Design And Testing Of 3-Phase Converter Applicable To Four Quadrant Operation

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ABSTRACT

It is needless to say that four quadrant principle plays a vital role in industrial applications .Running a machine both in motoring and generating action illustrates the four quadrant operation. In electric locomotives, the motor may run clock wise and anti clockwise, and the torque may act either with or against the direction of rotation. In other words the speed and torque may be positive or negative. An attempt is made in this paper to demonstrate this principle by designing the required converter. Here, converter performs dual function i.e. both as rectifier (AC to DC) and inverter (DC to AC)

Though the carrier period is fixed, the ON/OFF pulse widths are changing continuously that's why this type of switching is called Pulse Width Modulation,(PWM). This PWM technique has been adopted in this paper with six-number of Insulated Gate Bipolar Transistors (IGBT's) corresponding driver circuit. So designed converter has been tested with CRO at different stages .The same has been counter conformed by simulation process using MAT LAB/ Simulink.

The bi-directional operation of converter is successfully observed at respective stages by CRO which depicts four quadrant operations.

Keywords – Four quadrant, SPWM

I. INTRODUCTION

This paper is focus on design and testing of 3-phase converter applicable to four quadrant operation. The IGBT model is used as a switching device. To get the proper output by closing and opening the switches in appropriate sequence or switching scheme. For that sinusoidal pulse width modulation (SPWM) is used by controlling the closing and opening switches.

The basic designed converter is rectifier circuit it converts (AC to DC) i.e. the converter operates in first and third quadrants. By controlling the PWM signal amplitude and phase angle to get the reverse flow of the converter i.e. inversion (DC to AC) operation is takes place in this case the converter runs in second and fourth quadrants.

There are several applications where energy flow can be reversed during the operation these are Locomotives, Downhill conveyors, Cranes, Motoring and Generating action of the machine.

In all these applications, the line side converter must be able to deliver energy back to the power supply.

BLOCK DIAGRAM AND DISCRIPTION

The following fig 1 shows the basic blocks in four quadrant operation of the converter
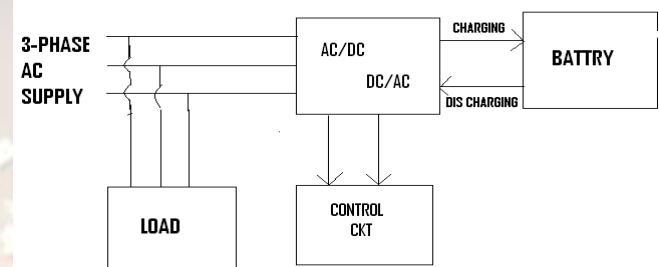
. Figure 1: Basic block diagram of four quadrant converter

The basic block diagram consists of 3-phase A.C supply as a input is given to the four quadrant converter and output of the converter connected to the battery. The basic block diagram is a voltage source rectifier; by controlled the PWM signal achieve the reverse flow. The rectifier diagram as shown in fig 5.Control circuit controls the phase angle and amplitude, of the PWM signal for four quadrant operation.   In this paper the input supply is 3-phase AC 430V 50HZ is given to the converter circuit .In first and third quadrant the converter act as a rectifier and second and fourth quadrant the converter act as a inverter mode. Hear battery was used to store the D.C power .When A.C source is available the converter converts the A.C to D.C i.e. the converter runs in first quadrant and third quadrant ,In this mode battery getes charged and A.C load is driven by the A.C source. If source is open circuit than the battery gets discharge through the converter in this case the converter act as a inverter i.e. the converter runs in second and fourth quadrant and A.C load driven by the D.C source[7].
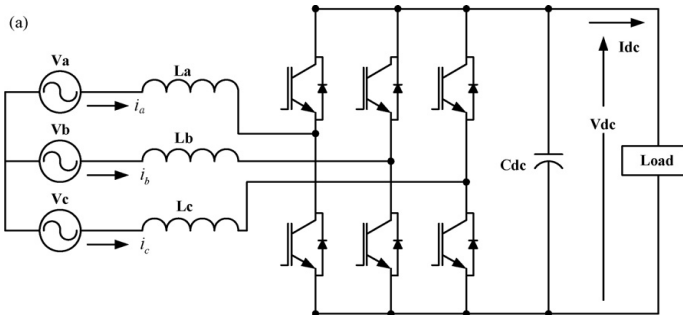
(a)

Figure 2: Topology of IGBT based converter

3. MODES OF OPERTION

In this paper the converter operates in two modes those are

1. 1st and 3rd quadrant operating mode (battery charging)
2. 2nd and 4th quadrant operating mode (battery dis-charging)

3.1 1st and 3rd QUADRENT OPERATION

In this two quadrant the converter act as a rectifier i.e. it converts A.C to D.C. The A.C to D.C conversion is used increasingly in a wide diversity of application: power supply for microelectronics, electronic ballast, battery charging, D.C motor drives etc. In this case A.C supply act as source and D.C act as load so in this quadrants battery charging is takes place .

3.2 2nd AND 4th QUADRENT OPERATION:

In this mode two quadrant the converter act as a inverter i.e, D.C battery act as a source and A.C act as a load the converter converts D.C to A.C and drive the3-phase A.C load in this case consider the A.C supply is open circuit so battery dis-charging is takes place through the converter.

3.3 V-I PLANE WITH THE QUADRANT DEMARCATED

When the plot the V-I plane with the quadrant demarcated as shown as fig:2 The average positive voltage and current of the converter indicating rectification mode and power flow   A.C source to D.C load and negative current and voltage indicating the inversion mode i.e. direction of the power is flow D.C to A.C[6]
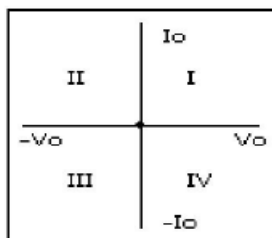

Figure 3: V-I Plane with the quadrant demarcated.
As shown as above fig:3 in first and third quadrant output current and voltages are positive i.e.

Power flow from A.C to D.C in this case machine act as a motoring mode.

Designing Datasheet
IGBTs: SEMIKRON SKM 50 GB 123D, Max ratings:
VCES = 1200 V,
IC = 80 A
DC- link voltage: V dc = 900 V
 Fundamental frequency: f = 50 Hz
 PWM (carrier) frequency: fz = 50 MHZ
 Modulation index: m=0.8
 Load: Load = 10KVA

4. IMPLIMENTATION OF 1st AND 3rd QUDRENT CONVERTER OPERATION

In this two quadrant the converter act as a rectifier i.e.it converts A.C to D.C. In this two quadrant battery gets charging and as well as the A.C load driven by the A.C source
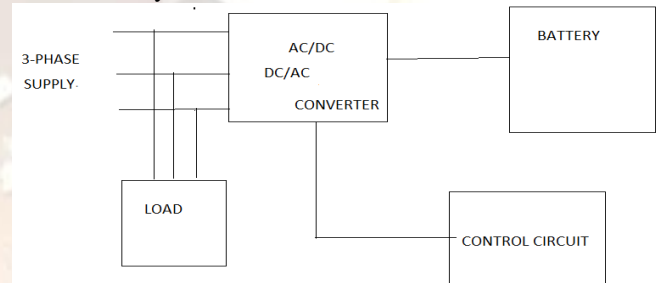

Figure 4 : Basic diagram of 1st and 3rd quadrant converter
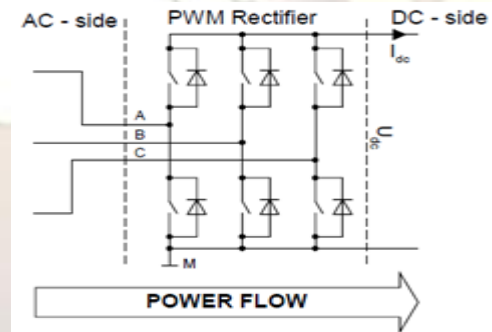

Figure 5: Rectification mode

In this mode of operation the power flow from A.C source to D.C side and to charge the battery .The above bridge having six switch as shown as the above figure5 the upper group switches are called positive group switches i.e. S1,S3,S5 and bellow group switches are called negative group switches i.e.S4,S6,S2.The positive group switches are conduct at an interval of 120◦, similarly the negative group switches are conduct with an interval of 120◦.At a time two switches are conduct in positive group and other from negative group or two in negative group and other from positive group.In this case the PWM signal generates based on the source sine wave i.e. PWM signal reference sine wave and source sine as same frequency and amplitude
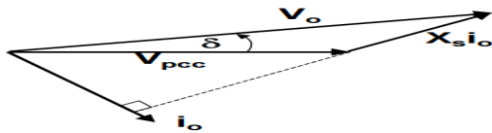
Figure 6: Phasor diagram for power flow A.C to D.C
Where,
V_{PCC}=Point for coman coupling (converter input voltage)
V_O= Converter output voltage,
I_o= Converter output current,
δ= Phase angle.

In this quadrant operation the output current(I_o) is lagging with converter input voltage(V_{pcc})as shown as fig 6[7] in this case the converter act as a rectifier it converts the A.C to D.C and to charge the battery.
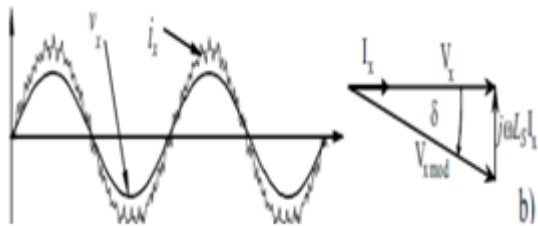

Figure 7:Phesor diagram of the 1st and 3rd quadrant operation
Where
V_x=Source input voltage V_{xmod}=PWM sine wave voltage I_x=input curent

As shown as fig:7 in rectification operation to make the rectification work properly ,the PWM pattern must generate a fundamental V_{xmode} with the same frequency of the source V_x.In this case V_{xmode} lags the source input voltage V_x and input voltage and currents are same directions, following fig 8 shows experimental set up.

Figure 8: Experimental setup of the rectifier circuit
FORMULAS:

$$Vo = \frac{3Vml}{2\pi}(1 + \cos \acute{\alpha})$$

$$I_s=I_O\sqrt{(2/3)}$$

Where V_o= Output Voltage
I_o=Output Current

Vml=input line voltage

THEORITICAL CALCULATIONS:

Output voltage(V_o)=$\frac{3*430}{2\pi}(1 + \cos137.4)$=54V

Here   Vml= 430V, α=137.4°
In this case output is getting 54V and battery current is 30A .
Then calculated I_s=30$\sqrt{(2/3)}$ =24.4A

5. PHASE ANGLE AND AMPLITUDE CONTROLE:

The following power circuit and working principle is given the information about the how the phase angle and amplitude changing of the PWM sin wave and how the four quadrant operation is possible
Power circuit and working principle: It is well known that voltage source inverter(VSI),like the one shown in Fig.9 can work in four quadrants .In two of these quadrants ,the VSI works as a rectifier, that means, as a voltage source Rectifier or VSR. However, a stand-alone VSR requires a special DC bus able to keep a voltage Vo without the requirement of a voltage supply. This is accomplished with a DC battery and a feedback control loop.
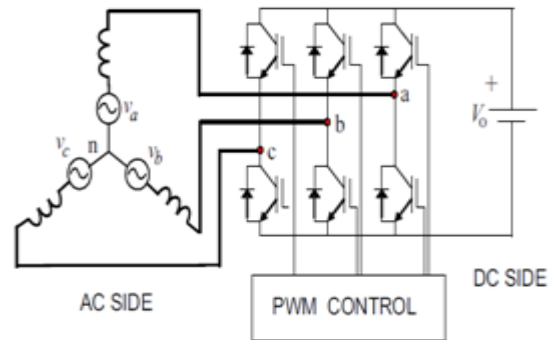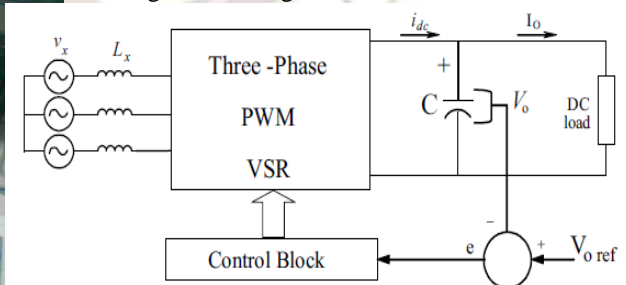

Figure 9.Voltage source PWM rectifier

Figure 10: Operating principle of SR

The basic operation principle of VSR consists on keeping the load DC-link voltage at a desired   reference value, using a feedback control loop as shown in Fig.10[1]. This reference value Va ref, has to be high enough to keep the diodes of the converter blocked. Once this condition is satisfied, the DC-link voltage is measured and compared with the reference Va ref, The error signal generated from this comparison is used to switch ON and OFF the valves of the VSR. In this way, power can comes or return to

the AC source according with the DC-link voltage value.

When the DC load current Io is positive (rectifier operation), the capacitor C is being discharged, and the error signal becomes positive. Under this condition, the control Block takes power from the supply by generating the appropriate PWM signals for the six power transistor of the   VSR. In this way, current flows from the AC to the dc side, and the capacitor voltage is recovered. Inversely, when Io becomes negatives (inverter operation), the capacitor C is overcharged, and the error signal asks the control to discharge the capacitor returning power to the AC mains.
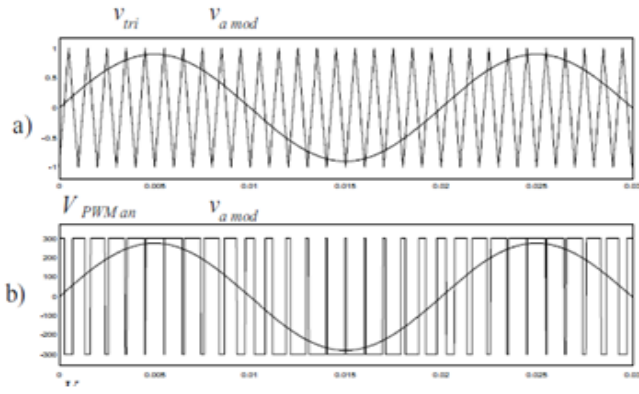

a)

Figure 11: PWM signal a) Triangular carrier and sinusoidal reference, b) PWM phase modulation

The modulator switches the valves ON and OFF, following a pre-established template. Particularly, this template could be a sinusoidal waveform of voltage (voltage source, current controlled PWM rectifier) or current (voltage source, current controlled PWM rectifier). For example, for a voltage controlled rectifier, the modulation could be as the one shown in Fig.11[1], which has a fundamental called Vx mod, proportional to the amplitude of the template. There are many methods of modulations. Being the most popular the so called Sinusoidal Pulse Width Modulation(SPWM), which uses , a triangular carrier(V_{tri})to generate the PWM patron. To make the rectifier work properly, the PWM pattern must generate a fundamental Vx mod with the same frequency of the power source Vx, Charging the amplitude of this fundamental, and its phase-shift with respect to the mains, the rectifier can be controlled to operation the four quadrant: leading power factor rectifier, lagging power factor rectifier, lead power factor inverter, lagging power factor inverter. Charging the pattern of modulation , modifies the magnitude of Vx mod, and displacing the PWM pattern changes the phase-shift.
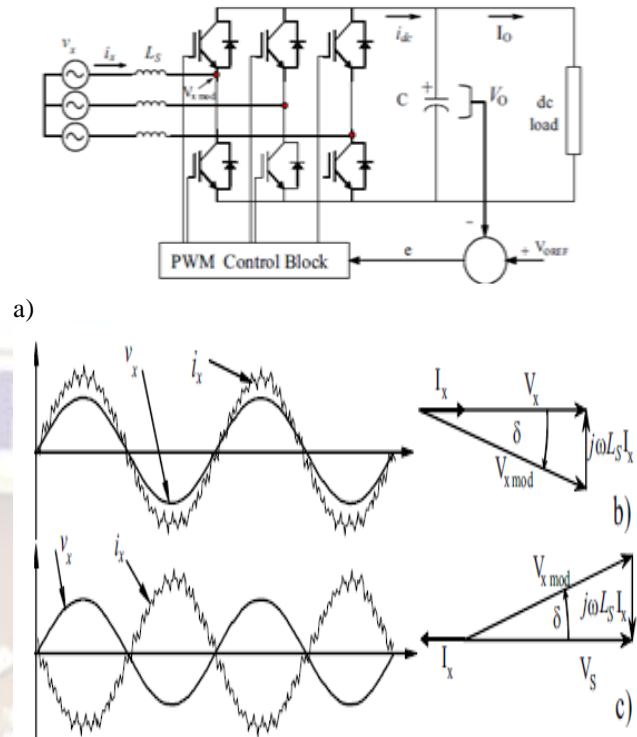

Figure 12: Four quadrant operation of the VSR a) Basic Rectifier diagrm, b) Rectifier operation, c)Inverter operation

Whear

V_x =Vs= Converter input voltage

I_x= Converter input voltage

V_{xmod}=PWM reference sin wave voltage amplitude

In rectifier operation i.e. 1st and 3rd quadrant PWM reference sin wave amplitude (V_{xmod}) lags the converter input voltage(V_x) in this case inptut current and input voltage is same direction as shown as above fig 12(b). Under this condition, the control Block takes power from the supply by generating the appropriate PWM signals for the six power transistor of the   VSR. In this way, current flows from the AC to the dc side

In inverter operation i.e.2nd and 4th quadrant operation PWM reference sin wave amplitude(V_{xmod}) leads the converter input voltage (V_x) in this case inptut current and input voltages are posit direction as shown as above fi12(c). When Io becomes negatives (inverter operation), the capacitor C is overcharged, and the error signal asks the control to discharge the capacitor returning power to the AC mains.

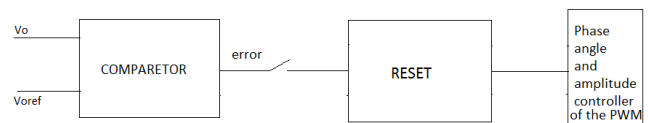In this way can controlling the phase angle and amplitude of the PWM signal

Figure 13: Over all control diagram

As shown as the above figure 13,Comparator (CR3260E) compare the DC output voltage with

reference voltage, if any variations in voltages it gives error signals. When error signal is present the switch is closed and the reset is ON and it   gives the signal to the phase angle and amplitude controller block. It controls the phase angle and amplitude of the PWM reference sin wave. When amplitude and phase angle of the PWM sin wave changes the reveres flow is occurred

6. IMPLIMENTATION OF 2nd AND 4th OPERATION
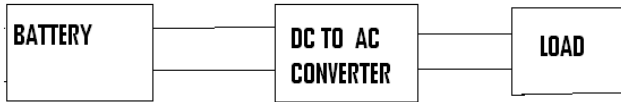

Figure 14: Basic block diagram of 2nd and 4th quadrant operation

In this two quadrant the converter act as a inverter i.e, D.C battery act as a source and A.C act as a load the converter converts D.C to A.C and drive the3-phase A.C load in this case consider the A.C supply is open circuit so battery dis-charging is takes place through the converter ,it contains above blocks as shown as fig 14.IGBT based converter as shown as fig 15.
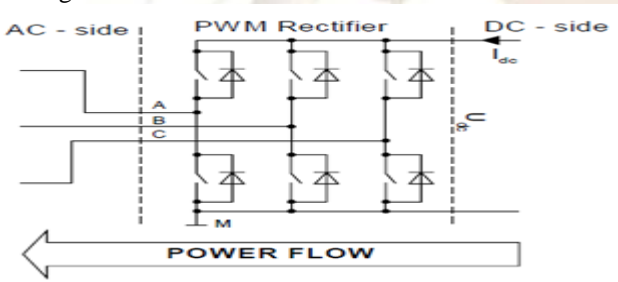

Figure 15: Power flow DC TO AC

In above figure 15[7] upper switches are called as a positive group elements i.e.S1,S3,S5, and lower group switches are called negative group elements i.e.S4,S6,S2.It operates 180∘ conduction mode so the switches pair in each arm i.e.S1,S4;S3,S6; and S5,S6 are turned on with a time interval of 180∘ it means that S1 conducts for 180∘ and S4 for the next 180∘ of a cycle. Switches in the upper group i.e. S1,S3,S5 conduct at an interval of 120∘.In this manor conduction of the switches are takes place.

FORMULAS:

Rms value of fundamental line voltage (V_L) = 0.8165 Vs

Rms value of phase voltage (V_P) = 0.4714V_s

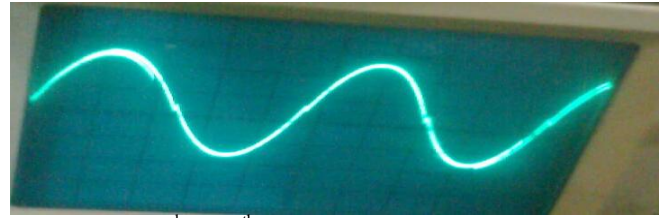the inversion mode of operation. Output wave form of the inverter is show in 16.

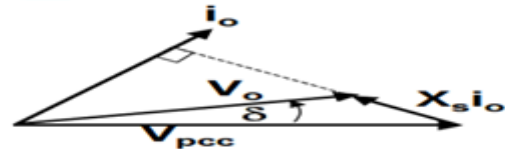Figure 16: 2nd and 4th Quadrant converter output waveform

Figure 17: Phaser diagram for power flow D.C to A.C

In inversion mode the above phaser diagram fig 17: is obtained the output current of the converter leads to the input voltage so that based up on this leading current power flows reveres direction i.e. D.C to A.C. So by varying the angle between converter output current and converter input voltage it converter A.C to D.C and D.C to A.C. when the taking of converter input voltage is reference the lagging converter output current gives the rectification operation and leading converter output current gives the inverter operation. In this way achieve the bi-directional   power   flow[7]
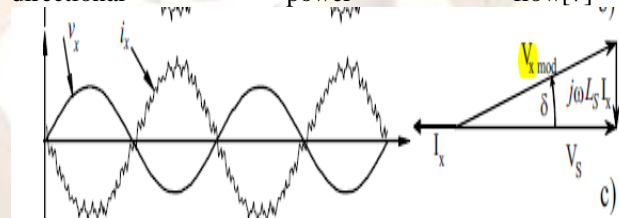

Figure18: 2nd and 4th quadrant operation mode

V_s=input voltage, V_{xmod}=PWM reference sine wave voltage

In this operation PWM reference sine wave voltage V_{xmod} leads the input voltage V_s so the current flows reverse direction as shown in fig 18:

SYSTEM PARAMETERS:

The system parameters for this converter are as follows

IGBTs: SEMIKRON SKM 50 GB 123D,
Max ratings: VCES = 1200 V,
IC = 80 A
DC- link voltage: V dc = 900 V
Fundamental frequency: f = 50 Hz
PWM (carrier) frequency: fz = 50 MHZ
Modulation index: m=0.8
Load: Load = 10KVA

7. SIMULATION RESULTS:

This total paper simulated in MAT LAB software using sim power systems blocks. The following fig :19 locks are used to simutate the circuit.
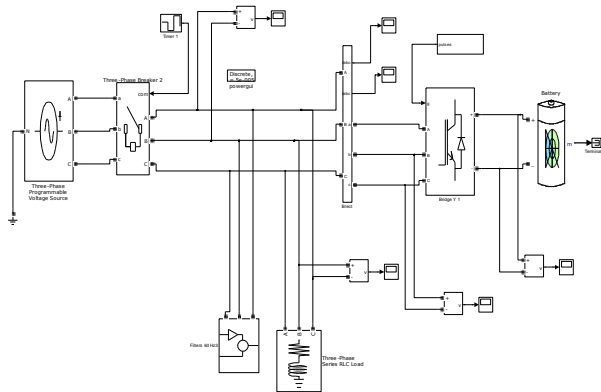

Figure:19 simulation diagram

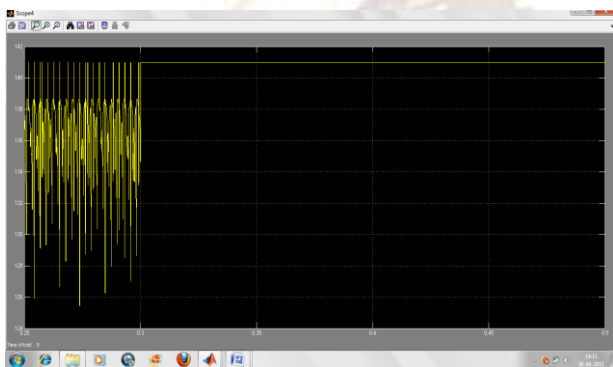Simulation diagram used to counter check of the hard ware results

Fig :20 Output wave form of the 1st and 3rd quadrant operation

The above wave form shows the rectifier operation of the converter, when AC source is open circuited DC act as a source and it supply the power to the AC mains it is shown in fig 21: after 3 cycle.
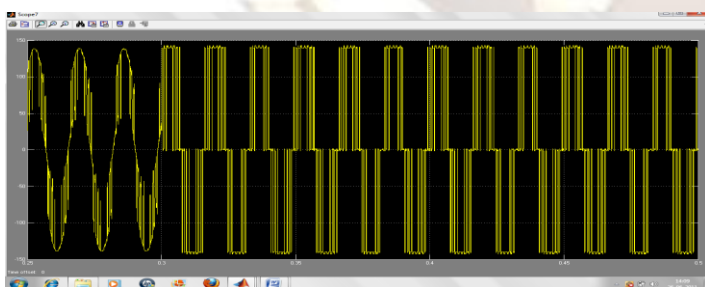

Figure 21: Simulation results

8. CONCLUSION:

1. The back bone of the 3-phase four quadrant operation system i.e. 3-phase converter has been design and tested successfully.
2. Various design stages of 3-phase converter
   i) Using six IGBT's a rectifier circuit is designed whose input is 430V,50HZ ,AC and output 54V DC.

ii) Control circuit for the converter also designed. Where in phase angle and Amplitude of the PWM can be changed. This control circuit is feed by storage DC batteries through an error amplifier.
3. A simulation is carried out on the converter circuit and the waveforms have been generated.

9. FEATURE SCOPE:

Has this paper focus on the demonstration of four quadrant operation, this so designed converter along with auxiliary circuits can be used for real time applications of four quadrant operation drive.

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