Vol. 2, No. 1 | January - June 2019

Reactive Power Compensation using Matrix Converter: Indirect Space Vector Pulse Width Modulation Technique

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Abstract:

In this paper, application of matrix converter for the compensation of reactive power is studied. Matrix converter is direct AC-AC converter composed of solid-state bi-directional switches. Space-vector modulation technique is used to control the matrix converter. Simulation are done in MATLAB/Simulink and filters are used to smooth out the output waveforms. Switching frequency optimization is done and its effect on THD and input/output currents/voltages is observed.

Keywords: *Matrix Converter Control, Space Vector PWM, Reactive Power Compensation*

1. Introduction

Reactive power (Q) limits the capacity of a transmission line because it is the unused power. Presence of large amount of Q, consequently, limits the amount of active useful power (P) which can be transmitted across the transmission line. It is therefore, extremely important in power systems to develop a system which can control and reduce reactive power. Higher Q also affects the voltage across the transmission line so this compensation system would also allow to control the voltage of transmission line.

There are many traditional methods to control and compensate reactive power such as FACTs controllers and capacitor banks. Capacitor banks are bulky, heavy and expensive and they also require regular maintenance. FACTs, on the other hand, are relatively better and more controllable but they still require the use of capacitors, such as in SVC large capacitor is used to handle high voltage [1]. Whereas, in STATCOM smaller electrolytic capacitor is used on DC side.

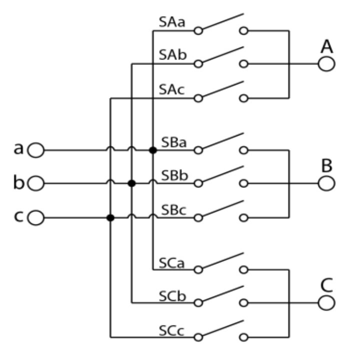

Fig 1:Matrix Converter Schematic

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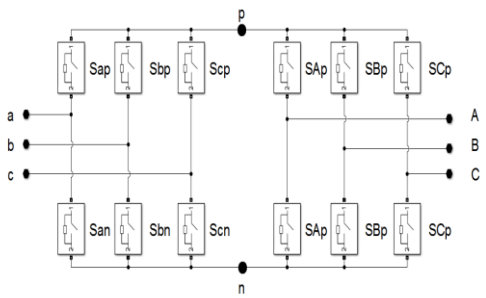

Fig 2:An indirect matrix converter

Reactive power can also be controlled by matrix converter (MC). MC was first proposed by Alesina and Venturini in 1989 [2]. They extensively studied MC and researched on low frequency behaviors of voltages and currents at the output of the system. Earliest difficulties in the research of MC were the commutation of the bidirectional switches [8]. Work around for commutation problems was found by [7] by using intelligent commutations techniques.

MC is direct AC-AC converter as shown in Figure 1. It consists of 9 bi-directional switches and it eliminates the need of intermediate DC-link required in traditional back to back converters. Features of MC includes sinusoidal waveforms at output, control of output amplitude and frequency, compact design due to use of solid-state semiconductor components, Regeneration and unity power factor at input [3].

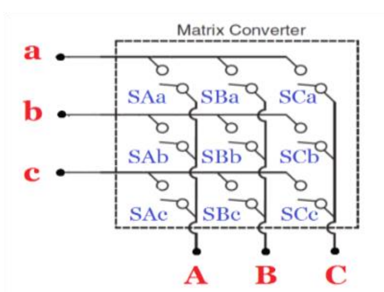

Fig 3: 3x3 Direct matrix converter.

2. Matrix Converter

Matrix converter is an ac-ac converter which is arranged in 3x3 array of 9 bi-directional switches. There are two main types of MC topologies: direct and indirect as shown in Figure 2. Indirect MC consists of two stages,

$$\begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}S_{Ba}S_{Ca} \\ S_{Ab}S_{Bb}S_{Cb} \\ S_{Ac}S_{Bc}S_{Cc} \end{bmatrix} * \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}S_{Ab}S_{Ac} \\ S_{Ba}S_{Bb}S_{Bc} \\ S_{Ca}S_{Cb}S_{Cc} \end{bmatrix} * \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \quad (2)$$

first is rectification stage and second is inversion stage. An imaginary dc-link is assumed between these two stages for the purpose of modulation of MC [4]. Relationship between input and output voltage and current is represented by (1) and (2).

Table I: 27 Switching states of Direct Matrix Converter.

No	Aa	Ab	Ac	Ba	Bb	Bc	Ca	Cb	Cc
1	1	0	0	0	1	0	0	0	1
2	0	1	0	0	0	1	1	0	0
3	0	0	1	1	0	0	0	1	0
4	1	0	0	0	0	1	0	1	0
5	0	1	0	1	0	0	0	0	1
6	0	0	1	0	1	0	1	0	0
7	1	0	0	0	1	0	0	1	0
8	0	1	0	1	0	0	1	0	0
9	0	1	0	0	0	1	0	0	1
10	0	0	1	0	1	0	0	1	0
11	0	0	1	1	0	0	1	0	0
12	1	0	0	0	0	1	0	0	1
13	0	1	0	1	0	0	0	1	0
14	1	0	0	0	1	0	1	0	0
15	0	0	1	0	1	0	0	0	1
16	0	1	0	0	0	1	0	1	0
17	1	0	0	0	0	1	1	0	0
18	0	0	1	1	0	0	0	0	1
19	0	1	0	0	1	0	1	0	0
20	1	0	0	1	0	0	0	1	0
21	0	0	1	0	0	1	0	1	0
22	0	1	0	0	1	0	0	0	1
23	1	0	0	1	0	0	0	0	1
24	0	0	1	0	0	1	1	0	0
25	1	0	0	1	0	0	1	0	0
26	0	1	0	0	1	0	0	1	0
27	0	0	1	0	0	1	0	0	1

(1) relates input voltage with output current whereas (2) relates output current with input current.

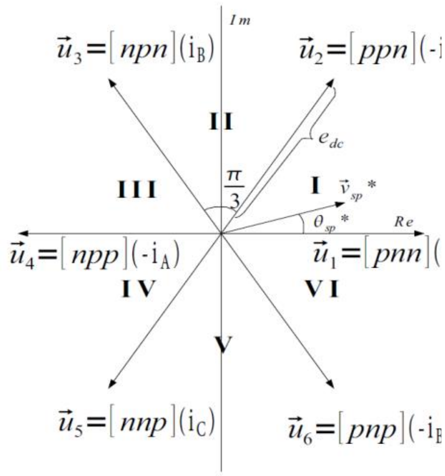

Fig 4: VSI stage voltage space- vectors in complex plane.

Direct MC has 9 switches. Therefore, total 29=512 switching combinations are possible. But these combinations are further constrained by following rules [5]:

- Two Input terminals cannot be short circuited.
- An output terminal cannot be left open.

These rules can be expressed by following equations [4]:

$$SAa+SAb+SAc=1 \quad (3)$$

$$SBa+SBb+SBc=1 \quad (4)$$

$$SCa+SCb+SCc=1 \quad (5)$$

27 switching combinations are categorized into three parts [5]:

- 3 zero vectors (all output lines connected to a same input terminal).
- 6 rotating vectors (every output line connected to a different input terminal).
- 18 active vectors (two output lines connected to one input terminal, the third line to another terminal one input terminal is not connected).

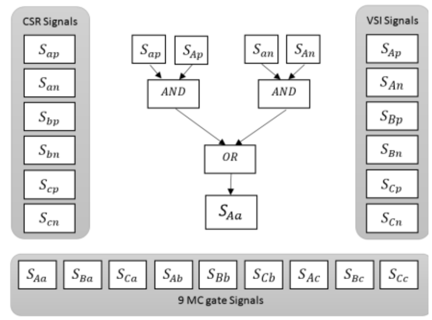

Fig 5: Transformation of 12 gate signals into 9.

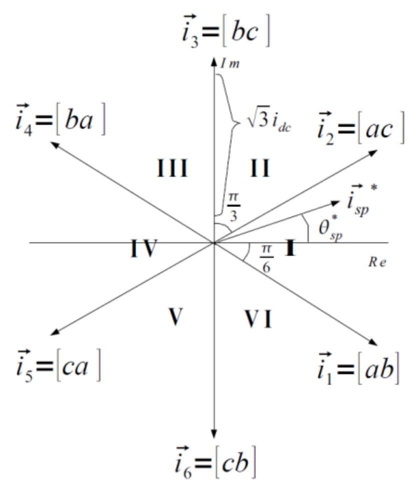

Fig 6: CSR stage current space-vectors.

3. Control Scheme For Matrix Converter

In this research direct topology of matrix converter will be used for simulation but for modulation, indirect matrix converter will be assumed in which first stage will be modulated as current source rectifier (CSR) and second

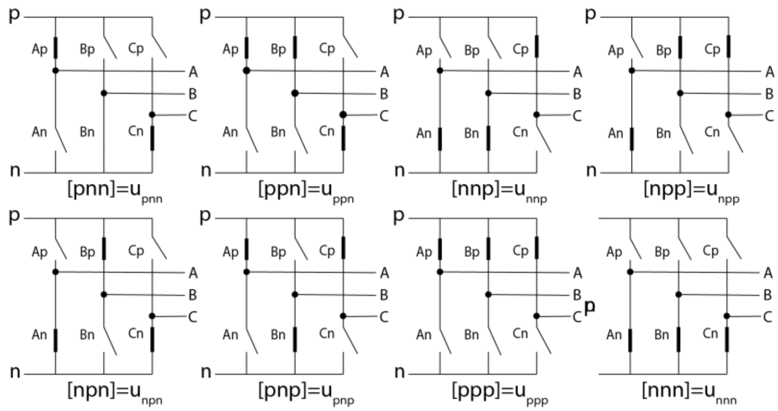

Fig 7: Switching states of VSI stage.

stage will be modulated as voltage source inverter (VSI) [6].

Voltage and current space vectors are shown in Figure 4 and 5 respectively. Control scheme outputs 12 gating signals, 6 signals for CSR namely Sap, San, Sbp, Sbn, Scp, Scn and 6 signals for VSI namely SAp, SAn, SBp, SBn, SCp, SCn. Conversion from 12 gating signals to 9 signals such as SAa, SAb, SAc, SBa, SBb, SBc, SCa, SCb, SCc, is done by the process demonstrated in Figure 6.

A reference input is given to each control stage such as current reference for CSR and voltage reference for VSI. There are 23 = 8 switching states of VSI because two switches in one leg cannot be closed simultaneously. There are 6 active vectors as shown in figure 5 and other two are called zero vector where

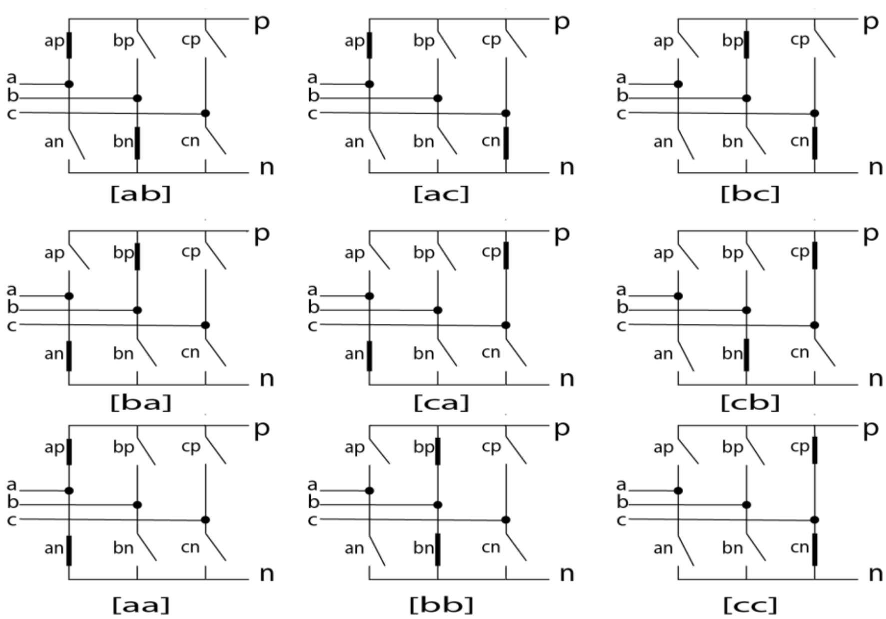

Fig 8: Switching states of CSR stage.

either all positive terminal switches or all negative terminal switches are closed. Expression (6) and (7) represent voltage and

$$\vec{v}_{sv} = \frac{3}{2}\vec{V}_0 e^{j\omega t} = \frac{3}{2} q \vec{V}_i e^{j\theta_{sv}} \qquad (6)$$

$$\vec{i}_{sv} = \frac{3}{2}\vec{I}_i e^{j\theta_{sv}} \qquad (7)$$

current space vectors [7].

where q is modulation index and θsv=ωt-φi, and φi is input displacement angle which is required to be controlled to reduce reactive power. The expression for virtual dc link is given in (8).

$$e_{dc} = \frac{3}{2}\frac{\vec{V}_i \vec{I}_i \cos\varphi_i}{i_{dc}} = \frac{3}{2}\vec{V}_i \cos\varphi_i \qquad (8)$$

e_{dc} is dc link voltage and it is also the length of all active vectors.

Reference vectors rotate in fig 4 and 5 with angular velocity of ω. Reference vectors are formed by 2 closely located active vectors and a zero vector [6].

Where Ta1 is time duration of application of first active vector and similarly Ta2 for second active vector and Tz for zero vector. Ts is sampling time.

4. Simulation Results

Two systems as shown in fig 9 are simulated, one with matrix converter and one without it. From these simulations, it can be

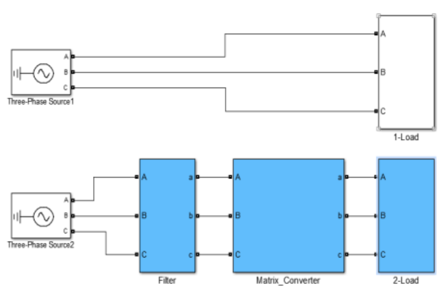

Fig 9: Simulation Diagram.

observed that using matrix converter to control the input displacement angle results in reduced reactive power in the system. Figure 10 shows voltage and current waveforms of system where reactive power control has not been implemented, here the displaced angle is about 51 degrees.

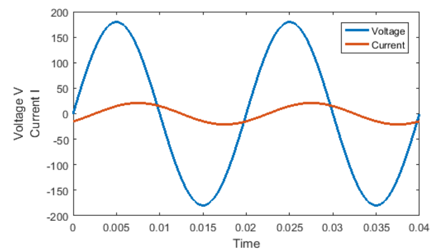

Fig 10: Displacement between voltage and current without matrix converter.

$$T_{a1} = T_s \frac{3 q V_i \sin\left(\frac{\pi}{3} - \theta_{sv}\right)}{2 \; e_{dc} \sin\left(\frac{\pi}{3}\right)}$$

$$T_{a2} = T_s \frac{3 q V_i \sin(\theta_{sv})}{2 \; e_{dc} \sin\left(\frac{\pi}{3}\right)}$$

$$T_z = T_s - T_{a1} - T_{a2}$$

Figure 12 shows output voltage and current at two different frequencies i.e 5000 Hz and 10000Hz. Although increasing switching frequency improves the output current waveform, it increases total harmonic distortion (THD) in output voltage. So, a tradeoff is found between switching frequency and acceptable amount of THD in Figure 11. Figure 13 shows input voltage and current waveform while using matrix converter to control displacement angle. It can be observed from the figure that current closely follows voltage resulting in reduced reactive power. Figure 14 shows improvement in smoothness of input current waveform when an input filter is used.

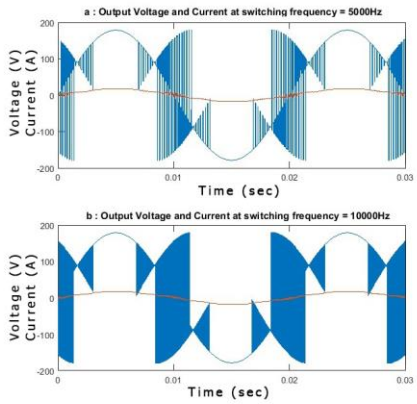

Fig 12: Output voltage and current after using filter.

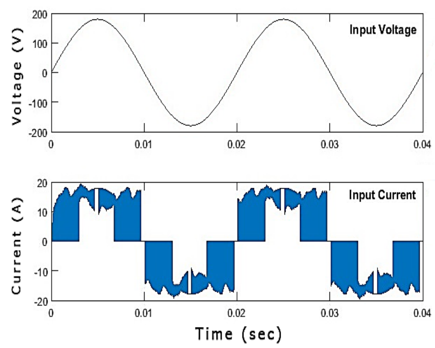

Fig 13: Input Voltage and Current waveforms of MC.

Different switching frequencies are tested to find a range of different switching to reduce power losses as well as total harmonic distortion of signals. It can be observed in figure 11 that range of switching frequency between 5000Hz to 7000Hz is sufficient because increasing frequency beyond this point don't have any significant effect on THD.

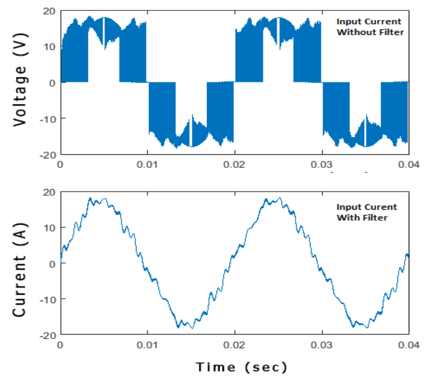

Fig 14: Input current after using filter.

5. Conclusion

In conclusion, Space Vector pulse width modulation technique (SVPWM) is indirectly applied to a 3x3 direct matrix converter (DMC). Simulation performed in Simulink are presented. This system of Matrix Converter has capability of performing in wide variety of situations and yield consistent results. Reactive power compensation is achieved by using inductive load. Any type of load can be used such as inductive or capacitive. Output waveforms are affected by distortion due to switching of bidirectional switches, this total harmonic distortion is reduced to an optimum level by extensively studying wide range of switching frequencies.

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