CYCLO-CONVERTER

DESIGN, SIMULATION AND HARDWARE REALIZATION OF SINGLE PHASE TO SINGLE PHASE STEP DOWN CYCLOCONVERTER

DISSERTATION

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ABSTRACT

In this project, the design, simulation and hardware realization of a single phase to single phase step down cycloconverter is carried out in detail. The simulation of control and power circuit of cycloconverter is being carried out in Proteus Isis software.

A single phase cycloconverter is a direct AC to AC converter for providing variable voltage and variable frequency A.C. Based on input supply; it is either single phase or three phase system which is usually designed for high rating applications such as A.C drives, electric heating etc. A single phase cycloconverter requires four SCRs which are turned ON by the appropriate control signals. It operates as a phase controlled converters. These converters need line or natural commutation which is provided by AC input supply. The thyristors of cycloconverter are switched ON and OFF in proper sequence by using control electronics and gate driver circuits to get a controlled ac output voltage. The function of the control circuit is to generate the trigger pulses in a desired sequence and feed them to the gates of the positive and negative group of thyristors so as to generate a desired output voltage of frequency equal to one fourth of input frequency across a resistive load. The simulation of cycloconverter for firing angle equal to zero and a variable firing angle is being carried out.

The systematic generation of the blanking and the gate pulses of switching devices (SCRs) and synchronizing them with the AC input signal is the most important requirement and is performed by means of comparator circuit.

In this work, attempt has been made to reduce the switches to reduce the complexity of the control circuit, reduces the switching losses and thereby increasing the efficiency. The total harmonic distortion is measured with and without load. The cycloconverter is designed as a prototype and tested under different operating conditions.

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CHAPTER 1 : INTRODUCTION

1.1 General

The vast majority of today’s industrial and commercial electronic systems use electrical energy. The main function of the electrical system is to deliver the power from source to load. The major challenges in such systems is that there is not a single universal form of power. First and foremost, there are the two forms of power of direct current (DC) and alternating current (AC). In addition, there can be variable amplitudes, as well as variable frequencies and multiple phases for AC. Sometimes, the form of the input source is different from the load requirements. An example is a high voltage transmission system interfacing with a lower voltage distribution system. This brings about the need for conversion between these different forms of electrical power via power electronics. Power electronics refer to the conversion of electrical power from one form to another using a power circuit and a control circuit. The basic block diagram of a conversion system is shown in figure 1.1.

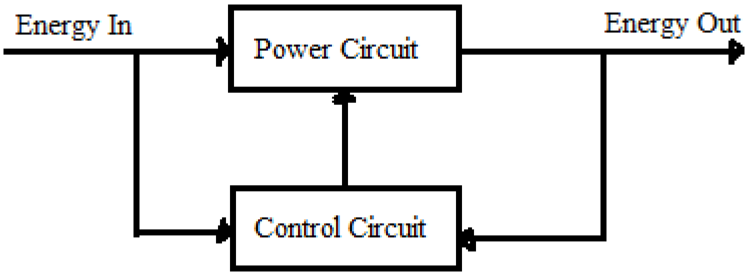


Figure 1.1: Block diagram

The power circuit contains the necessary switches and circuitry to convert the electrical power from one form to another. The controls circuit drives the solid-state devices with necessary logic. In addition to the circuit elements above, there may also be input and output filters to reduce the unwanted high frequency noise. This high frequency noise comes mostly from switching actions that create harmonics to the voltage or current waveforms. This occurs at both the input and output of the circuit. If ignored, these harmonics can interfere with performance and operation of equipment connected at either the source or load.

Power electronics involves four main power conversions. The first is from AC to DC, commonly known as rectification. This supplies power from an AC source to a DC load. It makes use of rectifiers. The next conversion is from DC to AC, called inversion. The inversion is the opposite of a rectifier. Major uses of inverters are for grid-connected solar panels and high-voltage direct current (HVDC) transmission lines. The third conversion is DC to DC. This is a growing field of power conversion today, especially with its applications in consumer electronics and the battery-powered devices. The final conversion is from AC to AC. This is generally used in high power applications, such as transferring power between the power grids as well as driving variable frequency loads such as induction motors synchronous motors etc.

Under AC to AC conversion, there are one-stage and two-stage approaches. In two-stage approach, AC normally at a fixed frequency is first rectified to DC, and then inverted back to AC typically at various frequencies. This method is commonly found in motor drive applications such as the adjustable speed drives (ASD) to control the speed of induction motors etc. The one-stage approach is called the direct method. Here the AC input is switched directly to different AC at varying RMS amplitude and/or frequency. One common application are the light dimmers. At high power level, one application that makes use of the one stage method is the cycloconverter. In a cycloconverter, input may be single or multiphase and the output may be single or multiphase. The output is usually lower in frequency than the input. This thesis focuses on the study of cycloconverter design and its performance.

1.2 Power Electronic Device - Thyristor

A thyristor is a four layer, three junction, p-n-p-n semiconductor switching device. Anode, cathode and gate are the three terminals. Nowadays, thyristors having 10kV voltage rating and 3000A rms current rating with 30MW power handling capacity are present in the market. The advantage of using SCR is that although it is a high power device but it can be switched on by a low voltage supply of 1A and 10W. Thus, SCRs have high power amplification capability.

When anode is positive with respect to cathode, a thyristor can be turned on by any of the following methods: (a) Forward voltage triggering (b) Gate triggering (c) dv/dt triggering (d) temperature triggering (e) light triggering.

(a). Forward voltage triggering : When forward voltage is applied between anode and cathode with gate circuit open, junction J2 is reverse biased and a depletion layer is formed across junction J2. If forward voltage increases, a stage comes when the depletion layer across J2 vanishes. The voltage at which breakdown of junction occurs is called forward breakover voltage V_{BO}.

(b). Gate Triggering: A positive gate current is required for the SCR to start conducting. When current starts flowing from gate to cathode, charges are injected into inner p layer and voltage at which forward breakover occurs is decreased. Higher the gate current, lower is the forward breakover voltage.

(c). dv/dt Triggering: In forward blocking mode, junction J2 has the characterstics of a capacitor due to charges existing across the junction. If forward voltage is suddenly applied, a charging current through junction capacitance Cj may turn on the SCR.

(d). Temperature Triggering: During forward blocking mode, most of the forward applied voltage exists across J2. This raises the temperature of junction J2. With increase in temperature, width of depletion layer decreases. This further leads to more leakage current and therefore, more junction temperature. With the cumulative process, at some high temperature, depletion layer of J2 vanishes and the device gets turned ON.

(e). Light Triggering: A recess is made in the inner p-layer. light is thrown and if the intensity of this light thrown on the recess exceeds a certain value, a forward biased SCR is turned ON.

Once the SCR starts conducting, gate current is not required for the thyristor to remain in conduction. However, if the gate current is reduced to zero before the rising anode current attains a value called the latching current, the thyristor will turn OFF again. In ac circuits with resistive load this happens automatically during negative A.C. supply voltage. This is called “natural commutation” or “line commutation”. However, in DC circuits some external circuitry has to be made to ensure this condition. This process is called “forced commutation”.

1.3 AC to AC Conversion

The major power present is in the form of A.C. Generation, transmission, and distribution networks using AC have dated back to 1800s. As such, AC to AC takes a given AC source and delivers AC power with different amplitude, frequency, or number of phases. For example, high voltage transmission can be converted to low voltage distribution via a step-down transformer. This is a simple way for a magnitude change. However, electricity networks and variable-speed motor drives show that frequency conversion is also necessary.

There are two main approaches to AC-AC power conversion. The first one is the two-stage process called a DC-link converter. The concept is to first use a rectifier to change the input AC to a DC signal. This DC stage will have capacitors and inductors to store energy from the input. This DC stage will then pass and serve as the input to an inverter to produce the AC output signal. Benefits of this approach are the flexibility in output amplitude, frequency, and phase. However, with intermediate filters on the DC bus as well as output filters, the system is larger and more complex.

The second approach to AC-AC conversion is one-stage method such as the cycloconverter. This avoids the intermediate DC bus and switches directly from the input AC signal to create the output AC signal. The benefits of this approach are less filtering complexity and large power capability. However, there is an upper limit to the output frequency which is proportional to the input frequency. One of the first commercially used cycloconverters was developed in 1930. German locomotive engines 5 required a low frequency of 16.6 Hz in order to generate large amounts of torque.

However, the electrical line frequency was 50 Hz. A combination of a transformer and thyristors are used for obtaining the desired output amplitude and frequency. With advances in thyristor technology, cycloconverters are a very efficient and straightforward platform for very high power AC-AC power conversion, typically in excess of 100 kW.

A cycloconverter can be simplified as two converter bridges. One bridge, called the positive converter, supplies AC power to load during the positive half cycle of the output. The second bridge, called the negative converter, supplies power to the load during the negative half cycle of the output. There are two possible mode of operations: circulating current mode and non-circulating current mode. In Circulating current mode, both the converters are operating simultaneously by placing reactors between the bridges. Circulating current maintains current flow across the converter bridges and prevents the output current from becoming discontinuous as a result of switching action.

The more popular mode is the non-circulating current mode. In this case, only one bridge is active at a given time. While one bridge is on, the other is off and vice-versa. Complexity of the circuit reduces by removing the large and heavy reactors. Efficiency is also improved, since the circulating current mode exhibits a power loss from circulating current through the reactors and idle converters.

1.4 Ideal Single Phase to Single Phase Cycloconverter

Cycloconverter is a direct frequency changer and does not require any intermediate DC link. It directly converts ac power from one frequency to another, generally at lower than the input frequency. In the late 1980’s when microprocessors came into light, the usage of cycloconverters became more popular due to the development of microprocessor based control systems [10]-[20]-[21] with thyristors as the power switching devices. It is used in higher power and rating applications such as in electric traction, rolling mills, variable frequency speed control of AC machines, constant frequency power supplies and controllable reactive power supplies for an AC system.

Cycloconverter comes in AC to AC controllers category but also provides variable frequency and are based on SCRs. They are used to generate AC output (single phase or three phase) from a single phase or a three phase input [2]. A cycloconverter is made of one or more pairs of back to back connected controlled rectifiers. The conventional cycloconverter uses two converters called the Positive converter and the Negative converter.

Applications of Cycloconverter:

The cycloconverter may be used in the following systems:

1. Speed Control of the AC motors.
2. To interconnect between two power grids operating at different frequencies.
3. Controlled induction heating.
4. In a variable frequency (speed) input and constant frequency output (VSCF) system, which are suitable for aircraft power supplies. In VSCF system, a rugged, compact and low weightage cycloconverter produces a constant frequency AC voltage from a variable speed alternator.

Advantages and Disadvantages:

A Cycloconverter has the following merits:

1. The thyristor based cycloconverter power circuit is a simple, cheap, rugged, compact and of a low weight because converter grade thyristors are used due to the line commutation is used to commutate thyristors.
2. The control circuit of the cyclo-converter is also simple and cheap.

3 The cycloconverter circuit can operate at any power factor because it has the capability of power flow in either of the direction.

4 Without any intermediate DC link, it changes AC voltage at line frequency into a lower frequency variable AC. So, it is cheaper, lighter and simpler than inverter which requires DC link.

5 The cycloconverter circuit can provide regenerative operation with active loads.

Advantages:

The advantages of cycloconverter are:

1 Cycloconverter functions by means of phase commutation, without auxiliary forced commutation circuits. The power circuit is compact, circuit losses associated with forced commutation are eliminated.

2 Cyclo-converter is inherently capable of power transfer in either direction between source and load. It can supply power to loads at any power factor, and is also capable of regeneration over the complete speed range, down to standstill. This feature makes it preferable for large reversing drives requiring rapid acceleration and deceleration, thus suited for metal rolling application.

3 Commutation failure causes a short circuit of ac supply. But, if an individual fuse blows off, a complete shutdown is not necessary, and cyclo-converter continues even to function with somewhat distorted waveforms. A balanced load is presented to the ac supply with unbalanced output conditions.

4 Cyclo-converter delivers a high quality sinusoidal waveform at low output frequencies, since it is fabricated from a large number of segments of the supply waveform. This is often preferable for very low speed applications.

5 Cyclo-converter is extremely attractive for large power and low speed drives.

Disadvantages:

1 The minimum output frequency is about one-third (1/3) of the input frequency.

2 It cannot provide more than the A.C input frequency.

3 The cycloconverter draws reactive power from the input source so the input power factor is poor.

1.5 Objectives of the Present Work

This project focuses on the following –

1. Design of control and power circuit of the single phase cycloconverter. Analog electronics is the heart of the control strategy used. The proposed design produces a power of about 9W and output frequency equal to one fourth of the input frequency (i.e12.5 Hz).A lamp and a resistance is used as a load.
2. Simulation of control and power circuit of single phase cycloconverter is being carried out in Proteus Isis software.
3. Hardware realization of step down cycloconverter is being carried out in laboratory and is tested under varying operating conditions.

1.6 Outline of the Chapters

This dissertation comprises of six chapters. While the present ongoing introduction and literature review is included in chapter 1, a review of all the past and recent advancement in the field of control of cycloconverter is given in second chapter which will entail the preliminary basics of each control algorithm alongwith their working principles.

Chapter 3 gives a basic insight to the control strategy or technique. Emphasis on the control electronics and power circuit of single phase to single phase cycloconverter is given in the chapter.

Chapter 4 describes the simulation of control and power circuit of the cycloconverter. The simulation of the proposed design is carried out in Proteus Isis software. The chapter shows the simulated results and discussions on the cycloconverter.

Chapter 5 shows the hardware results of both the control circuit and the power circuit step by step. The hardware realization of single phase to single phase cycloconverter is being carried out in Laboratory.

Chapter 6 concludes the dissertation with discussions on the performance of cycloconverter. The future scope of proposed cycloconverter or what other modifications can be done in the design of the proposed circuit to make it commercially useful is discussed.

CHAPTER 2: LITERATURE REVIEW

2.1 General

The most straightforward Cycloconverter is the Single-Phase to Single-phase Cycloconverter takes a single-phase input and converts it to the single phase output with different frequency and magnitude. Figure 2.1 shows schematic of bridge type single-phase to single-phase step down cycloconverter.

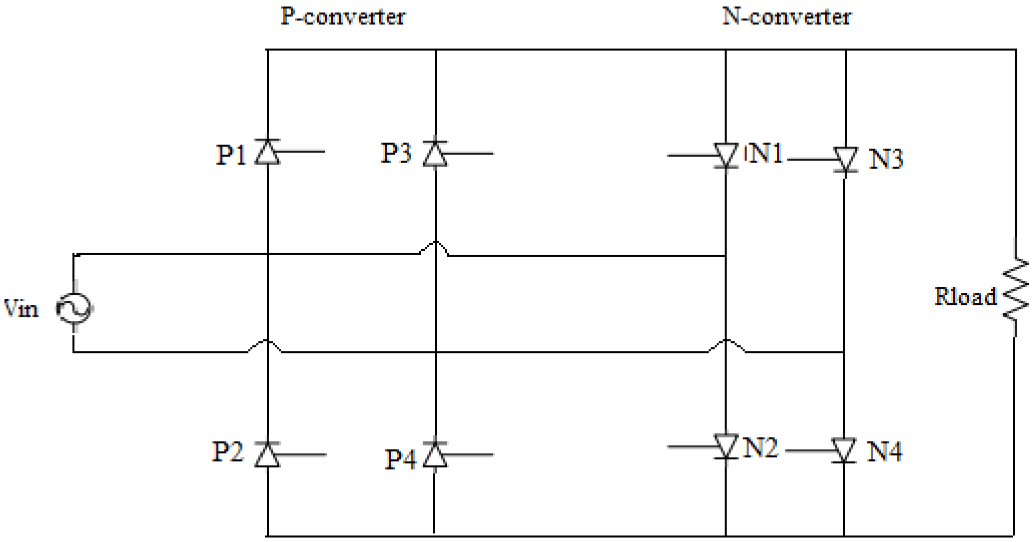


Figure 1.1: Single-phase/single-phase cycloconverter

Assume the input voltage has an arbitrary magnitude, V_m, and frequency, f_i. The phase angle, φ, will be zero for this case. The mathematical representation is shown in (1).

$$V_{in}(t) = \sqrt{2}V_{LN}\sin(2\pi f_i t + \phi) = V_m \sin(2\pi f_i t) = V_m \sin(\theta) \qquad (1)$$

In order to find the voltage at the load, the diode conduction rule is used. The rule states that the most positive anode conducts while the most negative cathode conducts. This means that for every positive half cycle of Vin, switches P1 and P4 will conduct for the positive converter. Switches N3 and N2 will conduct for the negative converter. Similarly, for every negative half cycle of Vin, switches P3 and P2 will be conducting for the positive converter and switches N1 and N4 will be conducting for the negative converter. A summary of switch conduction is shown in Table 1.1 with $\theta = 2\pi f_i t$.

Table 1.1: Switch conduction for Single-Phase/Single-Phase Cycloconverter

Vin	**N-Converter**				**P-Converter**			
Range of θ	N1	N2	N3	N4	P1	P2	P3	P4
$0 < \theta < \pi$	OFF	ON	ON	OFF	ON	OFF	OFF	ON
$\pi < \theta < 2\pi$	ON	OFF	OFF	ON	OFF	ON	ON	OFF

The concept of adjustable output frequency relates to the time duration the converter bridges are on. Only one converter bridge is on at any given time to avoid cross-firing of the switches and creating a short circuit across the source. Given a particular output frequency, the necessary conduction period of each converter can be calculated using the following Equation (2).

$$T_{P-on} = T_{N-on} = \frac{1}{2f_o} \qquad (2)$$

It is important for TP-on to equal TN-on in order to have a net DC voltage across equal to zero. This means that only AC voltage will be transferred to the load. In order to control the magnitude of the output voltage, the firing angle has to be adjusted. The firing angle is defined as the delay angle at which the switch turns on at each conduction interval. In order for this to be achieved, the switch control voltage must be phase-locked onto the input voltage. The firing angle is defined to be zero at local maxima of the input voltage. This gives a possible range of 0 degrees to 180 degrees of firing angle location. At the firing angle location, the switch starts conducting.

Since the switches for cycloconverters are generally thyristors, they will turn off when the anode-cathode voltage is less than zero.

Midpoint Cycloconverter:

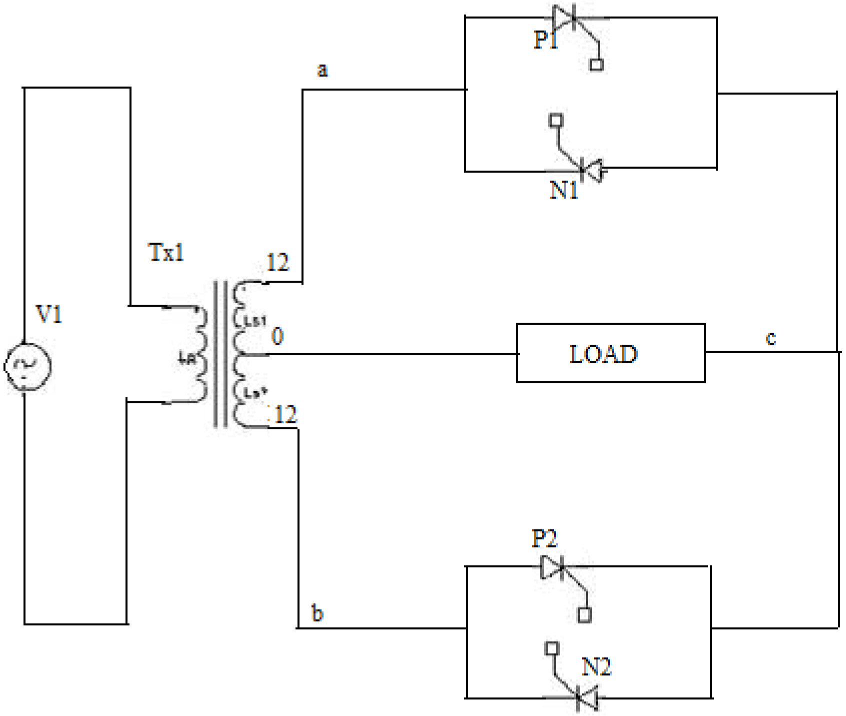


Figure 2.2: Midpoint type single phase step down Cyclo-converter

This type of cycloconverter will be described both for discontinuous as well as continuous load current. The load is now assumed to be R and L in series.

(a)Discontinuous Load Current

When a is positive with respect to O, forward biased SCR P1 is triggered at wt=α. With this, load current io starts building up in the positive direction from A to O. load current io becomes zero at wt=$\beta \geq \prod$ but less than $\prod+\alpha$. thyristor P1 is thus naturally commutated at wt=β which is already reverse biased after $\prod$. After half a cycle b is positive with respect to O. Now forward biased thyristor P2 is triggered at wt$\prod+\alpha$.load current is again positive from A to O and builds up from zero. At wt=$\prod+\beta$, io decays to zero and P2 is naturally commutated. At $2\prod+\alpha$, P1 is again turned on .load current is seen to be discontinuous. After four positive half cycles of output voltage and load current., thyristor N2 (after P2, N2 should be fired) is gated at $4\prod+\alpha$ when O is positive with respect to b. as N2 is forward biased, it starts conducting but load current direction is reversed , i.e. it is now from O to A. after N2 is triggered, load current builds up in the negative direction . in the next half cycle, O is positive with respect to a but before N1 is fired , i_O decays to zero and N2 is naturally commutated. Now when N1 is gated at $(5\prod+\alpha)$, i_O again builds up but it decays to zero before thyristor N2 in sequence is again gated. In this manner, four negative half cycles of output voltage and output current, equal to number of four positive half cycles are obtained. Now P1 is again triggered to fabricate further four positive half cycles of load voltage and so on. For discontinuous load current, natural commutation is achieved, i.e. P1 goes to blocking state before P2 is gated and so on.

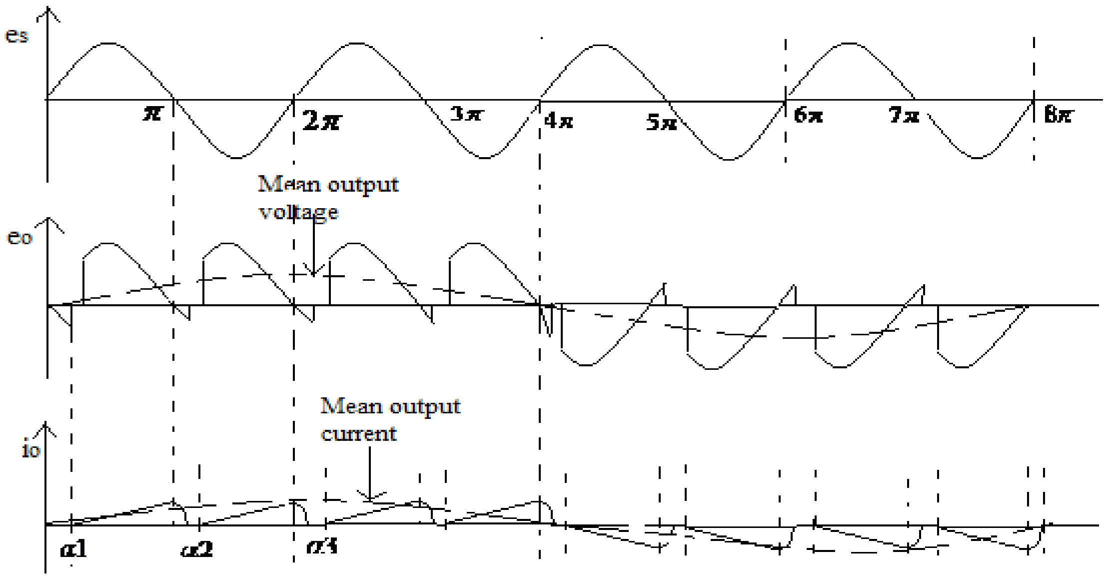


Figure 2.3: Input(a) and output(b) voltage, and current(c) waveforms for a cycloconverter with discontinuous load current

(b) Continuous Load Current

When a is positive with respect to O, P1 is triggered at $wt = \alpha$, positive output voltage appears across load and load current starts building up. At $wt = \prod$, supply and load voltages are zero. After $wt = \prod$, P1 is reverse biased. As load current is continuous, P1 is commutated, load current has built up to a value equal to RR. At $2\prod + \alpha$, when P1 is again turned on, P2 is naturally commutated and load current through P1 builds up beyond RS as shown. At the end of four positive half cycles of output voltage, load current is RU. . when N2 is now triggered after P2, load is subjected to a negative voltage cycle and load current io decreases from positive RU to negative AB (say) as shown. Now N2 is commutated and N1 is gated at $(5\prod + \alpha)$

Load current io becomes more negative than AB at $(6\prod + \alpha)$, this is because with N1 on , load voltage is negative. For four negative half cycles of output voltage, current is as shown. it is seen from load current waveform that io is symmetrical about wt axis. The positive group of voltage group and current wave consists of four pulses and same is true for negative group of wave. One positive group of pulses along with one negative group of identical pulses constitute one cycle for the load voltage and load current. The supply voltage has, however, gone through four cycles. The output frequency is, therefore, fo=1/4 fs.

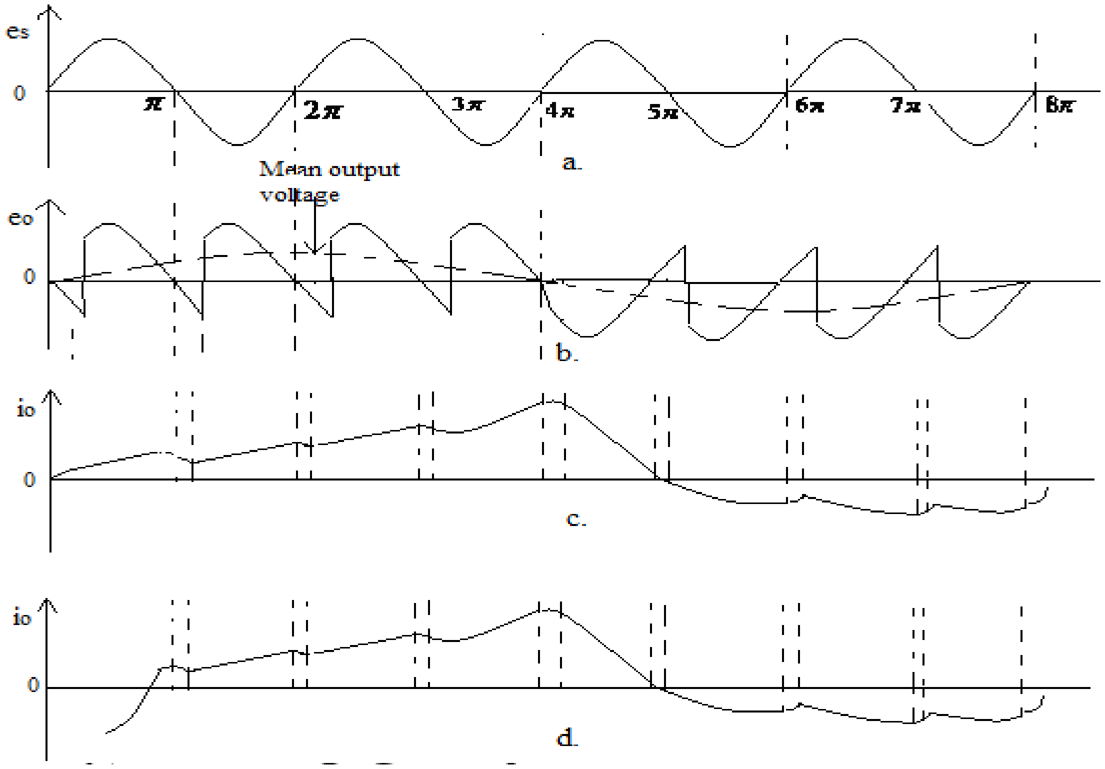


Figure 2.4: Input(a) and output(b) current and voltage (c and d) waveforms for a cycloconverter with continuous load current.

Bridge Type Cycloconverter:

The circuit of a single-phase to single-phase cyclo-converter is shown in Figure 2.4. Two full-wave fully controlled bridge converter circuits, using four thyristors for each bridge, are connected back to back with both bridges being fed from A.C supply having frequency 50 Hz. Positive Bridge 1 supplies load current in the positive half period of the output time period, while negative bridge 2 supplies load current in the negative half. The two bridges should not conduct together as this will produce short-circuit at the input. In this case, two thyristors come in series with each voltage source. When the load current is positive, the firing pulses to the thyristors of bridge 2 are not given, while the thyristors of bridge 1 are triggered by giving pulses at their gates at that time. Similarly, when the load current is negative, the thyristors of bridge 2 are triggered by giving the pulses at their gates, while the firing pulses to the thyristors of bridge 1 are not given at that time. This is the circulating-current free mode of operation. Thus, firing angle control scheme must be such that only one of the converter conduct at a time, and the change over of the firing pulses from one converter to other, should be periodic according to the output frequency. However, the firing angles the thyristors in both converters should be same to produce a symmetrical output.

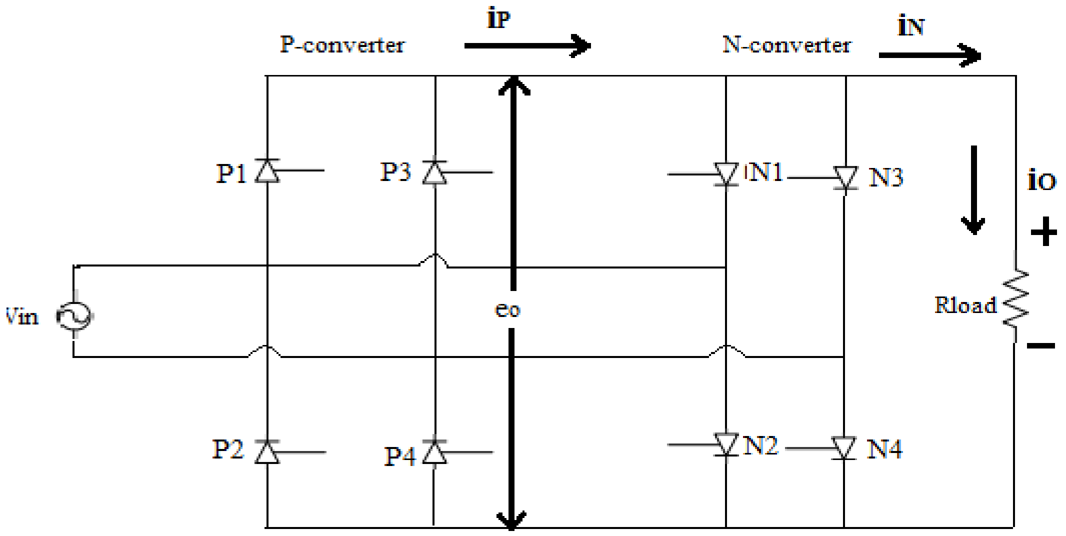


Figure 2.5: Single-Phase to Single-Phase Cyclo-converter (using thyristor bridges)

In circulating current mode, a circulating current limiting reactor is connected between the positive and negative converters, as is the case with dual converter, i.e. two fully controlled bridge converters connected back to back, in circulating-current mode. The circulating current by itself keeps both converters in virtually continuous conduction over the complete control range. This type of operation is termed as the circulating-current mode of operation.

Resistive (R) Load: For this load, the instantaneous load current goes to zero, as the input voltage at the end of each half cycle reaches zero. Thus, the conducting thyristor pair in one of the bridges turns off at that time, i.e. the thyristors undergo natural commutation. So, operation with discontinuous current in figure 2.2 takes place, as current flows in the load, only when the next thyristor pair in that bridge is triggered, or pulses are fed at respective gates. Taking positive bridge 1, and assuming the top point of the ac supply as positive with the bottom point as negative in the positive half cycle of ac input, the odd-numbered thyristor pair, P1 & P3 is triggered after phase delay , such that current starts flowing through the load in this half cycle. In the next negative half cycle, the other thyristor pair (even-numbered), P2 & P4 in that bridge conducts, by triggering them after suitable phase delay from the start of the zero-crossing. The current flows through the load in the same direction, with the output voltage also remaining positive. This process continues for one more half cycle, making a total of three of input voltage with f1=50 Hz. From three waveforms, one combined positive half cycle of output voltage is produced across the load resistance, with its frequency being one-third of input frequency with f2=16 2/3Hz. The following points may be noted. The firing angle (α) of the converter is first decreased, in this case for second cycle only, and then again increased in the next third cycle, as shown in Figure 2.2. This is, because only three cycles for each half cycle is used. If the output frequency needed is lower, the number of cycles is to be increased, with the firing angle decreasing for some of cycles, and then again increasing in the subsequent cycles, as described earlier.

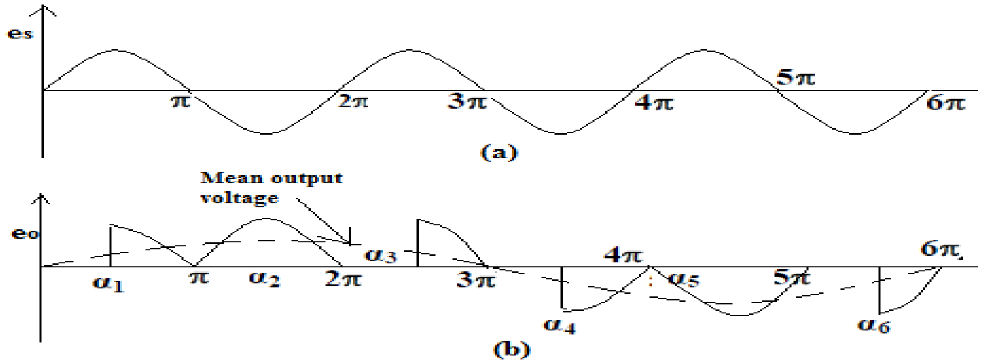


Figure 2.6: Input(a) and output(b) voltage waveforms of a cycloconverter with an output frequency of 16 2/3 Hz for resistive (R) load.

To obtain negative output voltage, in the next three half cycles of input voltage, bridge 2 is used. Following same logic, if the bottom point of the ac supply is taken as positive with the top point as negative in the negative half of ac input, the odd-numbered thyristor pair, N1 & N3 conducts, by triggering them after suitable phase delay from the zero-crossing. Similarly, the even-numbered thyristor pair, N2 & N4 conducts in the next half cycle. Both the output voltage and current are now negative. As in the previous case, the above process also continues for three consecutive half cycles of input voltage. From three waveforms, one combined negative half cycle of output voltage is produced, having same frequency as given earlier. The pattern of firing angle is first decreasing and the increasing, is also followed in the negative half cycle. One positive half cycle, along with one negative half cycle, constitute one complete cycle of output load voltage waveform, its frequency being 16 2/3Hz as stated earlier. The ripple frequency of the output voltage/ current for single–phase full-wave converter is 100 Hz, i.e., double of the input frequency. It may be noted that the load output current is discontinuous (Figure 2.2 (c)), as also load (output) voltage (Figure 2.2(b)). The supply input voltage is shown in Figure 2.2(a). Only one of two thyristor bridge conducts at a time, giving non-circulating current mode of operation in this circuit.

Inductive (R-L) Load: For this load, the load current may be continuous or discontinuous depending on the firing angle and load power factor. The load voltage and current waveforms are shown for continuous and discontinuous load current in Figure 2.3 and 2.2 respectively.

(a) <u>Discontinuous Load Current:</u>

The load current in this case is discontinuous, as the inductance, L in series with the resistance, R, is low. This is somewhat similar to the previous case, but difference also exists as described. Here, also non-circulating mode of operation takes place, with only one of the bridges positive, or negative, conducting at a time, but two bridges do not conduct at the same time, as this will result in a short circuit. In this case, the output frequency is assumed as (12.5 Hz), the input frequency being same as (50 Hz), i.e. So, four positive half cycles, or two full cycles of the input to the full-wave bridge converter (#1), are required to produce one positive half cycle of the output waveform, as the output frequency is one-fourth of the input frequency as given earlier. As in the previous case with resistive load, taking bridge 1, and assuming the top point of the ac supply as positive, in the positive half cycle of ac input, the odd-numbered thyristor pair, P1 & P3, is triggered after phase delay($\theta = \omega t = \alpha 1$), such that current starts flowing the inductive load in this half cycle. But here, the current flows even after the input voltage has reversed (after $\theta = \prod$), till it reaches zero at ($\theta = \beta 1$) with $(\prod + \alpha 2) > \beta 1 > \prod$, due to inductance being present in series with resistance, its value being low. It may be noted that the thyristor pair is, thus, naturally commutated. In the next (negative) half cycle, the other thyristor pair (even-numbered), P2 & P4, is triggered at ($\prod + \alpha 2$). The current flows through the load in the same direction, with the output voltage also remaining positive. The current goes to zero at ($\prod + \beta 2$), with $(\prod + \alpha 3) > \beta 2 > \prod$. This procedure continues for the next two half cycles, making a total of four positive half cycles. From these four waveforms, one combined positive half cycle of output voltage is produced across the inductive load. The firing angle (á) of the converter is first decreased, in this case for second half cycle only, kept nearly same in the third one, and finally increased in the last (fourth) one, as shown in Figure 2.2.

To obtain negative output voltage, in the next four half cycles of output voltage, bridge 2 is used. Following same logic, if the bottom point of the ac supply is taken as positive in the negative half of ac input, the odd-numbered thyristor pair, N1 & N3 conducts, by triggering them after phase delay ($\theta = 4.\prod + \alpha 1$). The current flows now in the opposite (negative) direction through the inductive load, with the output voltage being also negative. The current goes to zero at ($4.\prod + \beta 1$), due to load being inductive as given earlier. Similarly, the even-numbered thyristor pair, N2 & N4 conducts in the next half cycle, after they are triggered at ($5\prod + \alpha 2$). The current goes to zero at ($5.\prod + \beta 2$). Both the output voltage and current are now negative. As in the previous case, the above process also continues for two more half cycles of input voltage, making a total of four. From these four waveforms, one combined negative half cycle of output voltage is produced with same output frequency. The pattern of firing angle − first decreasing and then increasing, is also followed in the negative half cycle. It may be noted that the load (output) current is discontinuous (Figure 2.2(c)), as also load (output) voltage (Figure 2.2(b)). The supply (input) voltage is shown in Figure 2.2(a). One positive half cycle, along with one negative half cycle, constitute one complete cycle of output (load) voltage waveform, its frequency being 12.5 Hz as stated earlier. The ripple frequency remains also same at 100 Hz, with the ripple in load current being filtered by the inductance present in the load.

(b) Continuous Load Current:

As given above, the load current is discontinuous, as the inductance of the load is low. If the inductance is increased, the current will be continuous. Most of the points given earlier are applicable to this case, as described. To repeat, non-circulating mode of operation is used, i.e., only one of the bridges 1 positive and negative, conducts at a time, but two bridges do not conduct at the same time, as this will result in a short circuit. Also, the ripple frequency in the voltage and current waveforms remains the same at 100 Hz. The output frequency is one-fourth of input frequency (50 Hz), i.e., 12.5 Hz. So, for each half-cycle of output voltage waveform, four half cycles of input supply are required. Taking bridge 1, and assuming the top point of the ac supply as positive, in the positive half cycle of ac input, the odd-numbered thyristor pair, P_1 & P_3, is triggered after phase delay ($\theta = \omega t = \alpha 1$), such that current starts flowing the inductive load in this half cycle. But here, the current flows for about one complete half cycle, i.e., up to the angle, ($\prod + \alpha 1$) or ($2\prod + \alpha$), whichever is higher, even after the input voltage has reversed, due to the high value of load inductance. In the next (negative) half cycle, the other thyristor pair (even-numbered), P2 & P4, is triggered at ($\prod + \alpha 2$). At that time, reverse voltage is applied across each of the conducting thyristors, P1/P3, and the thyristors turn off. The current flows through the load in the same direction, with the output voltage also remaining positive. Also, the current flows for about one complete half cycle, i.e., up to the angle, ($\prod + \alpha 2$) or ($\prod + \alpha 3$), whichever is higher. This procedure continues for the next two half cycles, making a total of four positive half cycles. From these four waveforms, one combined positive half cycle of output voltage is produced across the inductive load. The firing angle (α) of the converter is first decreased, in this case for second half cycle only, kept nearly same in the third one, and finally increased in the last fourth cycle, as shown in Figure 2.3.

To obtain negative output voltage, in the next four half cycles of output voltage, bridge 2 is used. Following same logic, if the bottom point of the ac supply is taken as positive in the negative half of ac input, the odd-numbered thyristor pair, N1 & N3 conducts, by triggering them after phase delay ($\theta = \omega t = \alpha 1$). The current flows now in the opposite (negative) direction through the inductive load, with the output voltage being also negative. The current flows for about one complete half cycle, i.e., up to the angle, ($5.\prod + \alpha 1$) or ($5\prod + \alpha 2$), whichever is higher, as the load is inductive. Similarly, the even-numbered thyristor pair, N_2 & N_4 conducts in the next half cycle, after they are triggered at (25απ+·). As described earlier, both the conducting thyristors turn off, as reverse voltage is applied across each of them. Both the output voltage and current are now negative. Also, the current flows for about one complete half cycle, i.e. up to the angle, ($5.\prod + \alpha 2$) or

$(5.\prod+\alpha 3)$, whichever is higher. As in the previous case, the above process also continues for two more half cycles of input voltage, making a total of four. From these four waveforms, one combined negative half cycle of output voltage is produced with same output frequency of 12.5 Hz. The pattern of firing angle − first decreasing and then increasing, is also followed in the negative half cycle. It may be observed that the load (output) current is continuous (Figure 2.3(c)), as also load (output) voltage (Figure 2.3(b)). The load (output) current is redrawn in Figure 2.3(d), under steady state condition, while the supply (input) voltage is shown in Figure 2.3(a). One positive half cycle, along with one negative half cycle, constitute one complete cycle of output (load) voltage waveform.

2.2 Analytical Analysis of Processes in Cycloconverter

Analysis of steady state and transient processes in single phase cycloconverter, which are widely applied in industrial electronics and which are nonlinear, periodic structures is being done in [27]. The z-transform is used to derive the equation governing the cycloconverter’s current. Difference linear equation describing nonlinear processes in cycloconverters are found in [27].

2.3 Advancements in the Control Algorithms of Cycloconverter

Various alternative solutions for phase conversion are available. The control strategy must be choosen such that it has the advantage of simple structure and reasonably low cost.

When the input supply is single phase and output is not single phase, then there are two versions [23]. The first version is single phase to two phase cycloconverter [19] which employs a two phase motor with balanced starting and running windings. By using a double integral method [24], the motor flux linkage follows a sinusoidal reference and the motor speed ripple is low [19]. The second version is a single phase to three phase cycloconverter motor drive [25]. The advantage of this double integral control is to obtain sinusoidal motor flux linkage, no subharmonics in output voltage and ability to operate with discontinuous current [24]-[25]. Simulation, harmonic analysis and external performance of a single phase to two phase and single phase to three phase cycloconverter with the same motor is carried out in detail in [23].

AC is available in any phase. Sometimes the load requirement is different from supply present . Three phase induction motor, commonly used load in industries, can be operated from a single phase supply via cycloconverter using discrete hopping frequency technique based on open loop VVVF and VVCF control [26]. It has three operating modes. One of the strategy presents a simple converter topology for driving a three phase induction motor with a single phase ac supply. This uses only two active switches and a Triac, the converter can start the motor with high starting torque and low input current and can bring the motor up to full speed using very cost effective, single phase field oriented control strategy. The converter of [22] supplies balanced output voltages at rated frequency with virtually no output distortion and with very high input power factor.

Above system fits the requirements of large variety of single motor loads such as fans, pumps, or conveyers which may need a large operating torque to break friction yet allow moderate torque to bring the speed to rated value and stay at the rated speed for most of the operating time [14].

Another strategy is demonstrated for a single phase to three phase cycloconverter system in [15]. Single phase to three phase cycloconverter driven induction motor are ideal for use in single phase traction system [2]. It has been observed that for low and medium L/R loads, the constant firing angle method works well but for a highly inductive load it results in direct short circuit of supply voltage due to simultaneous triggering of SCRs in opposite groups, thus leading to undesirable output waveform and high short circuit circulating current [1]. Therefore, cosine wave crossing method is used. The CWCM works well for high L/R in reducing the short circuit occurrences and at the same time helps to reduce the harmonics in the load voltage waveform [15].

As more electronic controllers are used in variable speed drives, their harmonic impact on the power system has been of concern [7]-[17]. Such electronic controllers should not adversely effect the performance of other equipments connected to the supply network. Cycloconverter is one of the electronic controller that brings harmonics into the system. Delta modulated switching is employed for cycloconverter for harmonic reduction in output voltage. The conventional methods of filter [29] cannot be used for reduction of harmonics either in cycloconverter as the output frequency is varying and using tuned filter for each harmonics is not feasible. Various modulation techniques are employed to improve quality of load voltage [11]. Delta modulation [6] has become an estabalished alternative to sine PWM for offering a sinusoidal output with low frequency harmonic contents. The delta modulator is presented in [6].

An another topology for step down cycloconverter operation based on single phase matrix converter (SPMC) is used with the well known sinusoidal pulse width modulation

(SPWM) scheme [31]. The matrix converter is AC to AC converter offers possible solution for AC to AC conversion removing the need for reactive energy storage components used in conventional rectifier-inverter based system [3]. SPMC topology can be implemented as a rectifier, inverter, buck converter, boost converter, chopper and cycloconverter due to symmetrical bidirectional capabilities of IGBTs used [31].

A new single phase to single phase to single phase Z-source cycloconverter (SPZC) based on single phase matrix converter (SPMC) topology is proposed in [33]. The proposed SPZC can boost to a desired voltage with various frequency in which output frequency is an integer fraction of input frequency. It employs a Z-network bidirectional switches having two inductors and two capacitors and R-L load.

An another control strategy for single phase Matrix converter (SPMC) operating as a cycloconverter based on FPGA design is carried out in [30]. The control electronics comprises of a computer, a phase detector, isolated gate drivers and a Xilinx FPGA at the heart of its digital control. FPGA could be effectively used in SPMC with four bidirectional switching arrangements. It produces switching patterns for SPMC operating as cycloconverter. Within the Xilinx is the major components ;(a) desired frequency (b) switch selector unit (SSU) (c) Commutation switch selector (CSS). The overall system is compact with no external memory system required.

Nowadays, several attempts have been made to develop microprocessor based control strategies for controlling a cycloconverter [4]-[8].

2.4 Conclusions

The Chapter firstly describes in general the Single Phase to Single Phase Cycloconverter Configurations with continuous and discontinuous load current. Various control strategies for designing the cycloconverters for single as well as three phase systems are reviewed. The past as well as recent control topologies have been discussed.

CHAPTER 3: Design of Cycloconverter

3.1 General

The design is divided into three sections (a) Control Technique (b) Interfacing Circuit (c) Power Circuit. The control technique is to generate the firing pulses in a sequence and then give these to the gates of the positive and negative converters of thyristors so as to generate a desired output load voltage across a resistive load. The firing pulses are at low voltage levels and are not given directly to the SCRs in the power circuit. Optoisolators isolates the control circuit and the power circuit. The same sinusoidal A.C supply is used for the control circuit as well as power circuit for synchronization purpose. The control strategy is described in the ongoing chapter.

The synchronization is very important and it is achieved by the use of the operational amplifier (OPAMP 741).

3.2 Detailed Block Diagram of Cycloconverter

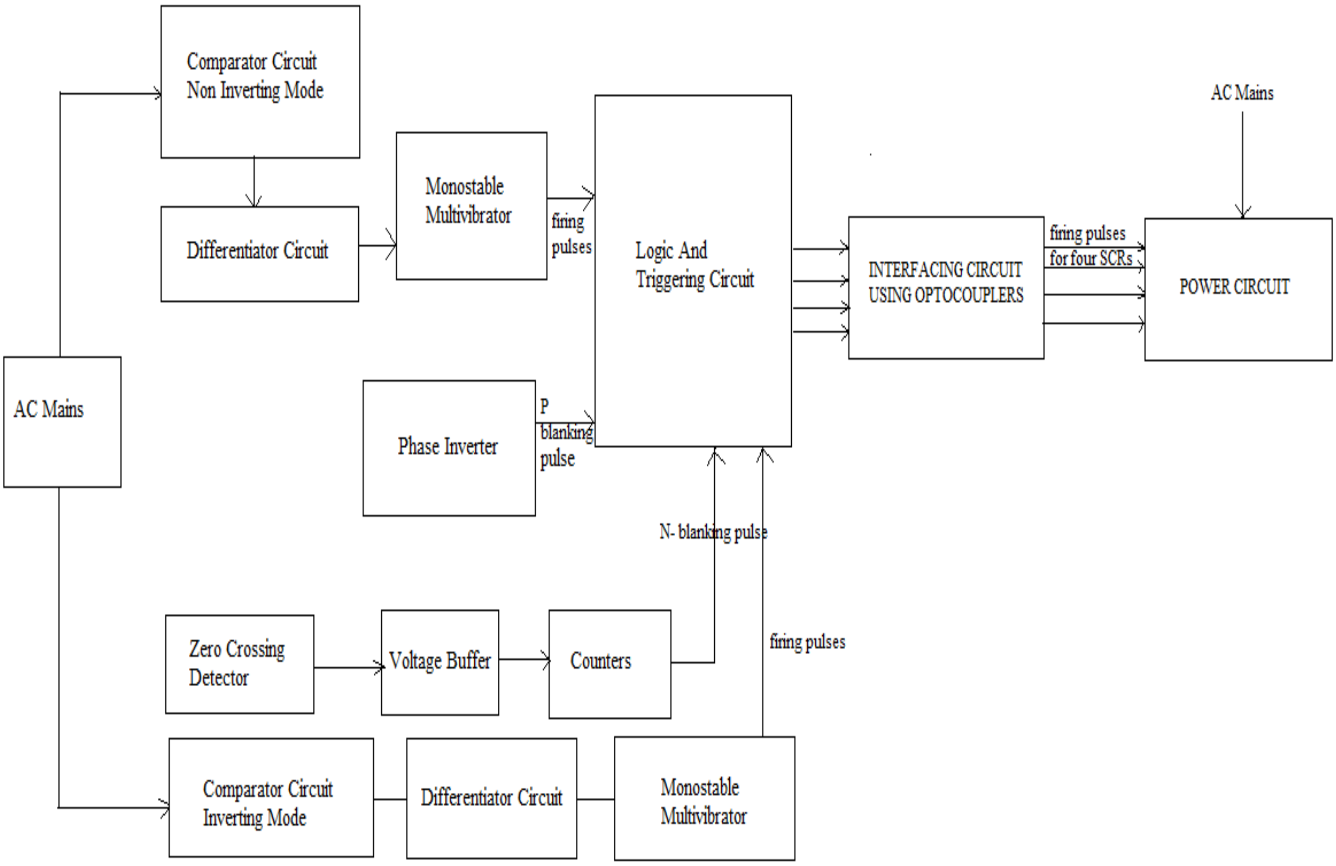


Figure 3.1: Detailed Block Diagram

In the block diagram 3.1, a comparator circuit in inverting and non-inverting mode is used that produces a full square wave output whose magnitude is limited to about +Vsat and –Vsat. The spikes are created using differentiator circuit. The positive spike triggers the transistor in the monostable multivibrator circuit. For non-inverting mode, we obtain short duration pulses on every positive half cycle of input supply mains. These pulses are used to fire the SCRs P1 and N2.

For the inverting mode, we obtain short duration pulses from the monostable multivibrator circuit on every negative half cycle of input supply. These pulses are used to fire the SCRs P2 and N1.

In figure 3.1, zero crossing detector produces a square wave whose output magnitude is limited to + 5V and -5V because of zener diodes with zener breakdown voltage of 5 Volts. This output is sent to the negative clipper where the negative going wave is clipped OFF. The square pulse is sent to JK flip flop where the input signal having frequency equal to 50 Hz is divided by four to obtain a pulse having frequency equal to 12.5 Hz. Hence, a blanking pulse of frequency 12.5 Hz is obtained and is phase inverted to obtain another blanking pulse of frequency 12.5 Hz.

Both these blanking pulses along with the MMV outputs are sent to logic and triggering circuit. The firing pulses for firing the SCRs P1, P2, N1 and N2 are obtained as shown in figure 3.1. These four pulses obtained from logic or converter selection circuit can never be given to SCRs in the power circuit directly so they are being passed to optocouplers in the interfacing circuit for isolation. These pulses are then given to the SCRs in the power circuit to obtain the desired output voltage. The control strategy used to produce firing pulses is discussed next with the necessary circuits.

3.2.1 Generation of Blanking Pulses

For converter group selection, two blanking pulses are required. The following sequence of circuits is employed to create blanking pulses of frequency one fourth of the input frequency, i.e. 12.5 Hz. The proposed circuits are described below:

3.2.1.1 Zero Crossing Detector

Without negative feedback, an op-amp acts as a comparator. Here, the non inverting input is held at ground (0V), and the input voltage Vin is applied to the inverting input; here zener diode of 5.1V is included so that output will be +5.1V, if Vin is negative; if Vin is positive, the output will be maximum negative. The circuit is shown in Figure 3.2.

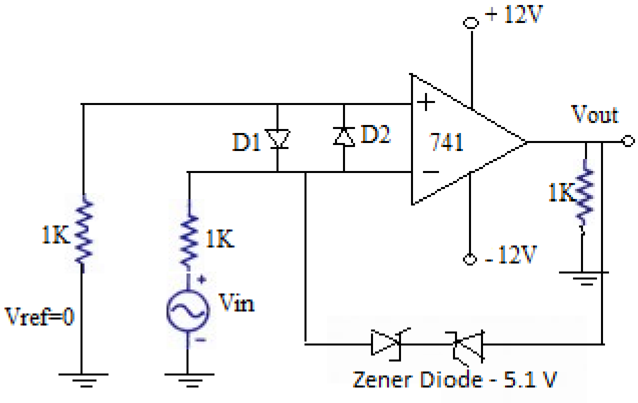


Figure 3.2: Zero Crossing Detector with Voltage Limiter Zener Diodes

Here, zener diodes are used so that the output voltage will not go to +Vsat and –Vsat. Instead, they will go upto +5.1V and -5.1V so that the voltages are limited.

3.2.1.2 Voltage Buffer:

Voltage Follower or Voltage Buffer is used to isolate an input signal by using an op-amp circuit with the input signal fed to the non-inverting terminal of the op-amp. The gain of a voltage follower or unit gain voltage buffer is one. ie, the exact input is given across the load in a voltage follower circuit without change in phase and polarity of the input signal at the non-inverting terminal of the op-amp.

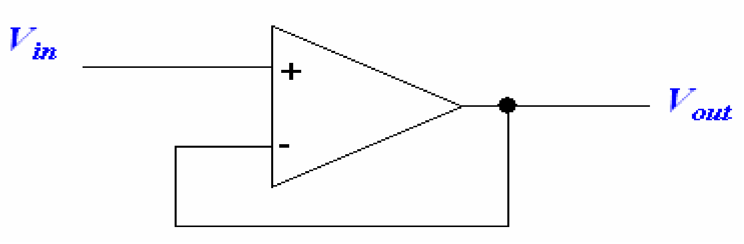


Figure 3.3: Voltage Buffer Circuit

3.2.1.3 Transistor as a Phase Inverter:

Transistor as a phase inverter: The output signal (voltage) is the inverse of the input signal. The input signal is a square wave with +5.1V during the negative half cycle and -5.1V during the positive half cycle and the output is +5.1V during the positive half cycle and -5.1V during the negative half cycle. The circuit employed is shown in figure 3.4.

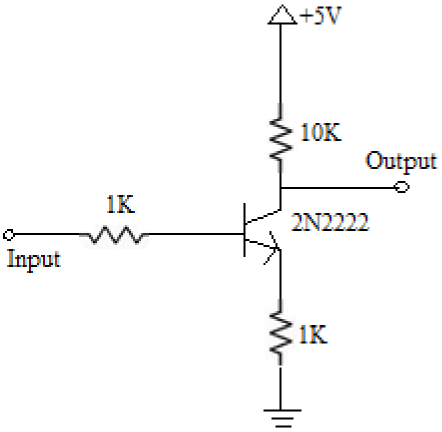


Figure 3.4: Transistor as a Phase Inverter

3.2.1.4 Negative Clipper:

The diode acts as a closed switch for a negative input voltage and as an open switch for a positive input voltage. The value of R is 10K ohms. The diode has 0.7V barrier potential. So, here we get a +5.1V during the positive half cycle and the negative wave is clipped out. The negative clipper is shown in Figure 3.5.

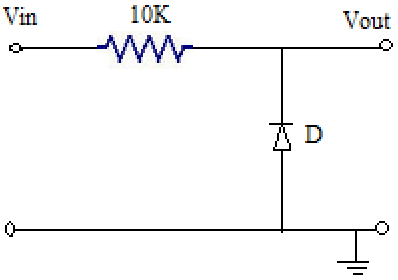


Figure 3.5: Negative Clipper

3.2.1.5 Divide By Four Counter:

This employs dual positive edge triggered JK flip flop IC 74109. These devices contain two independent J-K positive edge triggered flip flops. As these are active low, a high input is given to them and whatever the data at JK inputs are transferred to the outputs on the positive going edge of the clock pulse according to the truth table.

The input is a square pulse of frequency 50Hz and the output is a square pulse of frequency 12.5 Hz. The output of the JK flip flop is inverted with the help of a single transistor. Therefore two blanking pulses are obtained of 50/4 frequency.

3.2.2 Generation of Firing Pulses

3.2.2.1 Zero Crossing Detector in Non-Inverting Mode:

Zero crossing detector in non-inverting comparator mode: The AC input is given to non-inverting input of op-amp and inverting input is grounded. Without negative feedback, the output is a square wave, +Vsat for positive half cycle and –Vsat for negative half cycle.

3.2.2.2 Zero Crossing Detector in Inverting Mode:

Zero crossing detector in inverting comparator mode: The AC input is given to inverting input of op-amp and non-non inverting input is grounded. The output +Vsat is obtained for negative half cycle and –Vsat for positive half cycle of input AC mains. The square wave is synchronized with the input mains.

The above generated square waveforms are not used for triggering the thyristor because huge power dissipation would be there and the negative pulses will trigger the thyristor which is not required. So these are applied to differentiator circuit

3.2.2.3 Differentiator Circuit in Non-Inverting Mode:

The output of non-inverting comparator mode ZCD is given as an input to the differentiator. It produces narrow spikes, positive spike during positive half cycle and negative spike for the negative half cycle.

3.2.2.4 Differentiator circuit in Inverting Mode:

The output of inverting mode ZCD is given as an input to the differentiator. It produces positive spike during negative half cycle and a negative spike during the positive half cycle of input AC mains. This positive spike is used to trigger the transistor in the monostable multivibrator circuit. The differentiator circuit is shown in Figure 3.6.

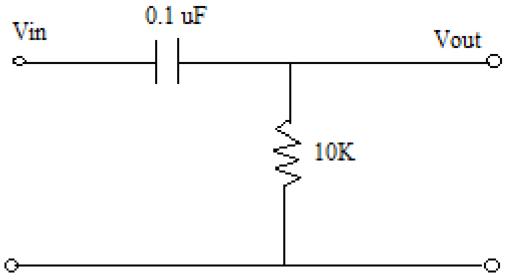


Figure 3.6 : Differentiator Circuit

3.2.2.5 Monostable Multivibrator:

Monostable multivibrator as the name states has only one stable state which is low. The moment the triggering spike is applied, the state changes to high and remins high for a duration equal to the RC time constant. The frequency of the output pulse is therefore, half of the triggering spikes.

The operation of monostable multivibrator is as described under. When the positive spike appears at the base of transistor T1, then transistor T1 turns ON. Its collector current rises and the collector to emitter voltage decreases and attains a low value. The transistor T1 is in conduction state. Since the voltage across the capacitor cannot change instantaneously, the whole abrupt change appears at the base of the transistor T2 and thus, it remains at cut OFF. Its collector current attains a low value and collector to emitter voltage becomes high. The output will remain in High state until the next positive trigger spike appears. Rf is the feedback resistor which provides the regenerative action. Thus, when transistor T1 is in saturation mode then the transistor T2 is in cut OFF mode and vice versa. The value of resistance R and capacitance C is choosen in such a way that the RC time constant is more than the turn ON time of SCR.

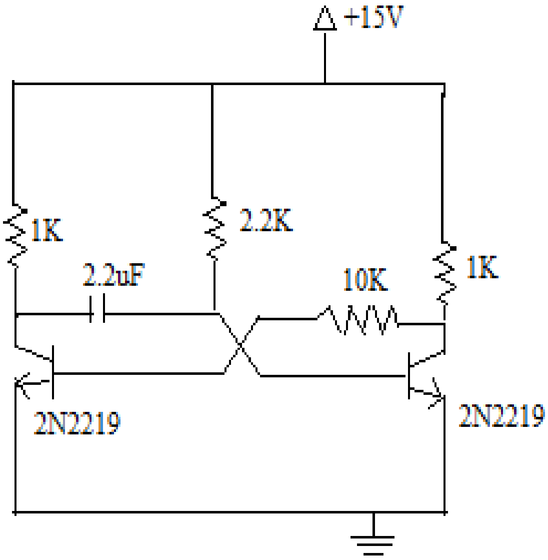
As we know the turn On time of SCR is

Generally the turn on time of the thyristor lies in the range of 200-500 usec. The values of R and C are 2.2K ohm and 2.2uF respectively.

The time period, T of monostable multivibrator is given :

$$T = 0.33 \times R \times C$$

The transistors (T1, T2) taken are 2N2219A. So, by sending the output of the differentiator circuit to the monostable multivibrator circuit, a positive pulse of duration sufficient enough to turn ON the SCR is obtained. The monostable multivibrator and its output is shown in the Figure 3.7 and 3.8.



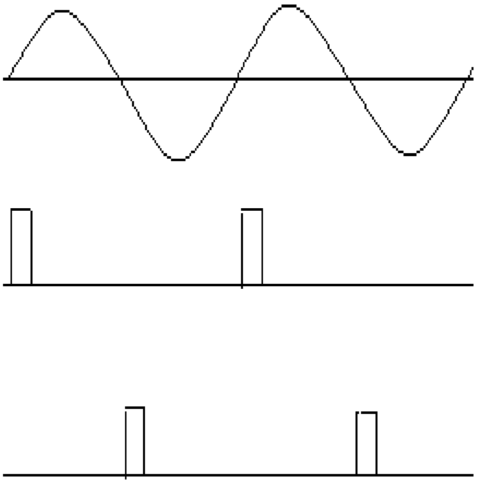


Figure 3.7: MMV Circuit

Figure3.8:MMV Output in inverting and noninverting mode

3.2.2.6 CONVERTER SELECTION

1. The P and N blanking pulses which are generated are used for P and N converter selection.

2. These blanking pulses are ANDed with the two firing pulses obtained from the comparator circuit using 741 op-amp in inverting and non-inverting configuration.

3. The P blanking pulse is ANDed with the MMV output obtained from the comparator circuit in non-inverting mode to obtain the firing pulse for the P1 scr.

4. The P- blanking pulse is ANDed with the MMV output obtained from the comparator circuit using 741 in inverting mode to obtain the firing pulse for the P2 scr.

5. The N- blanking pulse is ANDed with the MMV output obtained from the comparator circuit using 741 op-amp in non-inverting mode to obtain the firing pulse for the N1 scr.

6. The N-blanking pulse is ANDed with the MMV output obtained from the comparator circuit using 741 op-amp in inverting mode to obtain the firing pulse for the N2 scr.

The four firing pulses are obtained and are given to the four SCRs P1, N1, P2 and N2 after passing through an optocouplers. MOC 3052 optocoupler is used to isolate the low voltage control signals from high voltage power supply.

3.2.3 Interfacing Circuit

The four pulses obtained from logic or converter selection circuit can never be given to the SCRs in the power circuit directly to fire them as these pulses are generated from the control circuit which consists of op-amps, diodes, transistors and ICs like 555 and logic gate ICs like 7404, 7408 etc. These components work at low voltages.

If there would not be isolation between the control circuit and power circuit then the high voltages will damage the control circuit that works on low voltages.

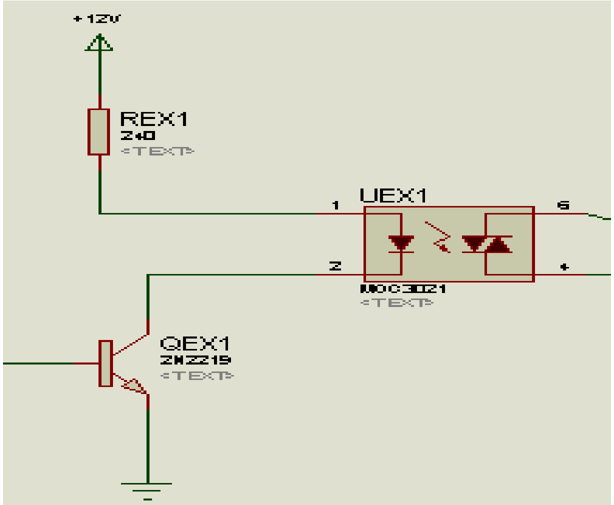
The isolation is provided by an optoisolator MOC3021. It consists of a light emitting diode, or laser diode for transmitting the signal and at the receiving end a photosensor is there for receiving the signal. The receiver converts the light signal to an electrical signal. The input signal is exactly regenerated at the output.

Four separate interfacing circuits are required for the firing of four SCRs. One separate interfacing circuit is shown in figure 3.9. This circuit has one transistor, one optocouplers, resistances and a diode. When the pulse is applied, then the SCR gets fired. The operation is as follows. During the pulse turn on period i.e during the pulse width, the transistor in the figure gets turned ON and due to the DC source +Vcc=12V, LED gets turned ON. A path is formed and current flows through +Vcc, LED, transitor and ground .

In figure 3.9, when the applied pulse is high, the transistor goes in saturation state, the collector to emitter voltage goes to zero. Current flows in the path containing source, resistance, LED and ground. LED emits the light. The emitted light falls on the triac and it turns ON. Now, there is a path where the gate current can flow and turns ON the SCR while it is forward biased.

When the pulse is low, no light is emitted and the gate current does not flow and SCR will not get turned ON, no matter SCR is forward biased or not .Say if the SCR is forward biased, SCR will not get turned ON because there is no current flowing from gate to cathode.

SCR will even not conduct when the pulse is applied and SCR is reverse biased by the negative half cycle of the output.



To Anode of SCR

To gate of SCR

Figure 3.9: One Separate SCR firing Circuit using Opto-Coupler

3.2.4 Power Circuit

The power circuit of cycloconverter contains a positive converter having two SCRs and a negative converter having two SCRs. The thyristors of positive group are turned ON when the positive half cycle of input A.C is applied. Similarly, the thyristors of negative group are turned ON when the negative half cycle of input A.C is applied. The control circuit provides the required triggering pulses and the proper synchronization of signal produced by the control circuit and the desired output voltage waveform produced by the power circuit. The single phase cycloconverter is shown as below:

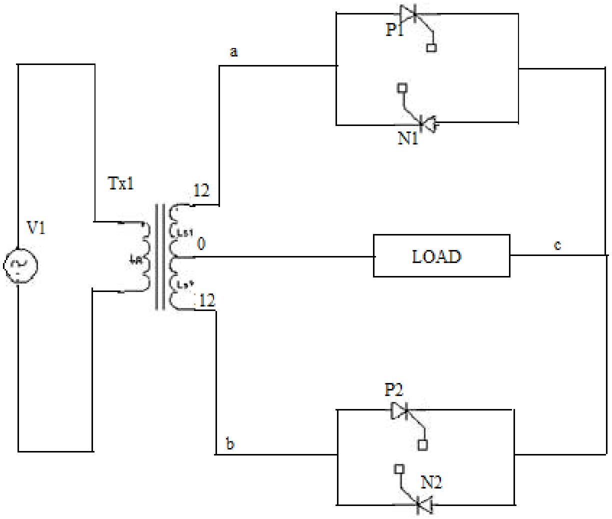


Figure 3.10 Single Phase Cycloconverter

By referring to the figure 3.10 and 3.11 during the positive half cycle, SCR P1 and N2 is forward biased but the firing pulse is applied to SCR P1 so which turns it on and load current from C to O and Vout = Vs = Vmsinwt. During negative half cycle of first cycle, SCR P2 and N1 are forward biased but the firing pulse is applied to SCR P1 turns it on and load current flows from C to O and Vout = Vs. Similarly during the positive half cycle of second cycle, SCR P1 and N2 are forward biased but firing pulse is applied to SCR P1 turns it on and load current flows from C to O and Vout = Vs. During the negative half cycle of second input cycle, SCR P2 and N1 are forward biased but the firing pulse is applied to SCR P2 turns it on and load current flows from C to O and Vout = -Vs.

During the positive half cycle of third input cycle, SCR P1 and N2 are forward biased but the firing pulse is applied to N2 due to N- blanking pulse present thereforeN2 turns on and load current now flows from O to C which is negative and negative half cycle is reproduced. During the negative half cycle of third Input cycle, SCR P2 and N1 are forward biased but the firing pulse is applied to N1 due to N- blanking pulse present therefore, N1 turns on and load current now flows from O to C which is negative and negative half cycle is obtained during that period. During the positive half cycle of fourth input cycle, SCR P1 and N2 are forward biased, but the firing pulse is applied to N2 due to N- blanking pulse present therefore, N2 turns on and load current now flows from O to C which is negative and negative half cycle is obtained during that period. During the negative half cycle of the fourth input cycle , SCR P2 and N1 are forward biased but the firing pulse is applied to N1 due to N- blanking pulse present, therefore N1 turns on and load current is negative. the input supply waveform along with the two blanking pulses P and N and the final output voltage wave form are shown in the figure 3.11.

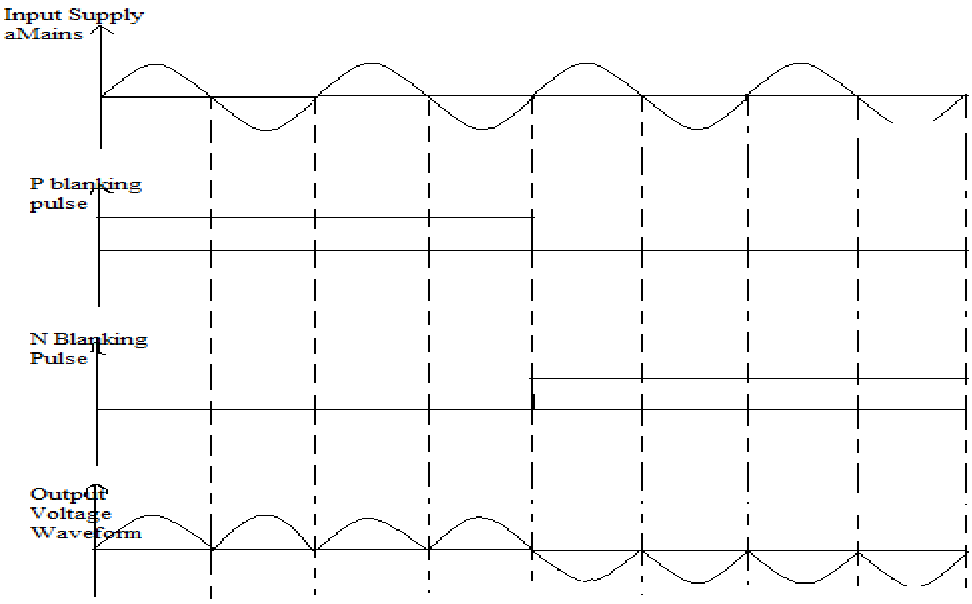


Figure 3.11: Input supply, P and N blanking pulses and output voltage waveforms

Gating Sequence:

1. During the first half period of output frequency To/2, operate converter P as a normal controlled rectifier with delay angle $\alpha = 0$, that is by gating P1 and P2 alternatively during positive and negative half cycles at $\alpha = 0$.

2. During the second half period T0/2, operate converter N as a normal controlled rectifier with delay angle $\alpha = 0$, that is by gating N2 and N1 alternatively during positive and negative half cycles of the input voltage.

The requisite firing pulses for SCRs P1, P2, N1 and N2 and the P and N blanking pulses are obtained through the control circuit. Their generation will be discussed in control section specifications chapter. The firing pulses obtained are given to gate of SCRs in power section. The desired output voltage waveform is obtained as shown in figure 2.5. The software and the hardware results for both resistive and lamp load are shown in next chapters.

Resistive Load: With the R load, the shape or the waveform of the output voltage is same as the output current waveform. The desired frequency of 12.5 Hz is obtained which is one fourth of the source frequency. Hence, the circuit serves the purpose.

Lamp Load: Here the lamp is used as load and the waveform obtained is ¼ the source frequency. The output current waveform is not exact as the output voltage waveform due to the presence of small inductance. Hence, the circuit serves the purpose.

3.3 PERFORMANCE EVALUATION

Total Harmonic Distortion:

$$THD_1 = \frac{\sqrt{\sum_{n=2}^{\infty} (I_{n,rms})^2}}{I_{1,rms}}$$

Here, $I_{1,rms}$ current is rms value of the fundamental component of the output current, the numerator term is the sum of rms values of all the components of the output current. The total harmonic distortion is found to be 104.7 percent.

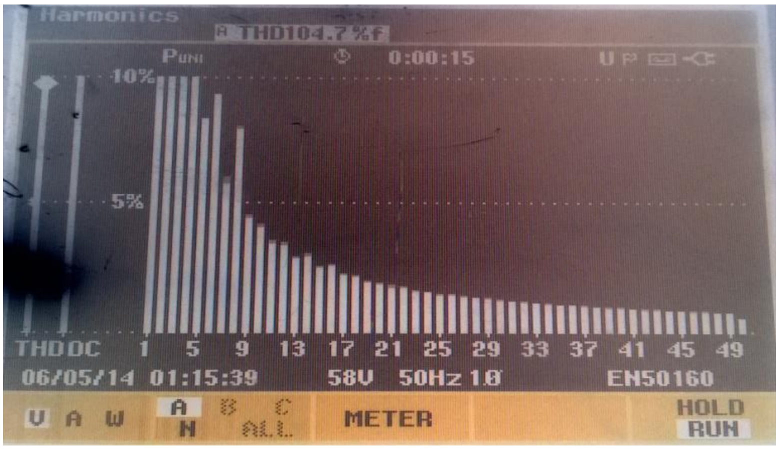


Figure 3.12: Total harmonic Distortion of the output voltage wave

The input voltage to a cycloconverter is 12 V(max), 50Hz the load resistance is 10 ohm. The frequency of the output voltage is 12.5Hz. The firing angle is taken zero.

then,

The rms value of the output voltage Vo is given as

$$V_o = V_s\left[\frac{1}{\Pi}\left(\Pi-\alpha+\frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

where firing angle , $\alpha = 0.$, therefore'

$$V_o = V_s = 8.5V(rms)$$

The rms load current is given as

$$I_o = \frac{V_o}{R} = \frac{8.5}{10}mA = 850mA.$$

The rms current through each thyristor is

$$I_R = \frac{I_p}{\sqrt{2}} = \frac{850}{\sqrt{2}\times\sqrt{2}}$$ =425 mA

The rms input current is $I_s = I_o = 850mA$

The VA rating is $VA = V_s I_s = 8.5\times 850mA = 7.2VA$

and output power is

$P_o = V_o I_o = 8.5\times 850mA$ =7.2 Watts

Input power factor = (power delivered to the load) $\div$ (Input VA)

Input PF $= \frac{V_O I_O}{V_S I_S}$ ’ as we know rms value of source current is same as the rms value of the output current.

therefore, power factor is equal to one.

Table3.1: Ideal and practical comparisons of output voltage, current, power and power factor.

Output Voltage V_O		**Output Current I_O**		**Output Power P o**		**Power factor**	
Practical	Ideal	Practical	Ideal	Practical	Ideal	Practical	Ideal
7.5V	8.5V	**500 mA**	750mA	**3.75W**	7.2 W	**0.85**	1

Power Calculations: The power calculations for the ideal and practical cases are described below. The load is a resistive load. A center tap transformer of secondary voltage 12V and 800mA is taken to design the proposed circuit of cycloconverter and it delievers a power of about 4 Watts.

The power calculations (Ideal Case) is shown below:

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

$$I_o = 750mA$$

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

3.4 Conclusions

This chapter discusses about the necessary circuits employed in design of the control circuit that generates the necessary signals to generate the required firing pulses in such a way that the power circuit produces the desired output voltage waveform. The procedure for the generation of blanking pulses and firing pulses is discussed along with the Detailed Block Diagram.

CHAPTER 4 : SIMULATION

4.1 General

Proteus is a software developed by Labcenter Electronics. This is the best software available to simulate a Power Electronics circuit. It has necessary ICs and flip flops to design the control circuit of the power converters like cycloconverter etc.

ISIS lies at the heart of the Proteus system, and is far more than just another schematics package. It combines a powerful design environment with the ability to define most aspects of the drawing appearance.

4.2 Simulated Circuit of Cycloconverter with firing angle equal to Zero

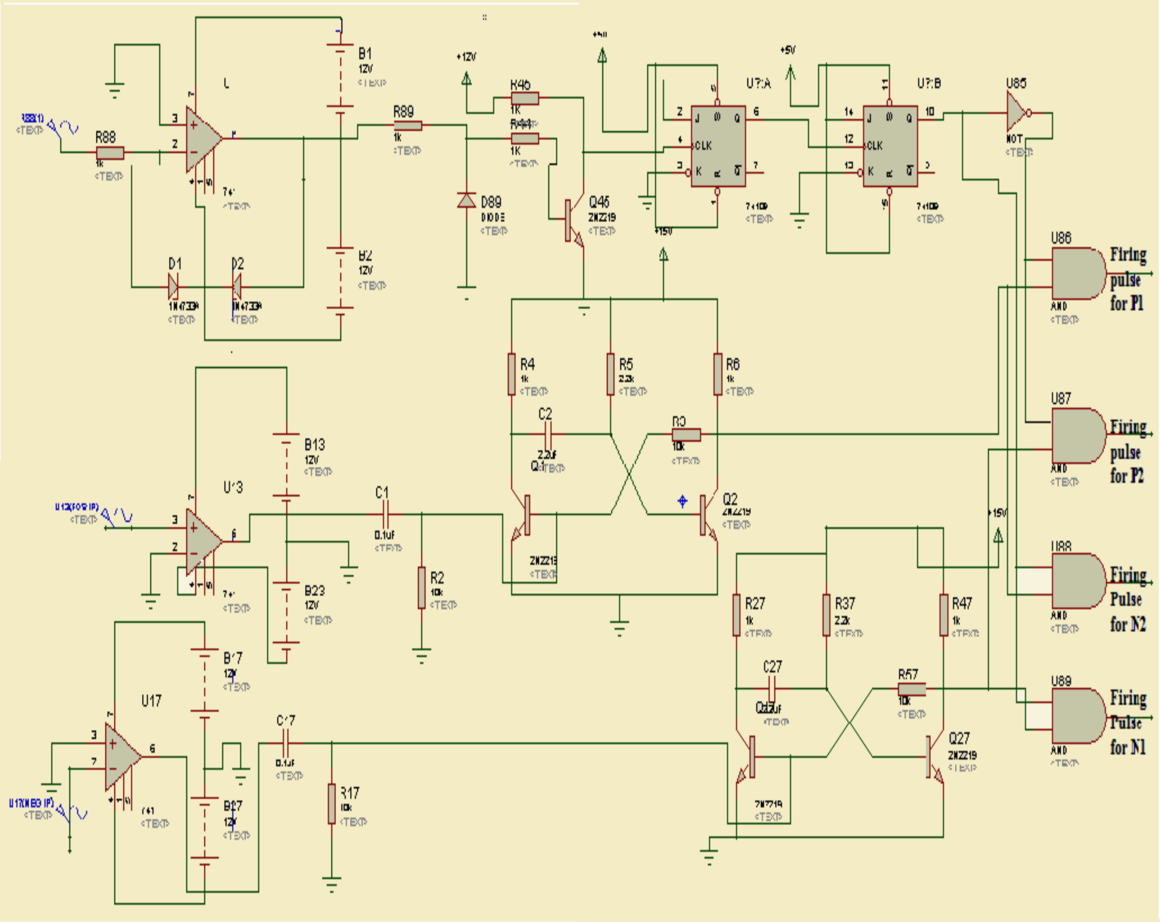


Figure 4.1 : Simulated Control Circuit Diagram

In the extreme upper left of simulated diagram, zero crossing detector produces a square wave whose output magnitude is limited to + 5V and -5V because of zener diodes with zener breakdown voltage of 5 Volts. This output is sent to the negative clipper where the negative going wave is clipped OFF. The square pulse is sent to JK flip flop where the input signal having frequency equal to 50 Hz is divided by four to obtain a pulse having frequency equal to 12.5 Hz. Hence, a blanking pulse of frequency 12.5 Hz is obtained and is phase inverted to obtain another blanking pulse of frequency 12.5 Hz.

In the lower section comparator circuit in inverting and non-inverting mode is used that produces a full square wave output whose magnitude is limited to about +Vsat and –Vsat. The spikes are created using differentiator circuit. The positive spike is used to trigger the transistor in the monostable multivibrator. For non-inverting mode, we obtain short duration pulses on every positive half cycle of input supply mains. These pulses are used to fire the SCRs P1 and N2.

For the inverting mode, we obtain short duration pulses from the monostable multivibrator circuit on every negative half cycle of input supply. These pulses are used to fire the SCRs P2 and N1.

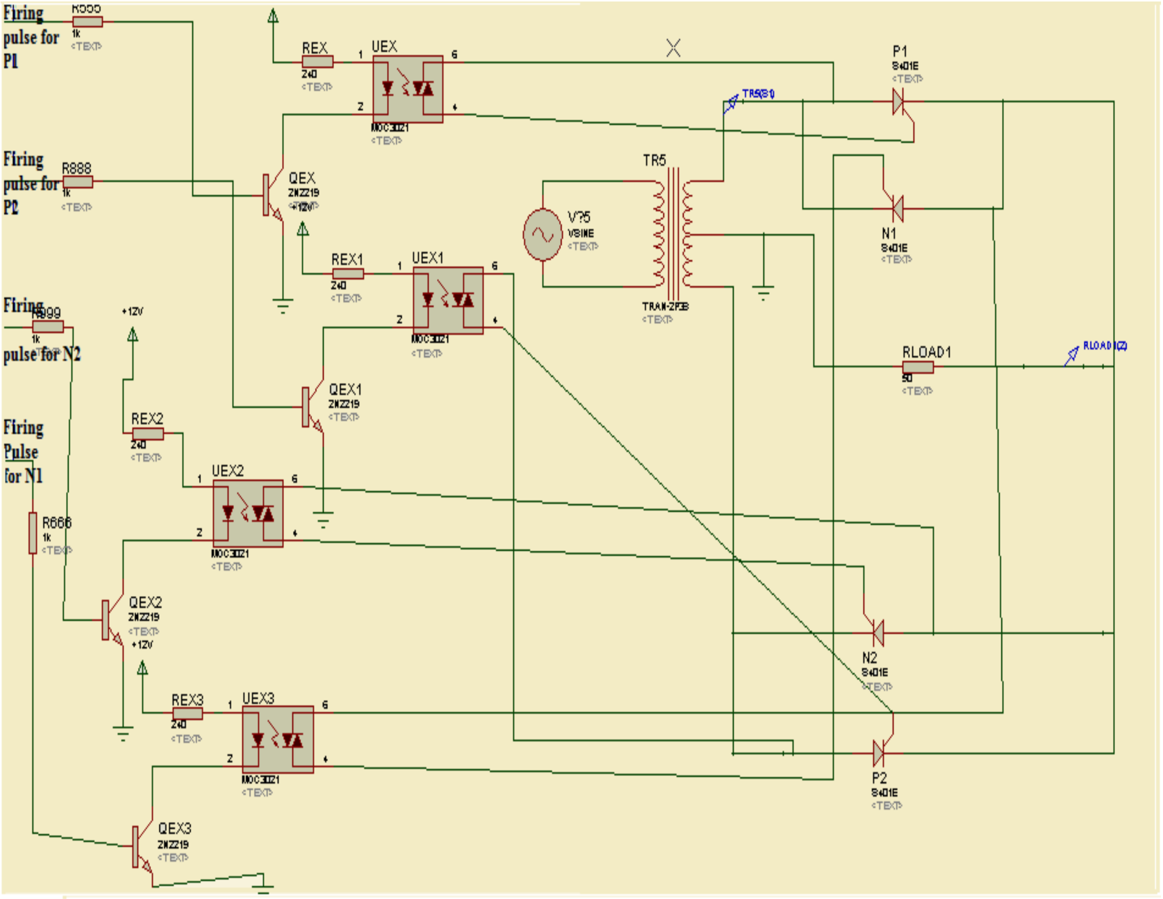


Figure 4.2: Interfacing circuit and the power circuit

Both these blanking pulses along with the MMV outputs are sent to logic and triggering circuit. The firing pulses for firing the SCRs P1, P2, N1 and N2 are obtained as shown in figure 4.1. These four pulses obtained from logic or converter selection circuit can never be given to SCRs in the power circuit directly so they are being passed to optocouplers in the interfacing circuit for isolation as shown in figure 4.2. These pulses are then given to the SCRs in the power circuit to obtain the desired output voltage.

4.3 Simulated Cycloconverter with varying firing angle

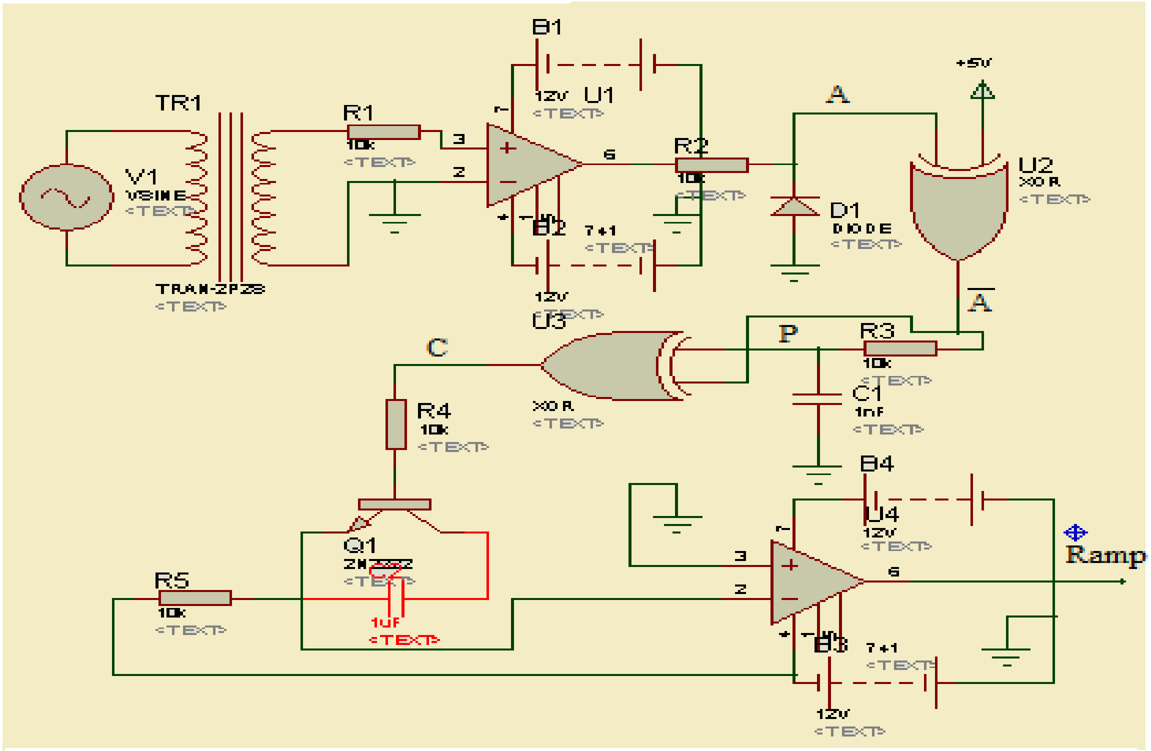


Figure 4.3 : Ramp Wave Generation

In the figure 4.3 the Zero Crossover Detector (ZCD), which uses operational amplifier transform the synchronous signal (V_{IS}) into a square wave signal (A) as shown in figure 4.3. The negative pulses are eliminated using diodes at the output stage of the op-amp.

The first exclusive OR- gate is used as an inverter. The waveform $\overline{A}$ is obtained at the output of the inverter.. The waveform P and $\overline{A}$ is given to the delay circuit (R-C integrator circuit) and waveform ‘P’ is obtained across the capacitor ‘C’ of the delay circuit.

The waveforms P and $\overline{A}$ are fed to the input terminals of the Ex-OR gate and the waveform C is obtained at the output of Ex-OR gate. This C waveform is used for resetting the ramp generator. The ramp wave generation requires capacitors and op-amp to realize the integrator function.

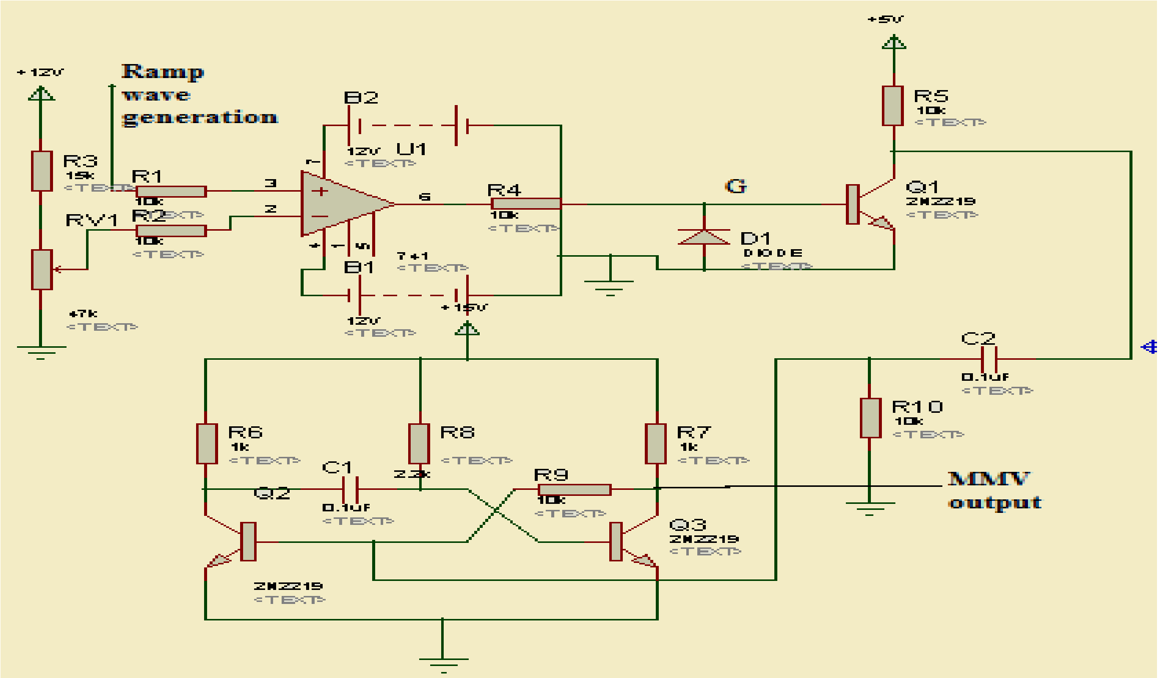


Figure 4.4: Comparator and Monostable Multivibrator Output

The DC control voltage EC that can be varied between ± 12V is used to vary the firing angle, α ranging from $0°$ to $180°$ is produced by the pot resistance. The DC control voltage and the ramp wave is given to the comparator circuit as shown in figure 6.4. The comparator compares the ramp with DC voltage which varies between 0V and about 10V and is controlled by the 47K POT. The output of the comparator is used for triggering IC 555 pulse shaper which output produces waveform ‘G’. The waveform ‘G’ is used for triggering thyristors.

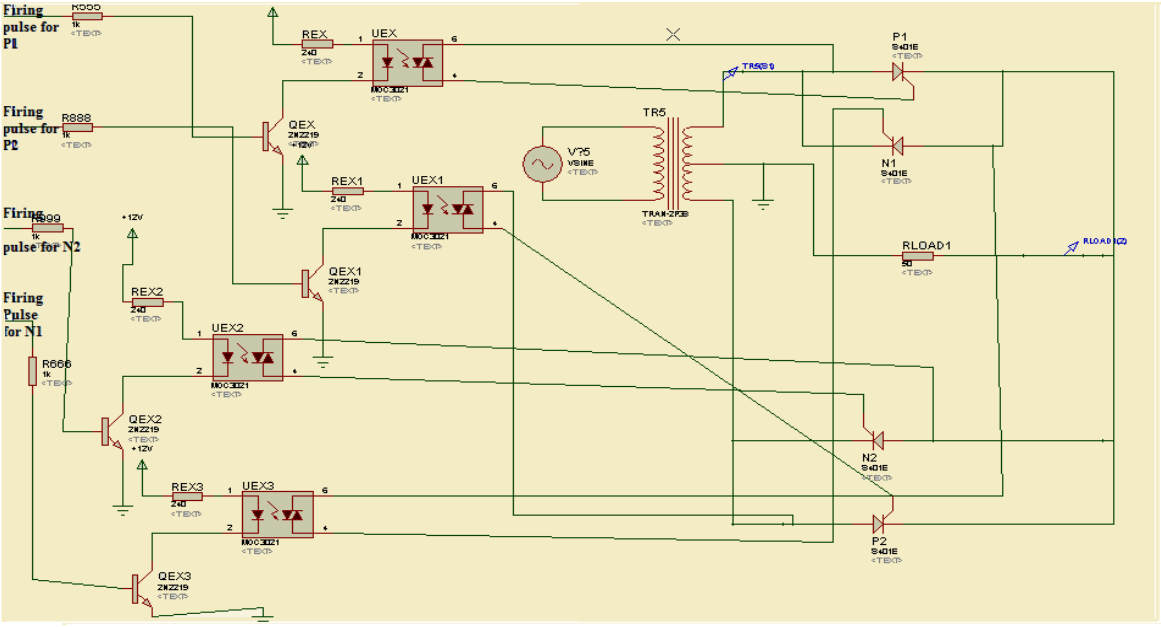


Figure 4.5: Interfacing and power circuit

Waveforms G, A, $\overline{C}$ and T are ANDed for getting triggering signal G_{P1} for thyristor T_{P1}. Similarly, waveforms G, $\overline{A}$, $\overline{C}$ and $\overline{T}$ are ANDed for getting firing signal 'G_{P1}' for thyristor T_{N1} and G, $\overline{A}$, $\overline{C}$ and T are ANDed for receiving triggering signal 'G_{P2}' for thyristor T_{P2};while waveforms G, A, $\overline{C}$ and $\overline{T}$ are ANDed for receiving 'G_{N2}' signal for thyristor T_{N2}. Waveforms $G_{P1}, G_{P2,}, G_{N1}$ and G_{N2} are fed to separate optocouplers used driver circuit which are also called pulse amplification and isolation stages. These drivers circuits produce triggering pulses $V_{gp1}, V_{gp2}, V_{gn1}$ and V_{gn2} for triggering thyristors T_{P1}, T_{p2}, T_{n1} and T_{n2} respectively.

4.4 Simulation Results with firing angle equal to zero:

Figure 4.6 shows the two P and N blanking pulses having frequency 12.5 Hz. These pulses are used for positive and negative converter selection. P blanking pulse is present in the first half period of output and N blanking pulse is present in the second half period of output wave.

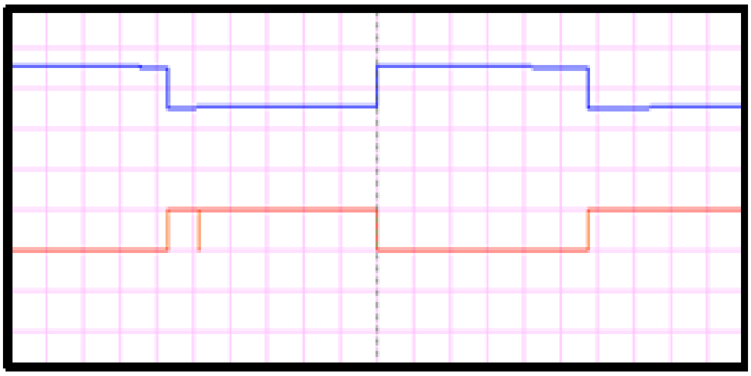


Figure 4.6: P and N Blanking Signals

Figure 4.7 shows the output of monostable multivibrator in which the transistors are switched on by the positive spikes obtained through op-amp output in non-inverting and inverting comparator mode. The above pulses are synchronized with the AC input mains.

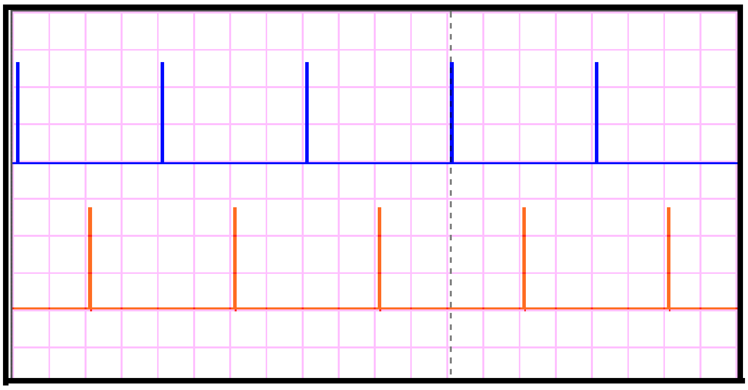


Figure 4.7: MMV1 and MMV2 outputs in inverting and non-inverting mode

Figure 4.8 shows the firing pulses given to the SCRs P1, P2, N2 and N1. These pulses have sufficient pulse width to turn ON the SCRs alternatively in positive and negative half cycle of input AC supply.

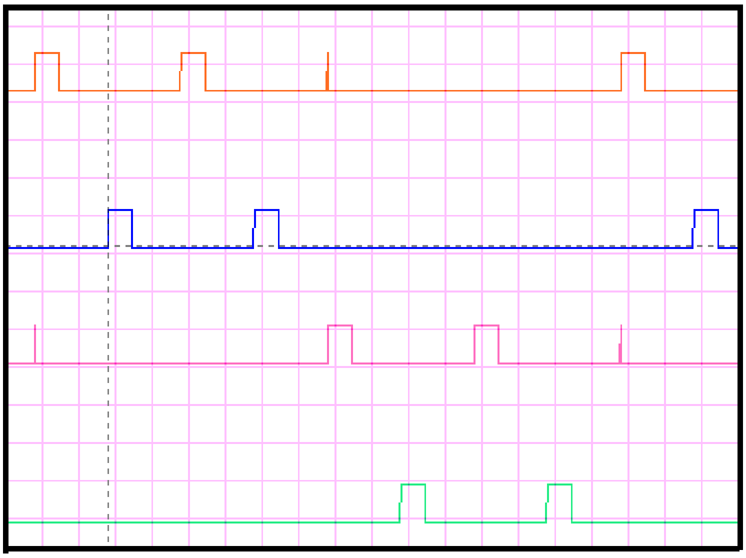


Figure 4.8: Trigger for scr P1(a), for scr N1(b), for scr N2(c) and for scr P2(d)

Figure 4.9 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.

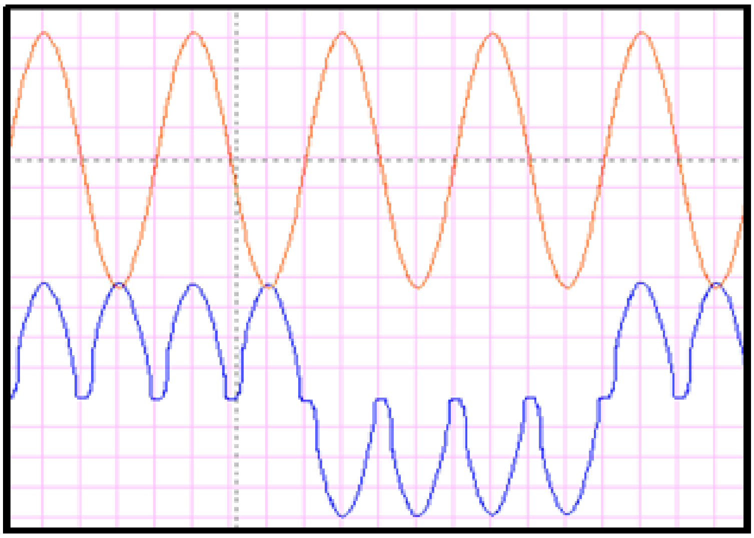


Figure 4.9 : Input(a)and output (b) voltage waveforms.

4.5 Simulations Results for Varying Firing Angle:

Figure 4.10 shows ramp wave which is generated using op-amps, resistance and capacitances.

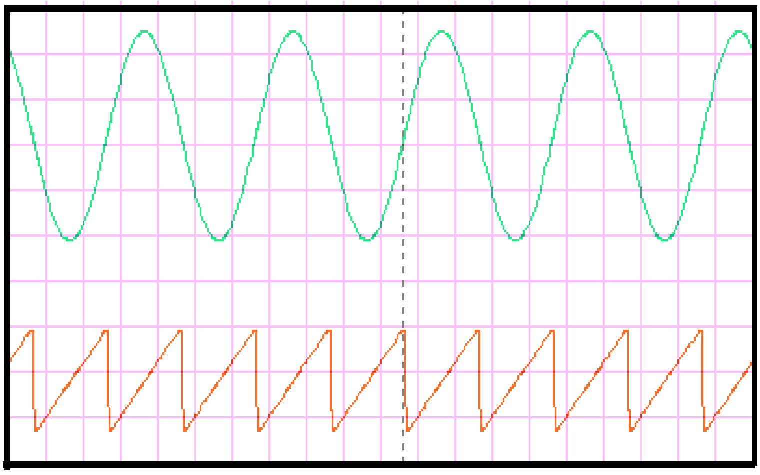


Figure 4.10: Synchronized Ramp Wave

Figure 4.11 shows the dc control voltage and ramp wave which are given as the input to the comparator. The Ramp wave is given to inverting terminal and dc control voltage is given to the non inverting pin of comparator. The output is the varying wave depending on the pot resistance. The negative going wave is eliminated using negative clipper. The output is shown in green colour. The output is inverted and is given to the differentiator circuit. The positive spike obtained is used to turn on the transistor in monostable multivibrator circuit.

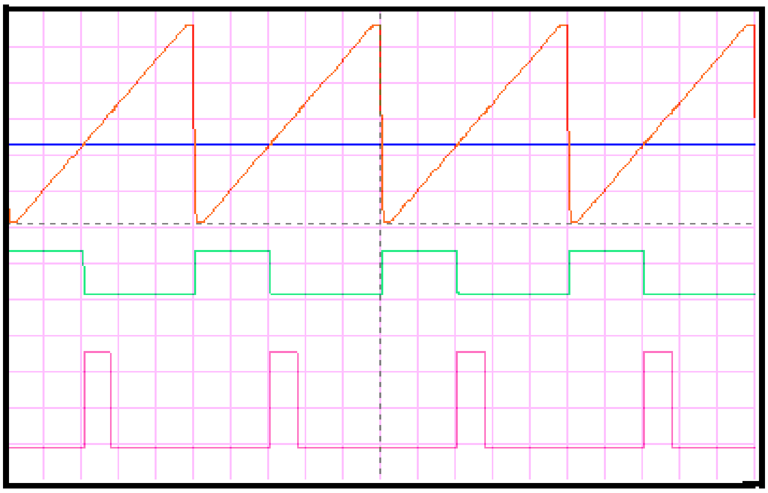


Figure 4.11: Comparator inputs (yellow and blue) and output (pink)

Figure 4.12 shows the monostable multivibrator pulses synchronized with a.c supply which are used to trigger the thyristors in the cycloconverter circuit. 0

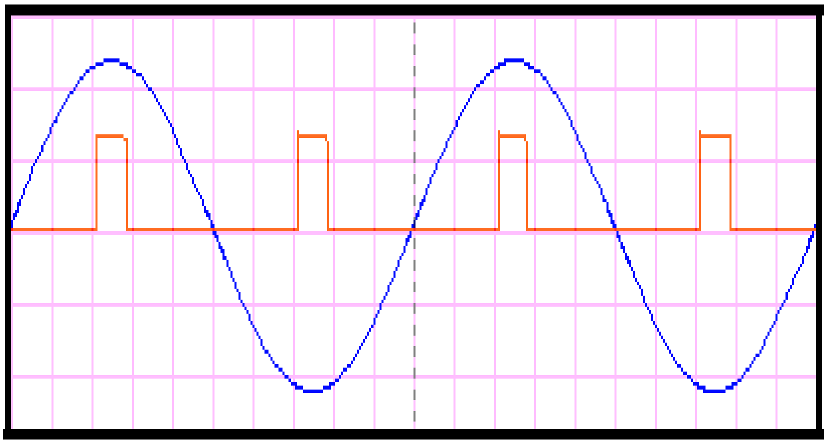


Figure 4.12 : MMVs output synchronized with input supply

Figure 4.13 shows the desired controlled AC output voltage, shown in blue. It is controlled by varying the firing angle. The input wave is shown in orange.

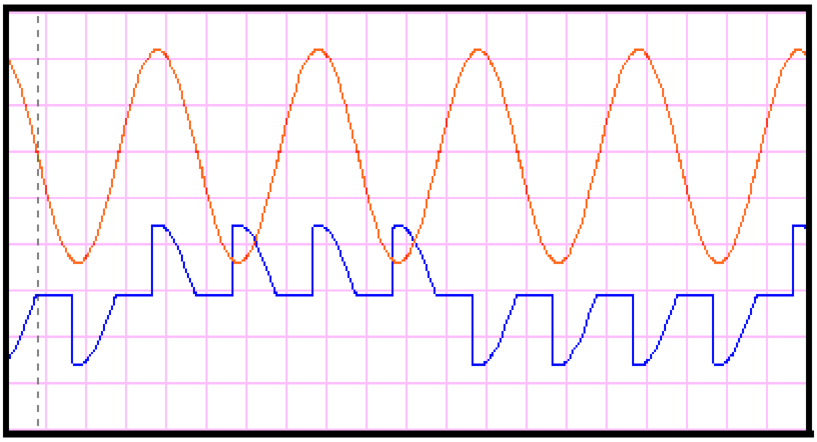


Figure 4.13: Controlled AC output voltage with resistive load

4.6 Conclusions

The simulation of control and power circuit of cycloconverter is being carried out in Proteus Isis software. Simulation results with firing angle equal to zero and with varying firing angle is being presented in this chapter. The results are found to be satisfactory.

CHAPTER 5: HARDWARE REALIZATION

5.1 General

The design is divided into three sections (a) Control Technique (b) Interfacing Circuit (c) Power Circuit. The control circuit generates the firing pulses so as to trigger the SCRs in positive and negative converters in such a way to produce a desired output voltage waveform across a resistive load. The firing pulses are at low voltage levels and are not given directly to the SCRs in the power circuit. Optoisolators isolates the signals produced by the control circuit and the desired output waveform produced by the power circuit. The same sinusoidal a.c supply is used for the control circuit as well as power circuit for synchronization purpose. The control strategy is described in the ongoing chapter.

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 (OPAMP 741).

5.2 Hardware Results

Figure 5.1 shows the P and N blanking pulses used for P and N-converter selection. These pulses are 180 degrees out of phase with each other.

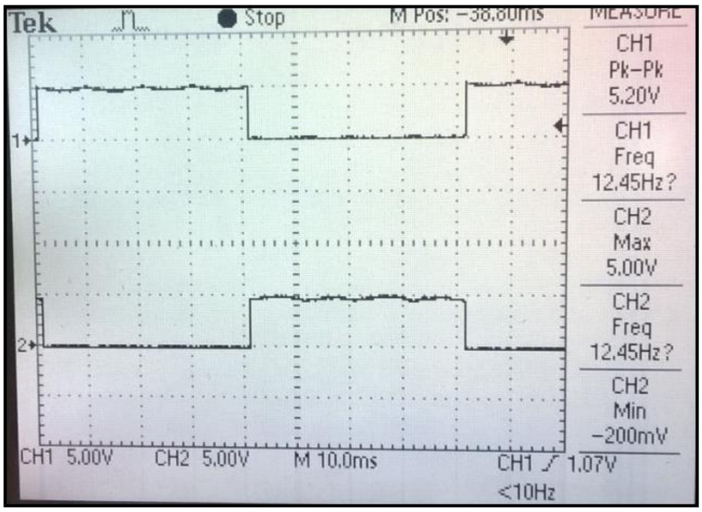


Figure 5.1: Flip flop output(P blanking signal) of frequency 12.5Hz

Figure 5.2 shows the Zero crossing detector output in noninverting comparator mode which is +Vsat during the positive half cycle and –Vsat during the negative half cycle of input supply.

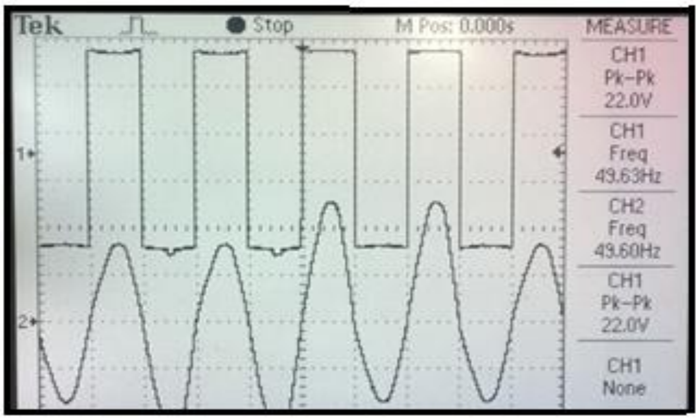


Figure 5.2: output of comparator circuit non inverting mode.

Figure 5.3 shows the differentiator output which produces positive spike for +Vsat and negative spike for –Vsat which is synchronized with the AC supply mains, positive spike is used to turn on the transistor of monostable multivibrator.

Figure 5.3: Output of Differentiator Circuit

Figure 5.4 shows the monostable multivibrator output wich is the positive pulse during the positive half cycle of Input Ac mains.

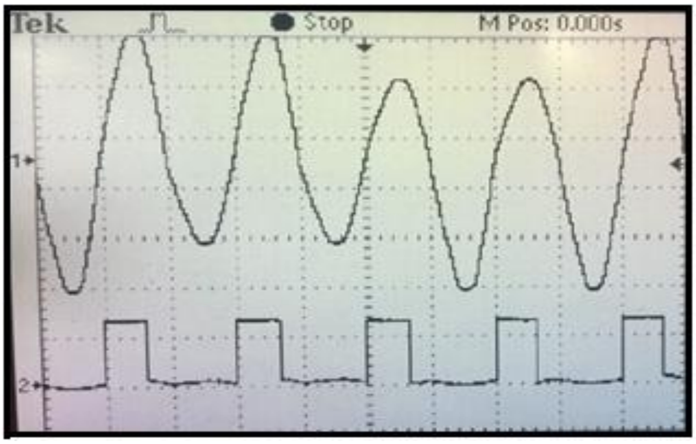


Figure 5.4: Output of monostable multivibrator in non-inverting mode

Figure 5.5 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.

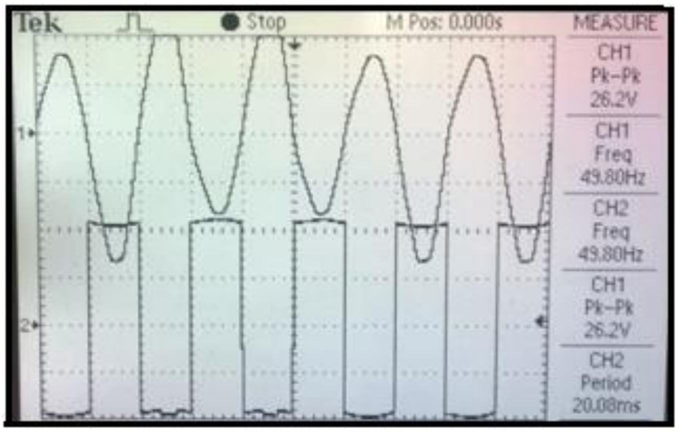


Figure 5.5: output of comparator circuit in inverting mode.

Figure 5.6 shows the differentiator circuit output which is a positive spike during the negative half cycle and negative spike during the positive supply.

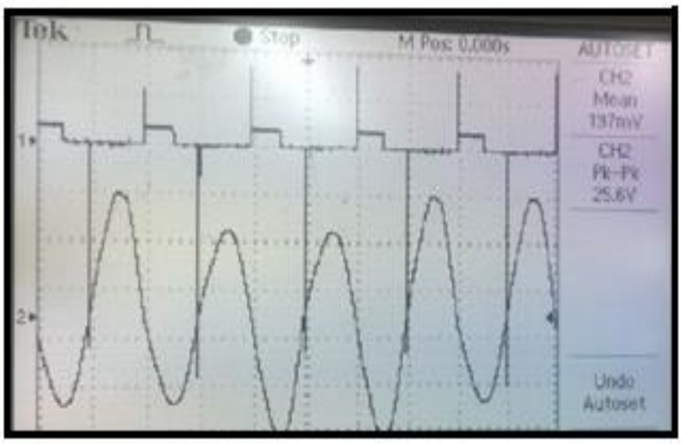


Figure 5.6: output of differentiator circuit

Figure 5.7 shows a pulse of duration sufficient enough to turn ON the SCR during the negative half cycle of every input cycle.

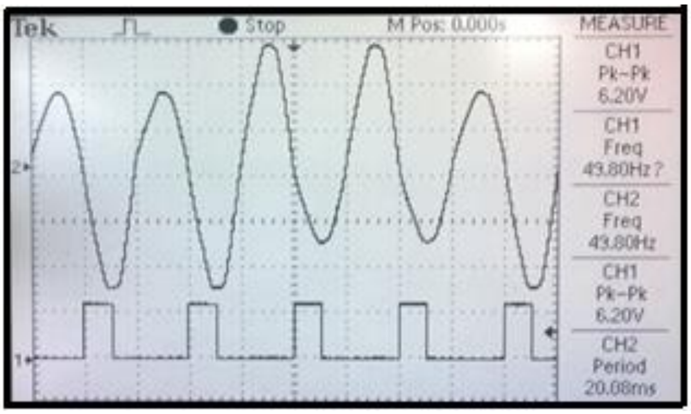


Figure 5.7: MMV output in inverting comparator mode output

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 5.8

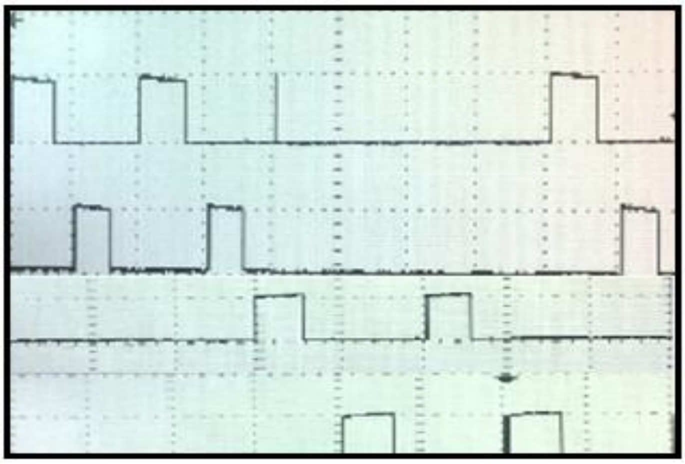


Figure 5.8: Triggering pulses given to the SCR P!, P2, N1 and N2.

Figure 5.9 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.

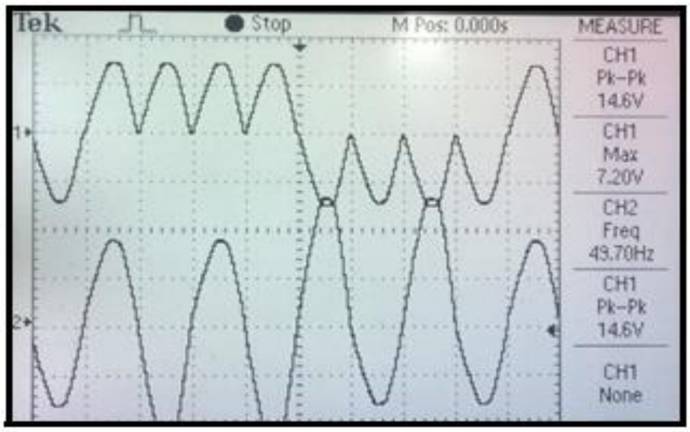


Figure 5.9: Output Voltage Waveform with 50 ohm load and frequency near about 12.5 Hz

5.3 Conclusions

The hardware realization of control and power circuit of cycloconverter is being carried out in Proteus Isis software in laboratory. Hardware results with firing angle equal to zero ares being presented in this chapter. The results are found to be satisfactory.

CHAPTER 6: CONCLUSIONS

A single phase to single phase step down Cyclo-converter has been designed which generates an output at a frequency lower than the input frequency. The input signal has 50Hz frequency and the output of cycloconverter has a frequency of 12.5 Hz. Hardware realization of control circuit and power circuit for a resistive load is being done with compact and less expensive ICs and flip flops

The control and power circuit is being simulated in the Proteus Isis Software. The results are obtained step by step and the final output waveform is obtained. It has been observed that by varying the firing angle, the shape of waveform changes. The trigger circuit has been tested qualitatively by observing the various waveforms on CRO. The cycloconverters are required in applications where variable frequencies are in demand such as in process and control industries, the cycloconverter is used to drive various electrical machines and control equipments.

The design is divided into three sections (a) Control Technique (b) Interfacing Circuit (c) Power Circuit. The control circuit generates the firing pulses so as to trigger the SCRs in positive and negative converters in such a way to produce a desired output voltage waveform across a resistive load. The firing pulses are at low voltage levels and are not given directly to the SCRs in the power circuit. Optoisolators isolates the power and the control circuit. The same sinusoidal a.c supply is used for the control circuit as well as power circuit for synchronization purpose. The synchronization of the signals in the control circuit and the desired output voltage waveform is obtained by using the concept of operational amplifier (OPAMP 741).

The proposed step down cycloconverter circuit is demonstrated completely with the help of simulation and hardware realization is also done under various operating conditions. However, the commercially used cycloconverter may employ different control circuit. The power delivered by the proposed circuit is about 3.75 watts. The Total Harmonic Distortion with and without load is also noted and with load it is found to be 104.7 percent.

The Hardware of Single Phase to Single Phase Cycloconverter has been realized in the laboratory. The pictorial view is shown below:

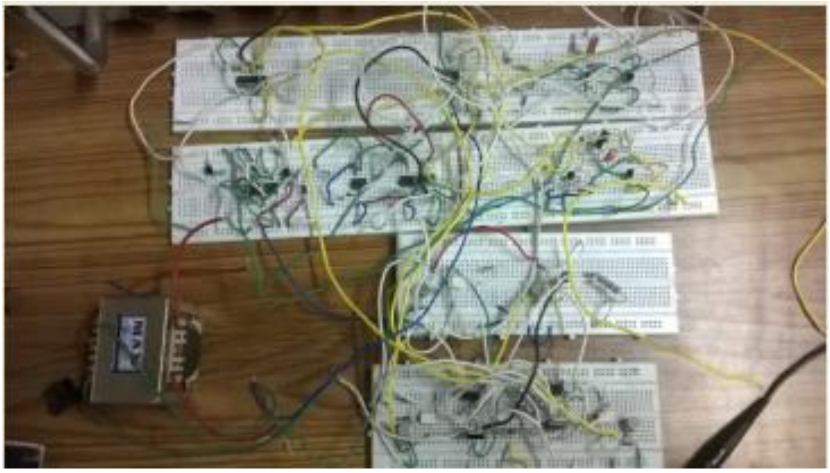


Figure 6.1 Hardware Realization of Cycloconverter

FURTHER SCOPE OF PROJECT

The proposed cycloconverter can be used for the speed control of induction motor. The power produced by the proposed cycloconverter is not huge to drive a single phase induction motor because the size of transformer used is 12 Volts only. By substituting a high voltage transformer the power produced can be increased. The goal of cycloconverter is to allow for variable frequency operation. Input frequency is provided by the source. This is not controllable by the cycloconverter itself. On the other hand, the variable output frequency is obtained by varying the periods of positive and negative bridges namely TP-ON and TN-ON. This is extremely entirely within the control circuit. In many cases, the control circuit will include a microcontroller. As the input frequency varies, the rms value also varies in proportion with each other. The ratio V/f is kept constant and the speed control a.c motors can be made possible. This is called the scalar control of Induction Motor.

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