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Matrix Converter: A Novel Topology for Single to Three Phase Conversion

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***Abstract*: -- In this technological era, where development and flexibility are of utmost significance the power requirement and demand is increasing. Currently, three phase supply is mostly pressed into service than single phase supply considering the economic aspects and efficiency. The requirement of flexible energy options gave rise to the introduction of the matrix converter topology which eliminates the drawbacks of conventional topologies presently used. This paper presents the matrix converter for single stage conversion of the single phase ac to three phase ac. The research work about the matrix converter topology has increased since last few decades thereby emphasizing it for industrial applications. This paper presents the basic operation strategy of single to three phase converter and is explained with the help of an analytic method of separation and link. Detailed analysis of the matrix converter with a three-phase balanced load is provided to confirm the validity and feasibility of this strategy.**

***Keywords:* - Matrix Converter, Bidirectional Switches, IGBT, Commutation, PWM.**

I. INTRODUCTION

Over the past decades, the demand of electrical energy is increasing continuously. As the demand was increased the use of non-conventional energy was also increased. Due to this lot of energy was exhausted, and wasted. At present, there are many sources which are used to generate electricity but the energy generation should be clean and safe. Exploring the possibilities of renewable, sustainable, green energy sources to replace fossil fuels is one of the most significant and challenging issues in past because of air/water pollution and oil depletion due to the use of fossil fuels. Now, renewable forms of energy such as sunlight, wind, tides/waves, geothermal heat have been extensively used as a alternative form of energy sources. These sources are continuously use to generate electricity. But over the past decades, the piezoelectric and turboelectric effects for harvesting mechanical energy, the piezoelectric and thermoelectric effects for harvesting thermal energy, and the photovoltaic (PV) effect for harvesting solar energy, have been extensively studied for practical applications. These energy technologies are simply classified by their different energy conversion mechanisms, but the aim of all the energy harvesters is the conversion of wasted environmental energy to electricity. Nevertheless, all of the energy harvesters utilize only one type of energy, with the other types wasted. A PV cell, for example, is only designed to generate electricity under light illumination, and efficiency will be dramatically decreased under room light in indoor situations where sunlight is not available. Furthermore, thermal energy also appears in conjunction with mechanical and light energy. Since micro/nano scale smart systems can work under complicated environments and conditions, the use of only one type of energy harvester is insufficient to drive their operation. Thus, It is highly desirable to integrate energy harvesters so as to accumulate multiple types of energy for conversion into electricity, so that waste energy can be fully utilized and smart systems can be powered at any time and in any place. So, we are using piezoelectric sensor as an energy harvesting device which can convert mechanical energy into an electrical energy.

II. MATRIX CONVERTER

The matrix converter is a single stage conversion topology which directly converts the ac to ac without the dc link or other additional storage elements [5]. It consists of an array of bidirectional switches. If the matrix converter is fed with an input of m-phase, then m x n bidirectional switches will be required to obtain an output of n-phase. Depending on the input phase fed and the output phase we require, there are a number of matrix converter phase conversion topologies and are follows-

A. Single phase Matrix Converter

In The single phase input is fed to the matrix converter which comprises of four bidirectional switches and the output obtained as single phase ac. The four switches S1, S2, S3, and S4 can conduct currents in both directions as well as they can block forward and reverse voltages.

B. Three phase to three phase matrix converter

Three phase input is provided to the converter which consists of nine bidirectional switches and the output obtained is three phase ac which are coordinated by a number of switching functions. Three phase matrix converter is constructed by connecting three sets of single output matrix converters.

C. Three phase to single phase matrix converter

This converter is fed through three phase input and it comprises of three bidirectional switches S1, S2, S3 to obtain a single phase output.

D. Single phase to three phase matrix converter

This converter is composed of six bidirectional switches S1, S2, S3, S4, S5, S6 fed through single phase supply to obtain an output of three phase ac. Single phase to three phase conversion is presented in this paper as three phase supply is more desirable at many aspects over the single phase supply. From the fixed frequency input supply the output can be obtained as the variable frequency which is an advantage of this converter topology. The bidirectional switches proposed to be used in the converter circuit are not commercially available. Thus the available switches in discrete are arranged in various switch cell arrangements [4] to form the required bidirectional switch.

Diode bridge arrangement

Common collector arrangement

Common emitter arrangement

The common emitter arrangement and common collector arrangement are same at operation and posses lesser losses than the diode bridge arrangement. The diode bridge has a single transistor surrounded by four diodes making the circuit more prone to losses. The common emitter configuration is preferred and is shown in fig. below.

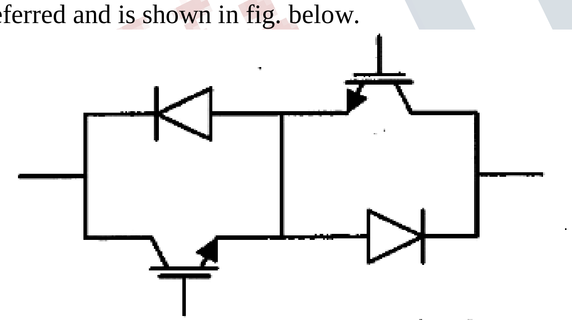


Fig.1 Common Emitter switch cell arrangement

The IGBT is preferred over other semiconductor devices for the conversion of ac to controlled ac due to its efficiency, lower cost compact size, lower switching losses, faster rise and fall time switching capability, high input impedance and no secondary breakdown problem, and so on. Matrix converter faces some commutation problems. It employs forced commutation. It is significant to know the load current direction and magnitude of relative input voltages so as to perform safe commutation. For this current commutation method seeks to be a four step safe commutation strategy, which follows two basic principles that are the input phase should not be short circuited and no open circuit of inductive load current. It all depends on the direction of the load current thus it has to be controlled all the way throughout the commutation process.

III. PWM AND SPWM TECHNIQUE

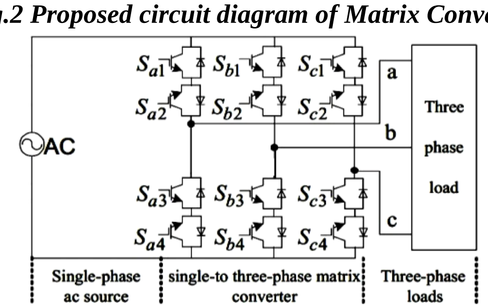
The attainable controlling of the output voltages is mostly performed by the PWM control strategy. The PWM converters are widely in use for their achievements in the solid state power devices [6]. The drive motors are fed with a frequency and magnitude of voltage and current whose control is possible with the PWM inverters. The different PWM techniques available are single PWM, Sinusoidal Pulse Width Modulation (SPWM), Space-Vector PWM (SVPWM). These techniques are commonly used for the control of ac induction, Brushless Direct Current (BLDC) and Switched Reluctance (SR) motors [6]. Thus an improved efficiency and performance is obtained by using PWM converter power motor drives.

IV.OPERATION OF MATRIX CONVERTER

Separation:-

The fig.2 shows the proposed circuit diagram of the Matrix Converter. The fig.2 configuration implies the complete one source voltage period which is further divided into two voltage source periods which can be depicted in fig.3. The separation implies the division of one source voltage period. One source voltage period is greater than zero and the other is less than zero. The positive half maybe considered as greater and the configuration for this is shown in fig.3(a) whereas fig.3(b) depicts the negative half voltage source period. Consider A-phase. [1]For the source side, the principle of no short circuit, the switches Sa1 and Sa3 must not be ON at the same time. For the load side the principle of no open circuit is followed, one of switches Sa1 and Sa3 must be ON. For the different load conditions, when switch Sa1 is ON and Sa3 is OFF, the diode switch Sa2 needs to be ON for providing a current path from load to source. Similarly, when switch Sa1 is OFF, the switch Sa4 should be ON.

Fig.2 Proposed circuit diagram of Matrix Converter



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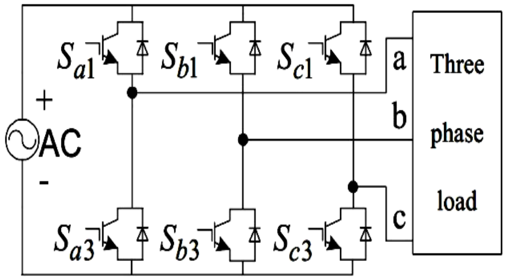

Fig.3 (a)

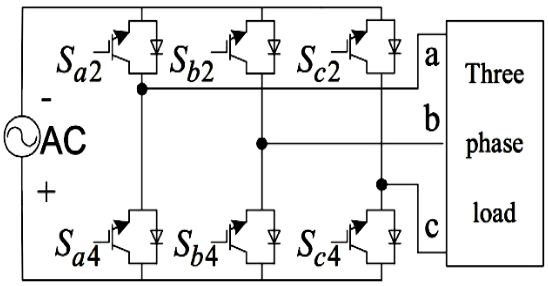

Fig.3 (b)

Fig.3 Separation of proposed Matrix converter

While taking in consideration the states of the controlled switches [1] there are 8 operation states during source positive period and 8 other operation states during source negative period. Thus, for one complete cycle of operation there are total 16- operating states. We can define the state functions as,[1]

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

San+ Sbn+ Scn =1,   n= (a,b,c) ……………   (2)

Where, '+' denotes the source positive period and '-' denotes the source negative period. For example, the state '+ (110)' denotes the source positive period, with switches Sa1, Sb1, Sc3 kept ON, and switches Sa3, Sb3, Sc1 are OFF. The table 1 shows the detailed operation.

Link:-

The operation states have been obtained for the source positive and negative periods. However, in fact, a rational states combination is necessary to gain anticipant output voltages and a smooth conversion must be ensured when two periods of the source are switched. When Sinusoidal Pulse Width Modulation (SPWM) is adopted, combined with the analysis for conventional converter, the switch control signals can be deduced.

Sr. No.	Modes	V_{ab}	V_{bc}	V_{ca}	Switching Operation
1	+(100)	V_s	0	$-V_s$	S_{a1} S_{a2d} S_{b1} S_{b4d} S_{c1} S_{c4d}
2	+(101)	V_s	$-V_s$	0	S_{a1} S_{a2d} S_{b1} S_{b4d} S_{c1} S_{c2d}
3	+(001)	0	$-V_s$	V_s	S_{a1} S_{b4d} S_{b1} S_{b4d} S_{c1} S_{c2d}
4	+(011)	$-V_s$	0	V_s	S_{a1} S_{a4d} S_{b1} S_{b2d} S_{c1} S_{c2d}
5	+(010)	$-V_s$	V_s	0	S_{b1} S_{b2d} S_{a1} S_{a4d} S_{c1} S_{c4d}
6	+(110)	0	V_s	$-V_s$	S_{a1} S_{a2d} S_{b1} S_{b2d} S_{c1} S_{c4d}
7	+(000)	0	0	0	S_{a1} S_{a4d} S_{b1} S_{b4d} S_{c1} S_{c4d}
8	+(111)	0	0	0	S_{a1} S_{a2d} S_{b1} S_{b2d} S_{c1} S_{c2d}
9	-(100)	V_s	0	$-V_s$	S_{b4} S_{b3d} S_{c4} S_{c3d} S_{a2} S_{a3d}
10	-(101)	V_s	$-V_s$	0	S_{b4} S_{b3d} S_{a2} S_{a3d} S_{c2} S_{c3d}
11	-(001)	0	$-V_s$	V_s	S_{a4} S_{a3d} S_{b4} S_{b3d} S_{c2} S_{c3d}
12	-(011)	$-V_s$	0	V_s	S_{a4} S_{a3d} S_{b2} S_{b3d} S_{c2} S_{c3d}
13	-(010)	$-V_s$	V_s	0	S_{a4} S_{a3d} S_{c4} S_{c3d} S_{b2} S_{b3d}
14	-(110)	0	V_s	$-V_s$	S_{c4} S_{c3d} S_{a2} S_{a3d} S_{b2} S_{b3d}
15	-(000)	0	0	0	S_{a4} S_{a3d} S_{b4} S_{b3d} S_{c4} S_{c3d}
16	-(111)	0	0	0	S_{a2} S_{a3d} S_{b2} S_{b3d} S_{c2} S_{c3d}

Table 1: Switching strategy for single to three phase Matrix Converter

The single stage ac-ac converter for single phase to three phase ac conversion consists of six bi-directional switches they are S1(Sa1,Sa2), S2(Sc3,Sc4), S3(Sb1.Sb2), S4(Sa3,Sa4), S5(Sc1,Sc2) and S6(Sb3,Sb4) it is analyzed with separation and link method. [1]The separation in Source positive period is shown in figures 4(a) and the separation in Source negative period in figures 4(b) and they are then linked. The output for single phase to three phase ac matrix converter is obtained by the sine pulse width modulation (SPWM)[7].

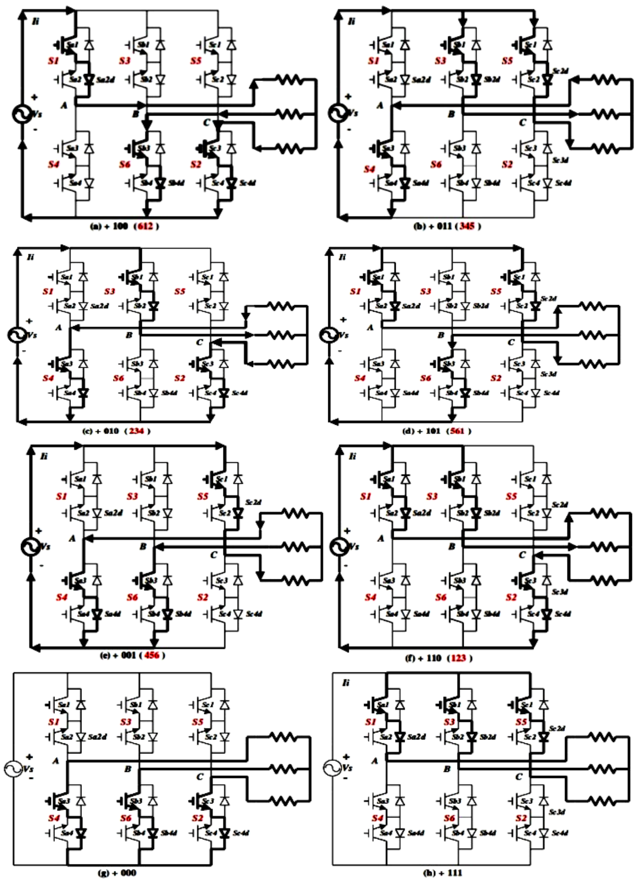

Figure 4: Switching operation for positive source period

Fig.4 [6]shows the switching operation for positive source period. From the above analysis, in the positive source period, switches Sa1, Sa3, Sb1, Sb3, Sc1, Sc3 are kept ON for the energy to flow from source to load and switches Sa2, Sa4, Sb2, Sb4, Sc2, Sc4 are kept ON for the current to flow from the load to source.[1],[6] Similarly, in the source negative period, switches Sa2, Sa4 & Sb2, Sb4 & Sc2, Sc4 are kept ON for the energy to flow from source to load and switches Sa1, Sa3 & Sb1, Sb3 & Sc1, and Sc3 are kept ON through its diodes to provide the current path from load to source whenever is necessary.

V. CONCLUSION

The analysis of the single phase to three phase matrix converter has been performed based on the method of separation and link. The basic operation strategy of the converter circuit is analyzed to suggest the operational features of Matrix Converter with 6 bidirectional switches. The associated PWM strategy of this topology is investigated. This converter topology proved to be better and efficient over conventional method.

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