Power Quality Improvement Using Bidirectional AC Chopper with RL Load

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Abstract- ***Some of the sensitive loads like the communication equipment's, computer systems and process automation equipment's could introduce voltage imbalance in the single phase power supply. In order to enhance the voltage or to manage the voltage regulators were used which introduced input side and output side harmonics. This paper is an attempt to develop an ac-ac buck boost topology that would introduce the voltage regulation in single phase AC systems. The system consists of an AC chopper which is derived from the DC buck boost chopper. The AC buck boost chopper would work in four quadrant operation and thus needs the bidirectional switches to operate it. According to the IEEE 519 standard for the total harmonic distortion (THD) the input current THD must be less than 5%. Thus an input side LC filter is used to obtain the input current THD reduction. The higher efficiency AC chopper for voltage regulation is developed with the regenerative DC snubber connected to the switches which observe the energy stored in the stray inductance. Mat lab Simulink model is created to have a closed loop operation of the implementation with the zero crossing detectors and to engage in the PWM that it would provide for the voltage regulation.***

An open loop AC chopper circuit is designed with RL load and hardware is implemented to observe the buck and boost operation of the converter. The FFT analysis is carried out in order check the Total Harmonic Distortion of source current, output voltage and current. The hardware results obtained is confirmed with the simulation result obtained.

I. INTRODUCTION TO AC TO AC CONVERTER

Electricity distribution in India is 230V designed for single phase and 415V line to line for three phase system. All appliances sold in India works in the range of 230V-240V. Voltage lower and higher than this range needs to be corrected, if the appliances cannot handle that voltage which are called as sag and swell corrections.

1.1 AC To AC Converter

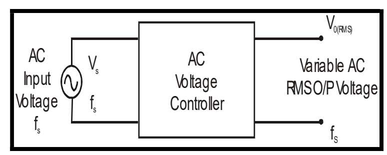

Fig.1.1 AC to AC Converter Block Diagram

The control and conversion of power from AC-DC to AC-DC is the main application of power electronics converter. The above block diagram is the AC to AC converter that uses thyristor family members which has fixed input voltage and variable output voltage. This AC to AC converter is also known as cycloconverter where both frequency and output voltage are variable.

These AC voltage controllers have low input power factor even for resistive loads. They have high value of lower order harmonics both at input and output sides. Hence they require large value of filter elements to reduce lower order harmonics.

These problems can be overcome by using AC chopper circuits. In this case, the PWM technique can be implemented to fluctuate the RMS value of the output electrical energy. In this circuit we can use transistor family members to chop the waveform at higher switching frequency. Now a day's these converters are mainly used in AC drives, series & shunt controllers, as a dimmer stat that handle up to 10 MW of power.

1.2 Single Phase Ac Voltage Controller With Rl Load

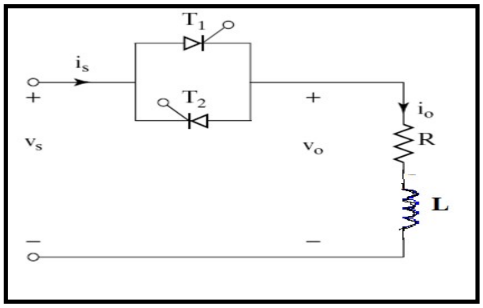

Fig.1.2 AC Voltage Controller by Connecting two thyristor are in Inverse for RL load

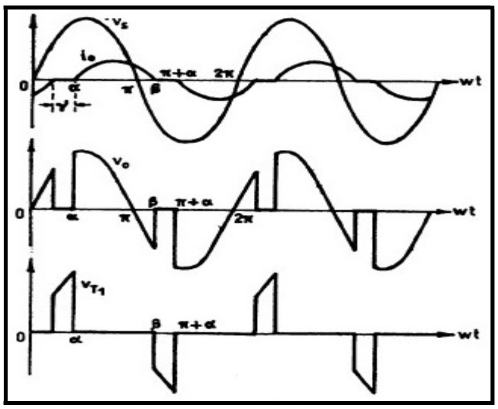

Fig.1.3 Waveforms of single phase AC voltage controller for RL load

A full-wave controller with an RL load is shown in fig. (10) The thyristor 'T_1' is fired during the positive half-cycle and it carries the load current. Due to the presence of inductor in the circuit, the current of thyristor 'T_1'will not fall to zero, at $\omega t = \pi$, when the input voltage starts to be negatives. The thyristor 'T_1' continues to conduct until its current i_1 falls to zero the thyristor 'T_1' turned off at extinction angle 'β'therefore negative voltage will appear from $\omega t = \pi$ to β.

When the thyristor 'T_2' is fired at $\omega = \pi + \alpha$ the load current flows in negative direction and input negative load. It is required vary α from $\theta(\cos\Phi = 0.9)$ to π that is if $\alpha < \theta$, then output voltage and current will be pure sine wave.

The RMS output voltage is given by

$$V_0 = \left[\frac{2}{2\pi}\int_{\alpha}^{\beta} 2Vs^2 \sin^2 \omega t d(\omega t)\right]^{1/2}$$

$$V_0 == \left[\frac{1}{\pi}\left(\beta - \alpha + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}\right)\right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

Applications of AC Voltage Controller:
Lighting Control; Domestic and Industrial Heating; Speed Control of Fan, Pump or Hoist Drives, Soft Starting of Induction Motors, Static AC Switches (Temperature Control, Transformer Tap Changing, etc.).

Load Calculation:
Load resistance R=100Ω, load power factor considered is 0.9
Therefore 'L' is calculated and considered in simulation,

a. $Z = \frac{R}{\cos\Phi}$

$Z = \frac{100}{0.9}$

Z=111.1Ω

b. $X_L = \sqrt{Z^2 - R^2}$

$= \sqrt{111.1^2 - 100^2}$

X_L =48.48

c. $X_L = 2\pi f L$

48.48=2π (50)

L=0.15H

Hence load value are R=100Ω, L=0.15H

1.1.4 Simulation of AC voltage Controller with RL load in Mat lab/Simulink

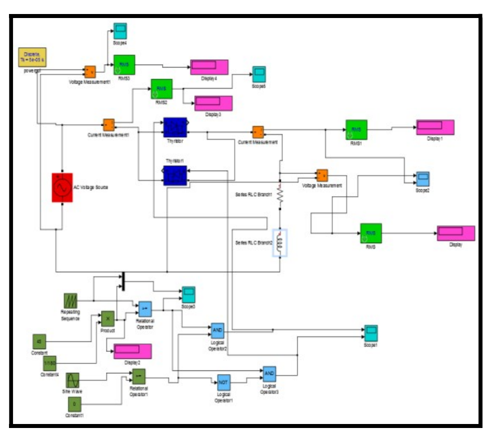

Fig.1.4 Simulation model of AC Voltage controller with RL load

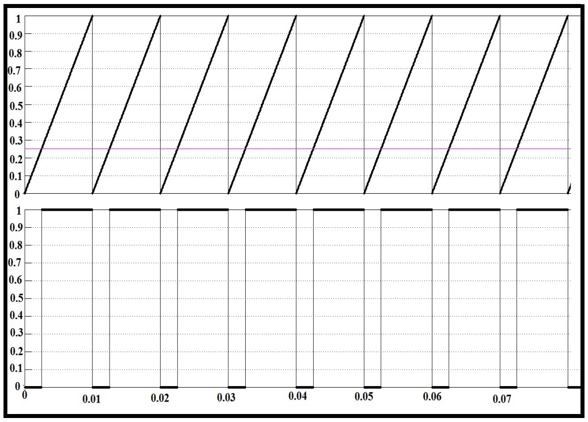

Fig. 1.5 AC voltage controller pulses generated with Ramp and control voltage comparison

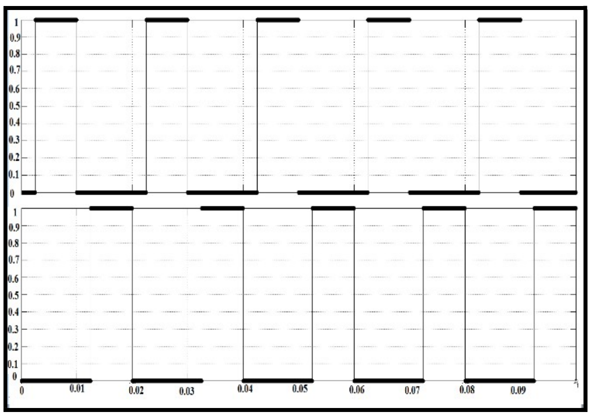

Fig.1.6 Gating signals created for Thyristor switch T_1 and T_2 with RL load

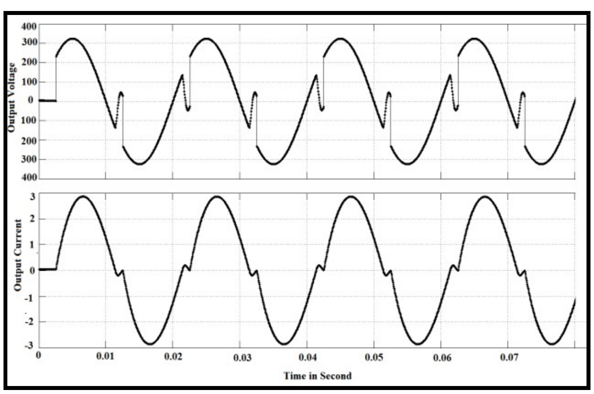

Fig.1.7 Output Voltage and current waveform of AC voltage controller with RL load at an angle of 45^0

Table I. AC Voltage Controller with RL load

Supply Voltage V_s=230

Alpha	V_o RMS	I_o RMS	I_s RMS	V_o THD	I_o THD
15	229.3	2.07	2.07	4.11%	8.93%
30	228.3	2.06	2.06	11.69%	10.23%
45	221.2	1.93	1.93	27.07%	16.65%
60	208	1.77	1.77	40.08%	25.96%
75	188.7	1.54	1.54	55.16%	36.87%
90	164.4	1.28	1.28	71.60%	48.88%
105	135.9	0.99	0.99	93.45%	64.33%
120	104	0.68	0.68	124.29%	85.05%
135	73.58	0.41	0.41	172.76%	116.16%
150	43.33	0.18	0.18	208.34	207.54%

The plots in figures 1.8 to 1.11 shows the chracterstics diagram of AC voltage controller with RL load

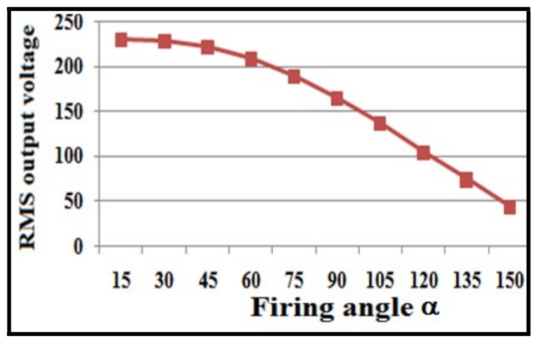

Fig.1.8 RMS output voltage versus Firing Angle α

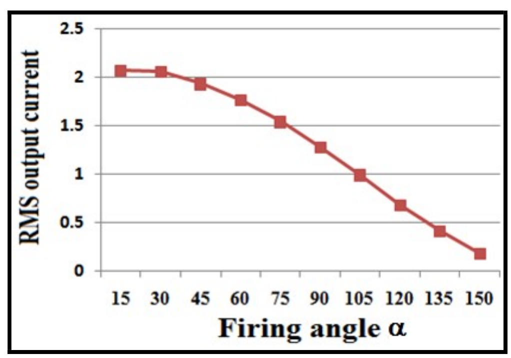

Fig.1.9 RMS output current versus Firing Angle α

The fig. 1.9 shows RMS output current versus firing angle 'α', the RMS output current decreases 2.70 to 0.18 with increase in 'α'.

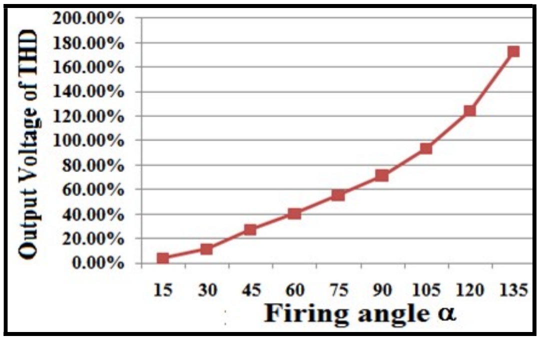

Fig.1.10 Output voltage of THD versus Firing angle α

The fig. 1.19 shows output voltage of THD versus firing angle alpha. With the increase in ‘α’, the output voltage THD is also increases from 4.11% to 208.34% therefore there is more distortion in the output voltage waveform with respect to increase in ‘α’ because of ‘RL’ load.

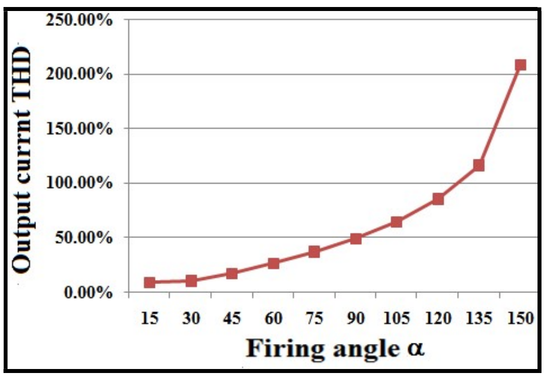

Fig.1.11Output current of THD versus firing angle α

The fig.1.11 shows output current of THD versus firing angle ‘α’. With the increase in ‘α’, the output current THD is also increases from 8.93% to 207.54% therefore there is more distortion in the output current waveform with respect to increase in ‘α’ because of ‘RL’ load.

1.2 Four Quadrant Bidirectional Switch:

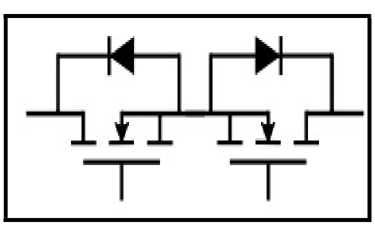

Fig.1.12 MOSFET Bidirectional switch

The use of switches in the bidirectional power transfer in the AC regulators, to block the voltage of both the polarities and to the control of conduction of current in forward and reverse direction is shown in fig.20. The two anti-series MOSFET are used which has body diode to support for bidirectional current flows these type of switches are suitable for four quadrant operation in AC to AC converter operated with PWM technique.

II. LITERATURE SURVEY

The power quality disturbances sensitive loads such as communication equipment’s, computers and method of automation system results in loss of valuable data, interruption to communication services and long production shutdowns. As per IEEE standard 446-1987 describe the voltage tolerance limits for sensitive loads, such as computer power supplies [2-3]. As per this standard, a voltage drop of more than 15% cannot be tolerated for more than 25 cycles. Similarly, a 35% voltage drop can be tolerated for only one cycle (20ms). Loads like heaters, illumination control, furnaces, and ac motor speed control and theatre dimmers uses ac voltage controllers. Such voltage regulators, however, have slow response, poor input power factor, and high magnitude of low order harmonic at both input and output sides. And they require large input-output filters to reduce the low order harmonics which are large in the line current. These drawbacks have been overcome by designing various topologies of ac chopper [4-8]. In most standard ac choppers, the commutation causes high voltage spikes and another current path has to be provided when current paths are changed. This alternative current path is implemented using additional bidirectional switches or ac snubber. Such topologies are difficult and expensive to realize and the voltage stress of the switch is also high, resulting in reduced reliability. A fast voltage control technique using a conventional peak voltage detector has been proposed [9]. This scheme still has a dynamic speed of the half period of the line voltage when increasing the output voltage and longer dynamic speed when decreasing the output voltage.

2.1 Problem Statement

The harmonic content introduced by the AC-AC converter usually used in the voltage regulation in both the input and the output side is a big problem that has to be considered. And care must be taken to increase the efficiency of the AC at higher values. The problem statements are:

- To reduce the Total Harmonic Distortion of load and source which should be less than 5%?
- To improve the power factor.
- To improve the efficiency.
- To reduce the output voltage sag and improving efficiency of the converter.

2.2 Proposed Work

The power circuit is made up of a PWM based buck boost ac chopper with regenerative dc snubber, the converter uses two sets of 4-quadrant bidirectional switches. In the ac chopper, the commutation scheme allows dead-time to avoid current spikes from switches and at the same time establishes a current path in the inductor to avoid voltage spikes. The ac chopper uses regenerative dc snubber attached directly to power semiconductor switches to absorb energy stored in stray line inductances. This dc snubber enhances the conversion efficiency as it has very simple structure consisting of a capacitor only, without a discharging resistor or a complicated regenerative circuit for snubber energy. Therefore, the ac chopper gives high efficiency and high reliability. The voltage regulator is controlled in the equal PWM pattern which is efficient and simple to implement.

By using this AC chopper it is required to reduce the Total Harmonic Distortion to achieved good power factor, good efficiency and also reduce the size of the filter element can be reduced. The circuit is designed in open-loop mode and tested for buck and boost operation AC chopper. The efficiency of the converter can be increased by using regenerative dc snubber and a circuit is designed with input LC filter to reduce the Total Harmonic Distortion of source current and output current to reduce ripple contents output voltage in turn to reduce the Total Harmonic Distortion of the load voltage and current.

III. BLOCK DIAGRAM OF PROPOSED AC TO AC CONVERTER

3.1 Basic Block Diagram

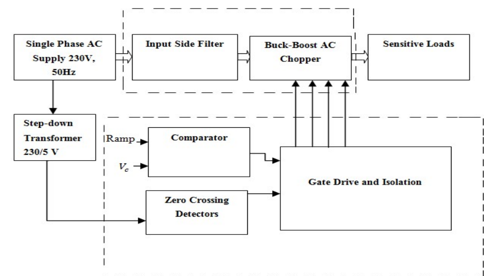

Fig.3.1 Basic Block Diagram of Proposed AC to AC Converter

3.1.1 Single Phase AC Supply

Single phase 230V, AC supply is given to the circuit whose frequency is 50 Hz, sinusoidal waveform.

3.1.2 Input Side Filter

In input side we are using an LC filter this LC filter reduces the Total Harmonic Distortion of the source current. The desirable Total Harmonics Distortion of source current is less than 5%.

3.1.3 Buck-Boost AC Chopper

The AC chopper which will converts fixed AC voltage to Variable AC voltage, this simple buck boost converter produce voltage less than or more than the input voltage. The sag and swell corrections can be taken care using AC chopper circuit.

3.1.4 Sensitive Loads

In sensitive loads, voltage quality is the most important part of the power quality. The voltage disturbances in the form of voltage sag, swell and harmonics can cause huge financial losses. The dynamic voltage regulators are provided based on single phase direct ac to ac converter. The sensitive loads such as communication equipments, computer and process automation system.

3.1.5 Zero Crossing Detectors

Zero crossing detectors is a voltage comparator that switches the output between positive voltage saturation and negative voltage saturation when the input crosses zero reference voltage. It is a common point, where the signals of the function will get changes that are from positive to negative and negative to positive. And it is indicated by crossing of an axis in the waveform of a function. In each cycle it occurs two times, at the instant of zero crossing point the voltage will be zero.

3.1.6 Gate Drive and Isolation Circuit

We use opto-coupler for electrical isolation between control circuits and power circuit's driver IC to switch the MOSFET's increasing the voltage and current strength for proper switching operation.

IV. SINGLE PHASE OPEN LOOP AC CHOPPER USING BIDIRECTIONAL SWITCHES

4.1 Circuit Diagram

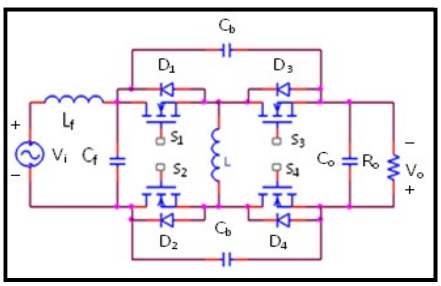

Fig.4.1 AC chopper using bidirectional switches and regenerative dc snubber

The figure shows the basic circuit of buck-boost AC converter with unidirectional switches and a regenerative DC snubber. The circuit will operate directly by the supply voltage V_s and it will regulate the input voltage by using the switches. The DC snubber consists of capacitor only C_b only. It does not contain any resistance with it and it will absorb bidirectional turn-off spike energy due to line stray inductance. The snubber energy is regenerated during charging mode and it will provide energy to inductor. The input filter L_f and C_f absorb the harmonic currents.

The circuit uses bidirectional switch module that is made up of two MOSFET's, the switches S1, S2, S3 and S4 are unidirectional and therefore the inductor 'L' which is used to store the input energy and transfer it to the output side. A switching method is used for solving the commutation problem, and it is based on the polarity of the switches the unidirectional switches S2 and S4 are also turned ON, during positive half cycle when input voltage Vi is less than zero then the switch S1 and S3 are turned ON additionally to avoid commutation process of switches and open path for inductor current Here the inductor current is by passed through the input side or output side that depends on the direction of the inductor current.

The Modes of Operation

- During Positive Half cycle ($V_{I>}0$)

During the analysis of positive half cycle the switch S_2 and S_4 are turned ON and modulating signals are given to switch S_1 and complementary modulating signals to S_3 during positive half cycle, the source current flows through Vs→S1→L1→diode across S2 and back to source.

During the regeneration process the switch S_1 will gets turned OFF then the inductor current i_L is positive it will passes through switch S_4 and to the load 'R' then it will goes back to inductor 'L' through a switch S_3 across diode D_3($L \rightarrow S_4 \rightarrow R \rightarrow D_3 \rightarrow L$).when the inductor current i_L is negative then it will flows from inductor 'L' to diode D_1 it will come back to supply V_s, from V_s it will flows to switch S_2 to the inductor 'L'($L \rightarrow D_1 \rightarrow Vs \rightarrow S_2 \rightarrow L$).

- During Negative Half cycle ($V_{I<}0$)

During the analysis of negative half cycle the switch S_1 and S_3 are turned ON then the modulating signal are given to switch S_2. The current will flows to the switch S_2 from the supply V_s and it will passes through the inductor 'L' then to the diode D_1 to the supply V_s ($V_s \rightarrow S_2 \rightarrow L \rightarrow D1 \rightarrow V_s$). When the inductor current i_L is positive then the current will flows through switch S_3 to the load 'R' and passes to diode 'D_4' and come back to inductor 'L'($L \rightarrow S_3 \rightarrow R \rightarrow D_4 \rightarrow L$). The negative inductor current will flows through diode 'D_2' to the supply V_s then to switch S1 and goes back to inductor 'L' ($L \rightarrow D_2 \rightarrow V_s \rightarrow S1 \rightarrow L$). It have many advantages Sinusoidal input current with nearly unity power factor, Low magnitude of lower order harmonics (up to 20^{th} order) both at input side and output can be achieved. This can be achieved by putting the filters in input side and output side $THD_V<5\%$ $THD_I<5\%$, DC snubber can be used in order to improve the efficiency of the converter, fast dynamic response: Converter responds sag, swell faster within one switching period time, Continuous monitoring of sag and swell can be achieved. Its applications are process automation, IC fabrication, precision machinery process, medical equipment (critical load), heater, illumination, speed control, Reactive power components STATCOM Series voltage controller Shunt voltage controller.

V. DESIGN OF HARDWARE CIRCUIT

5.1 Selection of Switches

In the AC chopper circuit MOSFET switches are used as it is a high speed switching device. Hence it can be used for low/medium power application with higher efficiency and also this MOSFET switches require a more voltage and do not require current on their control pin since it is a voltage control device.
The switches must have high reliability and good life span. MOSFET shows advantages compare to BJT's, base current for the BJT'S is more whereas for MOSFET gate current is almost equal to zero. The losses in the MOSFET are directly depends on drain resistance $R_{ds.}$a There are two types of MOSFET

- Enhancement type
- Depletion type

5.2 In enhancement type MOSFET, devices will be OFF while gate to source voltages are zero as well as will be turning ON when gate voltage is applied.

5.3 In depletion type MOSFET, devices will be ON while gate to source voltages are zero as well as will be turning OFF when the voltage is applied.

5.4 Inductor Design

Vs=230V, V_{smax}=325.25, D=0.5, $V_{O=}$230V, V_{omax}=325.25V, F=50Hz, F_s=20 kHz, P_s=100w

Step1: $\Delta I_{max} = 2\left(I_{pmax} - \frac{2P_s}{V_{Smax}D_{max}}\right)$

$\frac{2P_s}{V_{smax}D_{max}} = \frac{200}{325.5\times0.5}$= 1.23A

Let $I_{pmax} = 1.5A$

ΔI_{max}=2$(1.5 - 1.23)$

ΔI_{max}=0.54

L=$\frac{D_{max}V_{smax}}{F_s\Delta I_{max}}$

L=$\frac{0.5\times325.25}{20K\times0.54}$

L=15.05mH

Step2: Energy stored EL =$\frac{1}{2}LI^2{}_m$

=$\frac{1}{2}(7.53m)(1.5)^2$

=8.47125mJ

Step3: $A_p = A_w$

A_c=$\frac{2E_L}{K_W K_c B_m}$

K_w=0.6 (single winding) window utilization factor

=3$\times 10^6$ A/m^2($2m to\ 5mAm^2$)

$B_m = 0.25T$ For ferrites

Step3: A_p=$\frac{2\times8.4712m}{6\times1.3\times10^6\times0.25}$

=20.9$\times 19^{-9}m^4$

=20,916mm^4

$A_p = 28,392mm^4$ =A_c=169mm^2, A_w=168mm^2 core type number INT41

A_p=4778mm^4=$A_c = 264\,mm^2$, A_w=181mm^2 mean m_g length l_m=68.67mm

Step4: Permeance in H/turns Λ=$\frac{\mu_0\mu_r A_c}{l_m\mu_r l_g}$

=$\frac{4\pi\times10^{-7}\times2500\times264\times264\times10^{-6}}{68.6\times10^{-3}+2500\times0.5\times10^{-3}}$

=6.289$\times 10^{-7}$H/turns

Step5: Number of turns N=$\sqrt{\frac{L}{\Lambda}}$

=$\sqrt{\frac{7.53m}{6.78\times10^{-7}}}$=109.4 ≅110turns

Step6: a =$\frac{I_{rms}}{s}$=$\frac{1}{3\times10^{-8}}$=0.333mm^2=SWG22

5.5 Driver Circuit

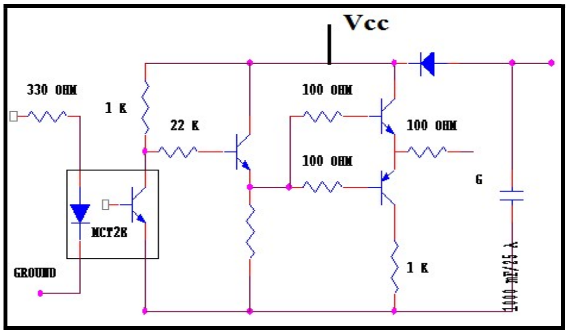

Fig. 5.1 Circuit Diagram of Driver Circuit

For all switching devices it is necessary to increase the switching voltage and strengthen the current. The driver circuit will receive the pulses from the microcontroller which send by the buffer IC CD4050 and is connected to the MCT2E opto-coupler. This opto-coupler is used to protect the power circuit by the isolation with microcontroller circuit, the driver circuit after receiving the signals from the microcontroller it will get enhanced using the 2N2222 transistor to the higher level of voltage. After the higher level voltage, the voltage is changed with the help of Darlington pair. .

5.6 Hardware components and specifications

Table III. Hardware Specifications

Input voltage	12V, 50Hz
Capacitors	0.05 µ F, 9.25µF
Resistance	0.001 Ω,1kΩ
Inductance	20 mH, 26µH, 13,1mH
MOSFET	IRFP250N
Push pull Resistor	R_{11} 10k, R_{12} 10k
Diode	IN4007
microcontroller	8051
Inductor winding	EDT
Buffer IC	CD4050 -4
Opto-coupler	MCT2E
Transistors	2N2222 NPN, SK100 PNP
Linear Transformers	500 M.A. 0-12V -4, 750 M.A 0-12V
Resistive load	1k,50w, 23µH
PIC microcontroller	8051, 40pin IC

VI. RESULTS AND DISCUSSION

6.1 Modeling of open-loop single phase AC chopper in Matlab/simulink using bidirectional switches with R load

The below block shows the three phase programmable voltage source, it consist of following parameters positive cycle in this we are puted the values of 398 of line to line voltage, phase is zero and freqency is 50Hz. Which describes three phase zero impedance voltage source. The time variation of the amplitude, phase and frequency of the fundamenatal can be programmed.

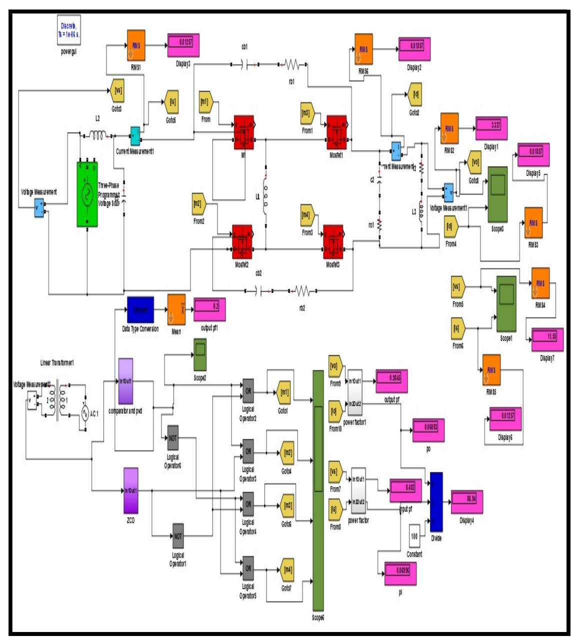

Fig.6.1 Simulation model of open-loop single phase AC chopper using bidirectional switches

6.2 Design of Passive filter Elements for AC Chopper

Input voltage $V_{I=}230V$,

Peak value $V_{imax}=325.25V$,

Output voltage $V_{O=}230V$,

Peak value $V_{omax}=325.25V$,

Switching frequency $F_s=20$ KHz,

Input power $P_i=300W$,

Load resistance R=176.4 ohms &

Inductance L=100mH,

Efficiency η=1 or 100% (efficiency of the ideal converter).

Dc snubber capacitor $C_b=0.1\mu F$, Dead time $t_d=1\mu s$.

We design the converter parameters having the designed step as follows:

a. Peak to peak ripple current result

$$\Delta I_{max} = 2\left(I_{imax} - \frac{2P_i}{V_{imax}k_{max}}\right)$$

$$\Delta I_{max} = 2\left(4 - \frac{2X300}{325.25X0.5}\right)$$

$$\Delta I_{max} = 0.62A$$

b. Inductance calculation

$$L = \frac{k_{max}V_{imax}}{F_s\Delta I_{max}} = \frac{0.5\ X\ 325.24}{20X\ 10^3\ X0.54} = 13.1mH$$

c. Maximum output current

$$I_{omax} = \frac{2P_o}{V_{omax}} = \frac{2X300}{325.25} = 1.85A$$

d. Output capacitor C_o

$$Co = \frac{I_{omax}}{2F_s\,\Delta V_c} = \frac{1.845}{2X20X\,10^3\,X5} = 9.22\mu F$$

e. Load resistance

$$R_o = \frac{V_o}{I_o} = \frac{230}{1.85}$$

=124.32Ω

6.3 Open-loop single phase AC chopper using bidirectional switches with RL (V_i=230V)

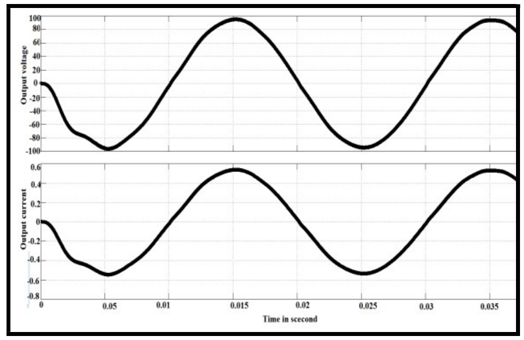

Fig.6.2 Output voltage and current waveform with duty ratio 0.2

(V_ORMS=66.21, I_o RMS=0.36)

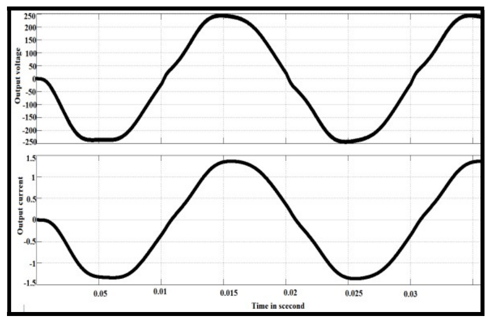

Fig.6.3 Output voltage and current wave form with duty ratio 0.4

(V_ORMS=174.4, I_o RMS=0.97)

Table V. Open-loop single phase AC chopper with RL load

Supply Voltage V_s=230V

D	Is	Io	Vo	Is THD	Io THD	Vo THD	Power factor		Efficiency	Modes of operation
							Input	Output		
0.1	0.09	0.17	31.75	234.31%	0.49%	0.87%	0.38	0.98	66.69%	
0.2	0.25	0.36	66.21	154.29%	0.36%	0.59%	0.48	0.98	86.94%	
0.3	0.56	0.62	111.8	138.60%	1.00%	2%	0.56	0.98	92.29%	
0.31	0.56	0.62	112	138.47%	1%	1.51%	0.56	0.98	93.00%	
0.32	0.65	0.68	122.7	132.83%	1.11%	1.66%	0.58	0.98	93.60%	Sag 20% Vs=230-20% of 230 =184
0.34	0.76	0.74	134.4	127.62%	1.46%	2.07%	0.6	0.98	94.10%	
0.35	0.76	0.75	134.6	127.60%	1.53%	2.18%	0.6	0.98	94.10%	
0.36	0.88	0.81	146.8	122.65%	1.81%	2.56%	0.61	0.98	95.51%	
0.37	0.88	0.82	147	122.58%	1.86%	2.06%	0.61	0.98	94.51%	
0.38	1.02	0.89	160.1	117.93%	2.15%	2.96%	0.63	0.98	94.84%	
0.4	1.18	0.97	174.4	113.58%	2.66%	3.60%	0.64	0.98	95.09%	
0.41	1.18	0.97	174.7	113.47%	2.73%	3.69%	0.64	0.98	95.10%	
0.42	1.36	1.05	189.8	109.44%	3.13%	4.21%	0.66	0.98	95.30%	
0.44	1.56	1.15	206.33	105.30%	3.65%	4.89%	0.67	0.98	95.47%	
0.45	1.57	1.15	206.6	105.24%	3.66%	4.88%	0.67	0.98	95.47%	
0.46	1.79	1.24	223.8	101.44%	4.02%	5.35%	0.69	0.98	95.60%	Swell 20% Vs=230+20%230 =275
0.47	1.8	1.24	224	101.40%	4.06%	5.39%	0.69	0.98	95.60%	
0.48	2.04	1.34	241.6	97.70%	4.73%	6.02%	0.71	0.98	95.69%	
0.5	2.32	1.45	260	94.28%	5.40%	6.62%	0.72	0.98	95.75%	
0.51	2.32	1.45	260.2	94.18%	5.37%	6.58%	0.72	0.98	95.75%	

The fig. below 6.4 to 6.11 shows the charestrictics diagram of open-loop single phase AC chopper using bidirectional switches.

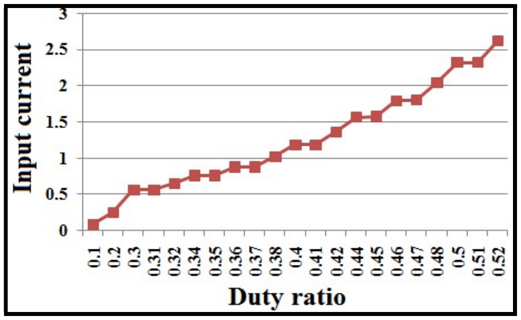

Fig. 6.4 the input current versus duty ratio

The fig. 6.4 shows the input current versus duty ratio. Input current increases from 0.09 to 2.32 with increase in duty ratio.

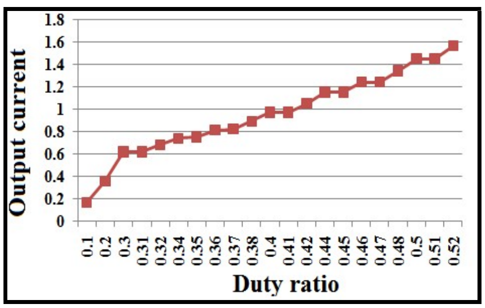

Fig. 6.5 Output current versus Duty ratio

The fig. 6.5 represents the output current versus duty. Output current increases from 0.17 to 1.45 with increase in duty ratio.

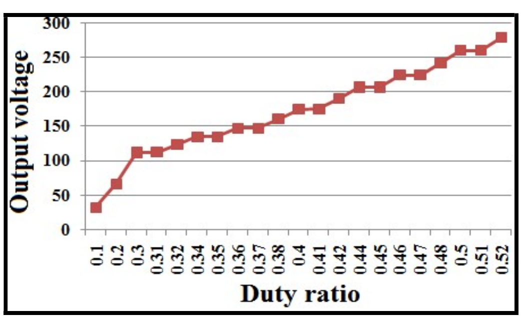

Fig.6.6 Output voltage versus Duty Ratio

The fig.6.6 represents the output voltage versus duty ratio. Output voltage increases from 31.75 to 260.2 with increase in duty ratio.

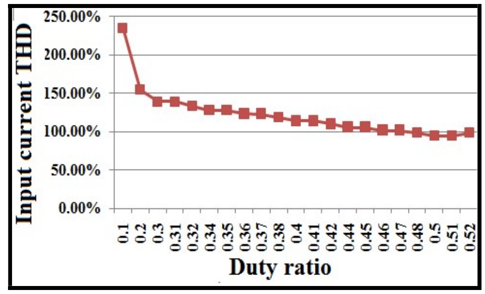

Fig.6.7 Input current THD versus Duty ratio

The above fig.6.7 shows that input current THD versus duty ratio. Input current THD decreases from 234.31% to 94.18% with increase in duty ratio.

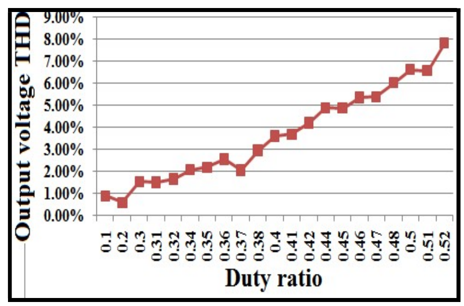

Fig.6.8 Output voltage THD versus duty ratio

The fig. 6.8 shows that output voltage THD versus duty ratio. Output voltage THD increases from 0.87% to 6.58% with increase in duty ratio.

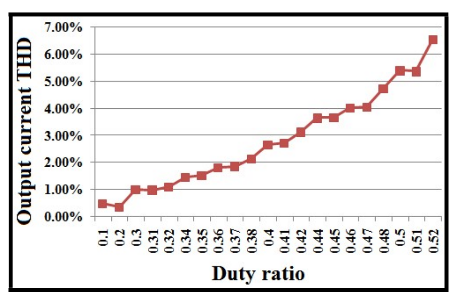

Fig.6.9 Output current THD versus Duty ratio

The fig. 6.9 shows that output current THD versus duty ratio. Output current THD increases from 0.49% to 5.37% with increase in duty ratio.

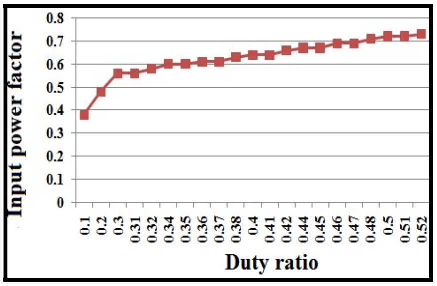

Fig.6.10 Input power factor versus Duty ratio

The fig. 6.10 shows that input power factor versus duty ratio. Input power factor increases from 0.38% to 0.72% linearly with increase in duty ratio.

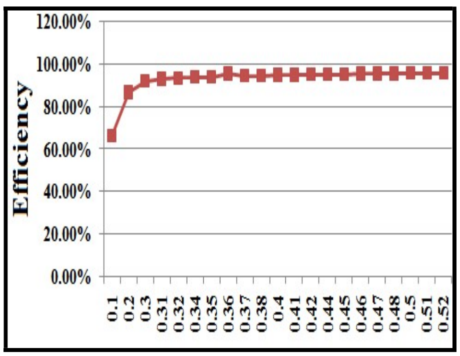

Fig.6.11 Efficiency versus Duty ratio

The above fig. 6.11 shows that efficiency versus duty ratio. Efficiency increases from 66.69% to 95.75% with increase in duty ratio.

6.5.3 Open-loop single phase AC chopper using bidirectional switches with RL Load (VI=15V)

The hardware of AC chopper is designed with input voltage Vs=15V. Therefore simulation is carried out with input voltage 15V. Therefore all the passive elements are redesigned for the same and hardware is implemented.

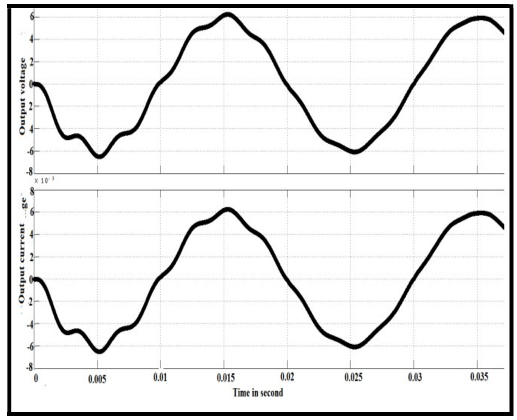

Fig.6.12 Output voltage and current wave form with duty ratio 0.2

(V_ORMS=4.2, I_o RMS=0.004)

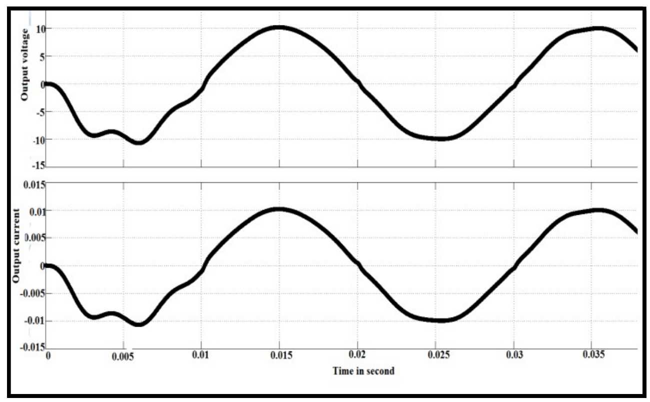

Fig.6.13 Output voltage and current wave form with duty ratio 0.3

(V_ORMS=7.86, I_o RMS=0.007)

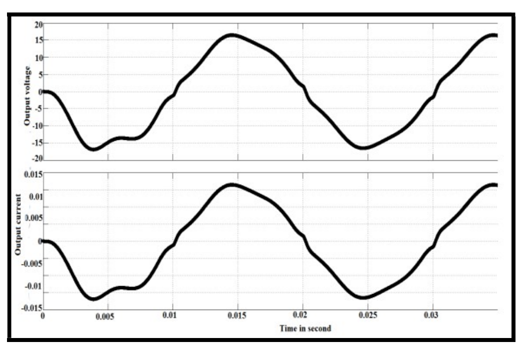

Fig.6.14 Output voltage and current wave form with duty ratio 0.4

(V_ORMS=11.31, I_o RMS=0.01)

Table IV. Open-loop single phase AC chopper with RL load

Supply voltage
Vs=15V

D	Is	Io	Vo	Is THD	Io THD	Vo THD	Power factor		Efficiency	Modes of operation
							Input	Output		
0.1	0.003	0.002	2.06	252.65%	2.91%	2.91%	0.29	1	26.95%	
0.2	0.008	0.004	4.2	183.34%	2.53%	2.53%	0.25	1	55.48%	
0.3	0.01	0.007	7.14	144.28%	2.37%	2.37%	0.25	1	72.59%	
0.31	0.01	0.007	7.16	144.32%	3%	3%	0.25	1	72.54%	
0.32	0.02	0.007	7.86	138.96%	2.76%	2.76%	0.26	1	75.01%	Sag 20% Vs=15-20%15=12
0.34	0.02	0.008	8.63	136.43%	4.35%	4.35%	0.25	1	76.88%	
0.35	0.02	0.008	8.64	136.47%	4.61%	4.61%	0.25	1	76.90%	
0.36	0.03	0.009	9.47	133.50%	5.77%	5.77%	0.25	1	78.54%	
0.37	0.03	0.009	9.48	134.15%	6.20%	6.20%	0.25	1	78.50%	
0.38	0.03	0.01	10.36	125.71%	4.84%	4.84%	0.26	1	80.01%	
0.4	0.03	0.01	11.31	121.00%	4.64%	4.64%	0.27	1	81.60%	
0.41	0.03	0.01	11.32	120.74%	4.71%	4.71%	0.27	1	81.64%	
0.42	0.04	0.01	12.34	119.90%	5.65%	5.65%	0.28	1	82.99%	
0.44	0.05	0.01	13.46	117.64%	6.41%	6.41%	0.29	1	83.83%	
0.45	0.05	0.01	13.48	117.55%	6.38%	6.38%	0.29	1	83.81%	
0.46	0.05	0.01	14.7	114.85%	7.18%	7.18%	0.3	1	84.65%	Swell 20% Vs=15+20%15=18
0.47	0.05	0.01	14.71	115.43%	7.34%	7.34%	0.3	1	84.55%	
0.48	0.06	0.01	16.05	112.70%	8.14%	8.14%	0.3	1	85.43%	
0.5	0.08	0.01	17.56	112.08%	9.37%	9.37%	0.3	1	86.24%	
0.51	0.08	0.01	17.56	112.47%	9.53%	9.53%	0.3	1	86.28%	
0.52	0.09	0.01	19.27	112.04%	11.17%	11.17%	0.3	1	86.73%	

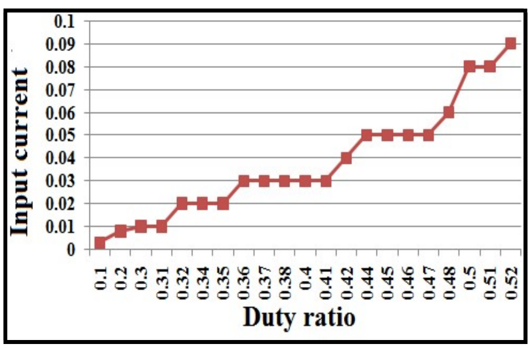

Fig. 6.15 Input current versus Duty ratio

The fig. 6.15 shows the input current versus duty ratio. Input current increases from 0.003 to 0.09 with increase in duty ratio.

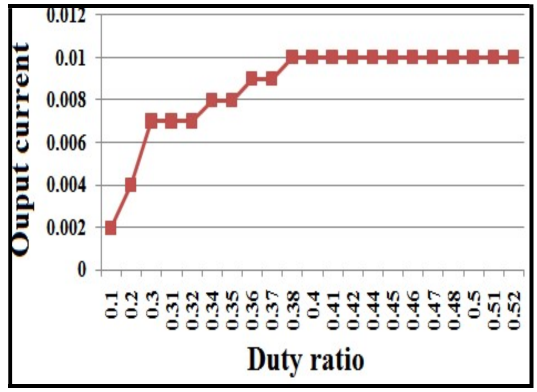

Fig.6.16 Output current versus Duty ratio

The fig.6.16 shows that output current versus duty ratio. Output current increases from 0.002 to 0.01 with increase in duty ratio.

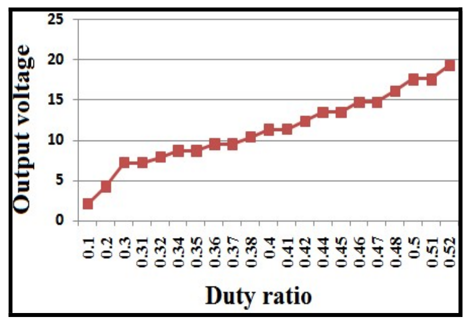

Fig.6.17 Output voltage versus Duty ratio

The fig. 6.17 shows that output voltage versus duty ratio. Output voltage increases from 2.06 to 19.27 with increase in duty ratio.

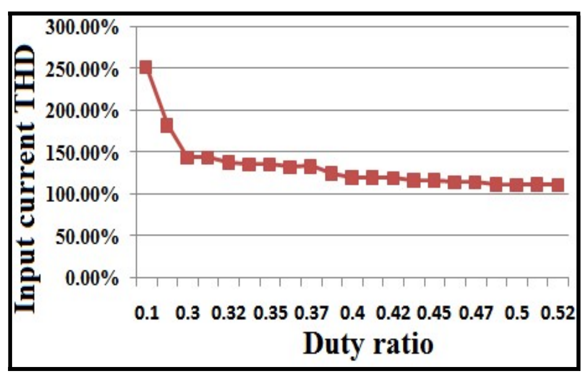

Fig.6.18 Input current THD versus Duty ratio

The fig. 6.18 shows that input current THD versus duty ratio. Input current THD decreases from 252.65% to112.04% with increase in duty ratio.

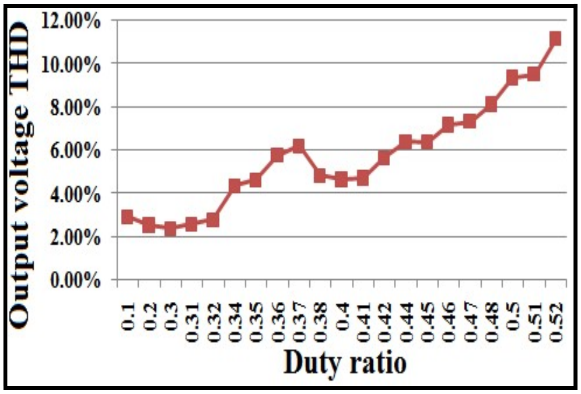

Fig.6.18 Output voltage THD versus Duty ratio

The fig.6.18 shows that output voltage THD versus duty ratio. Output voltage THD increases from 2.91% to 11.17% with increase in duty ratio.

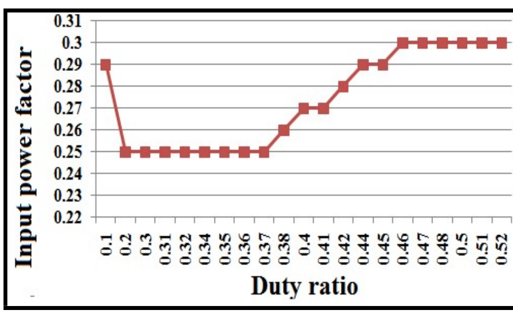

Fig.6. 19 Input power factor versus duty ratio

The fig. 6.19 shows that input power factor versus duty ratio. Input power factor increases from 0.38% to 0.72% linearly with increase in duty ratio.

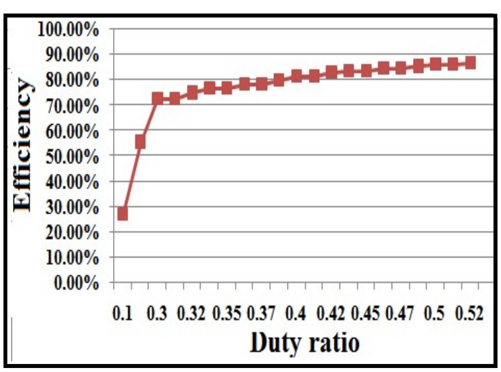

Fig.6.19 Efficiency versus Duty ratio

The above fig.6.19 shows that efficiency versus duty ratio. Efficiency increases from 26.95% to 86.73% with increase in duty ratio.

The above plots from fig. 13 to 19 shows that, with the variation of duty ratio from 0.1 to 0.52, the output voltage, output current, V_oTHD, input power factor and efficiency increases gradually. But input source current I_sTHD reduces gradually with the increase of duty ratio from 0.1 to 0.52.

Sag correction can be done by varying duty ratio from 0.42 to 0.47 (V_O varies from 12V to 15V).

Swell correction can be done by varying duty ratio from 0.47 to 0.52 (V_O varies from 15V to 18V).

6.6 Model of Hardware

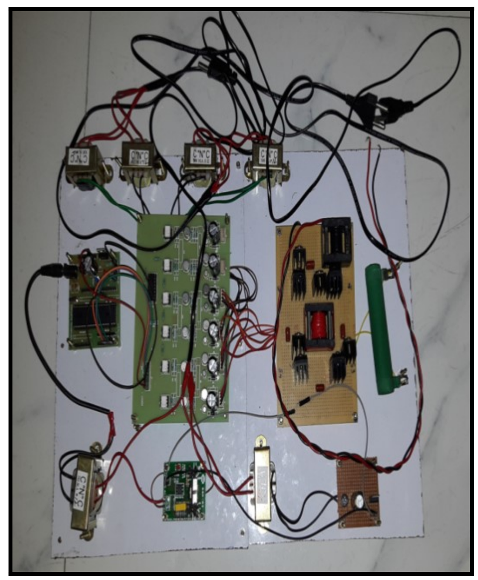

Fig. 6.36 Complete Hardware Circuit

6.7 Output Voltage

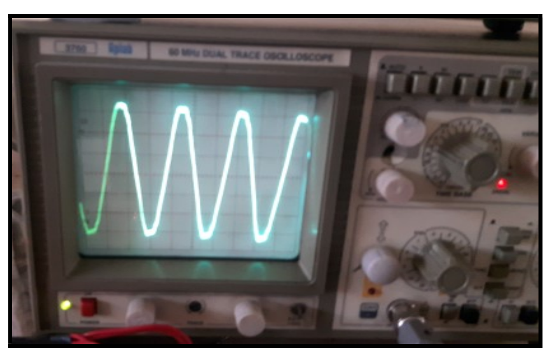

Fig.6.37 Boosted output voltage

For the 15V, 50Hz input supply, the voltage is boosted to 17.25volts at output observed in CRO.

Table VII. Comparison of practical output voltage and simulation output voltage

Supply Voltage V_s=15V

D	V_s	V_o(practical)	V_o(simulation)
0.5	15V	17.20	17.56

CONCLUSION

An open loop bidirectional AC to AC boost converter with regenerative circuit has been designed, simulated and implemented with input voltage of 15V. In this project to avoid the voltage and current transients for the short duration the commutation scheme uses dead time. At the same time it will set up a current path in the inductor to avoid voltage transients. The output voltage, current, power factor and efficiency with increase in duty ratio. The Total Harmonic Distortion of source current is decreased with increase in duty ratio. But the Total Harmonic Distortion of voltage and current is increasing with increase in duty ratio.

The hardware is implemented with input AC voltage of 15V, 50Hz and checked for both buck and boost modes of operation. Simulation is carried out for the same and conformed to the hardware result obtained.

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