Matrix Converter: A Power Quality Conditioner

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Abstract: ***In this paper, a Matrix Converter (MC) a forced commutated converter which makes directly Ac to Ac Power conversion is simulated using Matlab & Simulink. Here we are analyzing the fundamentals of Matrix Converters, different models of Matrix converters .This method provides the amplitude of output voltage up to 87% of input voltage. Here along with the matrix converter a hybrid filter is used & comparisons of results are presented. The obtained results prove that the power quality of power system can be improved with the use of matrix converter along with hybrid filter.***

Keywords: Matrix converter, Hybrid filter, Modulation Techniques, Power Quality.

1. Introduction

There are many nonlinear loads drawing non sinusoidal currents from electrical power systems. These non sinusoidal currents pass through different impedances in the power systems and produce voltage harmonics. These voltage harmonics propagate in power systems and affect all of the power system components. The important harmonic source is ac/dc converters/inverters. Due to the discontinuous input currents, the matrix converter behaves as a source of current harmonics, which are injected back into the AC mains. Since these current harmonics results in voltage distortions that affect the overall operation of the AC system, they have to be reduced. Therefore, an Hybrid filter is used along with Matrix converter to improve the power quality and it is simulated using MATLAB Simulink.

2. Matrix Converter

Matrix converter is an Ac – Ac Converter, which is also called direct energy converter. The main advantage of MCs is the absence of bulky reactive elements that are subject to ageing, and reduce the system reliability.

Furthermore, MCs provide bidirectional power flow, nearly sinusoidal input and output waveforms and controllable input power factor. The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. The Matrix Converter is a forced commutated converter which uses an array of controlled bi-directional switches as the main power elements to create a variable output voltage system with unrestricted frequency. The advantages of Matrix converter are:

i. Simple and compact power circuit.
ii. Generation of load voltage with arbitrary amplitude and frequency.
iii. Sinusoidal input and output currents.
iv. Operation with unity power factor for any load.
v. Regeneration capability.

The direct AC/AC converter provides a direct connection between the input and output terminals without an intermediate energy storage element through an array of semiconductor switches. It has an array of m×n bidirectional power switches to connect an m phase voltage source to a n phase load. It does not have any dc-link circuit and does not need any large energy storage elements.

3. Fundamentals

Matrix Converter consists of nine bi-directional switches, which are required to be commutated in the right way and sequence in order to minimize losses and produce the desired output with a high quality input and output waveforms. It is a single stage converter which has an array of mxn bidirectional power switches to connect, directly, an m-phase voltage source to an n-phase load. The Matrix Converter of 3x3 switches, shown in figure 1, has the highest practical interest because it connects a three-phase voltage source with a three-phase load, typically a motor. Nine bi -directional switches in the matrix converter can theoretically assume 512 (29) different switching states combinations.

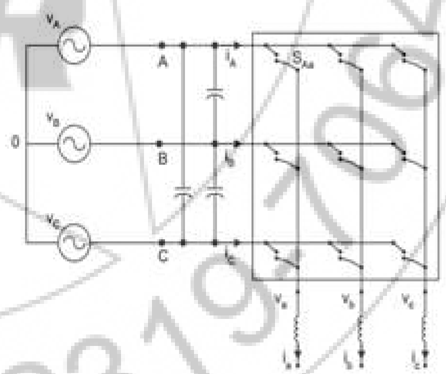

Figure 3: Simplified Circuit of a 3x3 Matrix Converter

Normally, the Matrix Converter is fed by a voltage source and for this reason; the input terminals should not be short-circuited. On the other hand, the load has typically an inductive nature and for this reason an output phase must never be opened. Defining the switching function of a single switch

$$S_{Kj} = \begin{cases} 1, switch\ S_{Kj} closed \\ 0, switch\ S_{Kj}\ open \end{cases} \quad K = A, B, C\ \&\ j = a, b, c \quad (1)$$

The constraints discussed above can be expressed by

$$S_{Aj} + S_{Bj} + S_{Cj} = 1\ j = a, b, c \quad (2)$$

With these restrictions, the 3x3 Matrix Converter has 27 possible switching states .The load and source voltages are referenced to the supply neutral, '0' in figure 1, and can be expressed as vectors defined by:

$$V_o = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix}; \; V_i = \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \quad (3)$$

The relationship between load and input voltages can be expressed as:

$$\begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix}$$

$$V_o = T \, V_i \quad (4)$$

Where T is the instantaneous transfer matrix.

In the same form, the following relationships are valid for the input and output currents:

$$i_i = \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}; i_o = \begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix} \quad (5)$$

$$i_i = T^T . i_0 \quad (6)$$

Where T is the transpose matrix of T.

Equations (4) and (6) give the instantaneous relationships between input and output quantities. To derive modulation rules, it is also necessary to consider the switching pattern that is employed. This typically follows a form similar to that shown in figure 2.

By considering that the bidirectional power switches work with high switching frequency, a low frequency output voltage of variable amplitude and frequency can be generated by modulating the duty cycle of the switches using their respective switching functions. Let mKj (t) be the duty cycle of switch SKj , defined as mKj(t) = tKj / Tseq, which can have the following values:

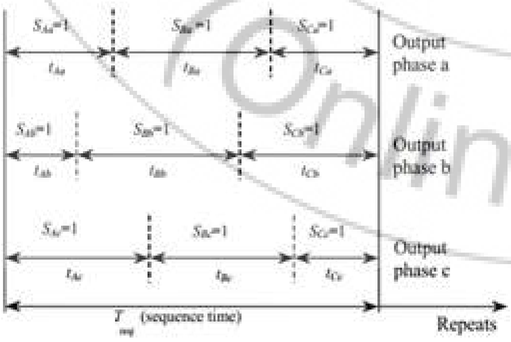

Figure 3: General Form of switching pattern

$$0 < m_{kj} < 1 \; K = A, B, C \; \& \; j = a, b, c \quad (7)$$

The low-frequency transfer matrix is defined by

$$M(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix} \quad (8)$$

The low-frequency component of the output phase voltage is given by:

$$\overline{V_0(t)} = M(t) V_i(\mathrm{t}) \quad (9)$$

The low-frequency component of the input current is:

$$\overline{\iota_i} = M(t)^T i_0 \quad (10)$$

Comparison of Matrix Converter with conventional system:

A PWM rectifier (inverter) was often used to reduce the input current harmonics and to realize motor regeneration. The matrix converter, on the other hand, is able realize motor regeneration with almost no input current harmonics. In other word, a single converter unit is able to provide performance equivalent to that of PWM rectifier and an inverter. Additionally, the charge up circuit is unnecessary since the large electrolyte capacitor is not needed for the matrix converter. As a result, smaller size longer lifespan can be achieved. The conventional system needs a filter reactor and boost-up reactor in additional to main unit. The matrix converter system, however, only need a main unit and filter reactor. Therefore the configuration becomes simple and panel size of the system can be reducing by ½ or more. In addition, since the matrix converter uses one-stage AC-AC direct conversion, a low loss system can be realized, achieving at least 1/3 lower loss then in the conventional system.

4. Modulation Techniques

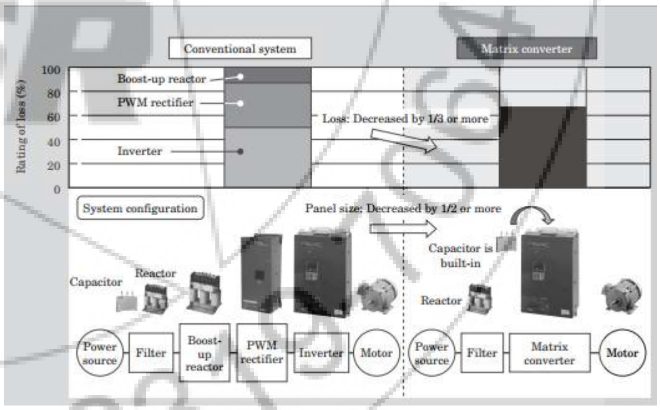

Figure 3: Comparison of Matrix converter with conventional circuit

4.1 Venturini Modulation

The first modulation technique for the matrix converter named as Venturini modulation. In Venturini each leg of the matrix converter was switched one by one for a sampling period of T. To understand Venturini modulation more clearly let us assume only one leg of the matrix converter. One leg of the matrix converter consists only three semiconductors switches, these switches are switched ON one by one for switching interval of T_1, T2, T3. Now, the output voltage of one leg of the matrix converter is given by:

$$v_1 = \frac{1}{T[v_{11}(t)t_1 + v_{12}(t)t_2 + v_{13}(t)t_3]} \quad (11)$$

and the duty cycles of one leg associated to the times t1, t2, t3,are given by-

$$m_1 = \frac{t_1}{T} = \frac{1}{3} + \frac{2}{3}\, V_S/V_e \cos\,[(\omega_o - \omega_i)t] \quad (2)$$

$$m_1 = \frac{t_2}{T} = \frac{1}{3} + \frac{2}{3}\, V_S/V_e \cos\,[(\omega_o - \omega_i)t + 2\pi/3] \quad (3)$$

$$m_1 = \frac{t_1}{T} = \frac{1}{3} + \frac{2}{3}\, V_S/V_e \cos\,[(\omega_o - \omega_i)t - 2\pi/3] \quad (4)$$

The Equation (1) shows the output voltage of the one leg of the matrix converter. Equation (2), (3) & (4) shows the modulating signals of the three switches of one leg of the matrix converter. The Venturini modulation technique is very easy to implement but it has the drawback to limit the output voltage to input voltage ratio is only 50%.

4.2 Space Vector Modulation

The SVM strategy, based on space vector representation became very popular due to its simplicity. The concept of space vector is derived from the rotating field of ac machine which is used for modulating the converter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent two phase quantity either in synchronously rotating frame (or) stationary d-q frame. From this two phase component, the reference vector magnitude can be found and used for modulating the converter output. SVM treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This technique approximates the reference voltage V_{ref} by a combination o f the eight switching pattern ($V_0 - V_7$).

Table 4.1: Switching states and corresponding outputs of a matrix converter

a	b	c	V_a	V_b	V_c	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0	1	1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

5. Hybrid Filter Design

The hybrid filter design depends on the load to be compensated. It must contain some passive LC branches one for each important load current harmonic to be removed from the source current. In the case of many typical loads, it is usually enough to employ one, two or three branches for the main harmonics. By three -phase systems it is possible to reduce or eliminate the 3rd harmonic order and its multiples by suitable connections of the transformers supplying the power to the load. Therefore it is usual to include LC branches tuned for the 5thand 7thharmonic order. The values of L and C parameter of a branch tuned for an "n" order harmonic must satisfy this equation.

$$2\pi fn = 1/\sqrt{L\,n\,Cn}$$

Where f corresponds to the fundamental frequency = 50 Hz .

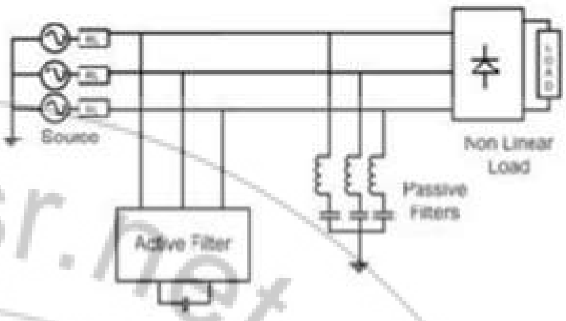

Figure 4: Hybrid Filter in power system.

6. Simulation Results

Table 1: Simulation Parameters

Source voltage amplitude, V_{im}	311 V
Input frequency, f_i	50 Hz
Load resistance, R	10 Ω
Load inductance, L	30 mH
Input filter inductance, L_f	3 mH
Input filter resistance, R_f	0.1 Ω
Input filter capacitance, C_f	25 µF
Switching frequency, f_s	10 kHz

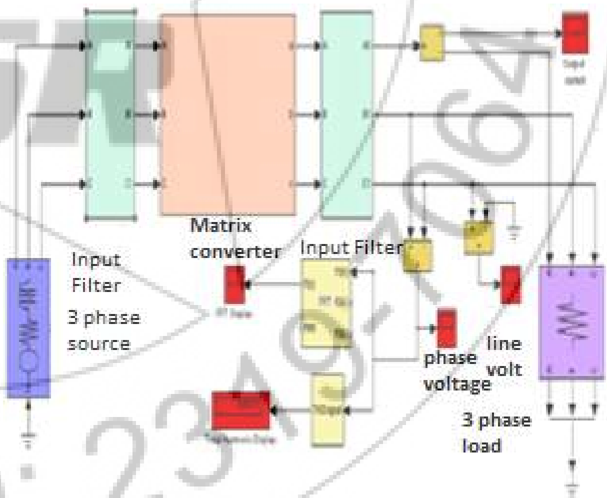

Figure 5: Schematic of Matrix Converter using Matlab Simulink

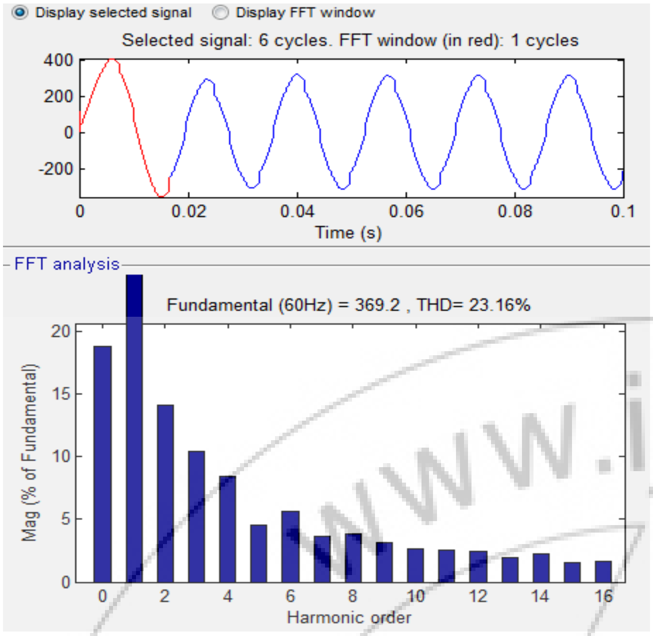

Figure 6: Harmonic analysis for the output voltage without filter

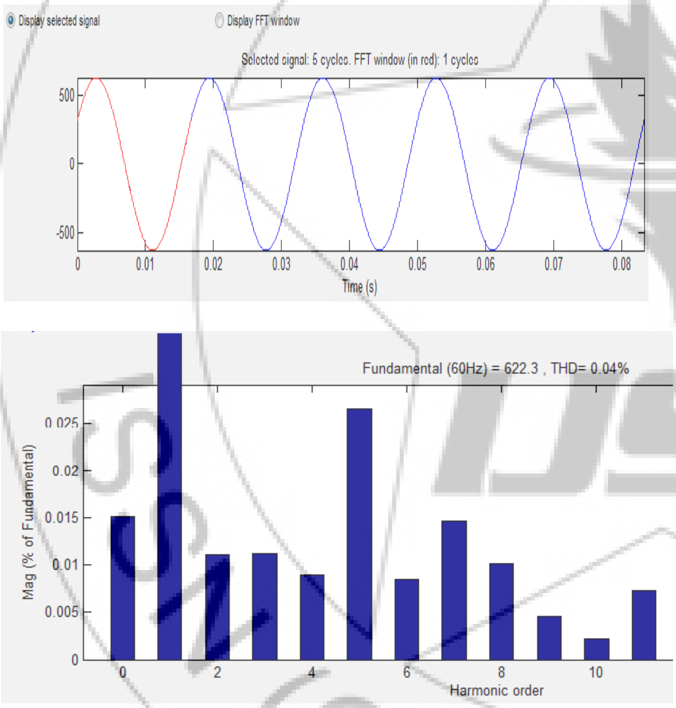

Figure 7: Harmonic analysis for the output voltage with filter

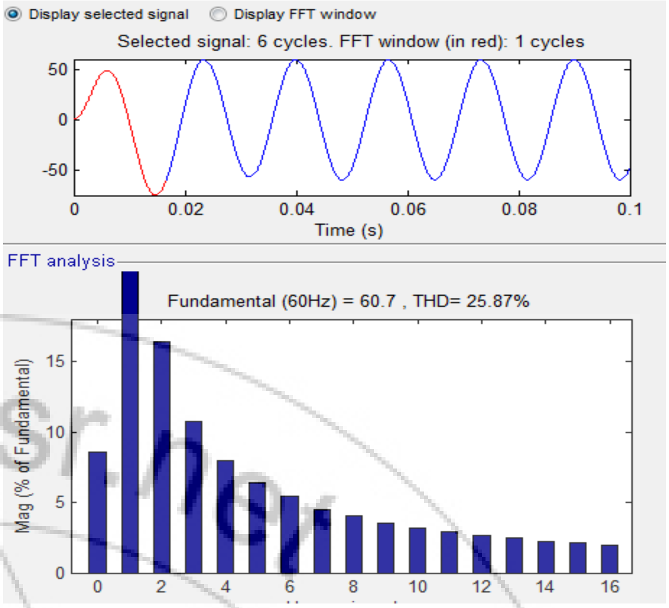

Figure 8: Harmonic analysis for the output current without filter

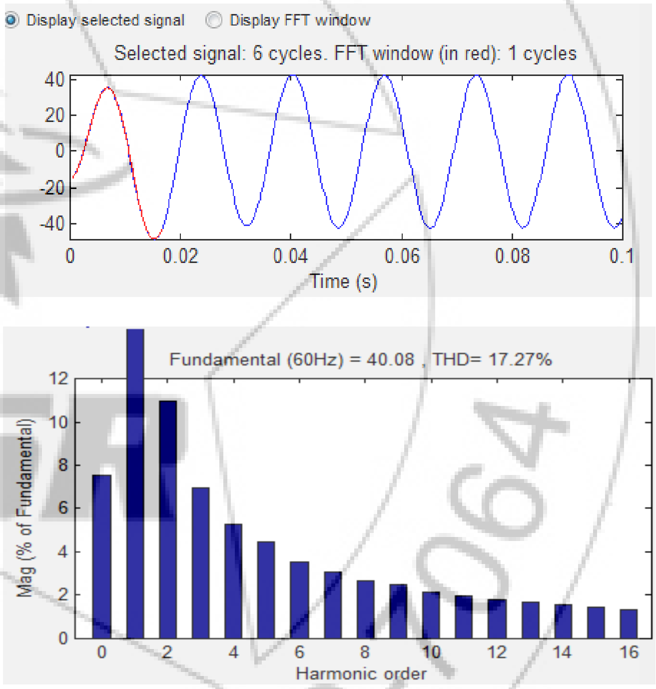

Figure 9: Harmonic analysis for the output current with filter

7. Conclusion

In this paper Modeling & simulation of Matrix Converter has been done & also discussed about the Fundamentals of Matrix Converters, different modulation techniques used. FFT analysis is being done where THD in % is compared with filter & without filter. The harmonic analysis is being done for both voltage & current. These Matrix converters are frequently called as future converter for AC drive application. The Modeling & Simulation of Matrix converter using Matlab Simulink software Package.

References

[1] J. Oyama, T. Higuchi, E. Yamada, T. Koga and T. Lipo, "New control strategy for Matrix Converter," in Conf. Rec. IEEE PESC'89, pp. 360-367.

[2] M. Venturini, A new sine wave in sine wave out, conversion technique which eliminates reactive elements," Proceeding Powercon 7, vol. E3, pp. 1 {15, 1980.

[3] Joao Afonso, Mauricio Aredes, Edson Watanabe & Julio Martins, "Shunt Active Filter for Power Quality Improvement", International Conference UIE2000-Electric ity for Sustainable Urban Development, 1- 4 November, 2000 pp. 683 -691.

[4] P. W. Wheeler, J. Rodriguez, J. C. Clare, L. Empringham, and A. Weinstein, "Matrix converters: A technological review," IEEE Trans. Ind. Electron., vol. 49, no. 2, pp. 276–288, Apr. 2002.

[5] F. Bradaschia, M. C. Cavalcanti, F. Neves, and H. de Souza, "A modulation technique to reduce switching losses in matrix converters," IEEE Trans. Ind. Electron., vol. 56, no. 4, pp. 1186–1195, Apr. 2009