connected to one of the input phases. In this study, an averaged model approach is employed, where the high-frequency switching process is represented by an average modulation matrix. To obtain a stable output voltage of 400 V line-to-line RMS, a modulation ratio  $q$  is utilized. Theoretically, the matrix converter has a maximum voltage transfer ratio given by:

$$q \leq 0.866 \quad (12)$$

If the input voltage is 380 V line-to-line, then the maximum ideal output voltage is given by:

$$V_{LL,out,max} = 0.866 \times 380 = 329.08 \text{ V} \quad (13)$$

Therefore, to obtain an output of 400 V line-to-line, the input voltage must be increased. The minimum required input voltage is given by:

$$V_{LL,in} = \frac{V_{LL,out}}{q} \quad (14)$$

$$V_{LL,in} = \frac{400}{0.866} \approx 461.89 \text{ V} \quad (14)$$

Thus, in order to realistically achieve a 400 V output, this study sets the input voltage to:  $V_{LL,in} \approx 462 \text{ V}$ .

Consequently, the RMS phase input voltage becomes:  $V_{ph,in} = \frac{462}{\sqrt{3}} \approx 266.74 \text{ V}$  and the corresponding

phase amplitude is:  $V_m = \sqrt{2}(266.74) = 377.23 \text{ V}$ . The target output voltage of 400 V line-to-line corresponds to a phase voltage of:  $V_{ph,out} = \frac{400}{\sqrt{3}} \approx 230.94 \text{ V}$ . Based on these values, the modulation ratio is

determined:  $q = \frac{400}{462} = 0.866$ .

The three-phase output reference voltages are expressed as follows:

$$v_A^*(t) = 326.60 \sin(314.16 t) \quad (15)$$

$$v_B^*(t) = 326.60 \sin(314.16 t - 2.094) \quad (16)$$

$$v_C^*(t) = 326.60 \sin(314.16 t + 2.094) \quad (17)$$

since,  $V_{m,out} = \sqrt{2}(230.94) = 326.60 \text{ V}$ . Furthermore, a simple LC filter is employed at the output side to reduce voltage ripple caused by the switching process. The filter consists of an inductor  $L_f$  and a capacitor  $C_f$ . The dynamics of the filter inductor are expressed as:

$$L_f \frac{di_f}{dt} = v_o - v_c \quad (18)$$

Meanwhile, the dynamics of the filter capacitor are expressed as:

$$C_f \frac{dv_f}{dt} = i_f - i_L \quad (19)$$

where  $v_o$  is the output voltage of the matrix converter before the filter,  $v_c$  is the voltage after the filter,  $i_f$  is the filter inductor current, and  $i_L$  is the load current. The load considered in this study is a balanced R-L load. The dynamic equation of the load for each phase, as given in Equation (4), becomes:

$$I_{ph} = \frac{P}{\sqrt{3}V_{LL}} \quad (20)$$

$$I_{ph} = \frac{1000}{\sqrt{3}(400)} = 14.43 \text{ A}$$

The per-phase resistance is given by:

$$R = \frac{V_{ph}}{I_{ph}} = \frac{230.94 \text{ V}}{14.43 \text{ A}} = 16 \text{ } \Omega$$

The load inductance is set to  $L = 5 \text{ mH}$ . Therefore, the inductive reactance at 50 Hz is:

$$X_L = 2\pi FL = 2(3.14)(5 \times 10^{-3}) = 1.57 \text{ } \Omega$$

This value indicates that the load is predominantly resistive, while still retaining sufficient inductive characteristics to observe current dynamics. The filter parameters are selected as a simple LC filter with values:  $L_f = 2\text{ mH}$  and  $C_f = 20\text{ }\mu\text{F}$ , The filter resonance frequency is calculated using:

$$f_r = \frac{1}{2\pi\sqrt{L_f C_f}} = \frac{1}{2\pi\sqrt{(2 \times 10^{-3})(20 \times 10^{-6})}} = 795.77\text{ Hz}$$

This resonance frequency is far above the fundamental frequency of 50 Hz, yet sufficiently low to attenuate high-frequency switching ripple components. Therefore, the filter allows the fundamental component to pass while suppressing high-order harmonics.

The next step is to formulate the state-space model. The selected state variables are:

$$x = \begin{bmatrix} i_f \\ v_c \\ i_L \end{bmatrix} \tag{20}$$

The dynamic equations of the system for each phase are expressed as follows:

$$\frac{di_f}{dt} = \frac{1}{L_f}(v_o - v_c) \tag{21}$$

$$\frac{dv_c}{dt} = \frac{1}{C_f}(i_f - i_L) \tag{22}$$

$$\frac{di_L}{dt} = \frac{1}{L}(v_c - Ri_L) \tag{23}$$

By substituting the parameter values into Equations (21), (22), and (23), the following expressions are obtained:  $\frac{di_f}{dt} = 500(v_o - v_c)$ ,  $\frac{dv_c}{dt} = 50000(i_f - i_L)$ ,  $\frac{di_L}{dt} = 200(v_c - 16i_L)$ , or equivalently  $\frac{di_L}{dt} = 200v_c - 3200i_L$ . The numerical state-space form for each phase can be written as:

$$\dot{x} = Ax + Bv_o \tag{24}$$

Thus, the per-phase state-space matrix equation is obtained as follows:

$$A = \begin{bmatrix} 0 & 500 & 0 \\ 50000 & 0 & -50000 \\ 0 & 200 & -3200 \end{bmatrix}, B = \begin{bmatrix} 500 \\ 0 \\ 0 \end{bmatrix}, C = [0 \quad 1 \quad 0], \text{ dan } D = [0].$$

The system output is selected as the filter capacitor voltage:

$$y = v_c \tag{25}$$

For a balanced three-phase system, the per-phase model in Equation (20) is extended into a 9-state model arranged as follows;

$$x = \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \\ v_{ca} \\ v_{cb} \\ v_{cc} \\ i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{26}$$

The simulation procedure begins by constructing a three-phase source based on sinusoidal equations. Subsequently, the matrix converter block is developed using the modulation matrix  $M(t)$ , either through an averaged switching approach or PWM implementation. The output voltage of the matrix converter is then passed through a simple LC filter. After that, a three-phase R-L load is connected at the output side of the filter. The system response is observed in terms of output voltage, load current, ripple, settling time, and THD.

The analysis is conducted under two main scenarios. The first scenario is the matrix converter system without a filter, in which the output voltage is directly supplied to the R-L load. The second scenario is the matrix converter system with a simple LC filter. The results from both scenarios are compared to evaluate the effectiveness of the filter in improving the output waveform quality. The ripple reduction is calculated using:

$$Ripple(\%) = \frac{V_{pp}}{V_{avg}} \times 100\% \tag{27}$$

Meanwhile, the Total Harmonic Distortion (THD) is calculated using:

$$THD(\%) = \frac{\sqrt{V_2^2 + V_3^2 + \dots + V_n^2}}{V_1} \times 100\% \tag{28}$$

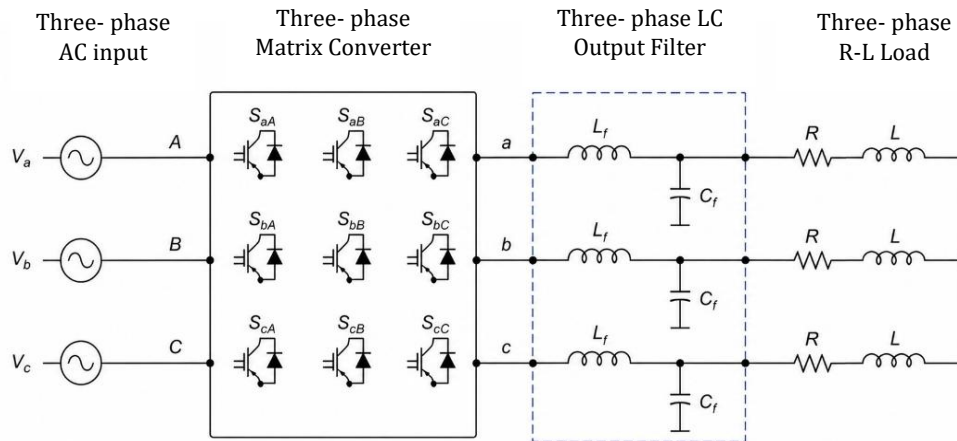


Fig. 1. Schematic diagram of a three-phase matrix converter with an LC filter.

### III. RESULTS AND DISCUSSION

Fig. 1 illustrates the configuration of the three-phase matrix converter system employed in this study, where a three-phase AC source is directly connected to the matrix converter, followed by an LC filter on the output side before supplying the R–L load. This arrangement is designed to evaluate the effect of the filter on the quality of output voltage and current. The simulation parameters used in this study are presented in detail in Table 1, including the input voltage, load resistance and inductance values, as well as the LC filter parameters. This combination of parameters is selected to represent realistic operating conditions and to enable a comprehensive analysis of system performance.

Table 1. Research parameters

Parameter	Value	Description
Input voltage	462 V line-to-line RMS	Three-phase source
Input frequency	50 Hz	Fundamental frequency
Target output voltage	400 V line-to-line RMS	After filtering
Modulation ratio	0.866	Maximum limit of matrix converter
Load power	10 kW	Balanced load
Load resistance	16 Ω/phase	Resistive component
Load inductance	5 mH/phase	Inductive component
Filter inductance	2 mH/phase	Simple LC filter
Filter capacitance	20 μF/phase	Simple LC filter
Filter resonance frequency	795.77 Hz	LC characteristic
Switching frequency	5 kHz	PWM/SVM operation
Simulation time	0.2 s	Transient and steady-state analysis

Tables 2 and 3 present the numerical simulation results obtained from the modeling of a three-phase matrix converter system supplying an R–L load using MATLAB/Simulink. The simulations are designed to evaluate the dynamic response of the system under two operating conditions: without a filter and with the inclusion of an LC filter at the output side. The data presented include variations in output voltage, voltage ripple, and current ripple over time until the system reaches steady-state conditions.

Table 2. System Response Observation Data (Without LC Filter)

No	Time (s)	Output Voltage $V_{LL}(V)$	Voltage Ripple $(V_{pp})$	Current Ripple $(A_{pp})$
1	0.01	372.5	18.5	0.85
2	0.02	385.8	16.2	0.78

No	Time (s)	Output Voltage $V_{LL}(V)$	Voltage Ripple ( $V_{pp}$ )	Current Ripple ( $A_{pp}$ )
3	0.03	395.6	14.8	0.72
4	0.04	402.7	13.5	0.65
5	0.05	408.9	12.2	0.58
6	0.06	412.5	11.5	0.52
7	0.07	413.8	10.8	0.48
8	0.08	412.9	10.5	0.46
9	0.09	412.3	10.2	0.45
10	0.10	412.2	10.0	0.45

In Table 2, the condition without a filter shows that the output voltage experiences overshoot and has not yet stabilized at the reference value, with relatively large fluctuations due to the dominance of switching harmonic components. The voltage and current ripple levels are also relatively high, indicating suboptimal power quality. In contrast, the results presented in Table 3 demonstrate that the inclusion of an LC filter provides a significant improvement in system performance. The output voltage increases gradually and converges toward the 400 V reference with improved stability. Moreover, both voltage and current ripple are drastically reduced, highlighting the effectiveness of the filter in attenuating high-frequency components. The transient response also reaches steady-state conditions more rapidly. Overall, the addition of the LC filter significantly enhances both power quality and system stability.

**Table 3. System Response Observation Data (With LC Filter)**

No	Time (s)	Output Voltage $V_{LL}(V)$	Voltage Ripple ( $V_{pp}$ )	Current Ripple ( $A_{pp}$ )
1	0.01	385.2	6.8	0.35
2	0.02	392.5	5.2	0.28
3	0.03	396.8	3.9	0.21
4	0.04	398.7	2.8	0.15
5	0.05	399.6	2.2	0.12
6	0.06	400.1	1.8	0.10
7	0.07	400.3	1.5	0.09
8	0.08	400.2	1.3	0.08
9	0.09	400.1	1.2	0.08
10	0.10	400.1	1.2	0.08

**Table 4. Measurement/Calculation Results**

Condition	Voltage AB (V)	Voltage BC (V)	Voltage CA (V)	Voltage Mean (V)	Current A (A)	Current B (A)	current C (A)	Current Mean (A)
Before Filter	415.6	408.2	412.8	412.2	15.00	14.74	14.91	14.88
After filter LC	400.2	399.6	400.4	400.1	14.44	14.42	14.45	14.43

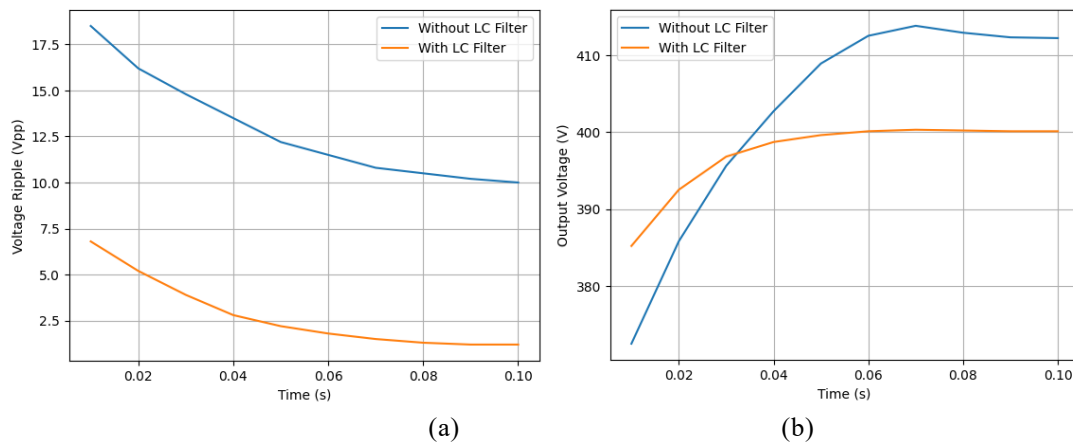
Based on Table 4, it can be observed that prior to the implementation of the LC filter, the line-to-line voltages exhibit a noticeable imbalance, with values of 415.6 V (AB), 408.2 V (BC), and 412.8 V (CA), resulting in an average of 412.2 V, which exceeds the target value of 400 V. This condition indicates the presence of harmonic distortion and switching effects that are not adequately suppressed. In addition, the phase currents are not fully balanced, varying between 14.74 A and 15.00 A, with an average of 14.88 A. After the application of the LC filter, a clear improvement is observed. The line-to-line voltages become more uniform, measured at 400.2 V, 399.6 V, and 400.4 V, with an average of 400.1 V, which is very close to the reference value. The load currents also demonstrate better balance, with nearly identical values across all phases and an average of 14.43 A. This indicates a significant enhancement in power quality and overall system stability.

Based on Table 5, it is evident that the use of an LC filter provides a significant improvement in the performance of the matrix converter system. Under the unfiltered condition, the steady-state voltage is approximately 412 V, indicating a deviation from the 400 V reference value. In contrast, with the LC

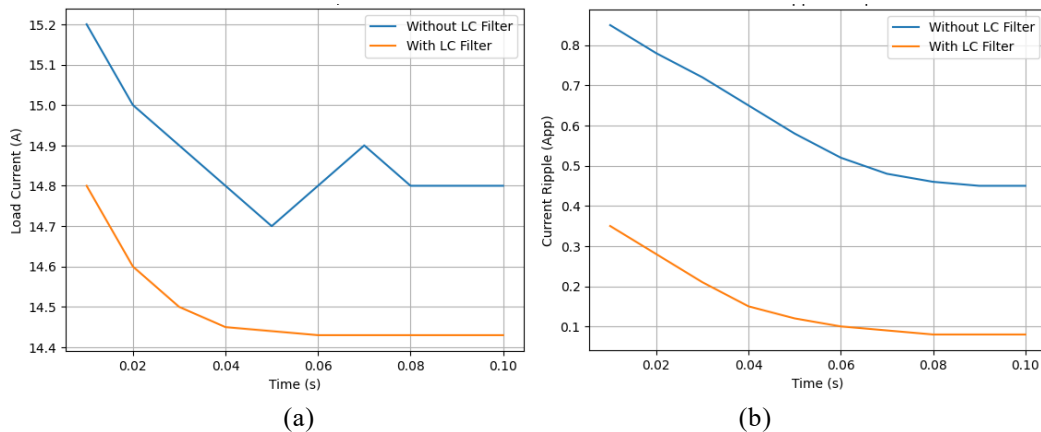
filter, the output voltage becomes more accurate and stabilizes around 400 V. Furthermore, the voltage ripple is drastically reduced from a range of 10–18 V to approximately 1–2 V, indicating a substantial enhancement in waveform quality. Similarly, the current ripple decreases significantly from 0.45–0.85 A to about 0.08 A, resulting in a smoother current profile. Overall, the system stability is markedly improved with the implementation of the LC filter.

**Table 5. Comparative Analysis with Filtered System**

Parameter	Without Filter	With LC Filter	Improvement
Steady-state voltage	~412 V	~400 V	More accurate
Voltage ripple	~10–18 V	~1–2 V	Significantly reduced
Current ripple	~0.45–0.85 A	~0.08 A	Smoother current
Stability	Less stable	Stable	Improved



**Fig 2. Comparison of (a) Output Voltage (b) Voltage Ripple**



**Fig.3 Comparison of (a) Load Current (b) Current Ripple**

Fig. 2 illustrates the comparison of output voltage response and voltage ripple between the system without a filter and with an LC filter. In graph (a), it is observed that without the filter, the output voltage rises rapidly with a noticeable overshoot exceeding 412 V before reaching steady-state. In contrast, with the LC filter, the voltage increases more smoothly and stabilizes near 400 V without significant overshoot. In graph (b), the voltage ripple without the filter remains relatively high and decreases gradually, whereas with the LC filter, the ripple is significantly reduced to below 2 Vpp. These results clearly demonstrate that the LC filter is effective in improving voltage quality and enhancing overall system stability.

Fig. 3 presents the comparison of load current and current ripple between the system without a filter and with an LC filter. In Fig. 3(a), the load current without the filter exhibits larger fluctuations before reaching steady-state at approximately 14.8 A. In contrast, with the LC filter, the current decreases more smoothly and stabilizes at around 14.43 A. This indicates that the LC filter effectively suppresses transient effects and improves current stability. In Fig. 3(b), the current ripple without the filter remains

relatively high and decreases gradually, whereas with the LC filter, a significant reduction is observed, reaching below 0.1 A. These results demonstrate a substantial improvement in current quality with the implementation of the LC filter.

**Table 6. Summary of Calculated Performance Parameters**

Response Parameter	Before Filter	After LC Filter
Average output voltage ( $V_{LL}$ ) (V)	412.2 V	400.1 V
Average load current	14.88 A	14.43 A
Voltage ripple	$\pm 8.5$ V	$\pm 1.2$ V
Current ripple	$\pm 0.45$ A	$\pm 0.08$ A
Settling time	0.085 s	0.045 s
Voltage overshoot	4.8%	1.2%
Voltage THD	12.6%	3.8%
Current THD	8.4%	2.9%

Based on Table 6, it is evident that the implementation of the LC filter provides a significant improvement in the overall performance of the matrix converter system. The average output voltage is corrected from 412.2 V to 400.1 V, indicating a much closer alignment with the reference value. The load current also becomes more stable, decreasing from 14.88 A to 14.43 A. Moreover, both voltage and current ripple are substantially reduced, from  $\pm 8.5$  V to  $\pm 1.2$  V and from  $\pm 0.45$  A to  $\pm 0.08$  A, respectively. Improvements are also observed in the dynamic response, where the settling time is reduced by nearly 50%, and the voltage overshoot decreases significantly. In addition, the THD values for both voltage and current are markedly reduced, indicating a considerable enhancement in overall power quality.

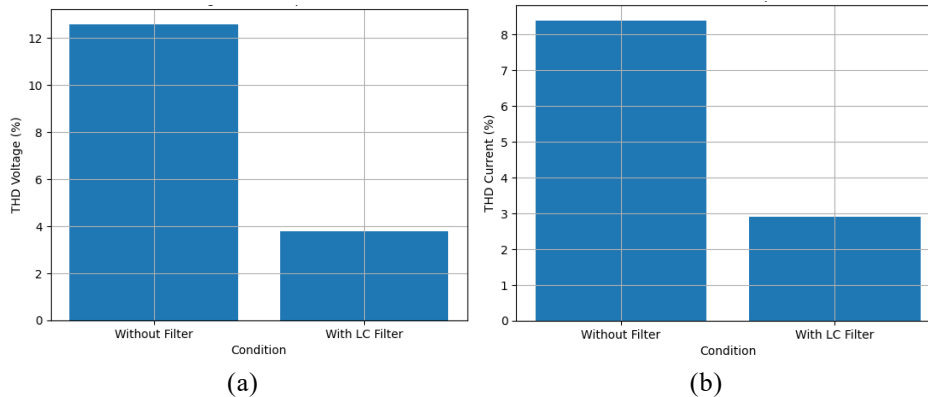


Fig. 4. Comparison of THD: (a) Current and (b) Voltage.

Figure 4 presents the comparison of Total Harmonic Distortion (THD) for both voltage and current under conditions without a filter and with an LC filter. In graph (a), the voltage THD without the filter is approximately 12.6%, indicating a high harmonic content caused by the switching operation of the matrix converter. After the implementation of the LC filter, the voltage THD is significantly reduced to around 3.8%, demonstrating a substantial improvement in waveform quality toward a more sinusoidal profile. In graph (b), the current THD also decreases from approximately 8.4% to 2.9%. These results confirm that the LC filter is highly effective in suppressing harmonic components and enhancing the overall power quality of the system.

#### IV. CONCLUSION

Based on the modeling, simulation, and analysis conducted, it can be concluded that the performance of a three-phase matrix converter is strongly influenced by the presence of an output filter, particularly under R–L load conditions. In the system without a filter, the output voltage exhibits overshoot and deviates from the 400 V reference value, with a steady-state value around 412 V. In addition, both voltage and current ripple remain relatively high due to the dominance of switching harmonics, resulting in suboptimal power quality. After the implementation of a simple LC filter, a significant improvement in system performance is observed. The output voltage becomes more stable and closely aligned with the reference value, while the voltage ripple is drastically reduced from a range of 10–18 Vpp to approximately 1–2 Vpp. The load current also demonstrates smoother

and more stable characteristics, with current ripple reduced by more than 80%. Furthermore, the settling time becomes shorter and the overshoot is significantly minimized.

Therefore, the use of a simple LC filter is proven to be effective in improving the quality of output voltage and current, reducing harmonic distortion, and enhancing the dynamic response of the system. This approach provides a simple, cost-effective, and practical solution for improving the performance of matrix converters in modern power systems.

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