Software Design and Hardware Realisation of Single Phase to Single Phase Step Down Cycloconverter

Shweta Sethi
Department of Electrical andElectronics Engineering
Maharaja Agrasen Institute of Technology, Delhi, India

Prof. G.K. Jindal
Department of Electrical and Electronics Engineering
Maharaja Agrasen Institute of Technology, Delhi, India

Prof. Madhusudan Singh
Department of Electrical Engineering
Delhi Technological University, Delhi, India

Abstract- The electricity produced at power stations has a frequency of 50 Hz which is not always applicable for some electrical equipments. Some electrical devices need variable frequency ranging from one tenth to one third of supply frequency. Some examples are induction motors used in AC traction, aircraft power supplies, rolling mills, cement kilns. The cycloconverter can serve the purpose by providing variable frequency. This paper emphasizes on step down frequency operation of single phase to single phase cycloconverter with output frequency of 12.5 Hz. The circuit is composed of back to back connected positive and negative converter that uses thyristors as power switching device in the cycloconverter implementation. Natural commutation strategy is used and no need of external circuitry is required. The cycloconverter design is divided into power circuit, control circuit and interfacing circuit. The switching signals are produced by the control circuit. The phase detector circuit is used to synchronize the output of control unit and the frequency of AC input supply voltage. The interfacing circuit is used to determine the required driver to generate the gating pulses for the SCR. In the proposed scheme, reduced number of switches reduce the complexity of the control circuit, minimizes the switching losses and thereby increase the efficiency. Total harmonic distortion is measured with and without load. The cycloconverter is designed as a prototype and converts 50Hz input frequency into 12.5 Hz output frequency. The simulation of cycloconverter is being carried out in Proteus ISIS software along with the hardware implementation and results are preSented for resistive load.

Keywords – Cycloconverter, Total Harmonic Distortion (THD), Zero crossing Detector (ZCD), Operational amplifier (op-amp)

I. INTRODUCTION

Cycloconverter is a direct frequency changer that converts AC power at one frequency to AC power at another frequency by AC-AC conversion [1]. Traditional cycloconverter requires a large number of thyristors and a complex control circuit for good performance. The input current of any cycloconverter circuit is distorted and its Fourier series involves harmonics which includes (a) higher order harmonics (b) sub harmonics (c) non standard harmonics. They are used to generate AC output (Single phase or three phase) from a single phase or a three phase input [6].

As more electronic controllers are used in variable speed drives, their harmonic impact on the power system has been of concern [8]-[9].Cycloconverter brings harmonics in the system. Delta modulated switching may be employed for cycloconverter for harmonic reduction in output voltage [10]. An another topology for step down cycloconverter operation based on single phase matrix converter with well known sinusoidal pulse width modulation scheme may be used[11].

An another control strategy based on FGPA design in which a single phase matrix converter (SPMC) can be made to operate as a cycloconverter[10]. The control electronics comprises of a computer, a phase detector, isolated gate drivers and a Xilinx FPGA at the heart of its digital control. Another control algorithm is a single phase to single phase Z-source cycloconverter based on SPMC topology. Nowadays, several attempts have been made to develop microprocessor based control strategies for controlling a cycloconverter [14]-[16].

The Cyclo-converter generally consists of two converter group one of which is called the positive converter and another one is negative converter. Positive converter has P1 and P2 SCRs and negative converter has N1 and N2 SCRs. The positive converter operates whenever the load current is positive with the negative converter remaining idle during this period. In a similar manner, the negative load current is supplied by the negative converter with the positive converter remaining idle during this period [1]. A cycloconverter circuit is comprised of power, control and interfacing sections.

A step down cycloconverter does not require forced commutation. It requires phase controlled converters. These converters need line or natural commutation which is provided by input supply. The number of degrees from the beginning of the cycle when the thyristor is gated or switched on is referred to as the firing angle, α. The output voltage is controlled by varying the firing angle and the frequency of output is controlled by controlling the duration of ON/OFF periods of positive and negative converter.

II. CONTROL ALGORITHM

The main function of the control circuit is to produce trigger pulses in a particular sequence and feed them to the gates of the positive and negative group of thyristors so as to generate a voltage of desired wave shape at the output terminals of a cycloconverter. The control circuit can be arranged broadly into four functional blocks which are (a) synchronizing circuit, (b) comparator circuit and reference voltage source, (c) converter group selection circuit and (d) logic and triggering circuit. These low voltage signals need to be synchronized with the voltage supplied to the main power circuit. The easiest method of achieving the synchronization of the low voltage signals with the voltages supplied to the main power circuit can be constructed by the use of the operational amplifier (OPAM 741) and is called a phase detector.

A. Generation of Blanking Pulses

For converter group selection, two blanking pulses of desired frequency i.e 12.5 Hz are required. The following sequence of circuits is employed.

A1.Units

- Zero crossing detector: Here, the non inverting input is held at ground (0V), and the ac input voltage Vin is applied to the inverting input; zener diode with zener voltage 5.1V is included so that output is limited to +5V during the negative ac input half cycle and during the positive half cycle, the output is -5.1V.
- Transistor as a phase inverter: It inverses the input square wave of 50Hz frequency. The output is then sent to the negative clipper circuit.
- Negative clipper: The negative going wave is clipped out. The output is positive wave during the positive half cycle.
- Divide by four counter: Dual positive edge triggered JK flip flop 74109 IC is used. The input is a square pulse of frequency 50Hz and the output is a square pulse of frequency 12.5 Hz.
- This pulse is phase inverted to get another square pulse of 12.5 Hz. Thus, two P and N-blanking pulses are obtained.

B. Generation of firing pulses

The firing pulses are generated in such a manner that in the first half period P1 and P2 SCRs of P converter are fired and in the second half period N1 and N2 SCRs of N converter are fired. The firing pulses are obtained by the following proposed circuits.

B1.Units

- Zero crossing detector: In the non-inverting comparator mode, the same ac input is given to non-inverting input of op-amp and inverting input is grounded. A positive square pulse during the positive half cycle of ac input is obtained. In inverting comparator mode, the ac input is given to inverting input of op-amp and non-inverting input is grounded. A positive square pulse during the negative half cycle is obtained with equal ON and OFF period.
- Differentiator circuit: The output of non-inverting comparator mode ZCD is given as an input to the differentiator. It produces narrow spikes during the pulse on-period and negative spike during the off-period. Similarly, the output of inverting mode ZCD is given as an input to the differentiator. It produces positive spike during pulse on-period and a negative spike during the off-period.

- Monostable multivibrator: By base of the transistor, Q1 then that transistor goes into conduction. Its collector current increases and thereby its collector to emitter voltage decreases adjusting the RC time constant of the multivibrator, it is possible to obtain the output pulse (only positive) of any time period. When the positive spike occurs at the to a low value. Since the capacitor can't change the voltage across it instantaneously the whole abrupt change appears at the base of the transistor Q2 and it remains at cutoff. Then its collector current becomes low and the collector to emitter voltage becomes high which drives the output of the multivibrator to a high value and the output remains at that value until the time period determined by RC time constant elapses. The output will remain in that stable state until the next spike pulse appears. So, when the transistor, Q1 will be in saturation state then the transistor, Q2will be in cutoff state and vice versa. In this case the RC time constant is considered of 500 µsec by selecting C = 2.2uf, R = 2.2kΩ, Rf =10kΩ and Rc=1kΩ. The transistors (Q1, Q2) are of 2N 2219A type.

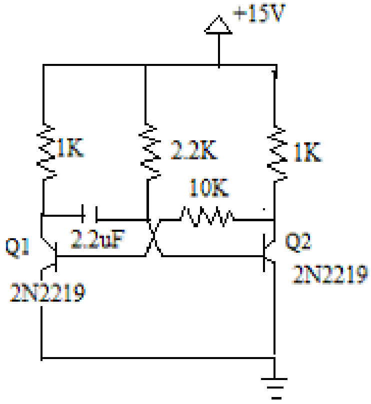


Figure1: Hardware circuit of monostable multivibrator

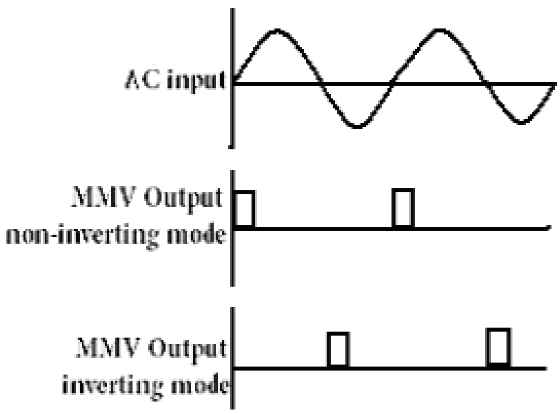


Figure2: MMV output in non-inverting and inverting comparator mode

- Converter Selection: The P and N blanking pulses generated are used for P and N converter selection. P-blanking pulse is ANDed with the pulses obtained during every positive half cycle of input AC to obtain the firing pulse for P1. P-blanking pulse is ANDed with the pulse obtained during every negative half of input mains to obtain firing pulses for P2. N-blanking pulse is ANDed with the pulses obtained during every positive half cycle of input mains to obtain firing pulses for N2. N-Blanking pulse is ANDed with the pulses obtained during every negative half cycle of input mains to obtain firing pulses for N1.After that we select the ordered coefficient from 1 to N to get N coefficient. the formulae of watermark embedding are as follows.

III. CONTROL CIRCUIT (WITH SOME FIRING ANGLE)

These circuits are very simple and requires less and easily available components. The Zero Crossover Detector (ZCD), which uses operational amplifier transform the AC signal (V_{IS}) into a synchronous square wave signal (A). The negative pulses are eliminated using diodes at the output stage of the op-amp.

A. Ramp wave generation

The ramp wave generation requires capacitors and opamp to realize the integrator function [3].

B. DC control voltage

The dc control voltage, EC that can be varied between ± 12V is used to vary the firing angle, α ranging from 0° to 180°

C. Comparator

An op-amp is used as comparator. The variable dc voltage
is applied to the non-inverting terminal and the Ramp wave is applied to the inverting terminal of the comparator. The diode is used to clip off the negative voltage wave.

D. Monostable multivibrator

The square wave output of the comparator is fed as input to the phase inverter and differentiator circuit and then the monostable multivibrator which gives outputs. This output is primary firing pulse which are modulated to trigger the thyristors.

E. AND

AND operation is performed between monostable output and carrier wave, thus pulses required for triggering the thyristors called firing pulses or gate pulses are obtained.

IV. POWER CIRCUIT

The power circuit consists of positive and negative converter which has two thyristors each. P1 and P2 SCRs conducts during the positive and negative half cycle of input AC supply in the first half output period To/2. N1 and N2 SCRs conducts during the positive and negative half cycles alternatively in second half time period To/2. The four firing pulses with $\alpha = 0^\circ$ and $\alpha \neq 0^\circ$ are given to SCRs after passing through four MOC 3021 optocouplers. The optocouplers are used to isolate low voltage control and high voltage power supply.

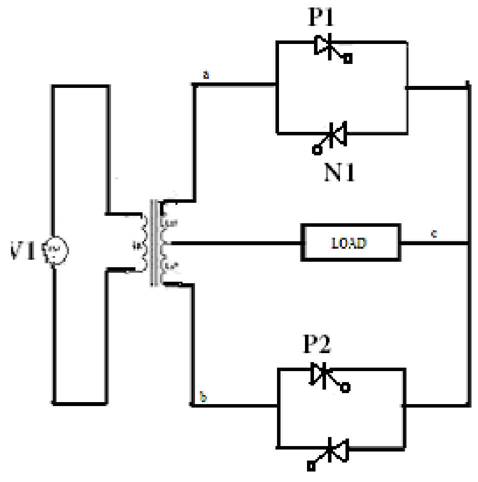
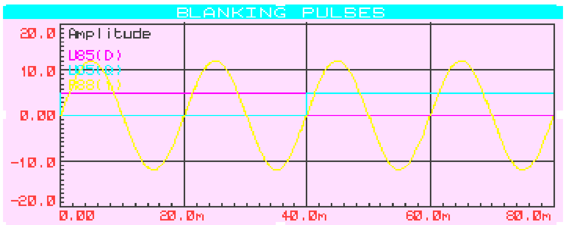


Figure3: Power Circuit-Single phase step down cycloconverter

V. SIMULATIONS AND EXPERIMENTAL RESULTS FOR SINGLE PHASE TO SINGLE PHASE STEP DOWN CYCLOCONVERTER WITH R LOAD

a. Generation of firing pulses

Figure4 shows the two P and N blanking pulses having frequency 12.5 Hz



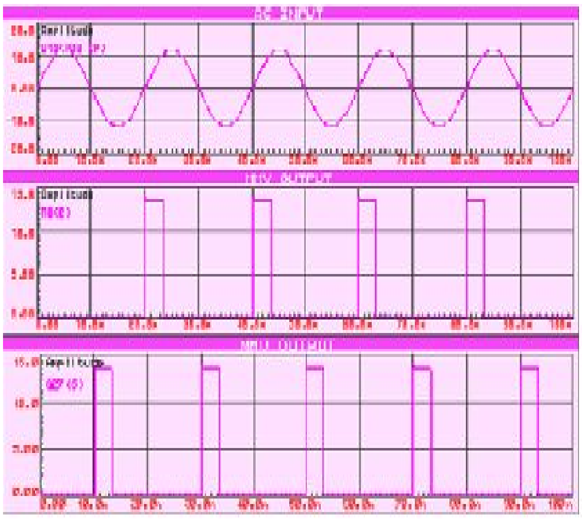


Figure5: MMV outputs

.Figure5 shows the output of monostable multivibrator.

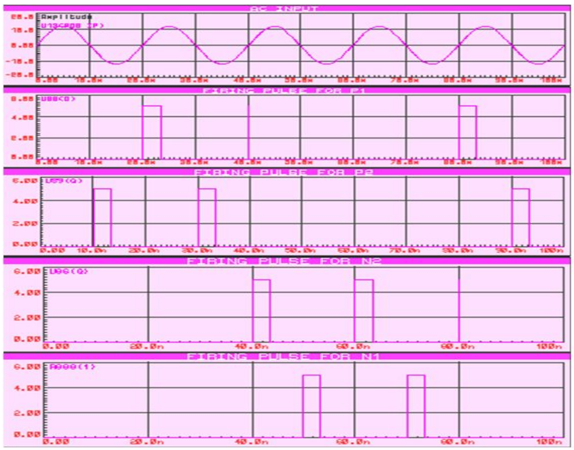


Figure6:The firing pulses given to the SCRs P1, P2, N2 and N1.

b. Power section output (desired waveform)

Figure7 shows the output voltage waveform for a resistive load. It is simulated in Proteus Isis software. Since the load is resistive, the output voltage waveform is same as the output current waveform.

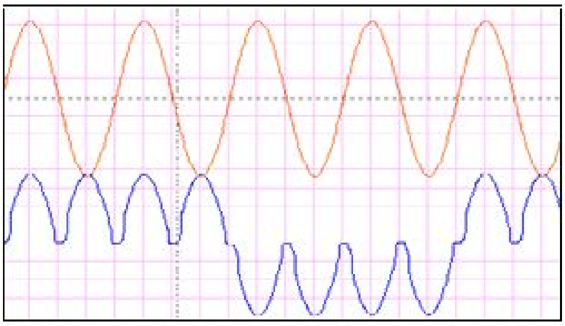


Figure.7 Desired output voltage waveform with $\alpha = 0°$.

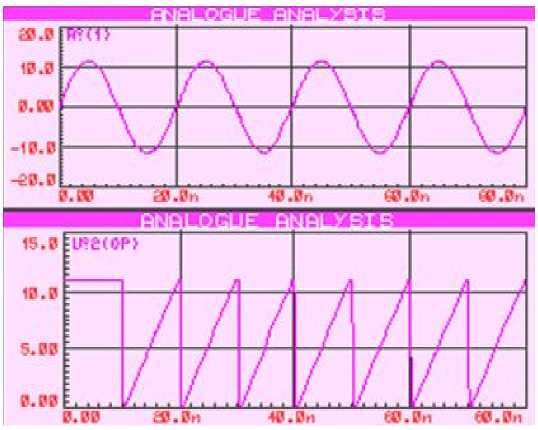


Figure 8: Synchronized Ramp Wave

Figure9 shows the dc control voltage and ramp wave which are given as the input to the comparator and the output is the varying pulse depending on the pot resistance.

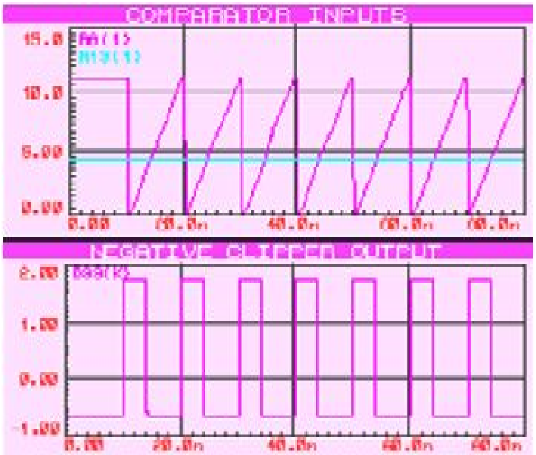


Figure9: Comparator inputs and outputs

Figure10 shows the monostable multivibrator pulses which are synchronized with the input A.C supply used to trigger the thyristors in the cycloconverter circuit.

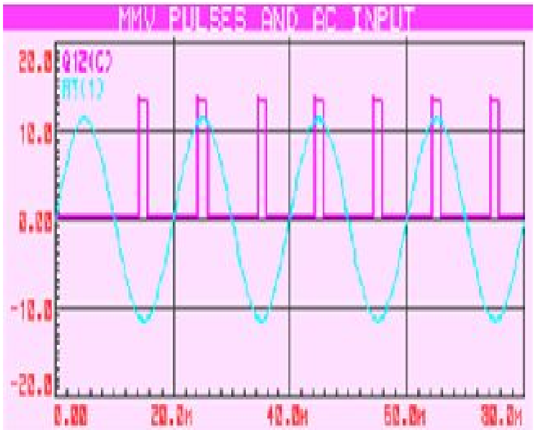


Figure10: MMV outputs synchronized with input supply

Figure11 shows the desired controlled AC output voltage controlled by varying the firing angle.

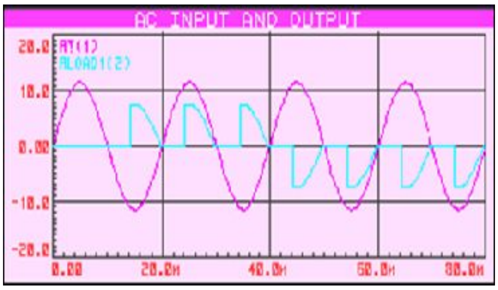


Figure11: Controlled AC output voltage with resistive load

The Hardware implementation of the proposed circuitry has been done. The results obtained are shown below. These are in accordance with the simulation results.

a. Generation of firing pulses (Hardware results)

Figure12 shows the P and N blanking pulses used for P and N-converter selection. Figure13 shows the Zero crossing detector output in non-inverting comparator mode.

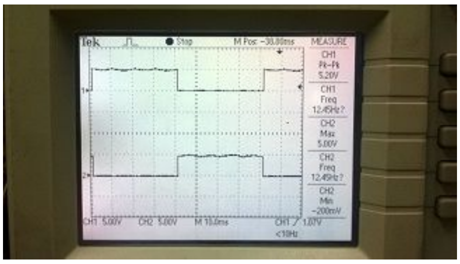


Figure 12: P and N blanking Pulses

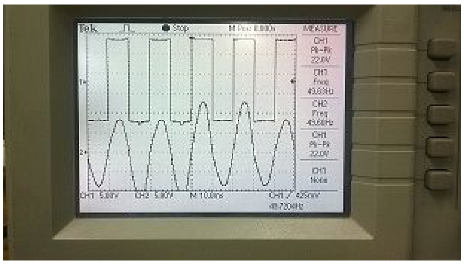


Figure13: Non-inverting comparator mode output

Figure14 shows the differentiator output which produces positive spike for +Vsat and negative spike for –Vsat and is synchronized with the AC supply mains, positive spike is used to turn on the transistor of monostable multivibrator.

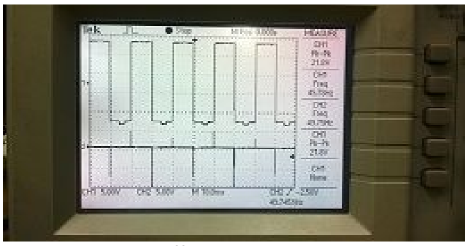


Figure14 Differentiator circuit output

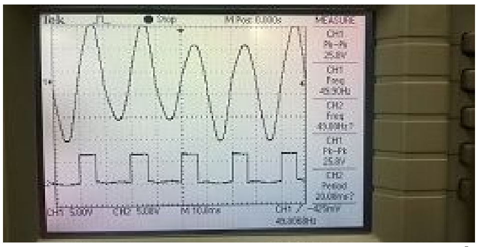


Figure15: MMV output in non-inverting comparator mode

Figure16 shows the Zero crossing detector output in inverting comparator mode which is +Vsat during the negative half cycle of AC mains and –Vsat during the positive half cycle of AC mains. Figure17 shows a pulse of duration sufficient enough to turn ON the SCR during the negative half cycle of every input cycle

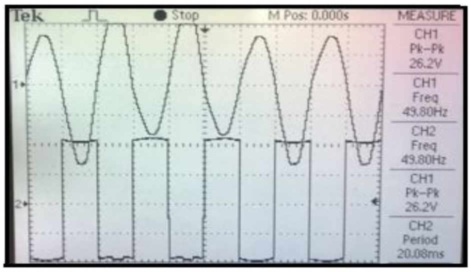


Figure16 Inverting Comparator Mode output

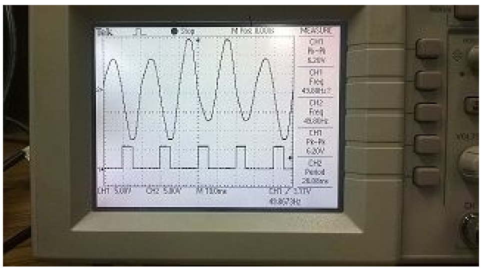


Figure17 MMV output in inverting comparator mode output

The P and N blanking pulses along with MMV outputs in both inverting and non-inverting mode are passed through four AND gates to obtain pulses for SCR P1, P2, N2 and N1.Here, the firing angle equal to zero.The pulses are shown in Figure 18. Figure19 shows the output voltage waveform for a resistive load having frequency one fourth of the input frequency. Therefore, output waveform obtained has a frequency 12.5 Hz.

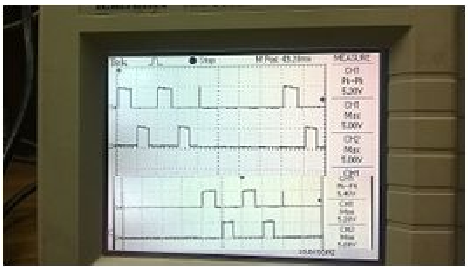


Figure18: *Firing pulses for SCR P1, P2, N2 and N1*

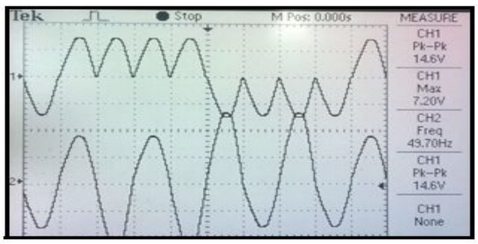


Figure19. Desired output voltage waveform

VI. PERFORMANCE EVALUATION

A transformer of secondary rating of 12 V and 800mA is considered for designing the cycloconverter which delivers a power of about 3.75 W.
The power calculation is shown below:

$$V_O = 12 / 1.4 = 8.5V$$

$$I_o = 750\ mA$$

$$P_O = V_O I_O = \frac{{V_O}^2}{R} = 8.5 * 8.5 \div 10 = 7.2 Watts$$

Here Po is the ideal power delivered to the load while practically it is 3.75 Watts. The THD is found to be 104.7 %.

VII. CONCLUSIONS

A single phase to single phase step down cyclo-converter has been developed which generates an output at a frequency lower than the input frequency. The simulation of Cycloconverter is being run in Proteus Isis software. Hardware realization of control circuit and power circuit has been done using readily available ICs and less expensive JK flip flops. The trigger circuit has been tested qualitatively by observing the various waveforms on CRO.

REFERENCES

[1] Rajib Baran Roy, Md. Ruhul Amin, “Design and Construction of Single Phase Cycloconverter” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-1, Issue-3, August 2012.

[2] Ebrahim Babaei and Ali Aghabeigi Heris, “PWM-Based Control Strategy for Forced Commutated Cycloconverters,” University of Tabriz, Tabriz, Iran, October 4-6, 2009.

[3] Mukesh Gupta, Sachin Kumar and Vagicharla Karthik, “Design and Implementation of Cosine Control Firing Scheme for Single Phase Fully Controlled Bridge Rectifier” International Journal of Emerging Trends in Electrical and Electronics (IJETEE – ISSN: 2320-9569) Vol. 3, Issue. 1, May-2013.

[4] O.P. Arora, “Power Electronics handbook vol. III,

[5] P.S Bhimra, “Power Electronics”, ISBN-13, 2012

[6] G.N. Acharya, U.N. Rao., and S.S. Shekhawat, “A single phase to three phase static converter”, in proc. IEE, power electronics, Power Semiconductors and their application, 1977.

[7] I.Katz, M.A., Uddin, M.B., Bhuyia, A.R Rahman, M.A., “Analytical Approach to the analysis of processes in single phase cycloconverter”, IEEE Trans., 1996, pp. 231-234.

[8] INTERNATIONAL ELECTROTECHNICAL COMMISION IEC STANDARD: “Disturbances in supply system caused by household appliances and similar electrical equipment”, IEC 555, 1982, pp.789-798.

[9] CHU, R.F., and BURNS, J.J.: “Impact of cycloconverter harmonics”, IEEE Trans., 1989, IA-25, (3), pp.427-435.

[10] [10] Ziogas, P.D. “The delta modulation technique in static PWM inverter”, IEEE Trans. On industry applications, Vol. 1A-17, Issue2, pp.199-204, Mar-1981.

[11] Zahirrudin Idris, M.K. Hamzah and N.R. Hamzah, “Modelling and simulation of a new single phase cycloconverter based on single phase Matrix converter Topology with sinusoidal pulse width modulation using Matlab/Simulink”, IEEE Trans., PEDS 2005, pp. 456-465.

[12] M.K. Nguyen, Y.G.Jung and H.Y. Yang, “Single phase Z-source cycloconverter with safe commutation strategy”, IET Power Electron., 2010, Vol.3, ISS.2, pp. 232-242.

[13] S.K. Tso, M.E. Spooner, and Consgrove, “Efficient microprocessor based cycloconverter control”, in Proc.IEE, pt.B, Vol.127, No.3, May 1980, pp.802-812.

[14] N.K. Sharda, S. Kumar, and R.Arcokiasamy, “Microprocessor control of cycloconverter: Techniques for implementation and testing”, IEEE Trans. Ind. Electrol., Vol.IE-2, (3), No.3, pp.232-236, Aug 1986.

[15] Miyazawa, S., Nakamura, F., Yamadeva.: ”A Novel strategy for microcontroller based control of a single phase output cycloconverter”, IEEE Transactions on Industrial Electronics, Vol.66 (4), Nov. 1989, pp. 560-567.

[16] Karamat, A., Thompson, T., Mehta, P., “Novel strategy for control of cycloconverters”, 22nd Annual IEEE Power Electronics Specialists Conference, 1991. PESC (9) Record., 24-27 June 1991, pp. 819-824.