International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 6, Number 5 (2013), pp. 569-581

http://www.irphouse.com

Cycloconverter Drive for AC Motors

Manishkumar M. Tayade and S.S. Dhamse

Department of Electrical Engineering,
Government College of Engineering, Aurangabad.

Abstract

This paper is going to discuss an efficient technique to control the speed of a single phase induction motor in three steps by using cyclo convertor technique by thyristors. The induction motor is most widely used machine in both industrial and domestic sector, the difficulty of varying its speed by a cost effective device is one of its main disadvantages. As the AC supply frequency cannot be changed, so this paper presents a thyristor controlled cyclo converter which enables the control of speed in steps for an induction motor. The microcontroller used here is from 8051 family, a pair of slide switches is used to select the desired speed range (f, f/2 and f/3) of operation of the induction motor. These switches are interfaced to the microcontroller. The status of the switches enables the microcontroller to deliver the pulses to trigger the SCR's in a dual bridge. Thus, the speed of the induction motor can be achieved in three steps i.e. (f, f/2 and f/3).

Index Terms—cycloconverter, single phase induction motors drives(SPIMDs), silicon controled rectifer(SCR). (key words)

INTRODUCTION

Induction motors are the most widely used electrical motors. Because motors do not inherently have the capability of variable speed operation. Due to this reason, earlier dc motors were applied in most of the electrical drives. Recently remarkable efforts have been made in adjustable speed single phase induction motor drives (SPIMDs). But the recent developments in speed control methods of the induction motor have led to their large scale use in almost all electrical drives.

The single-phase induction motor can successfully be driven from a variable frequency power supply. Hence, the motor speed can be easily adjusted. Other methods for speed control, such as voltage amplitude control do not allow for the range of speed, which is possible with the use of a variable frequency supply[8]. The cycloconverter, we can use as the best variable frequency drive, which has never been so popular but is rarely used in very large low-speed induction motor or synchronous motor drives. The cycloconverter can only produce acceptable output waveforms at frequencies well below the mains frequency. Also this coupled with the fact that it is feasible to make large induction motors with high-pole numbers. Means that a very low-speed direct (gearless) drive becomes practicable. A 20-pole motor will have a synchronous speed of only 30 rev/min at 5 Hz, making it suitable for mine winders, kilns, crushers, etc. [5].

LITERATURE REVIEW

High performance control strategies can be used for adjustable speed single-phase induction motor drives in combination with high performance converter topologies[1]. Also, low-cost high-performance converter topologies have been proposed. Advantages and disadvantages of different converter topologies have been discussed in table 1. [1]

Table 1

Comparison Table for Various Topologies

Characteristics	AC/AC Chopper	Cycloconverter		Single Phase PWM inv.						Two Phase PWM inv.			
		Conventional.	Non-conventional	Half Bridge inverter		Full Bridge inverter				Balanced		Unbalanced	
						Double DC-link voltage		Rated DC-link voltage					
Number of devices	4S + 4Ds	4S + 16Ds	1S + 4Ds	2S + 4Ds	4S + 4Ds	4S + 6D	6S + 6D	4S + 8Ds	6S + 8Ds	6S + 10D	8S + 10D	4S+ 8Ds	6S+ 8Ds
DC-Link Capacitor	Not used	Not used	Not used	Very large	Very large	Very large	Very large	Large	Large	Large	Large	Very large	Very large
Power factor	Good	Good	Good	Good	Best	Good	Best	Good	Best	Good	Best	Good	Best
Speed variation	Very small	Inter.* range	Inter. Range	wide range	wide range	wide range	Wide range	wide range	wide range	wide range	Wide range	wide range	wide range
Perform-ance	Good	Good	Poor	Better	Better	Better	Better	Better	Better	Best	Best	Best	Best
Cost	Low	Low	Lowest	Med.	High	Med.	High	Med.	High	High	Highest	High	Highest
Control Compl*	Simple	Inter.	Simplest	Inter.	Co.*	Inter.	Co.	Inter.	Co.	Co.	More Co.	Co.	More Co.
Efficiency	?	High	Low	High	High	High	High	High	High	Highest	Highest	Highest	Highest

*(Med.; medium, Inter.; intermediate, Co.; complex, Compl.; complexity)

Motor drives are mainly consist of predominant load for the agricultural and industrial sectors. In USA most rural communities are supplied with single phase ac powers. So these drives have to be realized with single phase motors or with three phase motors driven by phase converters. Autotransformer capacitor phase converters and rotary phase converters have been used for some past decades. But in case of autotransformer capacitor phase converters, they can't easily obtain balanced output voltage with reasonable cost and in case of the rotary phase converters, they are heavy and having significant no load losses. Also both topologies have high inrush current during motor start up. To solve such problems, the use of the three phase inverter was suggested to get the balanced output voltage and sinusoidal input current. However this also proved inefficient. Inverter current was very high during motor start up [8].

AC DRIVES OVER DC DRIVES

The dc drive fed with converter has attained a high technological standard. It is the most widely accepted solution, especially where slow-rotating high-capacity drives are concerned. With dc machines, the trend to ever higher unit ratings has in fact come to hit the limits of what is technically practicable. The only considerable problem is the reactance voltage of commutation under the shock load conditions. This reactance voltage is dependent upon the speed at which the commutation is carried. And also upon the armature inductance which can be decreased by reducing the armature length. (Apart from taking design measures to reduce slot leakage.) To solve this we have to make a rotor which is short in length and large in diameter and therefore has a high moment of inertia. But such rotors are not always advantageous and are definitely undesirable in certain applications, as for instance in the case of twin drives for roll stands [2].

But in case of a three-phase ac drive commutation and limit rating problems do not exist. The rotor diameter, the moment of inertia and the weight are smaller in comparison to that of dc machines of the same output rating. Moreover the ac drive has the advantage of better efficiency, higher overload capability, lower maintenance, and ventilation requirements[2].

WHY THE CYCLOCONVERTER ?

From the family of power converters used for driving electric motors, cycloconverter have the main advantages of its natural commutation and lack of energy storage. With these two advantages its use in variable speed motor drives up to 1400rev/min and in wide frequency range applications with high frequency link is most favorable[3]. Analysis of cycloconverter drive for induction motors has been investigated extensively. The single phase induction motor and a poly phase induction motor having a squirrel cage rotor are structurally same. Cycloconverters which are used in very large variable frequency drives with ratings from few megawatts up to many tens of megawatts[4]. Mostly the inverters are used as a variable-frequency sources in this field. And here the power is converted from d.c. to a.c. Usually the ac power is given an intermediate stage – the ‘d.c. link’– which is then chopped up to form a variable-frequency output. But in case of cycloconverter there is not such intermediate d.c. stage. The cycloconverter is a ‘direct’ converter. Instead, the output voltage is synthesised by switching the load directly across whichever phase of the mains gives the best approximation to the desired load voltage at each instant of time. The fixed frequency mains suply is readily avilable. This supply is then rectified by naturally commutated devices (thyristors) instead of self-commutating devices. This means that the cost of each device is lower and higher powers can be achieved. In principle we can have any combination of input and output phase numbers with the cycloconverter[5].

AC MOTOR SPEED CONTROL

Rotational speed N of an induction motor can be shown by the expression (1).

Whenever the voltage applied to the motor is increased and decreased, the slip s changes, then the rotational speed N will change.

$$N = \frac{120f}{P}(1 - s) \text{ --------------} \quad (1)$$

where N is the rotational speed (r/min), f is the frequency(Hz), P is the number of poles of a motor and s is the slip.

The rotational speed - torque curve of an induction motor is shown in fig.1. The curve is divided in a stable range and an unstable range. Simple voltage control is shown in fig. 2 As we can't reliably operate in the unstable range, simple voltage control (open loop control) is limited to controlling the speed in a narrow range like, N1~N3. To make it possible to operate reliably even in the above-mentioned unstable range, it is necessary to detect the rotational speed of the motor and use a voltage control mechanism (closed-loop control) that reduces the speed error when compared to a set value.

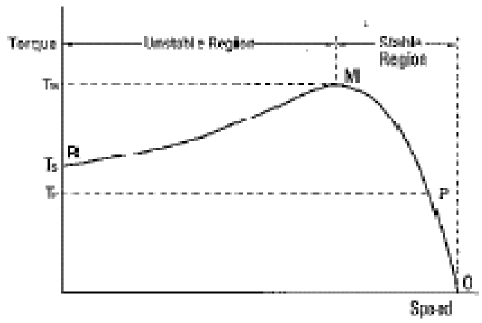

Fig.1. Rotational speed-toque characteristics of ac motors

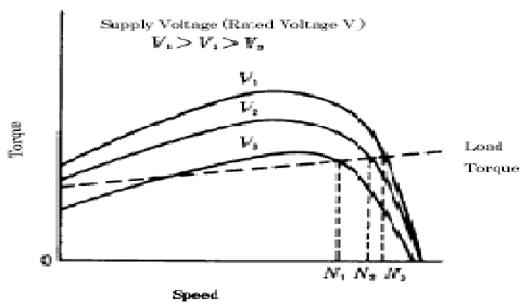

Fig.2. Simple voltage control

Available voltage control methods include control by a transformer or by frequency control. This transformer control method is not so easy to do with an AC speed control motor. Alternately, the AC voltage can be adjusted by setting the ON/OFF time of every half cycle of the AC voltage (50 or 60Hz) applied to the motor using a switching element (thyristor or triac) that can directly turn on and off the AC voltage[8].

In the industrial world, the variable frequency technique has always been of great importance. The generating station generates electricity of the fixed frequency of 50 Hz. which is not always applicable for some electrical appliances. There are some electrical devices which need variable frequency ranging from one tenth to one third of the supply frequency. Some examples are induction motors used in AC traction, aircraft power supplies, mobile power supplies and others. Therefore for meeting the ever growing demand of industrial application the variable frequency generation becomes necessary.The cycloconverter is such a device which generates variable frequency. With the development of the semiconductor devices it is possible to control the frequency of the cycloconverter according to the requirement and with the help of semiconductor switching devices like thyristors and others we can deliver a large amount of controlled power.

Now we are aiming to design and construct a single phase cycloconverter circuit which could generate variable frequency. The proper generation of the blanking and gate pulses of the switching devices and synchronizing them with the input signal is the most important thing in designing a cycloconverter circuit which becomes easier due to the availability of the integrated circuit(IC). The operational amplifier ICs has simplified the generation of blanking and triggering signals[6].

CYCLOCONVERTER

In industrial applications, we use two forms of electrical energy: direct current (dc) and alternating current (ac). Generally fixed voltage fixed frequency single-phase or three-phase ac is readily available. But, for various applications, different forms, magnitudes and/or frequencies are required. There are four different conversions between dc and ac power sources. These conversions are done by circuits called power converters. The converters are classified as:

1-rectifiers- from single or three-phase ac to variable dc

2-choppers- from dc to variable voltage dc

3-inverters- from dc to variable magnitude/frequency/phase ac

4-cycloconverters- from single or three-phase ac to variable magnitude/variable frequency, single-phase or three-phase ac

Without using any dc link as in case of traditional converter, we use cycloconverter(Fig. 3). Cycloconverters are used in high power applications. They are usually phase-controlled and they traditionally use thyristors due to their ease of phase commutation

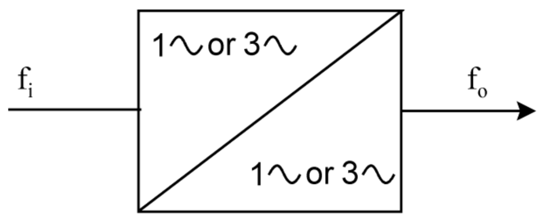

Fig. 3. Block diagram of cycloconverter

Operating Principle

To understand the operation principles of cycloconverter, the single-phase to single-phase cycloconverter (Fig.4) should be studied first. This converter consists of back-to-back connection of two full-wave rectifier circuits. Fig. 5 shows the operating waveforms for this converter with a resistive load.

The input voltage, Vs is an ac voltage at a frequency fi as shown in fig.5a. For easy understanding assume that all the thyristors are fired at a=0° firing angle, i.e. thyristors act like diodes. Note that the firing angles are named asαPfor the positive converter and αN for the negative converter.

To get one-fourth of the input frequency at the output. For the first two cycles of vs, the positive converter operates supplying current to the load. It rectifies the input voltage; therefore, the load sees 4 positive half cycles as seen in fig.5b. In the next two cycles, the negative converter operates supplying current to the load in the reverse direction. The current waveforms are not shown in the figures because the resistive load current will have the same waveform as the voltage but only scaled by the resistance. Note that when one of the converters operates the other one is disabled, so that there is no current circulating between the two rectifiers[7].

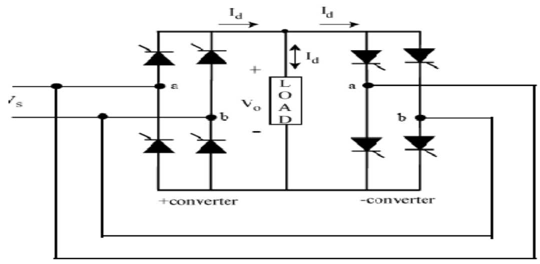

Fig. 4. Single phase to single phase cycloconverter

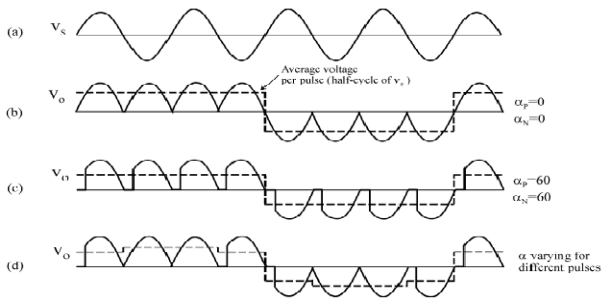

Fig. 5. Single phase to single phase cyclo. waveforms

a) input voltage b) output voltage for zero firing angle c) output voltage with firing angle π/3 rad. output voltage with varying firing angle

Design and Construction of Cycloconverter

The cycloconverter constitute of two converter group. One of which is called the positive converter and another one is negative converter. Generally the switching device of positive converter group conducts only for the positive half cycle whereas the negative converter group goes in conduction during negative half cycle of the input wave shape. Here we want one control circuit to control the operation of each converter group and also this provides synchronization of the output signal with the input signal. The basic circuit diagram of a single phase cycloconverter is shown in the figure 6. Basically the single phase cycloconv. is a 2 pulse cycloconverter because there are two phase controlled pulses per cycle of the output phase [6].

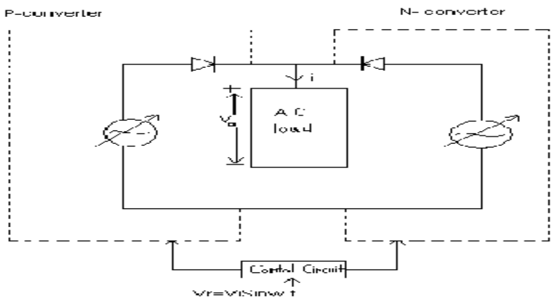

Fig. 6. Basic Diagram of Single Phase Cycloconverter

Generally for providing the alternating output, the transformer is used and the transformer can be removed if a neutral return is not required in a multiphase output application. In this the cycloconverter uses four thyristors divided into a positive and negative bank of two thyristors each. In accordance with the flow of positive and negative current in the load the output voltage is controlled by phase control of the positive and negative bank thyristors respectively. The two groups of the converter which can be defined as P and N. The P and N converters control the positive and negative half cycles of the output voltage of the desired frequency respectively which is shown in the figure 7. The conduction intervals of P and N converters are also marked in figure 7.

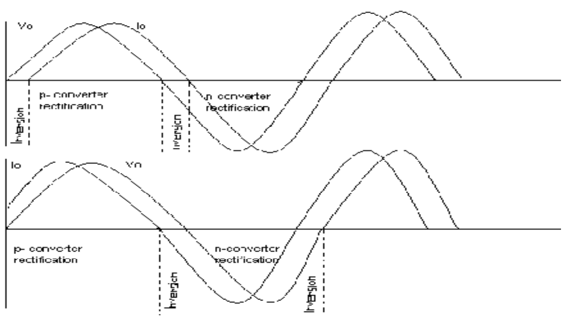

Fig. 7. Output Voltage and Current Waveforms of the Single Phase Cycloconverter

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 . A cycloconverter circuit is comprised of power, control and filter sections [6].

Power Section of Cycloconverter Circuit

The power section of cycloconverter comprises of a dual converter in which two groups of controlled rectifiers (thyristors) employ a common centre tapped transformer as their source. Figure 8 shows the power section of a single phase cyclo-converter.

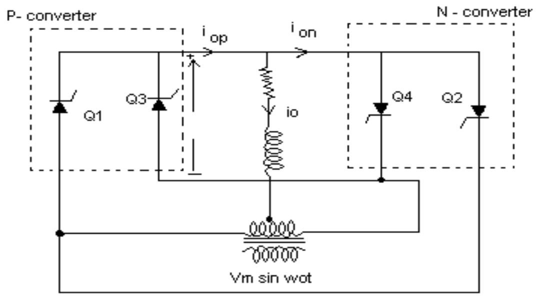

Fig. 8. Power section of Single Phase Cycloconverter

The transformer can be replaced by its equivalent and further equivalent circuit is shown in figure 9. The Q1 and Q3 thyristors comprise the positive P converter group whereas the thyristors Q2 and Q4 comprise the negative N converter group. The positive and negative load current is obtained from the conduction of Q1 and Q3 of the P converter and Q2 and Q4 of the N converter respectively. The control circuit should be designed in such a way that the P converter goes in conduction during the positive half cycle of the input signal when the N converter remains idle. Similarly when the N converter goes in conduction during negative half cycle of the input signal the P converter remains idle. Two blanking signals P and N determine the operation of the thyristors in each converter group according to the sequence of the gate trigger. Moreover the frequency of the output signal depends on the frequency of the P and N blanking signals. [6]

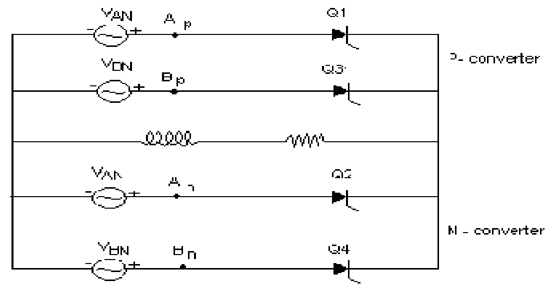

Fig. 9. Simplified Power Circuit of the Single Phase Cycloconverter

To turn off any conducting thyristor the natural or line commutation is employed . According to the sequence of the gate trigger the thyristors of any particular group go in conduction . By turning on a thyristor in a particular group, a reverse voltage appears across the thyristor which was in conduction before that thyristor in the same group and thus the natural commutation of thyristors occurs sequentially[6], [7]. So by turning on the thyristor Q1 of the positive converter group, the thyristor Q3 gets commutated and vice versa. Similarly the commutation of the thyristors in the negative converter group occurs. In case of the natural commutation, the current through a thyristor goes to zero before the incoming thyristor is turned on. The thyristors Q1 and Q4 or Q2 and Q3 cannot be turned on simultaneously because this causes the short circuiting of the secondary voltage sources Van and Vbn or the secondary winding of the transformer. When the load current is to be reversed from a positive value to a negative value, a changeover should take place from Q1 to Q2 or Q3 to Q4 [6].

CYCLOCONVERTER FED AC MOTORS DRIVE.

The main advantage of the cycloconverter is the fact that the turn-off of the SCRs is achieved by the process of line commutation. When a particular thyristor is turned ON it automatically turns off a previously conducting thyristor by applying a line voltage in reverse across it. The circuit is therefore extremely simple and can be scaled up to very high powers of the order of 10–20MW. The large number of SCRs is not an issue at such power levels. Cycloconverters have a limitation that the output (or motor) frequency cannot be more than about a third of the input frequency, as otherwise the quality of the output voltage waveform becomes poor in terms of the harmonic content. This type of drive is therefore used in high power applications with low motor speed. Steel rolling mills and ball mills in cement industry are examples. By enclosing current loops around the stator and applying vector control, high performance in terms of torque control can be achieved.

The cycloconverter is characterized by proper utilization of the thyristors because conduction is shared by the two component converters which are connected inversely parallel pair to each other in alternating succession. The utilization of these static converter valves is further improved by the fact that at higher motor voltages and speeds the phase-to-neutral voltages at the frequency converter output are given a nearly trapezoidal waveform which almost exclusively contains odd-numbered harmonics with order numbers that can be divided by three. These harmonics have the same phase relationship in the three frequency converter voltages and therefore cancel one another out when the phase-to-phase voltages for the motor are formed. The motor voltages and currents thus remain sinusoidal [2].

PROPOSED TOPOLOGY

Here the block diagram for the proposed topology is given in which the single phase to single phase cycloconverter is used along with the transformer, rectifier, IC regulator and the microcontroller .

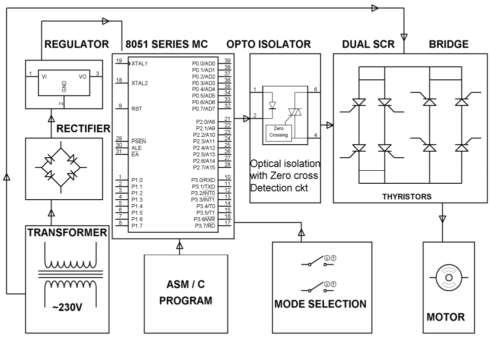

Fig. 10. Proposed topology for Cycloconverter drive of ac motors.

The block diagram starts from the power supply. Here the line supply is given to the transformer and the cycloconverter both.

As the cycloconverter needs the full supply, there is no need to connect anything inbetween the supply & the cycloconverter. But in this technique we are using the microcontroller which needs the power supply of 5V dc. Hence we are using step down transformer to stepdown the supply to 12V. Now this 12V ac is rectified through bridge rectifier and converted to dc. And then using regulator IC of 7805 we make this supply smooth and regulated exactly to 5V. And then this smooth and regulated 5V dc supply is given to the microcontroller.

The microcontroller used here is of 8051 series. The rectifier circuit and the regulator IC is used to supply the microcontroller only. It is a 40 pin IC. We write a programme in the microcontroller in such a way that time period of the ON state of the SCRs in cycloconverter can be increased or decreased according to mode of selection. This mode of selection is determined by the logic state of the two push to ON buttons. Also there are some opto isolator ICs used here to isolate two power levels. As we observe that the power level for the microcontroller and the cycloconverter are different, they must be separated . For this purpose opto isolators are used. This opto isolators are used alongwith the zero detection circuit.

And finally the ac motor is connected to the cycloconvrter. The cycloconverter is designed and consructed with eight SCRs as discussed previously. There are two switches given for to select the mode of operation i.e. frequency mode (f, f/2, f/3).

PERFORMANCE ANALYSIS

Here are the output waveforms of the practical model of our proposed topology.

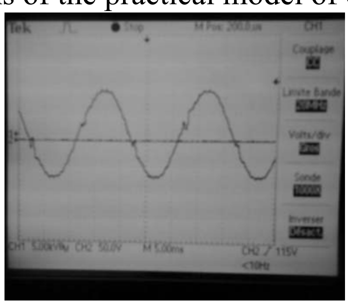

Fig. 11. Voltage waveform for the full frequency f.

Here in fig. 11 we can see that the voltage waveform is completely sinusoidal. Here we get the full speed . As the full line voltage is given to the motor, rated speed is observed alongwith the full ine voltage as seen from this waveform. Now as we change the mode of selection, we have fig. 12.

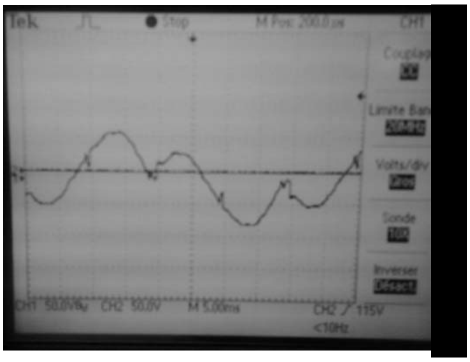

Fig.12. Voltage waveform for the frequency f/2

Now in the above figure12, we are getting the waveforms for the frequency f/2. Now in fig. 11 we can see that the voltage waveform is purely sinusoidal and we get the full speed . But as soon as we change the mode of the selection of the microcontroller by pressing the switch1, we increase the ON period of the scrs twice and get the frequency f/2. Hence getting the speed half of the full speed. The waveform for this frequency f/2 is shown in fig. 12.Here from this waveforms it is clear that the one complete cycle is converted to half cycle. And hence we are getting the frequency f/2. Also we observe the speed nearly half of the rated full speed.

In the same manner as we change the mode of selection of the microcontroller once again by pressing the switch2, we get the frequency f/3.

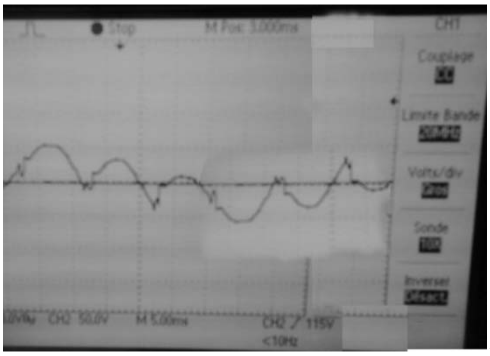

Fig.13. Voltage waveform for the frequency f/3

Here we can clearly observe that time period of the waveform is increased upto three times than that of original waveform of the full voltage. Hence we get frequency nearly about that of f/3. Also we observe that the speed at this instant is nerly about the 1/3 of the rated full speed. And the waveform for this is shown in fig. 13

Now one thing which we observe in the fig. 12 and 13 is that the waveforms are getting downwards and are not as clear as the standard waveforms. The reason of this is nothing but the reverse recovery time taken by the SCR while ON /OFF. Because of this reverse recovery time the waveform are not perfectly as the the standard one.

This model can be further extended for the three phase ac motors also.Using high power MOSFETs we can have its industrial working model also.

APPLICATION

Some applications of this type of drive are Cement mill drives, Ship propulsion drives, Rolling mill drives, Ore grinding mills and Mine winders. All the applications of this type of drive are found more efficient where the high power and low speed is required. Because of the use of the SCRs, MOSFETs and other power electronics devices these drives are economically stand better than any other drives. High power handling capability with larger torque and speed lesser than the rated is the unique speciality of such drives.

CONCLUSION

In manufacturing and process industries, the variable frequency is required for driving various electrical machineries. The cycloconverter or variable frequency generator plays a significant role in driving those electrical machineries. The study mainly focuses on the design and construction of the single phase cycloconverter. The commercially designed single phase cycloconverter circuit may use different design pattern than this one. This single phase cycloconverter circuit can be extended further for three phase application.

Also this paper presents successfully the new topology of cycloconverter drive for the AC motors. And prove it with the best literature review.

This paper is going to discuss an efficient technique to control the speed of a single phase induction motor in three steps by using cycloconvertor technique by thyristors. The induction motor is known as a constant-speed machine. And this paper is successfully proposing one of the efficient, easy and cheaper technique to control the speed of induction motor. Thus, the speed of the induction motor can be achieved in three steps i.e. (F, F/2 and F/3).

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