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TOPOLOGIES ADOPTED IN THE DESIGN AND DEVELOPMENT OF THE SINGLE PHASE TO THREE PHASE DIRECT AC-AC MATRIX CONVERTERS FOR POLY PHASE LOADS

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ABSTRACT

Three phase Induction Motors has numerous advantages compared to its single phase counter parts in terms of performance parameters. Due to its numerous advantages, single phase induction motors are being replaced by Poly phase induction motors in many applications. This change requires the three phase power supply readily available everywhere, but in real world, only single phase supply sources are available in most locations and its considered to be the most convenient form of energy source. On the other hand, its proven that the three phase equipment are more efficient and economical than single phase counterparts. In order to meet this requirement, techniques are being developed to utilize the readily available single phase source to produce a variable frequency three phase supply. Thus the Single Phase to Three Phase variable frequency Converter is highly desired. Advancement in the Power Electronics devices such as power switches, microelectronics devices, FPGA and DSP techniques leads to the innovation of more advanced converters with sophisticated characteristics. PWM inverters are widely adopted in the variable speed motor drives. IGBT Bi-directional switches based AC to AC converters are getting more popularity for its unrestricted performance. Cycloconverters are one of the popular circuits which are heavily utilized in the variable frequency drives. Cycloconverters can be classified into Naturally Commutated Cycloconverter (NCC) and Forced Commutated Cycloconverter (FCC). In NCC, switches can be turned off naturally by the supply voltage where as in the FCC, the turn off is independent of the supply voltage. Thus, the higher frequency conversion is only possible in FCC. Matrix Converters are one of the good examples for FCC. This paper attempts to explore various techniques and topologies adopted in the implementation of Matrix Converters for single phase to three phase conversion and recommends the appropriate topology with associated hardware.

KEYWORDS: Bi directional Switches, IGBT, Induction Motor drives, Matrix Converters

INTRODUCTION

Poly phase Induction Motors has many advantages compared to their single phase counter parts in terms of developed torque, performance efficiency and motor power factor. Due to its proven advantages, single phase induction motors are being replaced by Poly phase induction motors in many applications. This replacement of single phase motors by three phase motors requires the availability of three phase power supply source everywhere. In addition, there is a requirement of an AC to AC Conversion device capable of converting the constant frequency single phase source to variable frequency three phase source. Advancement in the Power Electronics devices such as power switches, microelectronics devices and advance firing techniques leads to invention of more advanced converters with sophisticated characteristics. IGBT Bi-directional switches based AC to AC converters are getting more popularity for its unrestricted performance. In cycloconverters, constant frequency AC signal is directly converted to variable frequency AC signal through an array of static power electronics switches connected between input and output terminals. The basic operating principle is to create an output waveform from the pieces of the input waveform with the desired fundamental frequency. Cycloconverters are one of the popular circuits which are heavily utilized in the variable frequency drives. Cycloconverters can be classified into Naturally Commutated Cycloconverter and Forced Commutated Cycloconverter In NCC, switches can be turned off naturally by the supply voltage where as in the FCC, the turn off is independent of the supply voltage. Thus, the higher frequency conversion is only possible in FCC. Matrix Converters are one of the good examples for FCC.

Matrix Converters schemes can be employed for both three phase to three phase power conversion (3Φ-3Φ) and single phase to three phase power conversion (1Φ-3Φ). The Matrix Converter is a single stage converter which has an array of (m x n) bidirectional power switches to connect, directly, an m-phase voltage source to an n-phase load. Normally, the Matrix Converter is fed by a voltage source and for this reason; the input terminals should not be short-circuited [1]. On the other hand, the load has typically an inductive nature and for this reason an output phase must never be opened [2]. Matrix Converters uses six to nine bidirectional switches based on the adopted topology for the direct AC/AC Three Phase power conversion. Matrix Converter has numerous advantages such as simple and compact power circuit, variable high and low frequency output, unity power factor operation etc [3].

CONVENTIONAL MATRIX CONVERTER

The following figure shows the conventional Single Phase to Three Phase Matrix Converter topology. In which, six bidirectional IGBT Switches are used to piece the input waveform to three output waveforms that are differ by an angle of 120^{o} from each other.

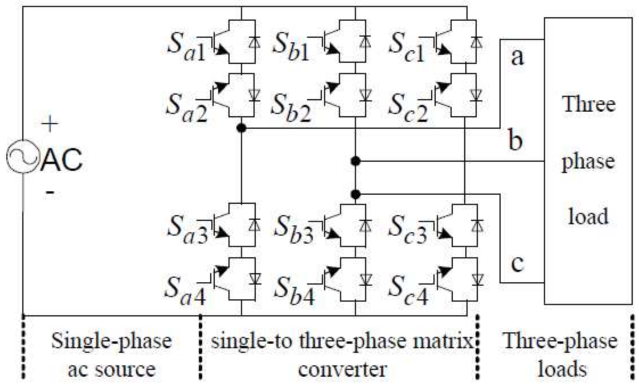

Figure 1: Conventional Matrix Converter. Courtesy: [1]

Sinusoidal Pulse Width Modulation (SPWM) technique is used to configure the firing sequences of the bidirectional switches. Eight operating states for every half cycle are used in the estimation of switch control signal durations. SPWM signals are generated using three phase reference voltages and its frequency and with a triangular carrier wave voltage and its frequency [1].

BIDIRECTIONAL SWITCH AND ITS REALIZATION

The Matrix Converter requires a bi-directional switch capable of blocking voltage and conducting current in both directions. Unfortunately there are no such devices currently available, so discrete devices need to be used to construct suitable switch cells.

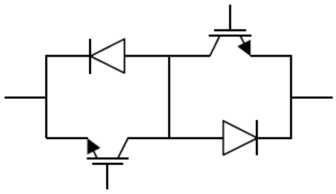

Figure 2: Mbidirectional Switch

The common emitter bi-directional switch cell arrangement consists of two diodes and two IGBTs connected in anti-parallel as shown in figure. The diodes are included to provide the reverse blocking capability. There are several advantages in using this arrangement when compared to other realizations.

The first is that it is possible to independently control the direction of the current. Conduction losses are also reduced since only two devices carry the current at any one time. One possible disadvantage is that each bi-directional switch cell requires an isolated power supply for the gate drives.

EXISTING MATRIX CONVERTERS

Basically, in all single phase converters, the three phase voltages and currents are found to be distorted due to the fluctuation of input instantaneous power. However Makoto, Takaharu and Nobuyuki from Gigu University and Nagoya Institute of Technology respectively proposed a new topology by employing an AC reactor and three additional bidirectional switches for the detection and storage of ripple component of instantaneous power.

Makoto and Nobuyuki in another paper proposed to include a power decoupling capacitor to compensate the torque vibration of induction motors. The proposed system is found to decouple the single phase power from the three phase power. The size of this capacitor is found to be only $1/40^{th}$ of the PWM based inverter system.

Udayagiri and Sarma from Central Electronics Engineering Research Institute proposed a topology based on full wave bridge rectifier and a three phase conventional converter. The proposed system is found to be working satisfactorily.

Jianmin Xiao & Wei Zhang and Hideki & Keizo from Zhejiang University and Panasonic Corporation Japan respectively proposed a Novel operational strategy for single phase Matrix Converters. An analytical method based on the Separation and Link strategy is used to increase the performance of the single phase Matrix Converters. This topology is found to be more stable and efficient compared to other topologies.

In the separation and link strategy based topology, every half cycle of the source voltage is treated as separate converter and treated as two equivalent converters in contrary series. The operations states have been obtained for the source positive and negative periods with rational states combinations. SPWM signals were used as the control signals. The proposed strategy was verified with a three phase balanced resistive load.

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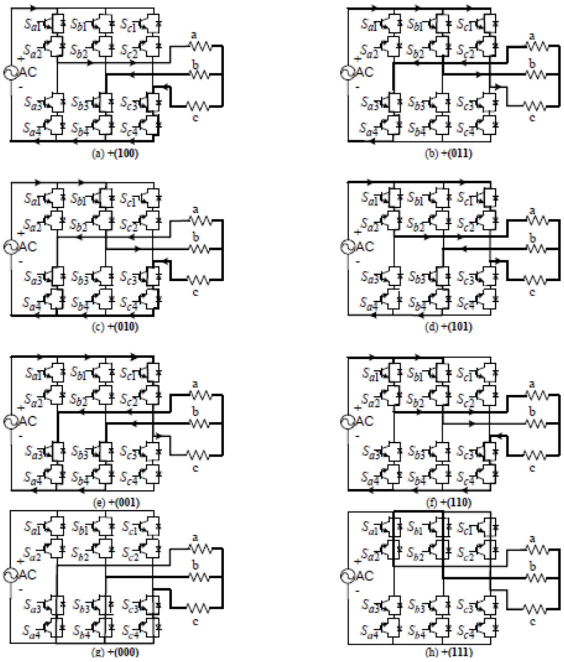

Figure 3: Matrix Converter Operation Stages. Courtesy: [1]

M and N are the modulation ratio and carrier wave ratio of the reference signal. It is found that the average voltage ratio for various output frequencies is around 0.30 to 0.32. Most part of the output frequencies falls between [f_o-2f_1] and [f_o+2f_1] where f_o is the fundamental frequency of the output waveform and f_1 is the source frequency. It is concluded that the proposed novel strategy has the strong capability of practical applications [2]. However, the voltage transfer ratio is found to be low and current zero surges causes vibration.

Table 1: Frequency Spectra of Output Voltages in Different Frequencies

V_s = 100 V, f_1 = 50 Hz, M = 1, N = 25			
	f_0	**$\lvert f_0 - 2 f_1 \rvert$**	**$\lvert f_0 + 2 f_1 \rvert$**
Amplitude (f_0 = 10 Hz)	31.74	10.74	10.63
Amplitude (f_0 = 20 Hz)	31.81	10.64	10.63
Amplitude (f_0 = 200 Hz)	31.47	11.06	10.74
Amplitude (f_0 = 500 Hz)	31.64	10.51	10.59
Amplitude (f_0 = 1000 Hz)	31.23	10.42	10.42
Amplitude (f_0 = 2000 Hz)	30.41	10.14	10.14
Amplitude (f_0 = 2500 Hz)	30.50	10.17	10.17

Courtesy: [1]

COMPARISON OF ADOPTED TOPOLOGIES

The following table provides the key features of various topologies adopted in the realization of Matrix

Converters in single phase to three phase conversions.

Table 2: Comparsion of Adopted Topologies

Existing Toplogies	Methods /Techniques Adopted	Unique Findings
Jianmin Xiao, Wei Zhang, Hideki Omori, Keizo Matsui, 2009, [1].	-Separation and link approach is used in bidirectional switches implementation in Matrix Converters -PWSM vector controlled speed adjustable system is used. -Three phase resistive load is adopted	-It is proved that single to three phase matrix converter is of the strong capability of practical application -With the SPWM strategy is adopted, the voltage transfer ratio is low -Space voltage pulse width modulation is recommended to increase the voltage transfer ratio -Vibration of motor is reported during operation
Iino.K.Kondo, Sato.Y, 2009, [3].	-Compensation Capacitor based Matrix Converter method is adopted -The amplitude of the compensated capacitor voltage is controlled to absorb the single phase power fluctuation -The compensation capacitor is asymmetrically connected over the input phase ‘s’ and the output phase ‘t’. $C_c \leq [P_r / \omega_s (4V_r)^2]$	-It is reported that the experimentation tests with a 0.75 kW class IM that voltage across the capacitor appropriate to the compensating power is continuously generated. -It is also reported that the proposed method achieved the unity power factor and eliminates the fluctuations.
Makoto Saito, Nobuyuki Matsui, 2008, [5].	-Matrix Converter with a power decoupling capacitor is used to reduce the torque vibration -A separate LC filter circuits are used in both input and output sides for the elimination of harmonic content and PWM ripples respectively -MC is composed on nine bidirectional devices Compensation capacitor is also used	-The proposed system can instantaneously decouple the single phase power from the three phase power by installing a small power capacitor in the conventional matrix converter. -The utility current is controlled to be sinusoidal and in phase with the utility voltage. -The decoupling capacitor voltage is controlled in proportion to the motor active power
Udayagiri.M.R, Sarma.V.S.S, 1992. [6].	-Unregulated single phase AC is converted to DC and later converted to balanced three phase AC -Full wave bridge circuit with three phase inverter circuits are used -The filter circuit consisting of electrolytic capacitors and dc chokes are used -A specific solution to obtain balanced three phase output voltages with no third harmonic is generated -Microprocessor based logic is used to generate different logic control pulses	-It is reported that the proposed system is operating satisfactorily -Voltage under utilization problem is reported
Makoto Saito, Takaharu Takeshita, Nobuyuki Matsui, 2004. [7].	-A new approach is presented to eliminate the distortion in the three phase voltages and currents -An AC reactor with three additional bidirectional switches are used to compensate the fluctuations to obtain the pure sine wave-Additional LC filter circuit is used in the output side	-Only simulation results were presented -The FFT analysis of the simulated results shows that the output three phase voltages and currents are to be pure sine waves with equal amplitude with 120^o displacement

HARDWARE CIRCUITRY DESIGN

Based on the comparison on existing topologies, it is found that the existing models are successful in eliminating the harmonics content and in blocking the reverse over voltages. However, these topologies suffer from the low voltage transfer ratio (G_v) [1] which is one of the key factors in determining the efficacy of the system. The voltage transfer gain (G_v) is defined as the ratio of per phase output voltage to that of input voltage of the matrix converter. The output voltage of the matrix converter is found to be only one third of the input voltage, thus only a reduce voltage is applied to the load which significantly affects the performance of the induction motors. It has been observed and reported that the low voltage transfer ratio (G_v) in most cases is around 0.31 to 0.33, thus there is need to explore ways and means to enhance the low voltage gain transfer ratio of the Matrix Converters.

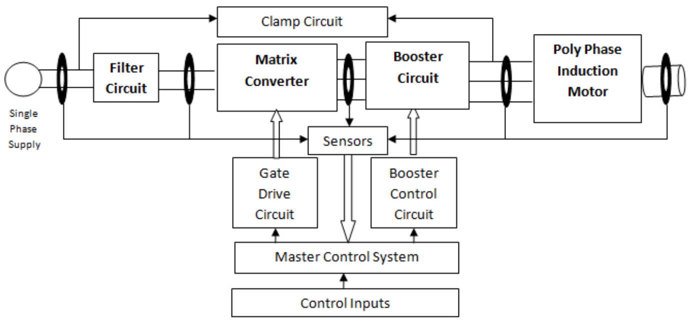

Figure 4: Block Diagram of Proposed Matrix Converter

A new topology is suggested to improve the low voltage transfer ratio of Matrix Converters. The proposed topology incorporates the conventional Matrix converter, a filter circuit to eliminate the harmonic content, a clamp circuit to block the reverse over voltages and a booster circuit to enhance the voltage transfer ratio. Sensors and actuators such as Current Transformers, Potential Transformers, Speed sensors, Pf transducers and other real time sensors are employed as closed loop feedback system. Master Control System acts as a backbone for the overall control executions of Gate drive circuit and Booster Control circuit.

The performance efficacy of the newly proposed Matrix Convertor topology depends on various parameters such as Switching Losses, Harmonic Content and Voltage Transfer Ratio (SHV parameters). The new model intends to realize the Matrix Converter using Reverse Blocking IGBTs (RGIGBT) which acts as four-quadrant switches and with a booster circuit. Various options are being considered in the implementation of Booster Circuit such as three phase transformers, open delta transformers, single phase transformers, variacs etc.

SUMMARY

Matrix Converters are gaining popularity due to its compact, convenient and robust operation. State of the art control techniques are being employed in the gate triggering control of the matrix converters. Research initiatives are currently being taken in order to stabilize the system and to produce harmonic free output voltages under variable load conditions. However, it can also be concluded that irrespective of advances made, finding a perfect way for converting single phase to three phase system with high voltage transfer ratio, less harmonic content, pure sinusoidal outputs and vibration less operation are long way to go. Thus future research should be towards finding a more appropriate and innovative gate triggering methodologies to enhance the performance of Matrix Converters.

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REFERENCES

1. J. Xiao, W. Zhang, H. Omori and K. Matsui, "A Novel Operation Stratgey for Single-to Three-Phase Matrix Converte,." International Conference on Electrical Machines and Systems, Tokyo, 2009.
2. M.Imayavarmban, K.Latha and G.Uma, "Analysis of different schemes of Matrix Converter with maximum voltage conversion ratio," Proceedings of 12th IEEE Mediterranean Electrotechnical Conference, Vol.3, Pg.1137-1140, 2004.
3. Lino.K, Kondo and Sato.Y," "An experimental study on induction motor drive with a single phase – Three phase matix converter," 13th European conference on Power Electronics and Applications, Barcelona , 2009.
4. H.Takahashi, R.Hisamichi and H.Haga, " High power factor control for current-source single-phase to three phase Matrix Converter," Energy Conversion Congress and Exposition IEEE, San Jose CA, 2009.
5. M.Saito and N.Matsui, "A Single to three-phase Matrix Converter for a vector-controlled Induction Motor," IEEE Industry Applications Society, Annual Meeting, Edmonton, Alta , 2008.
6. UDAYAGIRI.M.R and SARMA.V.S.S, "Single phae to three phase conversion without dc filter," Proceedings of the IEEE International Symposium on Industrial Electronics, Xian, China, 1992.
7. M.Saito, T.Takeshita and N.Matsui, "A single to three phase Matrix Converter with a Power Decoupling Capability," The 35th Annual IEEE Power Electronics Specialists Conference, Aachen, Germany, 2004.
8. S.Kwak and H.A.Toliyat, "An approach to fault tolerant three phase Matrix Converter drives," IEEE Transaction on Energy Conversion, Vol. 22, No.4. 2007.
9. J.Pontt; J.Rodriguez, J.San Martin, R. Aguilera, J.Rebolledo, E.Caceres, I.Illanes and P.Newman, "Inter harmonic currents assessment in high-power cycloconverter fed drives," 37th Annual IEEE Power Electronics Specialists Conference, Je Ju, Korea, 2006.