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Implementation of Sinusoidal PWM Technique for direct AC-AC Matrix Converter using Matlab

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Abstract: The matrix converters is a new single stage generation of the direct power converter AC/AC and can contribute to the realization of low volume, sinusoidal input current, bidirectional power flow and lack of bulky reactive elements Due to all these reasons, recently a lot of research has been picked up in the field of matrix converters. And the performance of this converter varies based on the control technique and the different topologies. So the main objective of this paper is to simulate and analyse the performance of matrix converter based on the different topologies i.e. single phase matrix converter, three phase to single phase matrix converter and three phase to three phase matrix converters using sinusoidal PWM technique. The simulation is carried out using Matlab and the results of switching sequence and the output voltage waveforms are presented in this paper.

Keywords: AC-AC conversion, Matrix Converter, Pulse Width Modulation (PWM).

I. INTRODUCTION

Different converters topologies are known since 70-th and 80-th years of the last century. Some of them have a thyristor implementation with natural commutation. The elements used now a day's require some kind of high performance commutation strategies to comply with the application requirements.

AC-AC power converters have many applications such as power regulators, induction motor drives, direct conversion systems in wind generators and many others. They are devices, which use a semiconductor switches in a different configuration of connection. These converters are unidirectional or bi-directional power flow compatible in function of used electric configuration, elements and, At present AC-AC converters are divided on two basic topologies (Fig.1):

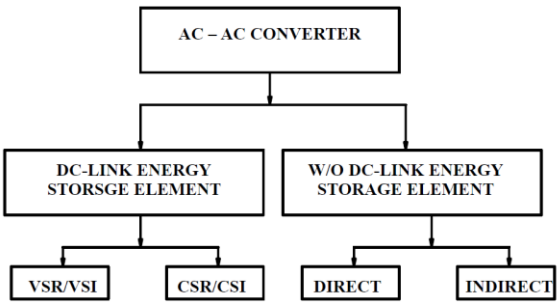

Fig. 1. converter topologies

DC-Link Converters- In basic configuration they have two sections-a rectifier stage and an inverter stage. A typical configuration use large and expensive energy storage intermediate elements such as inductors and capacitors. A rectifier bridge and an inverter bridge uses unidirectional or bi-directional switches and detached way of commutation. Depending of used energy store elements there are two main configurations, called DC current link (inductor-CSR/CSI) or DC Voltage link (capacitor-VSR/VSI), modification of some converter topologies may include diode bridge clamp circuits, thyristor choppers and other additional elements. A basic circuit is shown on Fig.2. The major disadvantages of these type converters are the energy storage elements, since the quality of output waveforms, harmonics and phase displacement of current depends on stability of the DC link voltage, commutation of rectifier/inverter stage and the need of additional filter elements for the output and input.

To overcome these problems, matrix converters [1] has been developed**.** It consists of an array of bidirectional switch Cells functioning as the main power circuit elements Each switch cell is composed of two forced commutated switches in an anti-parallel configuration. Basic topology of this type converter is shown on Fig.3.A matrix converter interfaces two three phase systems with different voltage magnitudes, frequencies and phase angles.

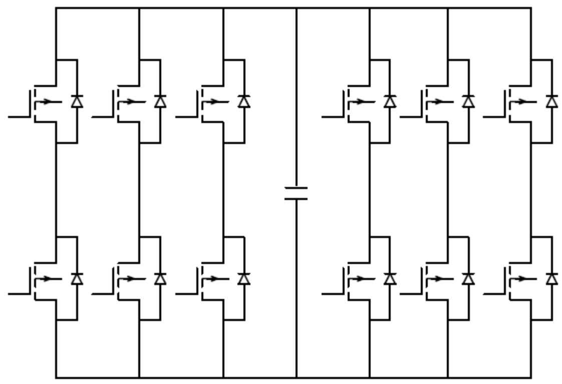

Fig. 2. Dc-link converter topology

Figure 2. The back-to-back converter is considered as one of the most competitive alternatives to matrix converter because it has the same desirable functionality for AC to AC power conversion applications, in terms of input quality and bidirectional power flow capabilities.

The general matrix converter is defined as a single stage converter which consists of a matrix of m×n bidirectional power switches to directly connect an m-phase voltage source to an n-phase load. Typically, a 3×3 matrix converter, shown in Figure 3, has attracted the highest practical interest because it connects a three-phase voltage

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source, a standard AC-mains, with a three-phase load, a standard motor.

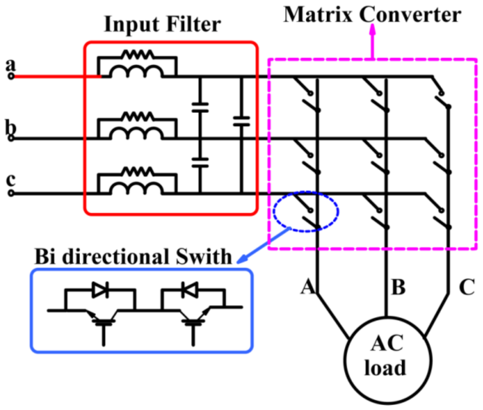

Fig. 3. Basic matrix converter

It can regenerate energy back into the mains from the load side, where the mains current is sinusoidal and the displacement factor seen by the mains can be adjusted by proper modulation irrespective of the type of load. This paper mainly focuses on the simulation of Sinusoidal PWM [4] based different topologies of matrix converter and verifies the switching sequence and output voltages using MATLAB. The idea presented in this paper is a novel approach that uses MATLAB as the simulation environment to study the behavior of a Matrix Converter.

II. MERITS AND DEMERITS OF MATRIX CONVERTERS[1]

The following are the some of advantages of the matrix converters

1. No dc link capacitor or inductor
2. Sinusoidal input and output currents
3. Possible power factor control
4. Four-quadrant operation
5. Compact and simple design
6. Regeneration capability

Some of the limitations of matrix converters include

1. Reduced maximum voltage transfer ratio (0.866).
2. Many bi-directional switches needed.
3. Increased complexity of control.
4. Sensitivity to input voltage disturbances.
5. Complex commutation method

Although the matrix converter has several disadvantages, these drawbacks have been mostly overcome. For example, the reduced voltage transfer ratio [5] problem has been worked around by designing motors that reach maximum flux at the reduced matrix converter output voltage. The problem of physical space needed by the increased number of switches has been overcome by the development of power electronic building blocks such as the Eupec ECONOMACTM[2] matrix module, or by modifying the matrix converter topologies to use a fewer number of switches. The complexity of control and sensitivity to input voltage disturbances has also been solved by the development of different control algorithms. In all,the progress of the matrix converter has significantly improved its performance, rendering it an acceptable choice for compact and integrated converter-motor drives.

III. PULSE WIDTH MODULATION[1]

Because of advances in solid state power devices PWM based converters are becoming most widely used in drives. PWM inverters make it possible to control both the frequency and magnitude of the voltage and current applied to drive motor. The energy that a PWM converter delivers to a motor is controlled by PWM signals applied to the gates of the power switches. Different PWM techniques are existing, that are Sinusoidal PWM, Hysteresis PWM and the relatively new Space-Vector PWM. These techniques are commonly used for the control of ac induction, Brushless Direct Current (BLDC) and Switched Reluctance (SR) motors. As a result, PWM converter powered motor drives offer better efficiency and higher performance compared to fixed frequency motor drives. It is clearly visible that the duty cycle of the rectangular wave is varying according to the momentary value of the required output voltage. The result is that the effective value of the rectangular wave is the same as that of the output voltage. This pulse is used to switch ON or OFF the power switches. The width of the pulse or duty cycle can be varied by varying the frequency of the reference wave.

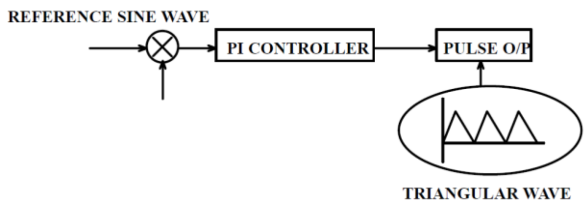

Fig. 4. PWM pulse generation circuit

IV. TOPOLOGIES OF MATRIX CONVERTERS[1]

The generation of PWM pulse requires reference sine wave and triangular wave. The reference sine wave is compared with the feedback from the output voltage, is amplified and integrated as shown in figure 4. This signal is then compared with a generated triangular wave. The rectangular wave is the result of this comparison. As the sine wave is reaching its peak, the pulses get wider. It can be analysed that the duty cycle of the rectangular wave is varying according to the momentary value of the required output voltage. The result is that the effective value of the rectangular wave is the same as that of the output voltage. This pulse is used to switch ON or OFF the power switches. The width of the pulse or duty cycle can be varied by varying the frequency of the reference wave.
Based on the number of input and output phases, a Matrix Converter of the following topologies have been discussed
A) Single Phase Matrix Converter.
B) Three phase to single phase matrix converter.
C) Three phase to Three Phase Matrix Converter.

A. SINGLE PHASE MATRIX CONVERTER[1]

The Single-Phase Matrix Converter consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections. It comprises of four ideal switches Sl, S2, S3 and S4 capable of conducting current in both directions, blocking forward and reverse voltages

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(symmetrical devices) and switching between states without any delays. The Single-Phase Matrix Converter is presented schematically in Fig. 5. Its instantaneous input voltage is Vi(t) and its output voltage is Vo(t). This topology converts the input voltage, Vi(t) with constant amplitude and frequency, through the four ideal switches to the output terminals in accordance with pre calculated switching angles. The input voltage of the Matrix Converter is given by

Vi (t) = 1.414 Vi cos ωi t (1)

where, V represents RMS value of the voltage and subscript i denotes input, while 0 denotes output. With input voltage from (1), the Matrix Converter switching angles will be calculated so that the fundamental of the output voltage will be as given in (2), keeping with the degrees of freedom specified by

vo-main (t) = 1.414 vo cos ωo t (2)

MODE-1: Vo(t)=Vi(t)
(S1 and S4) are in ON state
MODE-2: Vo(t)=-VI(t) (3)
(S2 and S3) are in ON state
Vo(t)=0 (S1 and S4) OR (S2 and S3)

The additional states (Sl and S3- on) and (S2 and S4-on) are forbidden states (they create a short circuit of the mains). The Single Phase Matrix Converter may operate.

~ In modes 1 and 2 or
~ In modes 1, 2 and 3

The four power switching devices are switched at high frequency, fs .(fs >> fi and fo, fi = Wi / 2π and fo=ωo / 2π) The simulation circuit developed in MATLAB is shown in Fig. 6. Circuit operation is analysed for a complete switching sequence assuming the load to be purely resistive.

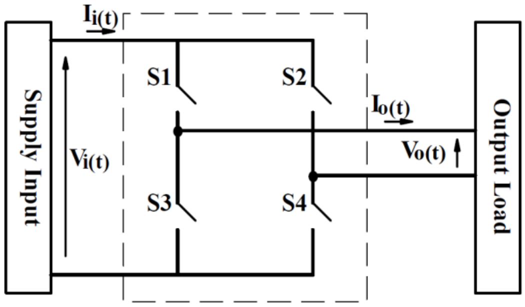

Fig. 5. Representation of a single phase matrix

For example, to achieve a frequency of 50 Hz, Sl and S4 are turned on, when the supply voltage is Positive and S2 and S3 are turned on, when the supply voltage is negative.

B. THREE PHASE TO SINGLE PHASE MATRIXCONVERTER[1]

A Three Phase to Single- Phase Matrix Converter is shown in Fig. 6. The converter is composed of three bidirectional switches S1, S2 and S3. Each switch connects the output line to an input phase. To avoid short-circuit in the source-side (three-phase side) and current interruption in the load side (single-phase side), only one switch can and must be on at any time. The switches are turned on the off in a sequential. And cyclical pattern. For the jth switching period, if tj1, tj2, and tj3 are the on-time intervals of S1,S2 and S3, respectively, we have

t j1 + tj2 + t j3 = Tm = 1/ f m (4)

where Tm is the switching period. The output line is connected to an input voltage for a specific period of time. Thus, the output voltage is a concatenation of segments of the three input voltages. Therefore, the output voltage waveform vo(t) is a function of the three input voltages Vai(t), Vbi(t) and Vci(t). In general, the output voltage harmonic components depend also on the input frequency and the switching strategy.

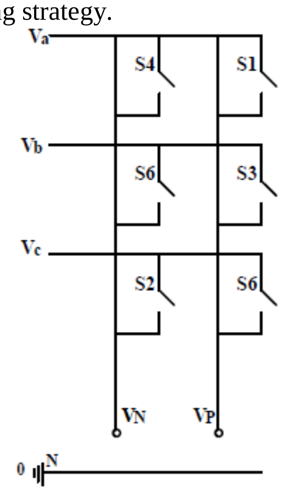

Fig. 6. Representation of 3-phase to 1-phase matrix converter

For the presented six intervals one of the phases is the most positive (V_{pmax}) and one – the most negative (V_{nmax}). when the odd switches (*S*1, *S*3, *S*5) are diodes with common cathodes connected to V_P, and the even switches (*S*4, *S*6, *S*2) are diodes with common anodes connected to V_N (Fig. 6). In this case the output voltage $V_{out} = V_P - V_N$

C. THREE PHASE TO THREE PHASE MATRIX CONVERTER[1]

A Three-Phase to Three-Phase Matrix Converter is structured based on the Three-Phase to Single-Phase Matrix Converter. If three sets of the single output Matrix Converters are connected to the same input voltages, a three-output Matrix Converter is constructed. The structure of a three-phase to threephase Matrix Converter is shown in Fig.9. The converter consists of nine bidirectional switches (Saa, Sba, and Sca) whose operations are coordinated by a number of switching functions. The Matrix Converter can represent a symmetric electrical system, if a proper switching strategy is used. The simulation circuit of a Three Phase to Three Phase Matrix Converter is shown in Fig. 10. [7], Sab , Sbb and Scb must be switched with a phase delay of 120' with respect to Saa, Sba and Sca. Also, a 240" phase delay must be considered for the switches Sac , Sbc and Scc to get a three phase output.

A three-phase/three-phase MC converter consists of nine bidirectional switches (Fig. 7), which allow any output phase to be connected to any input one. The capacitances located at the input side of the converter and the inductances located at the output side are necessary for

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MC operation and make it possible to mitigate any high frequency components.

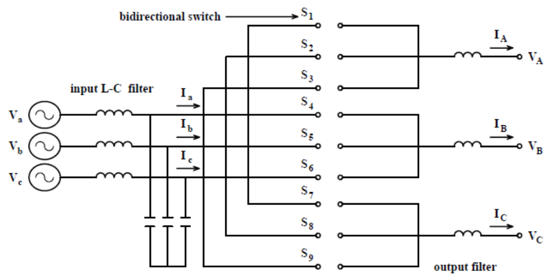

Fig. 7. Representation of a 3-phase to 3-phase matrix converter

V. SIMULATION RESULTS:[1]

Simulations were done using MATLAB software package . The Single Phase Matrix Circuit was constructed using the topology shown in Fig. 6. The output voltage and current waveforms were observed for a resistive load of R = 10 ohms and an input frequency of fj =50 Hz. Similarly, Three Phase to Single Phase Matrix Converter and Three Phase to Three Phase Matrix Converter were constructed and the output voltage and current waveforms were observed for different switching patterns. The following are sample of results:

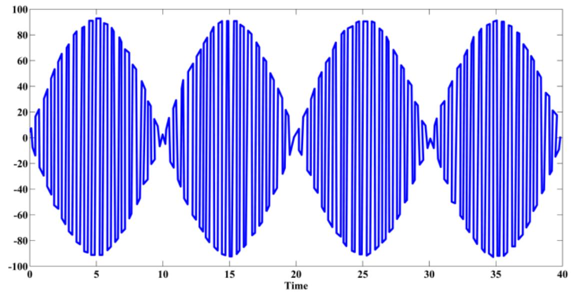

Fig. 8. Simulation result of Single Phase Matrix Converter output Voltage for Vi=110V (Peak Value), R=l0 ohms and fo=100Hz.

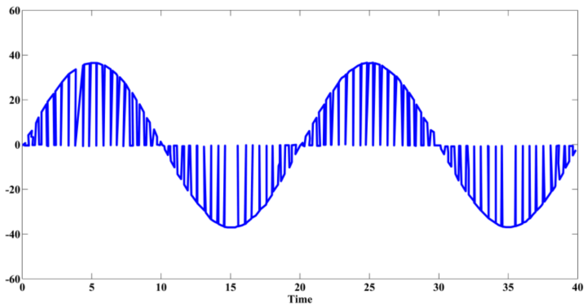

Fig. 9. Simulation result of Sine PWM Single Phase Matrix Converter output Voltage for desired frequency fr=50 Hz, Vi=110V (Peak Value), R= 10 ohms and carrier frequency fc =5 KHz with modulation index =1

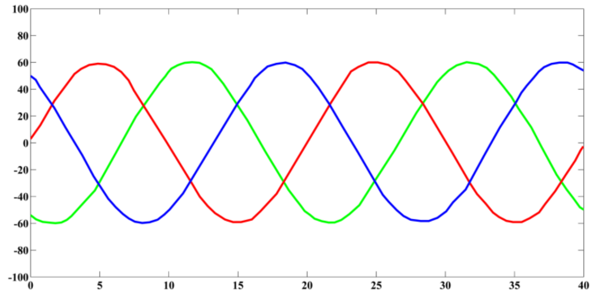

Fig. 10. (a) Three phase input waveform.

The waveform in Fig.10(a) examines the output voltage of a Three Phase to Single Phase Matrix Converter.

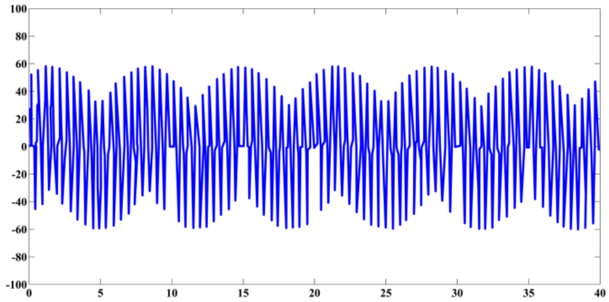

Fig. 10. (b) Simulation result of a Three Phase to Single Phase Matrix Converter for Vi =50V, R=10 ohms and output frequency fo=50 Hz.

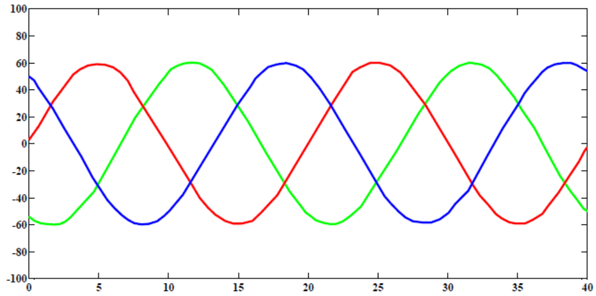

Fig. 11. (a) examines the output voltage of a Three Phase to Three Phase Matrix Converter.

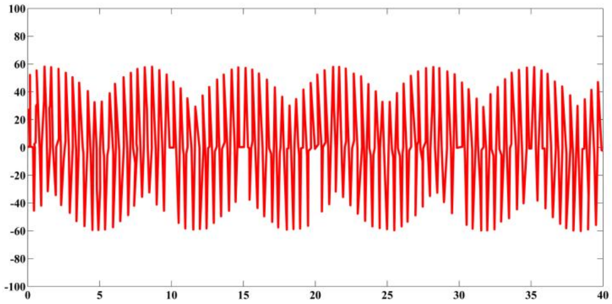

Fig. 11. (b) The input and the Simulation result of a Three Phase to Three Phase Matrix Converter for Vi=50V, R=10 ohms and output frequency fo=50 Hz.

The waveform in Fig.11 examines the output voltage of a Three Phase to Three Phase Matrix Converter.Sample simulations were also carried out to study the operation of a Single Phase Matrix Converter and Three Phase to Single Phase Matrix Converter.

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VI. CONCLUSION

Thus, in this paper a topology of a Single Phase Matrix Converter has been developed in MATLAB software environment and results are obtained for different output frequencies. Further, the operation of a Single Phase Matrix Converter synthesized using the Sinusoidal Pulse Width Modulation (SPWM) technique has been examined ,which has been executed. The electrical circuit of the Three Phase to Single Phase matrix converter is shown in Fig. 10. The principle of operation is illustrated using equivalent circuits, corresponding to the respective intervals, in which the bidirectional switches act. During a single switching cycle, only two (active) input phase legs are used to supply high frequency current to the load circuit, and these input phase legs play the role of the two phase legs in the single phase matrix converter proposed recently. The same switching pattern and single-step voltage commutation strategy are applicable to the two active input phase legs, implying the power control method of PWM and soft switching conditions remain realisable. Considering a balanced three-phase system, the sum of three input current must always be zero, implying either one input phase current will flow into two other input phases or two input phase currents will flow into the remaining input phase. By closely examining the ideal input current waveforms of a balanced three-phase system, Fig.10 (a) , a voltage shaping algorithm utilizing pulse density modulation can be proposed, as follows. In Fig. 10, the output voltage sectors have been numbered in such a way that they are convenient for the implementation of the switching algorithm. Simulation results for a Three Phase to Single Phase Matrix Converter and a Three Phase to Three Matrix Converter have also been shown. Hence, this paper attempts to give an overview of Matrix Converters there by providing an insight into one of the emerging trends of Power Converters. Future scope of work is to analyze the operation of a Matrix Converter for different loading conditions and synthesize the output voltage using various other modulation techniques and further this work can be extended to implement co-simulation approach.

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