Simulation, Design and Practical Realization of Single Phase PWM Boost Rectifier

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Abstract**— A PWM boost rectifier system using IGBTs is reported in this paper. This rectifier has feature of providing the desirable boost in D.C output voltage and still maintaining the unity power factor at the input side with low %THD (<5%). Pulse width modulation method is used for switching of IGBTs in selected topology. Firing scheme, required phase shifting circuit for boosting the output voltage and open loop control for this topology is explained. Simulation and experimental results are verified for the same.**

Keywords— **unity power Factor, PWM rectifier, pulse width modulation, boost rectifier, THD**

I. INTRODUCTION

The selected topology is IGBT based PWM rectifier with four IGBTs in full bridge configuration (with inductor at line side). PWM based rectifier has capabilities to achieve unity power factor at line side and reduces harmonics considerably. It is used as active front end for bi-directional power flow applications such as locomotives, downhill conveyers, cranes etc. Conventional diode bridge rectifier has poor power factor because of peaky current drawn from the utility. This current contains large harmonic components which are injected into the utility supply [1]. If vast numbers of such converters having high value of THD were to be used in industry, the harmonics that would be injected in the utility would be quite leading to increased volt-ampere ratings of utility equipments. Power quality can be improved to certain level by passive filter [2], however passive filter have the demerits of large size and resonance. Thus, single phase AC-DC converters, which are used as front-end PWM rectifiers (often called boost rectifier) for variety of applications, due to its advantages-high efficiency and quality power [3]. For a drive system in normal motoring mode, power flows to the motor. In this case the line side converter operates as a rectifier, whereas the load-side converter operates as an inverter. In regenerative braking mode, their roles are reversed. The system can continuously regenerate power if the machine is operated as generator, such as in wind generation system. At present large, number of application demand for the front end AC-DC converters with rectifying and regenerative abilities with fast response to improve the dynamic performance of whole system. Here, SPWM method is used for switching of IGBTs. In ASD, UPS and SMPS, the conventional rectifier section can be replaced by this PWM rectifier.

II. BLOCK DIAGRAM AND POWER CIRCUIT

The complete block diagram of PWM rectifier is shown in Fig. 1 and the power circuit of the single phase PWM boost rectifier is shown in Fig. 2. Sine triangular PWM technique is preferred to drive the power devices. Supply voltage is taken as input reference. The gate signals generated are processed through the driver circuit and used to trigger IGBTs. The desired phase shifting of reference signal is provided using the phase shifting circuit. The boost output voltage is obtained using an inductor at the input side.

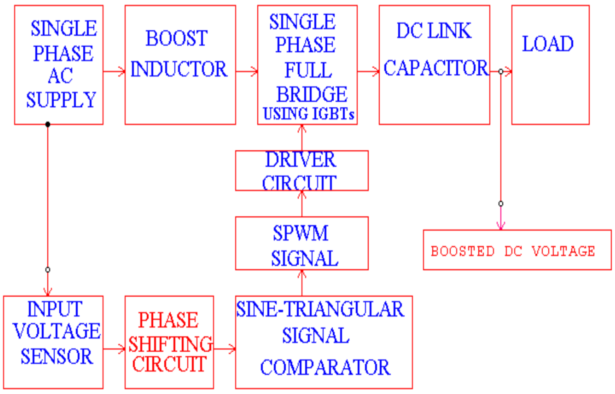

Fig. 1. Block diagram of PWM rectifier

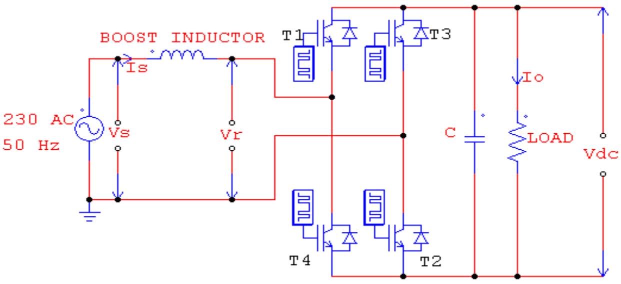

Fig. 2. Power circuit of single phase PWM boost rectifier

III. SINUSOIDAL PULSE WIDTH MODULATION AND MODULATION INDEX

From the available PWM techniques, sinusoidal pulse width modulation method is selected for switching of IGBTs. In this method, reference is compared with carrier signal. Input Sine signal of voltage is selected as reference signal and triangular signal is selected as carrier signal. When amplitude of reference exceeds or equal to the carrier signal, generation of pulses takes place. Comparison of sin-triangular signal and generated pulses are shown in Fig. 3 and Fig. 4 respectively. Duty cycle can be changed by changing the amplitude of reference signal.

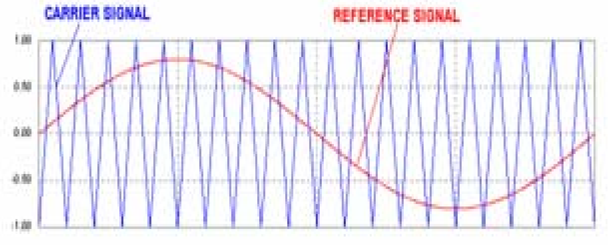

Fig. 3. Sine-triangular comparison

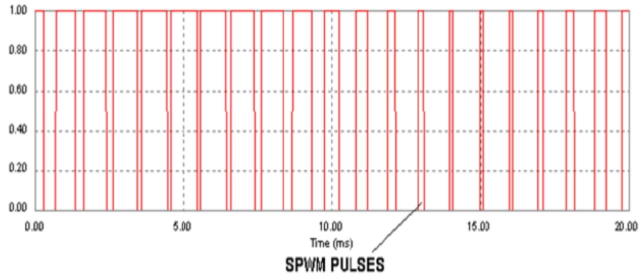

Fig. 4. SPWM pulses

Modulation index is the ratio of amplitude of carrier signal to the reference signal. It is denoted by m.

$m = \frac{A_r}{A_c}$ Where, A_r = Amplitude of Reference and

A_c = Amplitude of Carrier.

IV. DESIGN CONSIDERATION

The PWM rectifier shown in Fig. 1 consists of full bridge inverter configuration using IGBTs with an inductor at the A.C. input side. The supply voltage V_s and the fundamental component V_r of the output voltage $V_r(t)$ at the A.C. terminals of the inverter are two sinusoidal voltages separated by an inductor. Therefore the power flow depends on phase angle displacement between the two voltages phasors. The details regarding the phasor diagram explanation can be found in [3].

A. Power angle calculation

Power transferred from the source to the converter is defined as,

$$P = \frac{V_r V_s}{X_L} \sin\delta \qquad \ldots (1)$$

$$= V_s I_s \cos\phi$$

Where, V_s =Sending end voltage (before inductor)
V_r=Receiving end voltage (after inductor)
δ=Phase angle displacement (power angle)
X_L=Reactance of the inductor

From the eq. (1) power angle δ can be found between sending end voltage and receiving end voltage.

B. Source Inductance calculation

The power balance equation at unity power factor is,

$$V_S I_S = V_{dc} I_{dc}$$

$$V_{dc} = \frac{V_s I_s}{I_{dc}} \qquad \ldots (2)$$

Equation (2) shows, output voltage can control by controlling source current.

If $V_s = 13V$ (peak)

For load resistance= 100 Ω

and for V_{dc}=30 V

$I_S = 1.99A$ (peak) and $I_{dc} = 0.33A$

The minimum value of modulation index m is decided by the fact that the minimum value of   is equal to the supply voltage   .

Hence modulation index, $m_{\min} = \sqrt{2}\frac{V_s}{V_{dc}} = \frac{V_{r(peak)}}{V_{dc}}$

$$mV_{dc} = V_{r(peak)} = \sqrt{V_s^2 + \omega^2 I_{s(peak)}^2 L_s^2} \qquad \ldots (3)$$

$$\therefore L_s = \sqrt{\frac{(V_r^2 - V_s^2)}{\omega^2 I_s^2}} \qquad \ldots (4)$$

According to the specifications the value of source inductance $L_s = 50mH$

System can be design from the above equations for any ratings of load and also for any desire boost DC output.

C. Design considerations of filter capacitor

From the below equations value of output filter capacitor can be found.

$$\Delta V \geq \frac{V_r \times I_s}{2 \times V_{dc} \times 2 \times \omega \times C}$$

$$\therefore C = \frac{m \times V_{dc} \times I_s}{4 \times V_{dc} \times \omega \times \Delta V}$$

$$\therefore C = \frac{m \text{ x } \mathrm{I_s}}{4 \text{ x } 2\pi\mathrm{f} \text{ x } \Delta\mathrm{V}} \qquad \ldots(5)$$

Above equation is for minimum value of the filter capacitor.

V. CONTROL CIRCUIT

Control circuit has mainly three parts which is explained below:

1) Phase shifting circuit

Role of this circuit is very much important for this project work. Switching pattern is decided by this circuit. Due to input inductor the sending end voltage Vs lags behind receiving end voltage Vr. After finding this power angle using power transfer eqn. 1, phase advancement is provided by circuit shown in Fig. 5 and the outcome in Fig. 6.

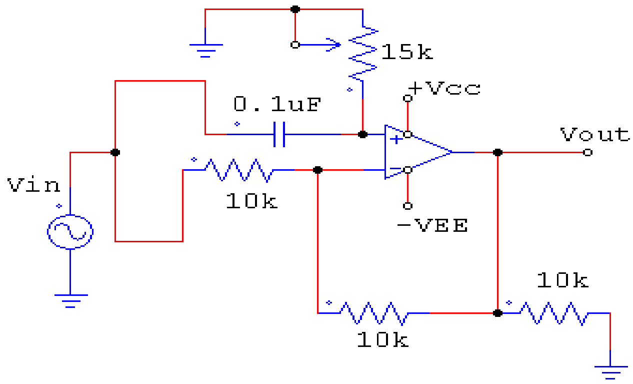

Fig. 5. Phase shifting circuit

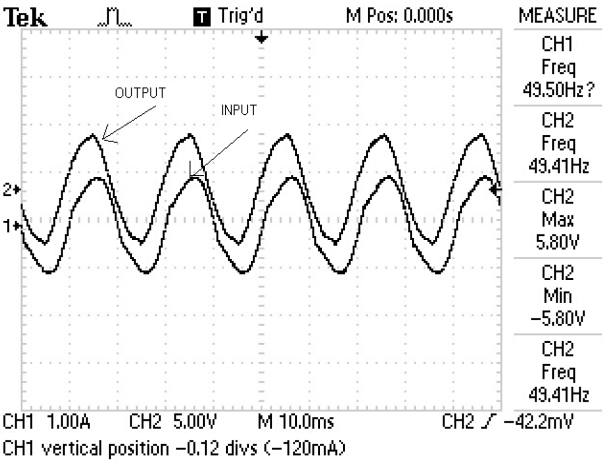

Fig. 6. practical results of phase shifting circuit

2) *Triangular signal generation*

Square signal generator circuit fed with integrator circuit for generation of triangular signal. Practical generation of triangular signal is shown in Fig. 7 and its output in Fig. 8.

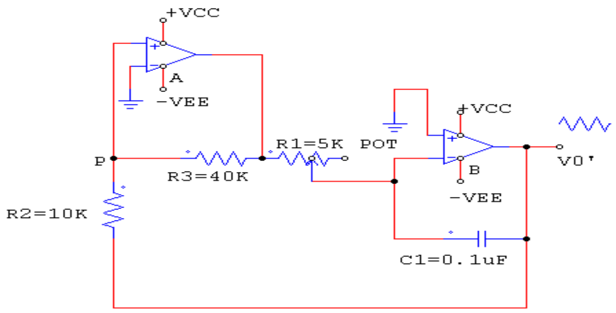

Fig.7. Triangular signal generation circuit

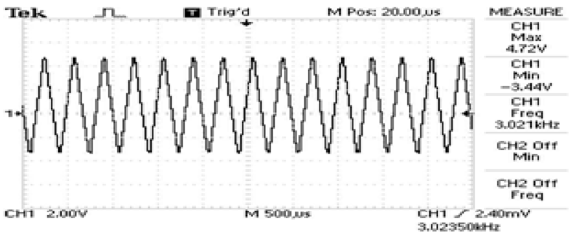

Fig. 8. Triangular signal with f = 3 kHz

3) *Final comparison circuit of sine-triangular signal*

Final comparator circuit and practical SPWM signals are shown in Fig. 9 and Fig.10 respectively.

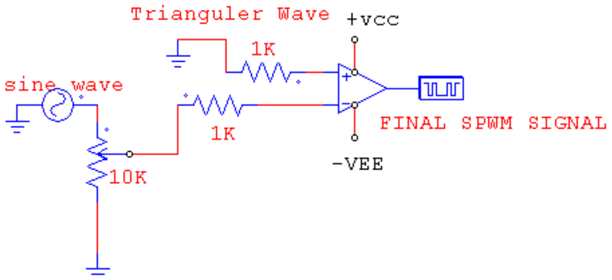

Fig. 9. final comparision circuit for SPWM

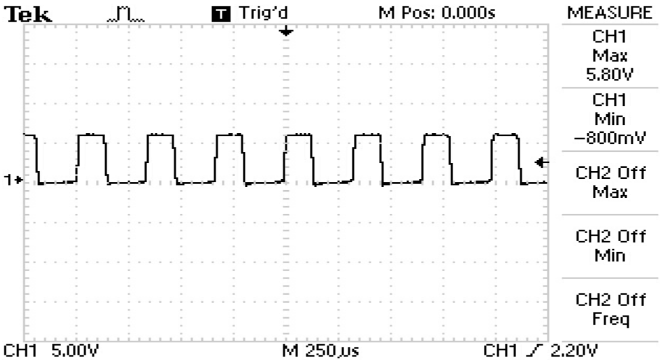

Fig. 10. Practical SPWM signals

VI. SIMULATION

In order to verify the proposed circuit, the simulations were carried out in PSIM software. Simulation model of converter mode for V_s = 13 V (peak) AC is shown in Fig. 11. Values selected in simulation model are according to calculations as discussed above.

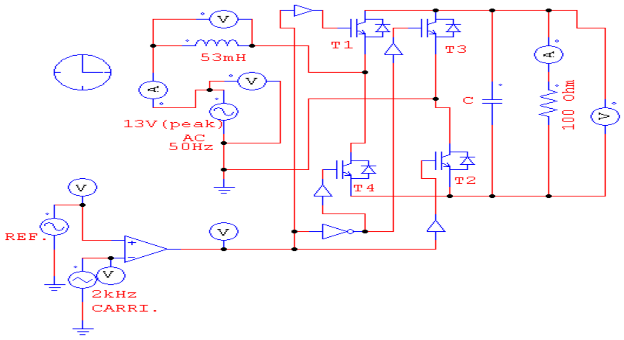

Fig. 11. Practical SPWM signals

D. Simulation results

According to given specifications simulation results are taken. Output voltage without filter capacitor, output voltage with capacitor, and load current, input voltage with input current and output voltage for different input voltage are shown from Fig. 12 to Fig. 17 respectively.

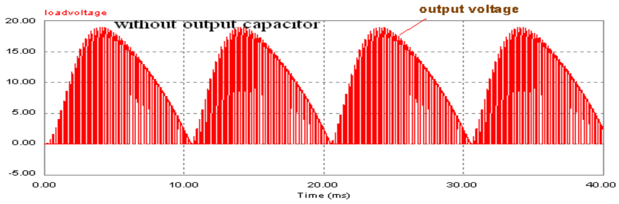

Fig. 12. Output voltage without capacitor filter

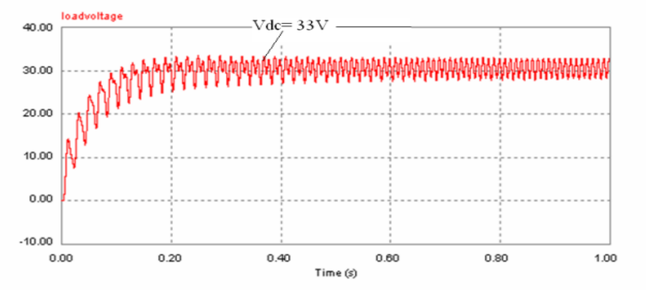

Fig. 13. Output voltage with capacitor filter

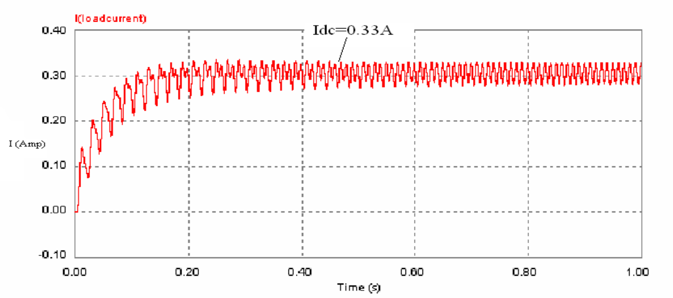

Fig. 14. Load current

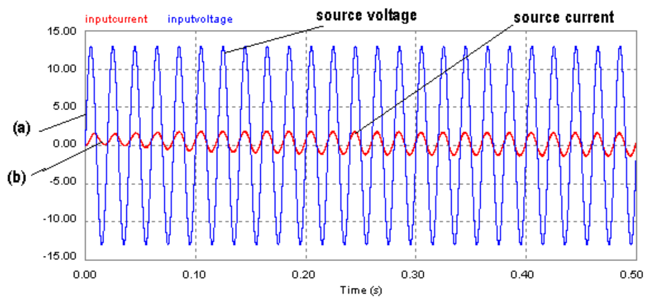

Fig. 15. Input voltage and current

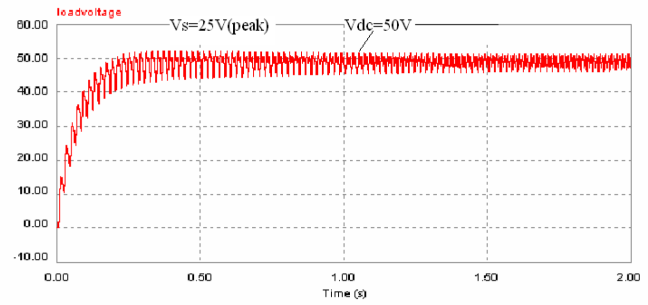

Fig. 16 Output voltage for Vac = 25V

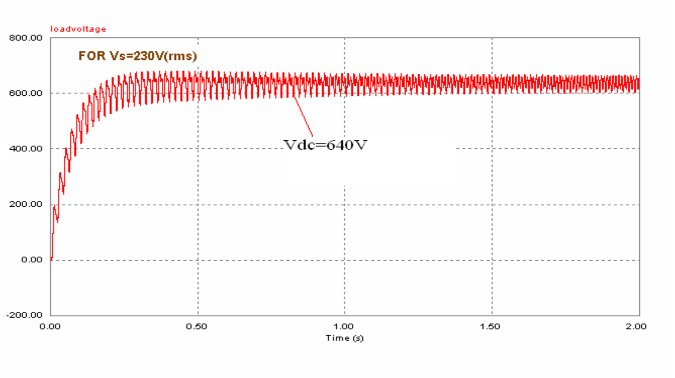

Fig. 17. Output voltage for Vac=230V

VII. FIRING SCHEME

For full bridge configuration of selected topology four proper pulses are required to fire four IGBTs. For that main generated pulses are inverted as shown in Fig. 18 and given to the two identical dead band generation circuit as shown in Fig. 19 Complimentary pulses and dead band of 1.2μsec are shown in Fig. 20. These pulses are given to the IGBTs by using proper driver circuit.

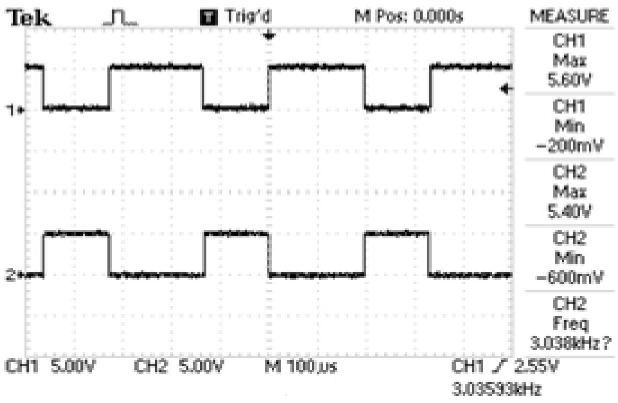

Fig. 18. Complimentary pulses

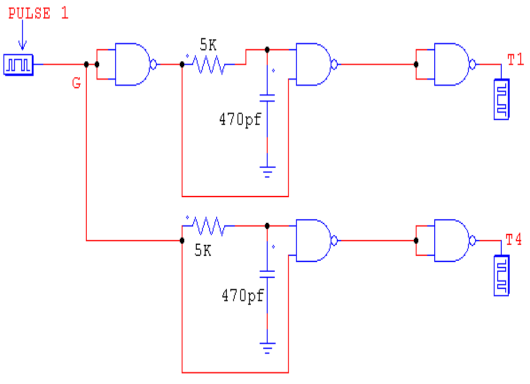

Fig. 19. Dead time generation circuit

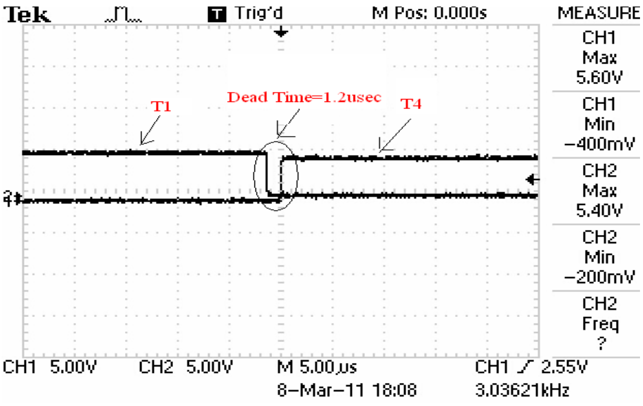

Fig. 20. Complimentary pulses with 1.2usec dead band

VIII. EXPERIMENTAL RESULTS

Experimental Results are taken during testing of system for 100Ω resistive load. Modulation index (m) is set at 0.8 and phase shifting is provided by phase shifting circuit. For input voltage AC = 13V (peak) various experimental results are taken. Further up to 98V (DC) results are taken which is shown from Fig. 21 to Fig. 30.

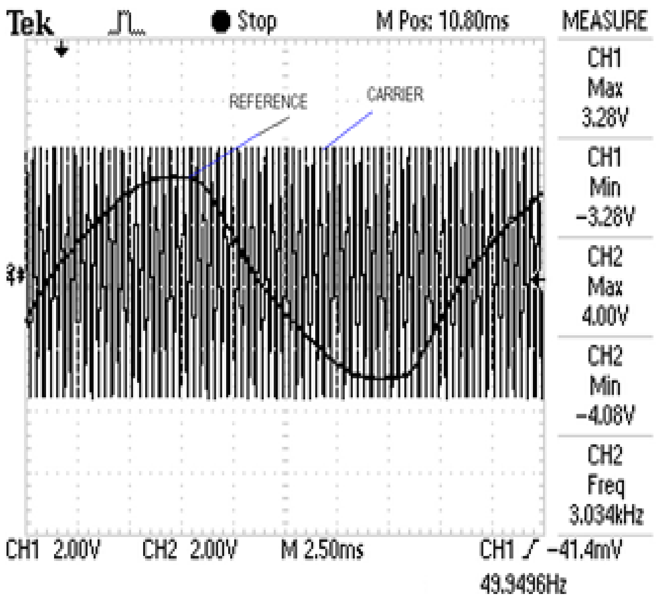

Fig. 21. SPWM with m=0.8

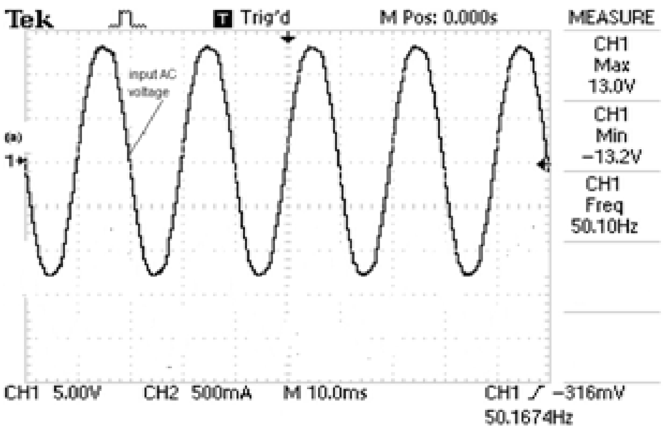

Fig. 22. Input voltage (AC=13Vpeak)

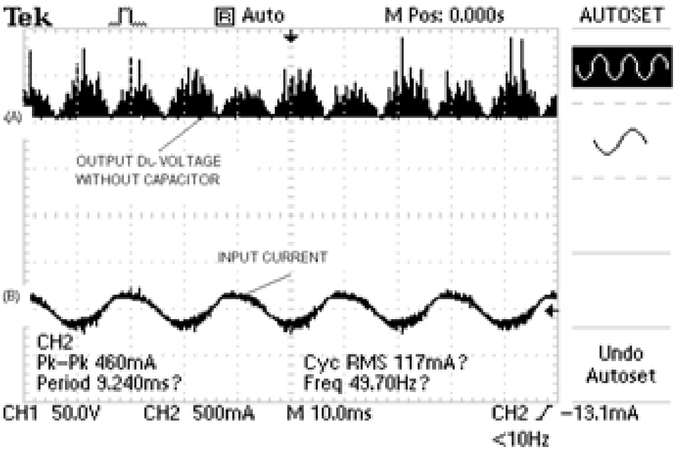

Fig. 23. (A) Output DC Voltage without filter capacitor (B) Input Current

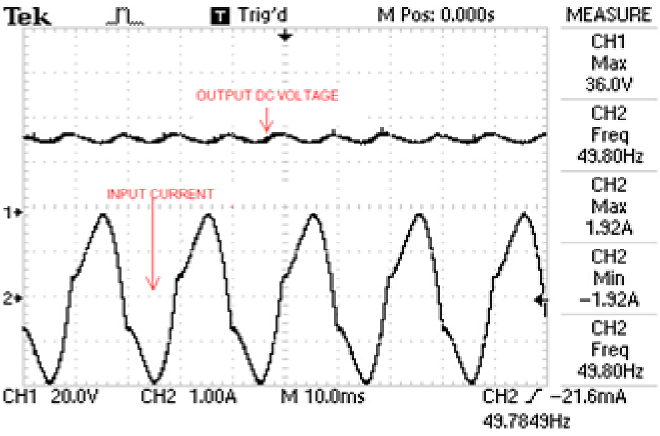

Fig. 24. (1) Output Dc Voltage (2) Input Current

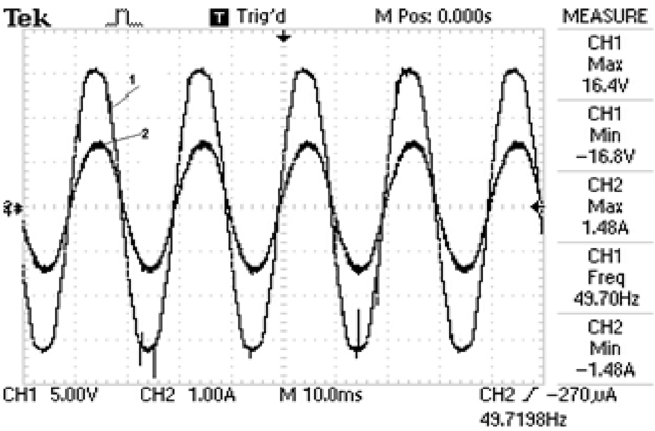

Fig. 25. (1)Input Voltage (2) Input Current

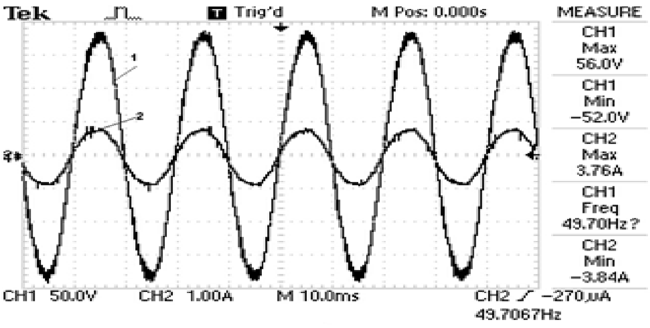

Fig. 26. (1)Input voltage and (2) current at 56 V

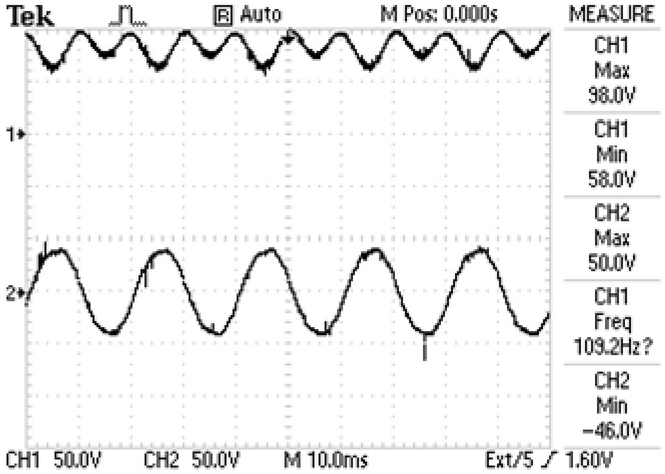

Fig. 27. (1)DC Output Voltage (Vdc=98V) (2) Input Voltage AC=50V (peak)

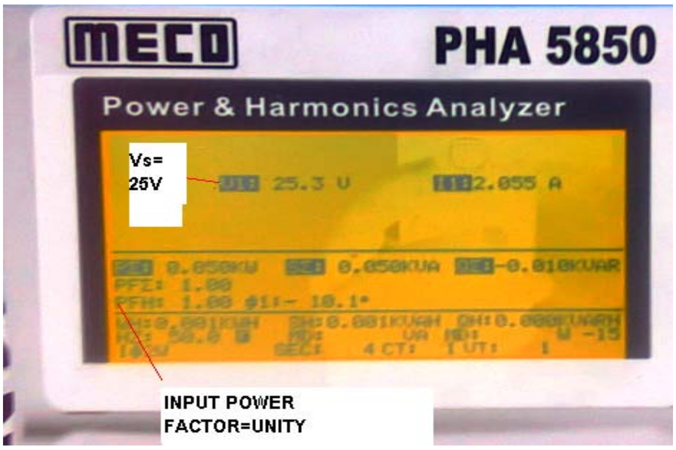

Fig. 28. Power Factor Measurement by Using Power Analyzer at 25V

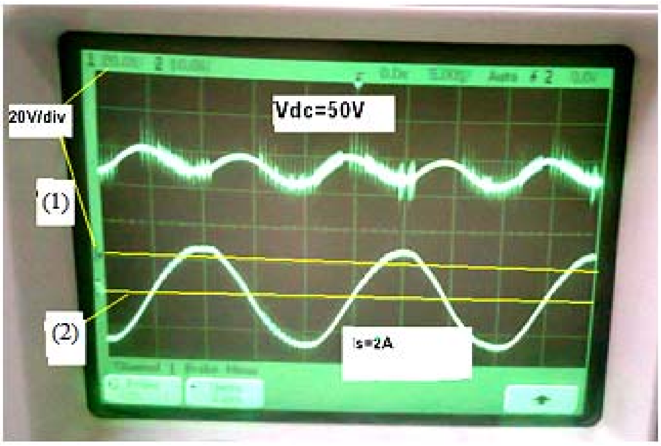

Fig. 29. (1) Boosted Output DC Voltage (Vdc=50V) (2) input current

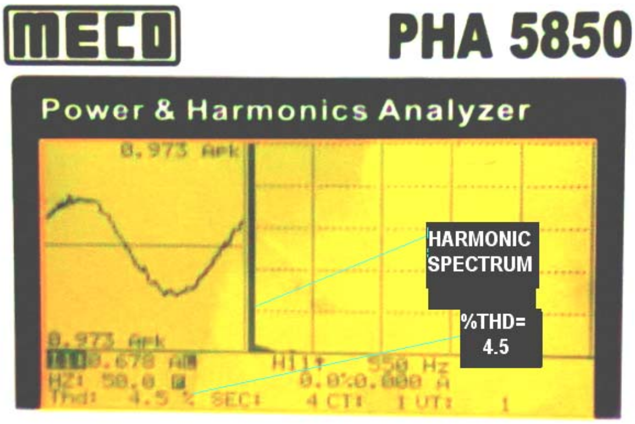

Fig.30. Harmonic Spectrum and %THD Measurement from Harmonic Analyzer

IX. CONCLUSION

From the obtained results according calculations and simulations, it can be concluded that proposed aim and objectives of this topology are achieved. Along with boosted output, lesser % THD (<5%) and unity power factor is achieved. Odd and Even order harmonics are reduced considerably in this topology.

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