Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-5, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Implementation of Single Phase Matrix Converter as a Cycloconverter

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Abstract: *With the development of Power Semiconductor Technology the power handling capacity and switching speed of devices have improved tremendously. It is not easy to demarcate the boundaries for the applications of Power Electronics. Matrix converter is also a result of this development with extensive researches still going on. There are more practical power processors that utilize more than one converter at a time which are isolated by filter circuit or simply say, bulky energy storing elements. Using matrix converter these bulky energy storing elements can be eliminated and single stage AC-AC conversion become possible.*

Single-phase Cyclo-converters are used for AC-AC power conversion particular for speed control of AC drives. In previous works the Single-phase matrix converter (SPMC) topology is used for cyclo-converter operation]. IGBTs are used for the power switches. The well-known sinusoidal pulse width modulation (SPWM) scheme is used in for switching the IGBTs.

In this work matrix converter topology is used for designing single phase cyclo-converter which may be used for speed control of AC drives. The basics of Cyclo-converter and Matrix Converter are also given in brief. This work presents the open-loop control strategy using well known sinusoidal pulse width modulation. Different output waveform shows that there is less degree of harmonics present in system. All the elements are taken as having ideal characteristics with no switching and conduction losses. For this purpose, well known simulation platform for power electronic simulation, MATLAB & SIMULINK is used. The switching strategy for IGBTs is given in detail as this is the main body of the work.

Introduction

1.1. General

In a cyclo-converter, the AC power at one frequency is converted directly to an AC Power at another frequency, generally lower than the input supply frequency without any intermediate DC stage. The technique of cyclo-conversion was known in Germany in the 1930's, when mercury- arc rectifiers were used to convert power from 50 Hz to 16 Hz for railway transportation. After the development of thyristors in the late 1950's, the first new cyclo-converter applications were in variable-speed constant-frequency supply system for air-crafts. The variable frequency induction motor drives were the next important application.

In the 1970's, various aspects of the cyclo-converter theory and practice were discussed by Pelly, Gyugyi and Pelly, and Mcmurry. Because of the complexity of the control circuits, the application of cyclo-converter is limited, mainly to large-scale system. Developments in microelectronic circuits and microprocessors make microprocessor control very attractive for use in cyclo converter system. In the late 1980's (1986) implementations on cyclo-converter, experienced growth in usage due to the development of microprocessor based control systems. The complex control circuit hardware can be replaced by microprocessor software which reduces manufacturing costs, increases reliability and improves maintenance and servicing.

Thyristor controlled cyclo-converter today, has found its way in higher power applications such as in electric traction, rolling mills, variable frequency speed control for AC machines, constant frequency power supply and controllable reactive power supply for an AC system.

Amongst previous development of the cyclo-converter includes; work on improvements of harmonic spectrum in the output voltage, easier implementation using microprocessors, elimination of possibility of short circuit between positive and negative groups of converters with new novel control strategy, reducing the cost of control switches with new topology, and study of dynamic behaviors of the cyclo-converter based on multi-processor, provides high output to input frequency ratio. The matrix converter offers possible "all silicon" solution for AC-AC conversion removing the need for reactive energy storage components used in conventional rectifier-inverter based system. Gyugyi first described the topology in 1976. The single phase matrix converter denoted as SPMC was first realized by Zuckerberger. Other works, such as those of Hossieni and Saiful does not include experimental verification.

1.2 Converters

1.2.1 AC-DC Converters

1.2.1.1 AC-DC Uncontrolled Converters

A diode rectifier shown as in figure 1.1 converts AC input voltage into DC voltage. This rectifier needs minimum number of diodes. The input voltage may be single-phase or three-phase. Diode rectifiers find wide use in electric traction, battery charging, electroplating, etc.

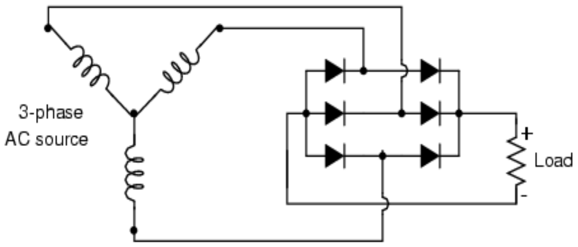

Fig. 1.1 (a) Three-phase full-wave bridge rectifier circuit

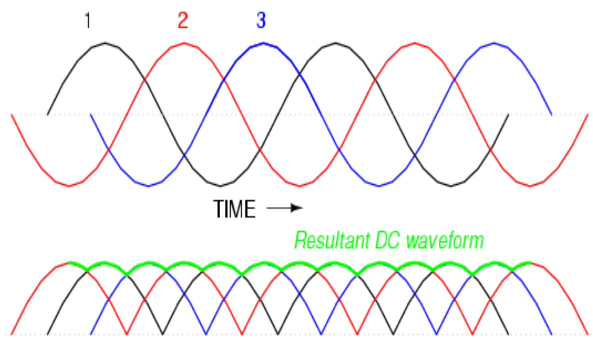

Fig. 1.1 (b) Three-phase full-wave bridge rectifier output

1.2.1.2 AC-DC Controlled Converters

In these converters, as shown in figure 1.2, the constant AC voltage can be converted into variable DC voltage by means of controlled switches. The switches are commutated by line voltage and called line commutated AC-DC converters. These may be of single-phase or three-phase.

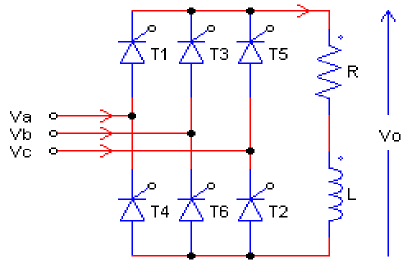

Fig. 1.2 (a) Three-Phase Thyristor Converter

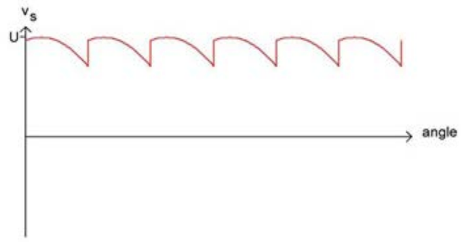

Fig. 1.2 (b) Three-Phase Thyristor Converter output

1.2.2 AC-AC Converters

1.2.2.1 AC Voltage Controller

These converter circuits convert fixed AC voltage directly to a variable AC voltage at same frequency. AC voltage directly controlled by two anti-parallel thyristors or by a triac. Turn off of both devices is obtained by line commutation. Output voltage is controlled by varying the firing angle delay. AC voltage controllers are widely used for lightening control, speed control of fans, pumps etc. Figure 1.3 shows typical Single Phase AC voltage controller.

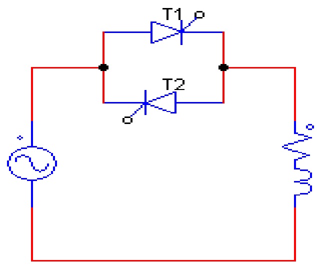

Fig. 1.3 (a) Single Phase AC Voltage Controller

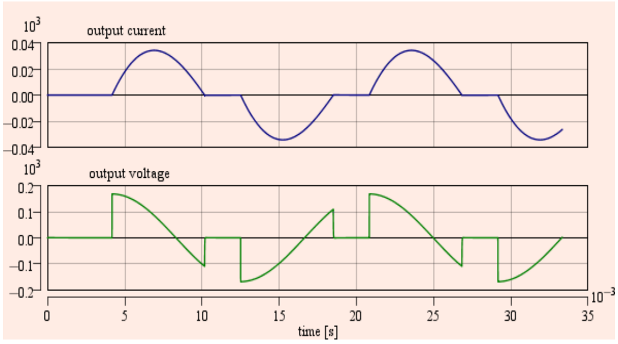

Fig. 1.3 (b) Single Phase AC Voltage Controller Output

1.2.2.2 Cyclo-Converter

These converters convert input power at one frequency to output power at different frequency through one stage conversion. Line commutation is more common in these converters, though forced and load commutated cyclo converters are also employed. Figure 1.4 shows typical single phase to single phase cyclo-converter. It is primarily used for slow speed large AC drives, like rotary kiln etc.

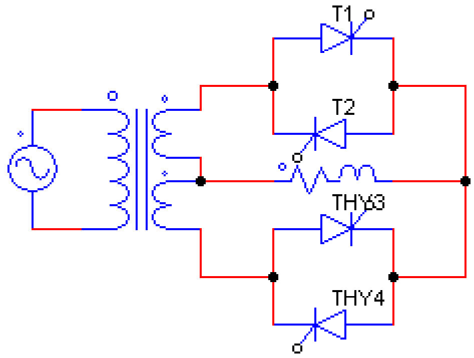

Fig. 1.4 (a) Single-phase cyclo-converter

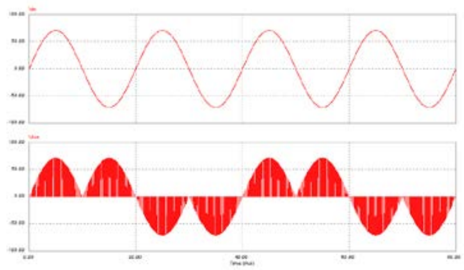

Fig. 1.4 (b) Single-phase cyclo-converter output

The Cycloconverter

2.1 Introduction

Cyclo-converters are a historical class of power converters based on SCRs. They are used to generate AC output (single- phase or three-phase) from a single-phase or three-phase input. A typical cyclo-converter consists of one or more pairs of back-to-back connected controlled rectifiers as shown in Fig. 2.1. Detailed treatment on the operation of conventional cyclo-converter could be obtained from reference but will be briefly described for completeness. As can be observed, the conventional cyclo-converter uses two separate converters called the P-converter and the N-converter; each performing similar to an H-bridge inverter because of the complexity of the control circuits, the application of cyclo-converter is limited, mainly to large-scale systems. Developments in microelectronic circuits and microprocessors make microprocessor control very attractive for use in cyclo-converter systems. The complex control circuit hardware can be replaced by microprocessor software which reduces manufacturing costs, increases reliability and improves maintenance and servicing.

2.2 Operational features

The principle of operation of single-phase/single-phase cyclo-converters can be explained with the help of Fig. 2.1. The two single- phase controlled converters are operated as bridge rectifiers. However, their delay angles are such that the output voltage of one converter is equal and opposite to that of other converter. If converter P is operating alone, the average output voltage is positive and if converter N is operating, the output voltage is negative. If the positive converter is on for time T0/2 and the negative converter operating for another time T0/2. The frequency of the output voltage is f01/T0.

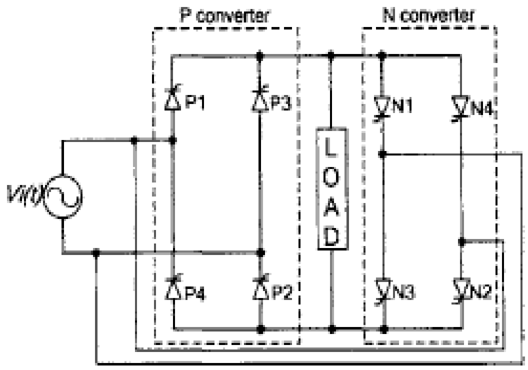

Fig. 2.l. Schematic of a conventional single-phase bridge cyclo-converter

2.3 Matrix Converter

The AC-AC matrix topology was first reported by Gyugyi in 1976 in a conceptual manner; very theoretical in nature but useful for providing insights for fundamental research. In its basic form the matrix converter is a special class of cyclo-converter that was developed in the early 1930s. This was later used by Alesina et al to develop a generalized high-frequency switching strategy providing several attractive features and described as a generalized transformer synthesis. There if could be realized in practice are a powerful solution of making an all silicon solution system.

The matrix converter is an array of controlled semiconductor switches that connects directly the single-phase source to the single-phase load. This converter has several attractive features that have been investigated in the last two decades. In the last few years, an increase in research work has been observed, bringing this topology closer to the industrial application.

The matrix converter offers an "all silicon" solution for AC/AC conversion, removing the need for reactive energy storage component used in conventional rectifier-inverter based systems. Matrix converters offer many advantages over traditional topologies, such as the ability to regenerate energy back to the utility, sinusoidal input and output currents and a controllable input current displacement factor. The size of the converter can also be reduced since there are no large reactive components for energy storage.

2.4 The SPMC as CYCLO-CONVERTER

In comparison the SPMC requires 4 bi-directional switches as illustrated in Fig. 2.2 for its cyclo-converter implementation. It requires the use of bidirectional switches capable of blocking voltage and conducting current in both directions. Unfortunately, there is no discrete semiconductor device currently that could fulfill the needs, and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Fig. 2.3. Diodes are in place to provide reverse blocking capability to the switch module. The IGBT were used due its high switching capabilities and high current carrying capacities desirable amongst researchers for high-power applications.

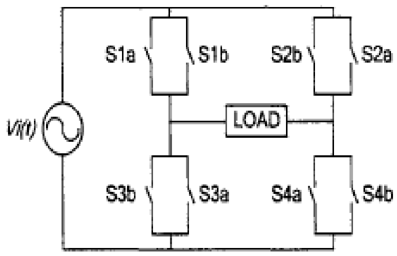

Fig.2.2 SPMC Circuit configuration

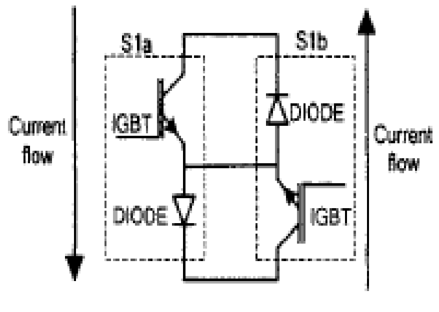

Fig. 2.3 Bi-directional switch module (common emitter)

Drive Circuit

3.1 Introduction

Driver circuit is used for the firing of the IGBTs used as switches in the power circuit. In this work Single-phase Sinusoidal Pulse Width Modulation (SPWM) is used for the firing of the IGBTs used in Matrix Converter.

3.2 Pulse Width Modulation

There is a need for a robust system for varying the AC frequency of a circuit. The main use for this type of converter is in AC-motor drive applications and in controlled-rectifier applications for AC-DC conversion devices. AC induction motors are the workhorses of the industry, yet there are serious limitations in the characteristics of such motors, such as difficulty in controlling their speed. Recently, a number of control methods have been proposed. But there are tradeoffs in terms of efficiency, simplicity, and cost. Pulse Width Modulation (PWM) techniques have been employed for many DC-AC drive applications due to their low ripple current, well-defined harmonic spectrum, and control of the output amplitude. We employ the bipolar triangle-intersection Sinusoidal PWM (SPWM) technique in our implementation in place of digital-pulse programming techniques. We previously considered analog-based techniques to achieve high accuracy and high bandwidth, but these techniques require high precision components and are not suitable for additional microprocessor-based implementation when the system needs various sinusoidal voltages and frequencies. Microprocessor-based methods are free from drift and disturbance, and are easily manipulated, but online PWM computation is considered laborious and time-consuming. EPROM-based designs need a great deal of memory and, thus, are characteristically more expensive and take longer to implement.

3.3 Basic Sinusoidal Pulse Width Modulation

The switches in the voltage source inverter can be turned on and off as required. In the simplest approach, the top switch is turned on. If turned on and off only once in each cycle, a square wave waveform results. In the most straightforward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high-frequency triangular 'carrier' wave. Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies close to the carrier frequency. Notice that the root mean square value of the AC voltage waveform is still equal to the DC bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the AC system.

3.4 SPWM Used

The Sinusoidal Pulse Width Modulation (SPWM) is a well-known wave shaping technique in power electronics as illustrated in Fig. 3.1. For realization, a high frequency triangular carrier signal, Vc, is compared with a sinusoidal reference signal, Vref, of the desired frequency. The crossover points are used to determine the switching instants

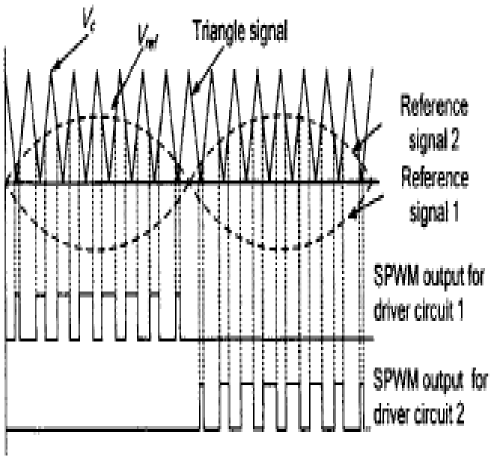

Fig. 3.1 Formation of SPWM

The magnitude ratio of the reference signal Vref to that of the triangular signal Vc is known as the modulation index mi. The magnitude of fundamental component of output voltage is proportional to mi. The amplitude Vc of the triangular signal is generally kept constant. By varying the modulation index, the output voltage could be controlled.

3.5 Switching Strategies

The implementation of the SPMC as a cycloconverter requires different bi- directional switching arrangements depending on the desired output frequency. The output voltage of the converter is controlled by SPWM, but the frequency of the converter is changed by controlling the duration of operation of the switch.
The switching sequences are dependent on the time interval and the state of the driver circuit following table 1 below (for one cycle).

Input Frequency	Target Output Frequency	Time Interval	State	Switch "Modulated"
		1	1	S1a & S4a
		2	2	S2b& S3b
50 Hz	25 Hz	3	3	S1b & S4b
		4	4	S3a & S2a

Table 1. Sequence of Switching Control

1) At any time, only two switches S1a & S4a will be in ON state and conduct the current flow during positive cycle.

2) At any time, only two switches S2b& S3b will be in ON state and conduct the current flow during negative cycle.

3) At any time, only two switches S1b & S4b will be in ON state and conduct the current flow during positive cycle.

4) At any time, only two switches S3a & S2a will be in ON state and conduct the current flow during negative cycle.

Simulation and Result

4.1 Main Simulation Model

Fig. 4.1 is the developed MATLAB model for SPMC that performs the operation of a cycloconverter.
Simulations results are presented in the following Parameters used are as shown in table 2.

Input Source(AC)	120Vrms
Reference Frequency Signal(fr)	50Hz
Carrier Signal(fc)	5kHz
Modulation Index(mi)	0.7 &1.0
Load	R= 50 ohm

Table 2

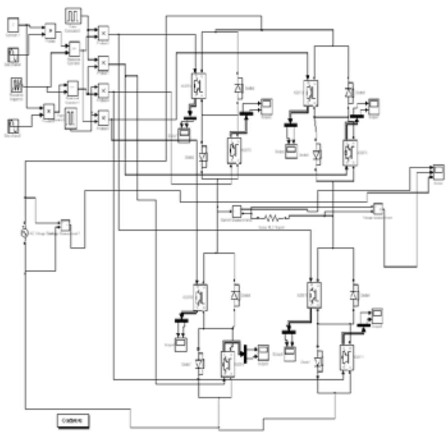

Fig. 4.1 Main model of SPMC

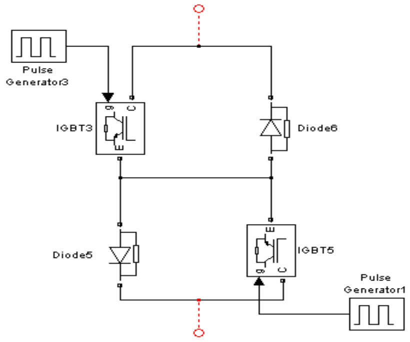

Fig. 4.2 shows the bi-directional switch model in MATLAB.

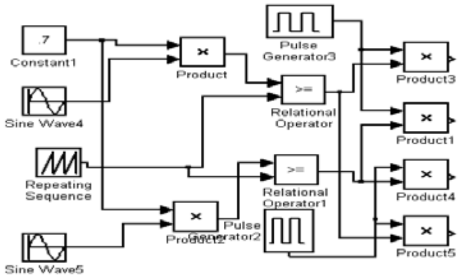

Fig.4.3 Actual Diagram of driver circuit.

The driver circuit is shown in Fig. 4.3, which comprises SPWM generator portion and state selector point. Driver circuit were designed to generate the SPWM pattern that is controlled using the switching states as in table 1.

4.2 Simulation Results

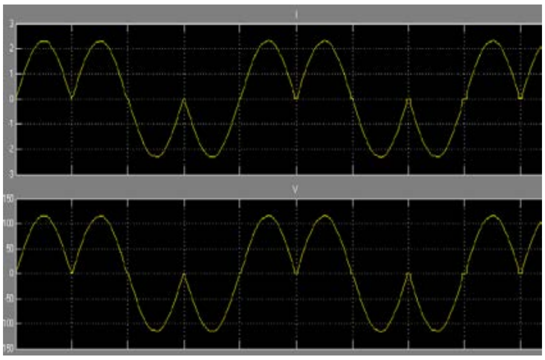

Fig.4.4 Simulation result of SPMC with R load at fc=50Hz

The simulation model could be used to study the behavior of the SPMC as a cycloconverter under a variety of operating conditions, including different reference frequencies and variety of load. In this paper we have focused into simulation of purely resistive load due to the absence of commutation strategy. However, simulation was also carried out with R-L load at fc =25 Hz and are as given in Fig.4.5. This is to observe the spikes being produced under those circumstances.

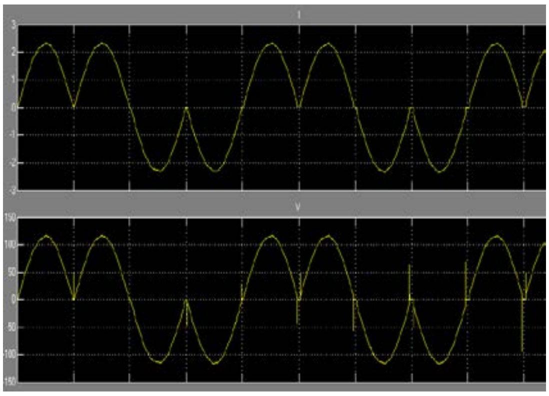

Fig.4.5 Simulation result of SPMC with R- L load at fc = 50Hz.

We could observe that the output voltage and current waveforms are indeed, distorted. An undesirable spike seems to be appear with a reasonable degree of magnitude that requires elimination. This could be solved using novel commutation strategy that could be investigated in future.

Conclusion and Future Scope

Conclusion

The computer simulation model on SPMC for cycloconverter operation using MATLAB and SIMULATION is presented. It includes the implementation of SPWM to synthesize the AC output supply for a given AC input.

Future Scope

Further simulation was also carried out with simple R-L load**.** An undesirable spike seems to be appear with a reasonable degree of magnitude that requires elimination. This could be solved using novel commutation strategy that could be investigated in future

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