Power Factor Corrected Isolated DC Power Supply with Low Harmonics

Preti Tyagi, Ganesh Wadmore, V.P. Sunder Singh

Abstract: **Without using power factor correction a typical switched-mode power supply would have a power factor of around 0.6. Hence PFC on the device side can become an important part of the system design for many power electronics products. The proposed PFC device can operate at high efficiency and contains Low weight transformer. In addition it has advantages such as fewer structural complications and ease of control. A prototype suitable for 1000 W output (extendable) with low harmonic distortion, input voltage of 230 V_{rms} and an output voltage of $120V_{dc}$ (extendable)is design and tested at such a Pulse width modulation (PWM) control scheme for single-phase power supply AC\DC converter is presented to improve the power quality.**

***Keywords*: Power factor correction, AC/DC converter, high efficiency, harmonics.**

I. INTRODUCTION

Power factor (PF) is defined as the ratio of the real power (P) to apparent power (S), or the cosine (for pure sine wave for both current and voltage) of the phase angle between the current and voltage waveforms (Fig1.1). The power factor can vary between 0 and 1, and can be either inductive (lagging, pointing up)or capacitive (leading, pointing down). In order to reduce an inductive lag, capacitors are added until PF equals 1. When the current and voltage waveforms are in phase, the power factor is 1 (cos (0°) = 1). The whole purpose of making the power factor equal to one is to make the circuit look purely resistive (apparent power equal to real power). Real power (watts) produces real work; this is the energy transfer component (example electricity-to-motor rpm). Reactive power is the power required to produce the magnetic fields (lost power) to enable the real work to be done, when apparent power is considered the total VA that the power company supplies, is shown in Figure 1.

This total power is the power supplied through the VA mains to produce the required amount of real power.

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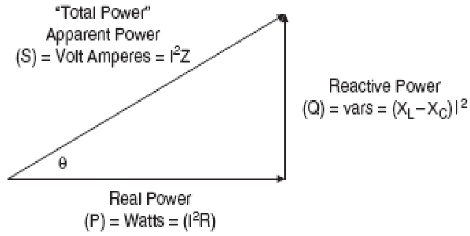

Fig1. Power factor triangle (lagging)

The previously-stated definition of power factor related to phase angle is valid when considering ideal sinusoidal waveforms for both current and voltage; however, most power supplies draw a non-sinusoidal current and the purpose of the power factor correction circuit is hence to minimize the input current distortion and make the current in phase with the voltage. When the power factor is not equal to 1, the current waveform does not follow the voltage waveform. This result not only in power losses, but May also cause harmonics that travel down the power line and disrupt other devices connected to the line. The closer the power factor is to 1, the closer the current harmonics will be to zero since all the power is contained in the fundamental frequency.

Harmonics: A harmonic is defined as a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. We define harmonics as voltages or currents at frequencies that are a multiple of the fundamental frequency. If the fundamental frequency is 50 Hz, then harmonic order is 100 Hz, 150 Hz, 200 Hz and so on. We usually specify these orders by their harmonic number or multiple of the fundamental frequency. For example, a harmonic with a frequency of 180 Hz is known as the third harmonic (60x3 = 180). The even multiples of the fundamental frequency are known as even-order harmonics while the odd multiples are known as the odd-order harmonics. The biggest problem with harmonics is the voltage waveform distortion.

II. POWER FACTOR CORRECTION (PFC)

Due to their large harmonic content, typical single-phase bridge rectifiers used for interfacing power electronic equipment with utility system may generate harmonics which exceed the limits on the individual current harmonics and THD (Total Harmonic Distortion) specified by international standards. The technique used to improve the value of power factor is called Power Factor Correction (PFC) (Lopez, 2001). PFC shapes the distorted input current waveform to approximate a sinusoidal current that is in phase with the input voltage. There are several effective techniques for getting a sinusoidal input current waveform with low distortion. The objective of PFC is to make the input to a power

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supply looks like a simple resistor (Wei, 2000). PFC techniques for PFC can be divided into Passive Power Factor Correction (PPFC) and Active Power Factor Correction (APFC). Regardless of the particular converter topology used, the output voltage carries a ripple at twice the line-frequency (Eissa, 1996). This is because in a single-phase system the available instantaneous power varies from zero to a maximum, due to the sinusoidal variation of the line voltage. On the other hand, the load power is assumed to be constant. Every single-phase PFC converter requires energy-storage (bulk) capacitor to handle difference between instantaneous input power and average output power.

There are several approaches that have been taken by power designers to improve the value of the power factor when they are designing SMPS. Most of them make used of PPFC as a solution to improve the waveform of line current in order to reduce the harmonic contents generated by the SMPS. One of these method is described here.

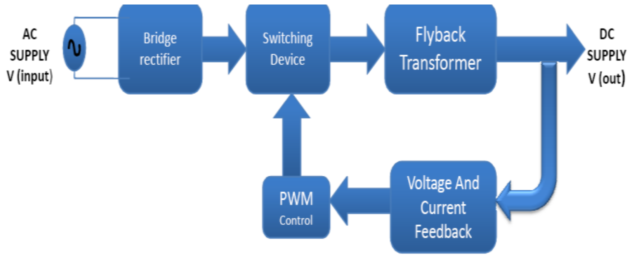

Fig: 2. Block diagram

In fig: 2 explain the block diagram of a power factor corrected isolated dc power supply is shown. Main supplies 50 Hz is fed to the bridge rectifiers which rectifies the input signal and generate unfiltered dc power supply. The output of the rectifier is given to the switching device, and controlled PWM signal is applied to gate of the device for switching conduction, finally, the out put signal (drain signal) is given to primary winding of a transformer and the output of transformer is rectified by a diode and produces the constant dc power supply.

III. POWER CIRCUIT

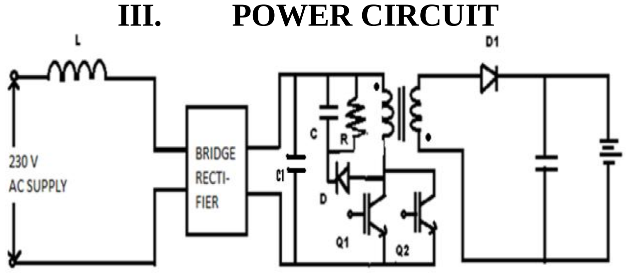

Fig.(3) power circuit diagram

The core of most power electronic apparatus consists of a converter using power semi conductor switching devices that works under the guidance of control electronics. This converter can be classified as rectifier (AC-to-DC converter). An AC to DC converter is shown in fig. (3). Here the main voltage converted to unfiltered DC by a bridge rectifier. Capacitor C1 is used to filter the switching harmonics. To improve the line-current waveform, an inductor (L) may be added in series on the ac side. We use fly-back transformer (operated at high frequency) is to isolate the output, and a single stage can accomplish power factor correction and isolation. The Fly-Back converter can provide current limiting, during both steady state operation and initial turn-on. The fly-back transformer operates in discontinuous mode which has advantages like smaller size transformer and additional filter is not required on secondary side. Ferrite is mainly used as the core material. The need to use semiconductor switching devices in power electronic circuits is based on their ability to control and manipulate very large amounts of power from the input to the output with relatively very low power dissipation in the switching device, resulting in very high efficiency power electronic system. There are two switching device having switching capability. Hence MOSFET or IGBT may one of them can be used. The gate signal control by electronic control circuit. At the output of transformer a fast diode is used as a rectifier and the rectifier output is filtered. Here only capacitor filter is needed at output of the circuit.

IV. OPERATION

The operation of the power circuit explained into two modes. Mode 1 and mode 2.

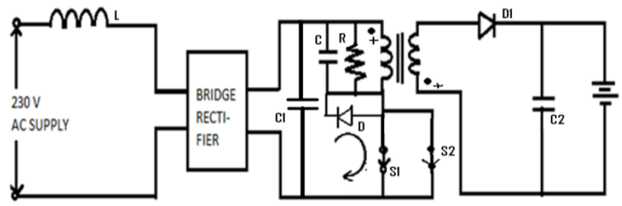

Fig:3 mode 1

Mode 1: When IGBT is ON: In mode 1 switching device S1, S2 ON. Primary current increases linearly and filter capacitor maintain the output voltage. So current increases linearly as shown in the waveform diagram. Linear increase in current is due to primary winding is being charged during mode I. Diode D1 is reverse bias due reverse dot convention used.

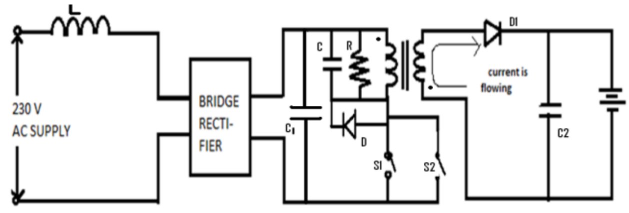

Fig:4 mode 2

Mode 2: When IGBT is OFF: In mode 2 switching devices S1, S2 are OFF. Diode D1 conducts due to voltage in secondary winding and secondary current decrease linearly to zero. Output capacitor C1 charges, and deliver the current to the load. Current decreases linearly as shown in the waveform diagram:

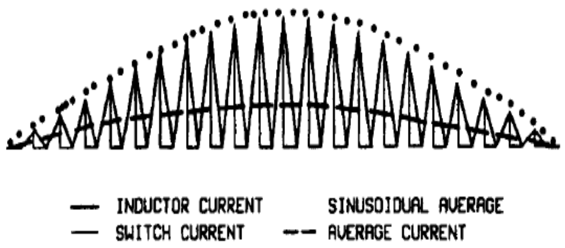

Fig:5 inductor and switching current waveform

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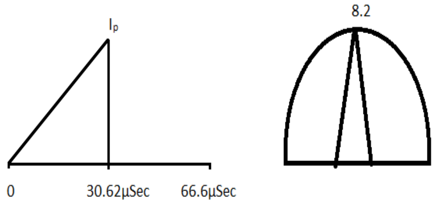
V. DEVICE SELECTION AND TRANSFORMER DESIGN

Minimum input voltage = 200$V_{ac,}$, Efficiency = 0.9 , Output power = 1KW

Input current = 200 X 0.9 =5.55A

Peak input voltage = 200 X $2^{0.5}$ =282.84V

Peak input current = 5.55 X $2^{0.5}$ = 7.84A



Current drawn from mains at peak voltage of 200V

Average peak current = (I_p/2) X (T_{on}/T) = 7.84A

I_p =34.02A , V = L(di/dt) =282.73V , L=254.73 µH

Transformer ratio = (N_p/N_s) = 2:1

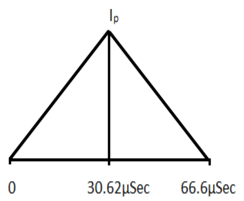
Output Voltage = 120V

Reflected primary voltage = 120 X 2 = 240V

The peak voltage across IGBT = (250 X $2^{0.5}$) + 240 = 593.55V

Therefore the <u>device selected</u> ≥ 900V

At minimum input voltage P = 1KW should be achieved.



During t_{on} voltage across primary of transformer = 282V. So during this time Current will ramp up.

During T_{off} reflected primary voltage = 240V

Induced voltage during T_{off} = 240V

During this time the flux should come back to zero

T_{on} = 66.6 X (240/240+282) = 30.62µSec

T_{off} = T – T_{on} = 66.6 – 30.62 = 35.98µSec

So number of turns in primary winding of transformer is:

$$N_1 = \frac{\text{Vm} * 10^4}{\text{Bmax} * A * \text{Kt} * f}$$

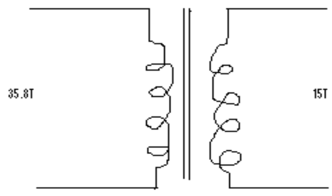
Bmax= magnetic flux, A=area of core , Kt=constant(4.44) , F=operating frequency

$$N_1 = \frac{282 * 10^4}{0.22 * (2.66 * 2) * 4.44 * 15K} = 35.8T$$

Number of turns in secondary winding of transformer is:

$$N_S = \frac{N_P}{V_1} * V_O = \frac{35.8}{282} * 120 = 15.2T$$

Gap in core is 2mm.



VI. CONTROL CIRCUIT

<u>Power supply and current sensing and mains sensing:</u>

To provide the supply voltage and reference voltage to control circuit, IC 7812, 7915, 7805are used and they give +12V,-15Vand +5V with respect to the ground as shown in fig.(6).

<u>Current sensing:</u> The current sensing amplifier is driven from shunt which is connected in series with the system output. For current sensing LM 358 is used. It is a low power a dual amplifier. The voltage across the shunt voltage (mV) is amplified Ic1. This voltage is then amplified by the other op-amp with gain (R31/R2) (pin1) of the same IC (LM358). The amplified shut voltage is compared with the reference voltage (2.5v) and the error is amplified by IC3. The gain of this operation amplifier determines the output regulation of the system. D25 cuts off the negative voltage and hence only positive voltage is fed to the PWM section.

<u>Circuit of oscillation part of control signal</u>: the output of the IC2 is fed to the osillator section. This voltage is converted to a current source using Q1 and Q5 which is used to charge C38. IC4 and IC5 along which constitute the oscillator whose frequency can be varied by varying the output of IC2. This is use to reduce the frequency of modulating signal at low output loading. When the output loading is greater then 10% the frequency of osillation become 18KHz. And remain constant beyond this.

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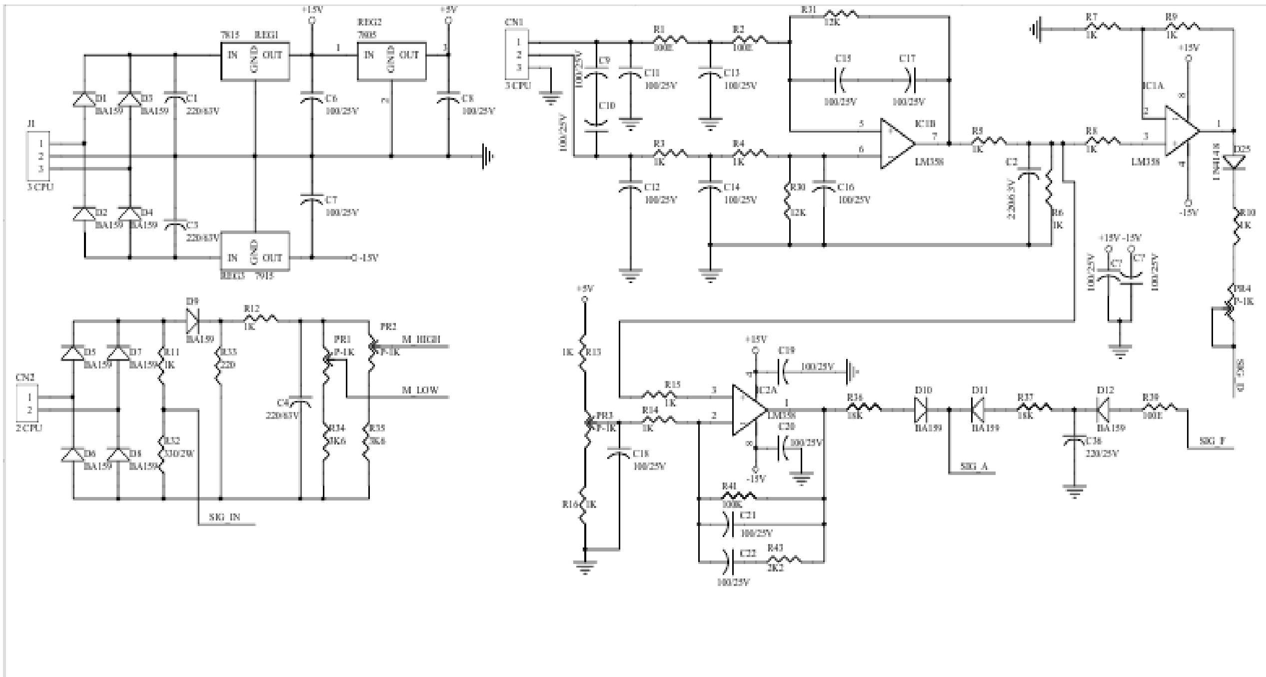

Fig:6 Power supply and current sensing and mains sensing

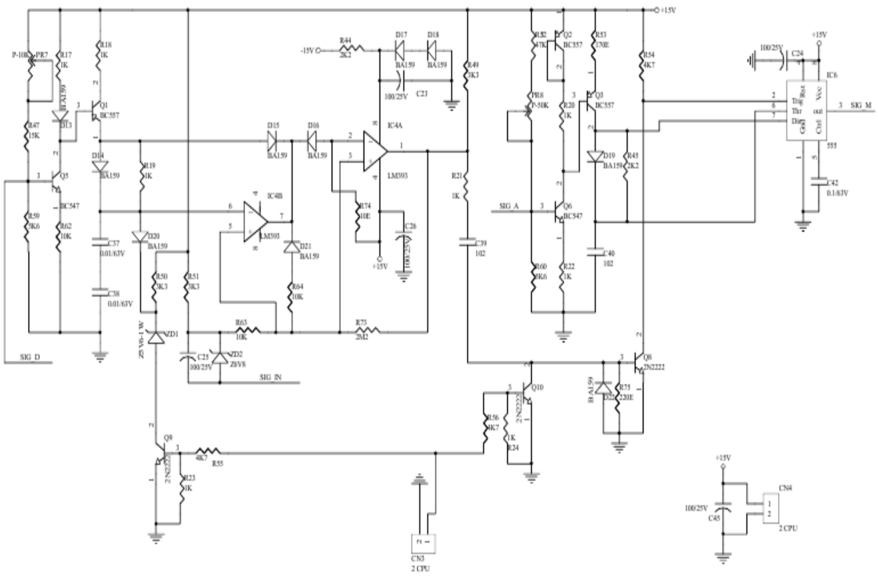

Fig 7:Circuit of oscillation part of control signal

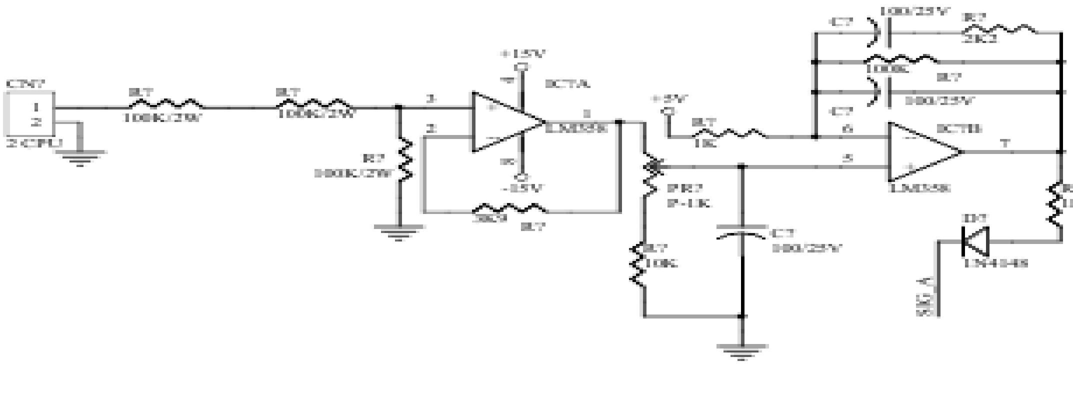

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Fig 8: Voltage sensing

Signal which is the amplified error voltage is converted to a current source using Q2 and Q6 and the current is used to charge C40. IC6 along with C40 determines the pulse width of the modulating signal. IC6 is mono stable qsillator triggered by the main osillator. Thus we have a PWM signal with variable frequency.

The DC output voltage is fed to IC7A is combined with 5v reference voltage and the error voltage is amplified by IC7B. The output of IC8 is again fed to signal such that which ever is higher (voltage as current) will control the pwm and the output voltage is either stablised as taken into fold back region.

VII. DRIVER CIRCUIT

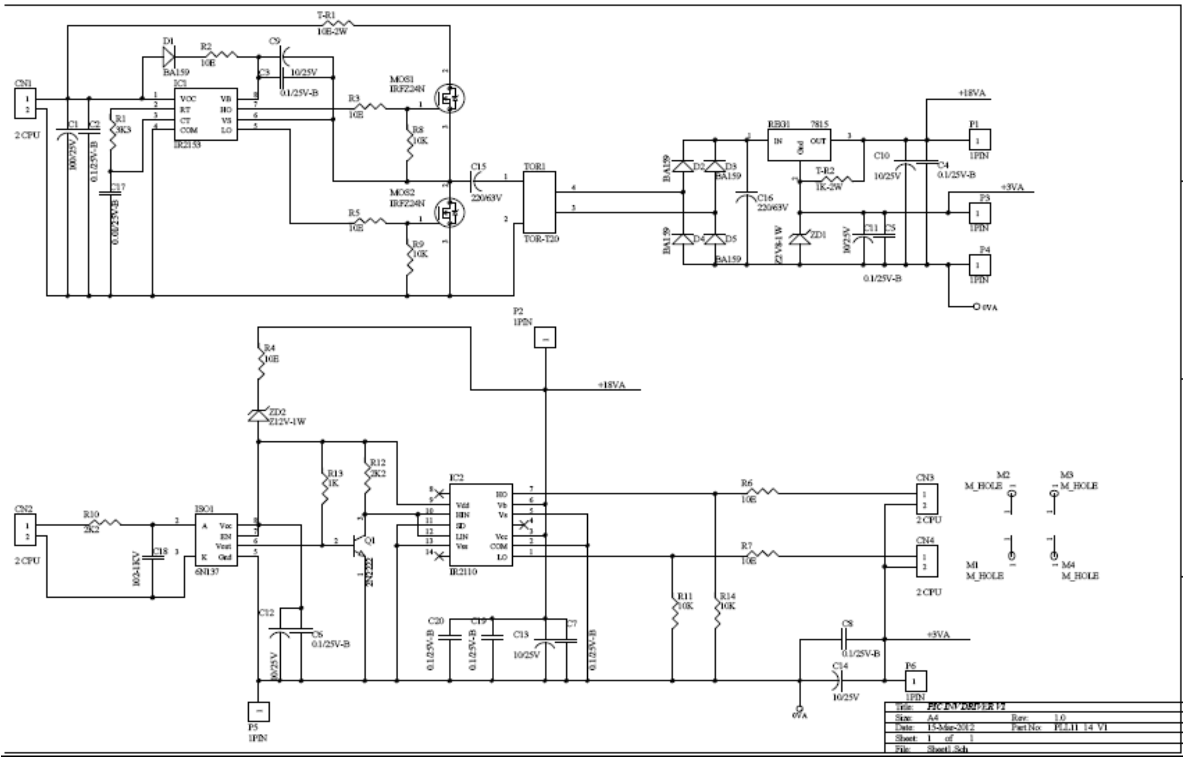

Fig 9: Driver Circuit

<u>Explanation of driver circuit:</u> for insulating the output from the control circuit and insulated power supply is design using IB2153 which is a half bridge self oscillating driver. The insulation is achieved using a ferrite transformer and its generators 2.5v DC which is stabilized using 2815 and a 4.7v zener so that +15, -5v supply is available. This voltage is fed to IC2110 driver IC. The signal from the control side is insulated using 2N137 which has opto-coupler insulation. The output of the driver is use to drive the IGBT.

VIII. RESULT WAVEFORMS ON CRO AND CONCLUSION

Figure 10 to 13 show the different waveform generate during the experiment. Figure 10 show the gate signal of the IGBT for a particular loading. In figure we see that main waveform has a flattened top and the current waveform follows it exactly.

Fig 10: Gate Signal to IGBT (PWM)

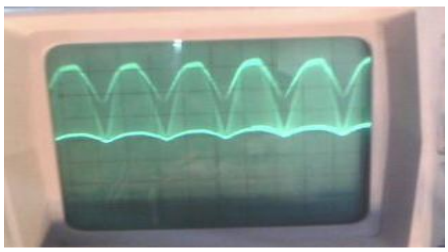

Fig11: The collector waveform of IGBT

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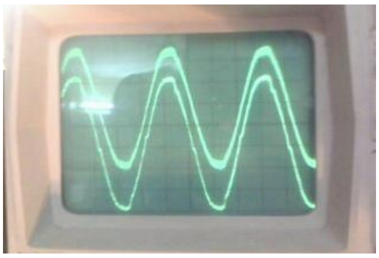

Fig 12: Waveform of output voltage and output current: (Upper is voltage waveform and lower is current waveform)

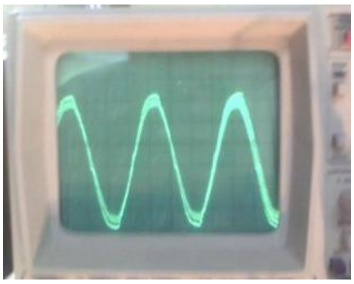

Fig 13: Output voltage and current waveform co inside to each other

The power factor achieved is 0.98 and the total harmonic distortion of the main voltage waveform and current waveform are 3.1%and 3.5% respectively. In conclusion, an insulated DC power supply of 120V DC and 1KW rating is achieved with at distorting the current drawn from the main.

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