An Operational Review of Matrix Conveter

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***Abstract*-** *In today's world, where power demand has enhanced significantly, the reliance on flexible energy options has also increased. Our design is an attempt to take a single phase AC input and convert it to a three phase AC output. A matrix converter is a converter with a single stage of conversion. Matrix Converter utilizes bidirectional controlled switch to achieve automatic conversion of power from AC-AC. The single-to three-phase matrix converter is an array of controlled semiconductor switches that connects the single-phase source to the three-phase load directly. This converter has some interesting features that have been investigated in the last two decades. In the last couple of years, an increase in research work has been observed, conveying this topology closer to the industrial application. This paper attempts to give an overview of Matrix Converter for phase conversion. The paper also introduces a basic operation strategy for a single to three phase Matrix Converter. To confirm the validity and feasibility of this strategy, the comprehensive analysis is provided for the matrix converter with a three phase balanced resistive load.*

Keywords- Bidirectional switch, Matrix Converter, Operational Strategy, Phase Converter.

I. INTRODUCTION

The three phase balanced network provides the most efficient and economical use of electrical power. This is mainly because three-phase ac equipments, such as three-phase induction motors, synchronous motors, etc. are more economical and efficient than their single-phase counterparts. A phase converter is defined as a device which converts electric power from single phase to multiple phase or vice versa. Mostly the phase converters are used to produce a three phase power from a single phase source. In general, where the availability of three-phase service is not possible from the utility, or is too costly to install due to a remote location, the phase converters are adopted.

Presently available phase converters can be broadly classified into three categories:

a) Rotary type converters which works on the principle of rotary motion
b) AC-DC-AC converters in which single phase AC is converted to DC and then to three phase AC using three phase inverter.
c) Static converters in which the power conversion is carry out through semiconductor devices.

Rotary converter employs bulky magnetic components of considerable size and weight due to which there are more frictional losses. Generally in remote areas, three phase residential equipments are connected to the single-phase utility through AC-DC-AC converter. Also the three-phase motors in electric railways and the air conditioners are driven by single-phase power supply through AC-DC-AC converter. In this converter, the single-phase voltage of the power supply is converted to dc voltage through a rectifier unit. Then the dc voltage is converted to the three-phase ac voltage with the desired amplitude and frequency by an inverter unit. The rectifier and inverter system is a two-stage converter system and a dc link is present in between them which consist of an electrolytic capacitor which has a short life. To improve the size, reliability and efficiency of this conventional system, single- to three-phase matrix converters have been proposed.

The matrix converter is a single stage converter, replaces the multiple intermediate energy storage elements (dc-link) converter as shown in fig.1. The primary component in a matrix converter is the fully controlled four-quadrant bidirectional switches, which permits high-frequency operation.

The most desirable features of matrix converter are:

1) Simple and compact power circuit.
2) Generation of load voltage with desired amplitude and frequency.
3) Sinusoidal input and output currents.
4) Operation with unity power factor for any load
5) Regeneration capability.
6) No reactive component for storage purposes.
7) All silicon converter and low cost.

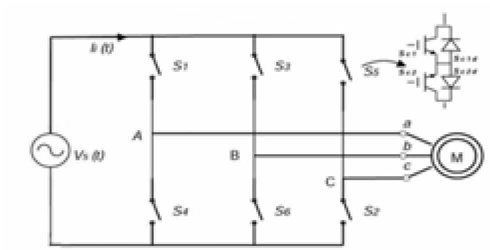


Fig.1: Proposed single-to-three phase matrix converter.

The present paper proposes a new simple approach named separation and link to analyze the basic single-to three-phase matrix converter shown in Fig.1. Based on this analytic method the operation states for the proposed matrix converter and the operation strategy are derived. To confirm the validity and feasibility of this scheme, the detailed analysis is provided for the matrix converter with a three-phase balanced resistive load. The control for the bi-directional switches in this converter is established by using the sinusoidal pulse width modulation (SPWM).

II. FUNDAMENTALS

The matrix converter is a single stage converter with (m x n) bidirectional power switches designed to connect directly, an m-phase voltage source to an n-phase load. From this it is observed that for a single to three phase conversion, it requires (2x3) i.e. 6 bi-directional switches. The proposed Matrix Converter converts a single phase AC input voltage of amplitude Vi at supply frequency ωi directly to three phase AC output voltage at either required amplitude Vo or frequency ωo in accordance with the pre-calculated switching angles. It uses high frequency forced commutated switching devices which are capable of conducting in both directions.

In Matrix Converter each switch is used to connect or disconnect any phase of the input to any phase of the load. This can be achieved only by selecting proper switching configuration. In order to avoid the interruption of load current suddenly, at least one switch in each column must be closed. Each switch can be defined with a commutation function described as below:-

$$S_{xn}\begin{pmatrix} x = a,b,c \\ n = 1,2,3,4 \end{pmatrix} = \pm \begin{cases} \text{'1' the upper arm switch is ON} \\ \text{'0' the lower arm switch is ON} \end{cases}$$

The constraints discussed above can be expressed

$$San + Sbn + Scn = 1, \quad n = (a,b,c). \qquad (1)$$

The equation (1) shows that a single to three phase Matrix Converter has got sixteen possible switching states. Fig.2 is the adopted configuration of the single-to three-phase matrix converter. In one complete cycle, the source voltage can be divided into two voltages. One is during the positive source period and another is during the negative source period. The single-to three-phase matrix converter can be regarded as two equivalent converters in contrary series shown in Fig.3.

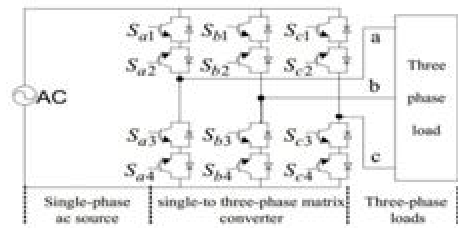
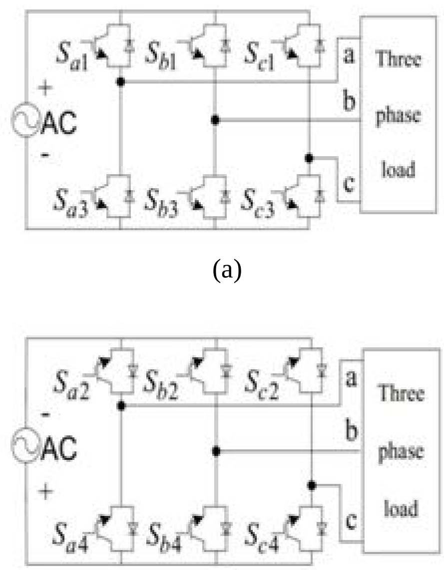


Fig.2: Adopted configuration of the single-to three-phase matrix converter



(a)

(b)

Fig.3: Separation of positive and negative source period

III. DETAILED ANALYSIS OF MATRIX CONVERTER

The single stage ac-ac converter for single to three phase conversion with 6 bi-directional switches are S_1 (S_{a1}, S_{a2}), S_2 (S_{c3}, S_{c4}), S_3 (S_{b1}, S_{b2}), S_4 (S_{a3}, S_{a4}), S_5 (S_{c1}, S_{c2}) and S_6 (S_{b3}, S_{b4}) is analysed with separation and link method. When the source voltage is during the positive period, the analysis of single-to three -phase matrix converter is simplified to the configuration shown in the upper one of Fig.1 (b).

Take A-phase for example. Following the principles of no short circuit for source side, switches $S_{a1}$and S_{a3} must not be on at the same time. Following the principle of no open circuit for load side, one of switches Sa1and Sa3 must be on.

Considering the balanced resistive load, when switch S_{a1} is ON and S_{a3} is OFF then switch S_{a2} must be ON to provide path for current through its diode from source to load. Similarly, when switch Sa1 is OFF and S_{a3} is ON then switch S_{a4} must be ON to provide path for current flow through its diode from load to source. The separation in Source positive period is shown in figures 4(a) and the separation in Source negative period in figures 4(b) and which are then linked, found equal to the results of the 1-3MC circuit. The sinusoidal pulse width modulation (SPWM) control technique is adopted to obtain the desired output results of single-to-three phase ac matrix converter.

When the source voltage Vs is in the positive period, the switches S_{a1}, S_{a3} & S_{b1}, S_{b3} & S_{c1}, S_{c3} should be controlled to keep energy flowing from source to load and switches S_{a2}, S_{a4} & S_{b2}, S_{b4} & S_{c2}, S_{c4} are kept ON through its diodes to provide the current path from source to load whenever necessary.

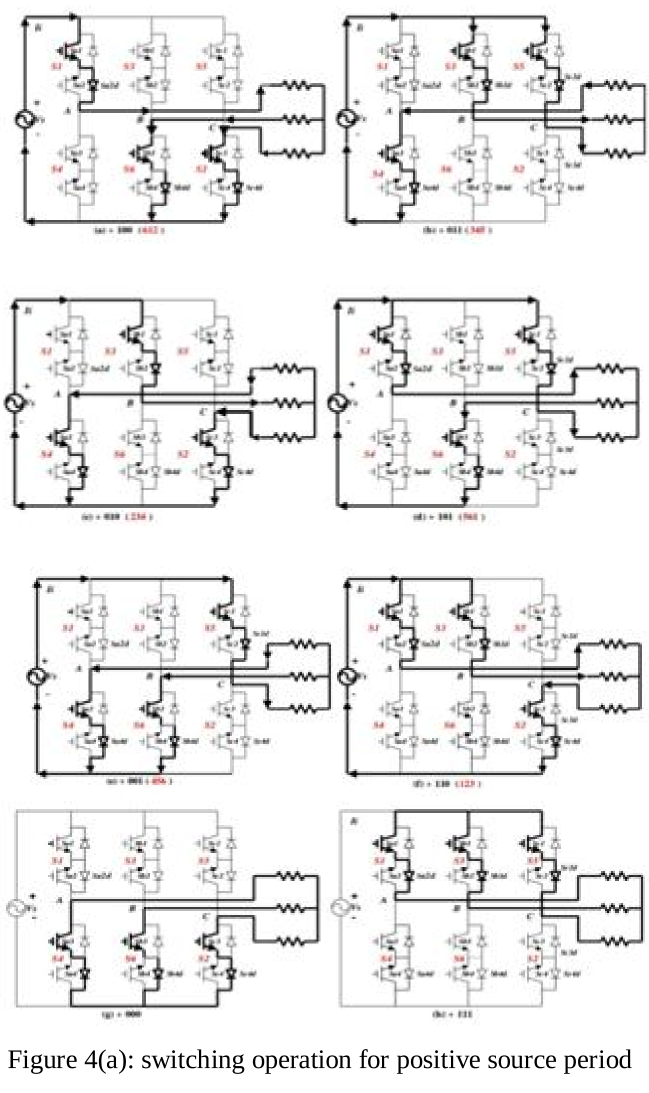


Figure 4(a): switching operation for positive source period

When the source voltage Vs is in negative period, the single to three phase ac matrix converter is simplified to the configuration shown in figure 4(b) with the same analysis as that in the source positive periods, the switches S_{a2}, S_{a4} & S_{b2}, S_{b4} & S_{c2}, S_{c4} should be controlled to keep energy flowing from load to source and switches S_{a1}, S_{a3} & S_{b1}, S_{b3} & S_{c1}, S_{c3} are kept ON through its diodes to provide the current path from load to source whenever is necessary.

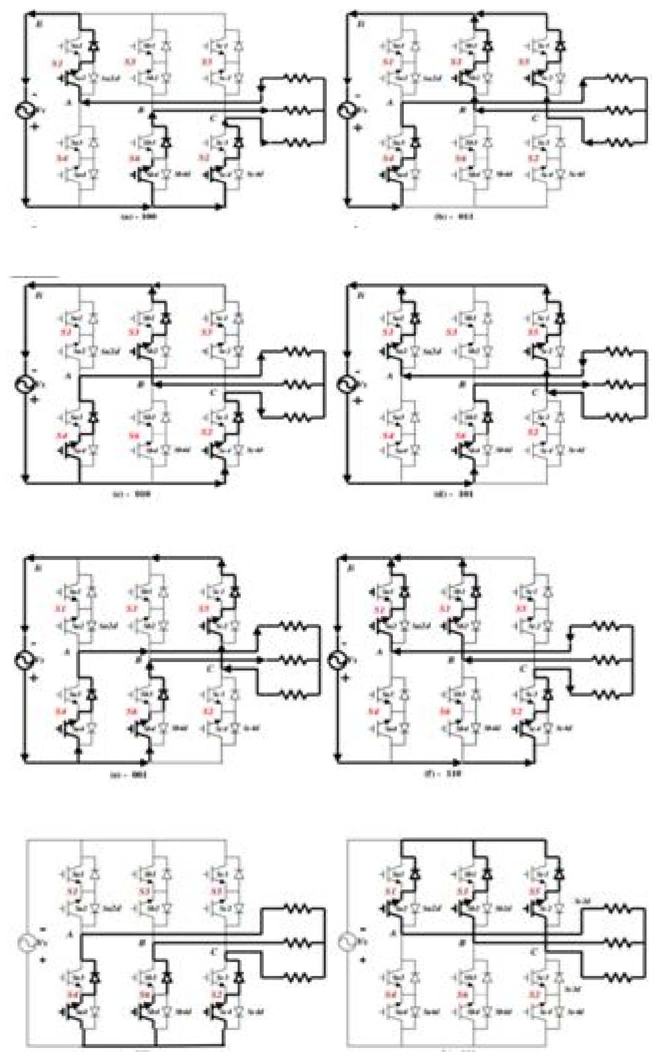


Figure 4(b): switching operation for negative source period

When the source voltage Vs is in negative period, the single to three phase ac matrix converter is simplified to the configuration shown in figure 4(b) with the same analysis as that in the source positive periods, the switches S_{a2}, S_{a4} & S_{b2}, S_{b4} & S_{c2}, S_{c4} should be controlled to keep energy flowing from load to source and switches S_{a1}, S_{a3} & S_{b1}, S_{b3} & S_{c1}, S_{c3} $_{are}$ kept ON through its diodes to provide the current path from load to source whenever is necessary.

There are total 16-operating modes which are shown in TABLE-1 for one complete cycle of operation. In this table the 6 operating states (+100 to +110) and 2 null states (+000 and +111) during positive source period are shown in figure 4(a). Similarly, another 6 operating states (-100 to -110) and 2 null states (-000 and -111) for negative source period, but the direction of current flow should be reversed are shown in figure 4(b). Similarly, all analysis for phase B and C is adopted

Table 1: Switching strategy for single to three phase MC

Modes	V_{ab}	V_{bc}	V_{ca}	Switching Operation
+(100)	V_S	0	$-V_S$	S_{a1} S_{a2d} S_{b3} S_{b4d} S_{c3} S_{c4d}
+(101)	V_S	$-V_S$	0	S_{a1} S_{a2d} S_{b3} S_{b4d} S_{c1} S_{c2d}
+(001)	0	$-V_S$	V_S	S_{a3} S_{b4d} S_{b3} S_{b4d} S_{c1} S_{c2d}
+(011)	$-V_S$	0	V_S	S_{a3} S_{a4d} S_{b1} S_{b2d} S_{c1} S_{c2d}
+(010)	$-V_S$	V_S	0	S_{b1} S_{b2d} S_{a3} S_{a4d} S_{c3} S_{c4d}
+(110)	0	V_S	$-V_S$	S_{a1} S_{a2d} S_{b1} S_{b2d} S_{c3} S_{c4d}
+(000)	0	0	0	S_{a3} S_{a4d} S_{b3} S_{b4d} S_{c3} S_{c4d}
+(111)	0	0	0	S_{a1} S_{a2d} S_{b1} S_{b2d} S_{c1} S_{c2d}
-(100)	V_S	0	$-V_S$	S_{b4} S_{b3d} S_{c4} S_{c3d} S_{a2} S_{a1d}
-(101)	V_S	$-V_S$	0	S_{b4} S_{b3d} S_{a2} S_{a1d} S_{c2} S_{c1d}
-(001)	0	$-V_S$	V_S	S_{a4} S_{a3d} S_{b4} S_{b3d} S_{c2} S_{c1d}
-(011)	$-V_S$	0	V_S	S_{a4} S_{a3d} S_{b2} S_{b1d} S_{c2} S_{c1d}
-(010)	$-V_S$	V_S	0	S_{a4} S_{a3d} S_{c4} S_{c3d} S_{b2} S_{b1d}
-(110)	0	V_S	$-V_S$	S_{c4} S_{c3d} S_{a2} S_{a1d} S_{b2} S_{b1d}
-(000)	0	0	0	S_{a4} S_{a3d} S_{b4} S_{b3d} S_{c4} S_{c3d}
-(111)	0	0	0	S_{a2} S_{a1d} S_{b2} S_{b1d} S_{c2} S_{c1d}

Where, “1” indicates Upper arm switch ON,
“0” indicates Lower arm switch ON.
“+” indicates positive period source voltage,
“-” indicates negative period source voltage.
“d” denotes diode to that switch.

IV. SPWM STRATEGY OF MATRIX CONVERTER

When sinusoidal pulse width modulation (SPWM) is adopted, as usual, the analysis for conventional converter, the switch control signals for single phase to three phase ac matrix converter can be understood from figure 4. Suppose $A = 1$ denotes the source is during the positive source period and $A = 0$ denotes the source is during the negative source period. $B = 1$ denotes SPWM signal is positive and $B = 0$ denotes SPWM signal is 0. The switch controls signal are shown in TABLE-2 are deduced from Figure 5. Take A-phase generation, for example, $x = a$, during the source positive or negative periods. Switches S_{a1}, S_{a2}, S_{a3} and S_{a4} are manipulated with SPWM signals and its anti-parallel diodes S_{a1d}, S_{a2d}, S_{a3d} and S_{a4d} will offer current paths as and when needed.

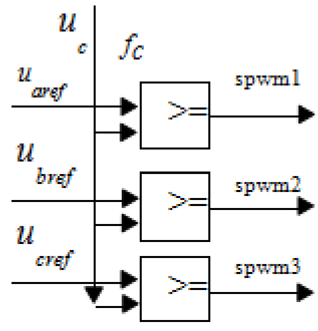


Fig.5: The generation principle of the SPWM signals

Table-2: Switch Controls Signal for single to three phase MC

SWITCH S_x (x = a, b, c)	PWM Switching Signals A=1 B=1	A=1 B=0	A=0 B=1	A=0 B=0
S_{x1}	1	0	0	1
S_{x2}	0	1	1	0
S_{x3}	0	1	1	0
S_{x4}	1	0	0	1

V. CONCLUSION

Based on the analytic method of separation and link, a detailed description has been given and the operation strategy for single to three phase conversion is obtained. This is analysed to suggest the operational features of Matrix Converter with 6 bidirectional switches. With a 3-phase balanced resistance load, the validity and feasibility of the operation strategy for the single to three phase matrix converter is sustained. The converter provides balanced three-phase output power and generates a sinusoidal input current. The proposed matrix converter topology for single phase to three phase ac conversion is suitable for general purpose implementation. This is also suitable for conversion of single phase transmission lines into three phase ac lines for Domestic, Industrial, Agricultural and Traction applications at remote places.

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