A Novel Dual Boost Rectifier for Power Factor Improvement

S.S Darly, Dr. P. Vanaja Ranjan
Dept of EEE, Anna University, Chennai.

Bindu. K.V, &Dr. B. Justus Rabi,
Dept of EEE, RREC, Chennai

Abstract— **This paper discuses the reduced high conduction loss and improved efficiency of the input rectifier-bridge of a conventional boost PFC converter. By designing the necessary techniques and methodology, the overall Power Factor (PF) can be improved to the expectation. The cause of having low PF for a diode-capacitor type of rectifiers is related to non-linearity of the input current. . Method of re-shaping the input current waveform to be similar pattern as the sinusoidal input voltage is done by the Boost converter and the related controls that act as a Power Factor Correction (PFC) circuit. The results of the designed system were compared with the boost rectifier without PFC control. Higher efficiency can be achieved by using the bridgeless boost topology. In this paper, digital simulation of bridgeless PFC boost rectifiers, also called dual boost PFC rectifiers, is presented. Performance comparison between the conventional PFC boost rectifier and the bridgeless PFC boost rectifier is performed.**
***Index Terms*-Dual boost PFC rectifier, power factor correction (PFC), single phase rectifier, boost converter.**

Keywords-Dual boost PFC rectifier, power factor correction (PFC), single phase rectifier, boost converter.

I. INTRODUCTION

In the world today, dc power supplies are extensively used inside most of electrical and electronic appliances such as in computers, monitors, televisions, audio sets and others . The high power non linear loads (such as static power converter, arc furnace, adjustable speed drives etc) and low power loads (such as fax machine, computer, etc) produce voltage fluctuations, harmonic currents and an imbalance in network system which results into low power factor operation of the power system [1]. There is a need of improved power factor and reduced harmonics content in input line currents as well as voltage regulation during power line over-voltage and under-voltage conditions. The uninterruptible power supplies (UPSs) have been extensively used for critical loads such as computers for controlling important processes, some medical equipment, etc. The traditional UPS draws harmonic currents. The uncontrolled diode bridge rectifier with capacitive filter is used as the basic block in many power electronic converters. Due to its non-linear nature, non-sinusoidal current is drawn from the utility and harmonics are injected into the utility lines. The nature of rectifiers either it is conventional or switch mode types, all of them contribute to low PF, high THD [2] and low efficiency to the power system [3]. It is well known that these harmonic currents cause several problems such as voltage distortion, heating, noises, reducing the capacity of the line to supply energy. Owing to this fact there's a need for power supplies that draw current with low harmonic content & also have power factor close to unity [4]. So far, a variety of passive [5] and active PFC techniques have been proposed. While the passive PFC techniques may be the best choice at low power, cost sensitive applications, the active PFC techniques are used in majority of the applications owing to their superior performance. The objective of this work is to develop a circuit with all the necessary components and control system that will incorporate into the design of any single-phase rectifier and hence, improves the power factor. The AC mains utility supply ideally is supposed to be cleaned and free from high voltage spikes and current harmonics in order to ensure good quality and efficient power system harmonics to electronics equipment. Discontinuous input current that exists on the AC mains caused by the non-linearity of the rectification process could be shaped to follow the sinusoidal form of the input voltage. The process of shaping the input current is done by the Boost converter, which is properly controlled by the related circuitry [6]. The control circuits for this project used low-cost components, easily available yet giving excellent performance and satisfactory results.

II. RECENT DEVELOPMENTS

The development of the technologies, have emerged as additional drivers for new applications. One such application is commercial transport airplanes where single-phase PFC converters capable of meeting stringent airborne power quality requirements for in-flight entertainment (IFE), avionics, communication, and other single-phase loads. The proliferation of variable-speed motor drives in home appliances has also generated a new need for high-power (up to a few kilowatts), high-efficiency, and low-cost single-phase PFC converters [7]. There are different drivers for home appliance applications of PFC converters in recent years: New functions, such as variable washing cycles in washing machines and different cooking modes in automatic rice cookers; Reduction of energy consumption in air conditioners and refrigerators through the use of variable-speed motor drives.

III. PRINCIPLE OF OPERATION RECTIFIER WITH BOOST CONVERTER

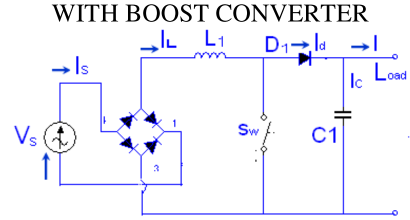

Fig 1a: Rectifier with Boost Converter

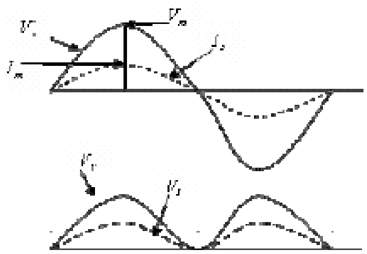

Fig 1b: Waveforms of related voltages and current

Figure 1a and 1b above show the basic configuration of a rectifier that uses Boost converter technique as PFC with its respective voltages and currents [8]. For an ordinary rectifier without PFC, the input current I would be highly non-linear especially when the capacitor C1 is having large value. By operating the Boost converter in Continuous-Conduction Mode (CCM, the input current would be Sinusoidal.

IV. DESIGN CONCEPT OF THE RECTIFIER WITH PFC

The mains AC input voltage is rectified and supplied to the Boost converter, which mainly consists of an inductor, a power MOSFET, a power diode and a bulk capacitor. The Error Amp 2 with predetermined reference voltage senses the DC output voltage across the bulk capacitor. The error voltage Ve2 from the amplifier then is fed to the multiplier and multiplied with the template sinusoidal input voltage to get the reference current, IL (reference). The error Ve1 that is the output of Error Amp 1, as the difference of IL (actual) and IL (reference) provides the correct timing logic for the switching driver circuit to turn on and off the MOSFET in the Boost converter. Hence, this method ensures continuous conduction of current flow for the full cycle of the input voltage.

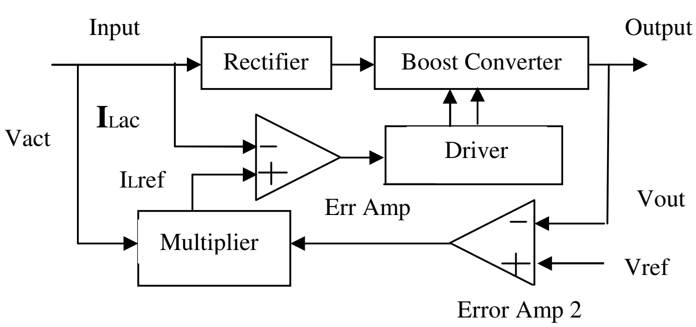

Fig 3: PFC control strategy block diagram

V. REVIEW OF CONVENTIONAL PFC BOOST RECTIFIERS

The conventional boost topology is the most efficient for PFC applications. It uses a dedicated diode bridge to rectify the AC input voltage to DC, which is then followed by the boost section [9]. The conventional input stage for single phase power supplies operates by rectifying the ac line voltage and filtering with large electrolytic capacitors. This process generates a distorted input current waveform with large harmonic content [10]. Thus, the resulting power factor is very poor (around 0.6). The reduction of input current harmonics and high power factor operation are important requirements for power supplies. In these applications, ac-dc converters featuring almost unity power factor are required [11]& [12].

The technique usually employed to correct power factor of single-phase power supplies consists of a front-end full-bridge diode rectifier followed by a boost converter, as shown in fig 4. This approach is good for a low to medium power range [13]. As the power level increases, the diode bridge begins to become an important part of the application and it is necessary for the designer to deal with the problem of how to dissipate the heat in limited surface area. The dissipated power is important from an efficiency point of view.

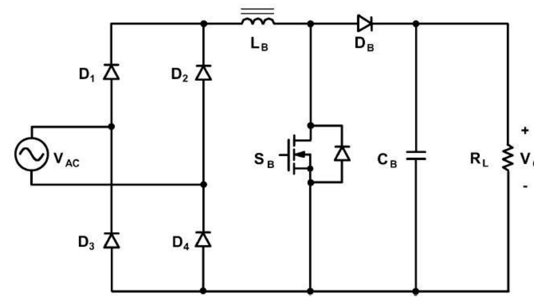

Fig 4: Conventional PFC Boost Rectifier

VI.BASIC BRIDGELESS PFC BOOST RECTIFIER

The circuit shown from a functional point of view is similar to the common boost converter.

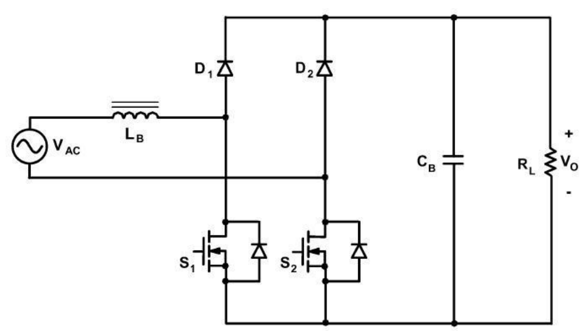

Fig: 5 Bridgeless PFC Boost rectifier

In the traditional topology current flows through two of the bridge diodes in series. In the bridgeless PFC configuration [14], current flows through only one diode with the Power MOS providing the return path. The operation can

Identify applicable sponsor/s here. *(sponsors)* be analyzed in two stages: operation as the boost converter and the operation for return path for the AC input signal.

When the AC input voltage goes positive, fig 5(a) the gate of S1 is driven high and current flows from the input through the inductor, storing energy. When S1 turns off, energy in the inductor is released as current flows through D1, through the load and returns through the body diode of S2.

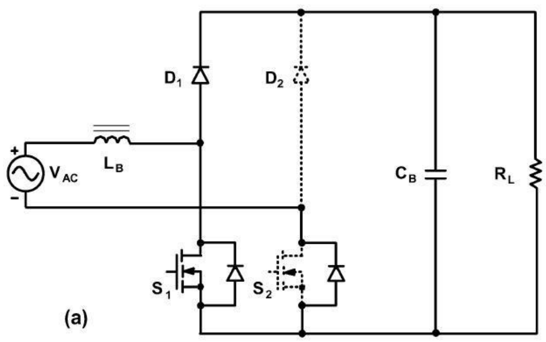

Fig. 5(a) Positive Half cycle of Basic bridgeless PFC boost rectifier

During the-off time, the current through the inductor L (i.e., during this time the inductor discharges its energy) flows in to the boost diode D1 and close the circuit through the load.

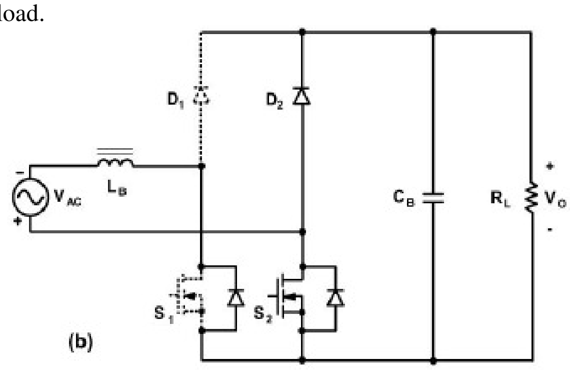

Fig 5(b): Negative Half cycle of Basic bridgeless PFC boost rectifier

During the negative half cycle circuit operation is mirrored as shown in fig 5(b) S2 turns on, current flows through the inductor, storing energy. When S2 turns off, energy is released as current flows through D2, through the load and back to the mains through the body diode of S1back to the input mains. Note that the two Power MOSFETs are driven synchronously. It doesn't matter whether the sections are performing as an active boost or as a path for the current to return. In either case there is benefit of lower power dissipation when current flows through the Power MOSFETs during the return phase.

Thus, in each half line cycle, one of the MOSFET operates as active switch and the other one operates as a diode, both the MOSFETs can be driven by the same signal [15]. The difference between the bridgeless PFC and conventional PFC is bridgeless PFC inductor current only goes through two semiconductor devices, but inductor current goes through three semiconductor devices for the conventional PFC circuit. The bridgeless PFC uses one MOSFET body diode to replace the two slow diodes of the conventional PFC [16]. Since both the circuits operates as a boost DC/DC converter; the switching loss should be the same. Thus the efficiency improvement relies on the conduction loss difference between the two slow diodes and the body diode of the MOSFET [17]. Besides, comparing with the conventional PFC, the bridgeless PFC not only reduces conduction loss, but also reduces the total components count.

VII. BRIDGELESS PFC BOOST RECTIFIER WITH TWO DC/DC BOOST CIRCUITS

To reduce the common-mode noise of the bridgeless PFC boost rectifier the topology of the bridgeless PFC boost rectifier needs to be modified to always provide a low-frequency (LF) path between the ac source and the positive or negative terminal of the output [18-19]. In Fig. 6, in addition to diodes D3 and D4, which are slow recovery diodes, a second inductor is also added, resulting in two dc/dc boost circuits, one for each half-line cycle. During a positive half-line cycle, the first dc/dc boost circuit, **LB1 -D1 –S2** is active through diode **D4** , which connects the ac source to the output ground. During a negative half-line cycle, the second dc/dc boost circuit, **LB2 -D2-S1** , is active through diode **D3**, which connects the ac source to the output ground.

It should be noted that switches S1 and S2, in both bridgeless PFC boost rectifiers can be driven with the same PWM signal, which significantly simplifies the implementation of the control circuit. The drawback of the bridgeless PFC boost rectifier in is that it requires an additional gate-drive transformer. The drawback of the bridgeless PFC boost rectifier in Fig.6 is that it requires two inductors. However, it should also be noted that two inductors compared to a single inductor have better thermal performance.

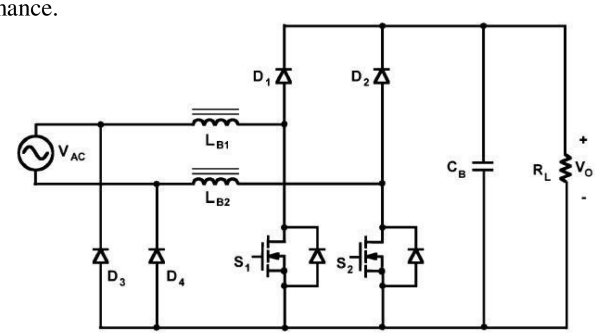

Fig 6: Bridgeless PFC rectifier with two DC/DC Boost Circuits

VII (a) SIMULATION RESULTS

The computer simulation of proposed converter is done using Matlab/Simulink and the results are presented. Bridgeless PFC rectifier with two DC/DC Boost Circuits is shown in Fig.7 (a). The controlled switch implemented is the power MOSFET with its inherently slow body diode. Simulated line voltage and line current waveforms of bridgeless PFC boost rectifier operating at 85-Vrms line voltage and 264-Vrms are shown in figure 7(b) and 7(d) respectively. It can be seen that from the waveforms current and voltage are out of phase. DC output voltage for different input voltage (rms) shown in Figs 7(c) and 7(e) respectively.

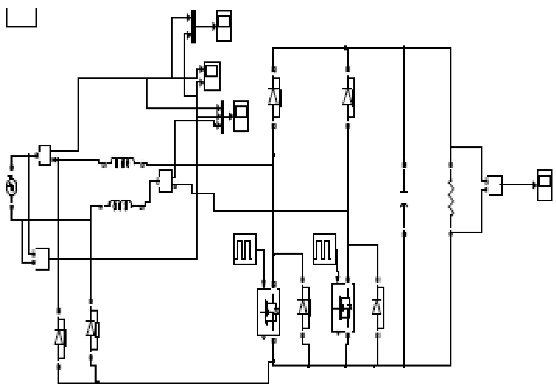

Fig 7(a): Bridgeless PFC rectifier with two DC/DC Boost Circuits

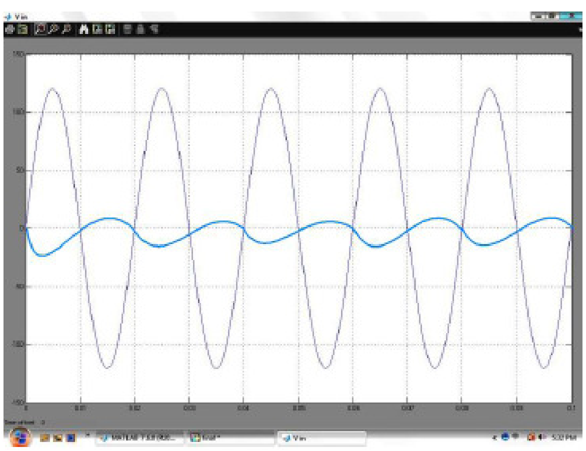

Fig 7(b) : Measured line voltage and line current waveforms of bridgeless PFC boost rectifier operating at 85-Vrms line voltage

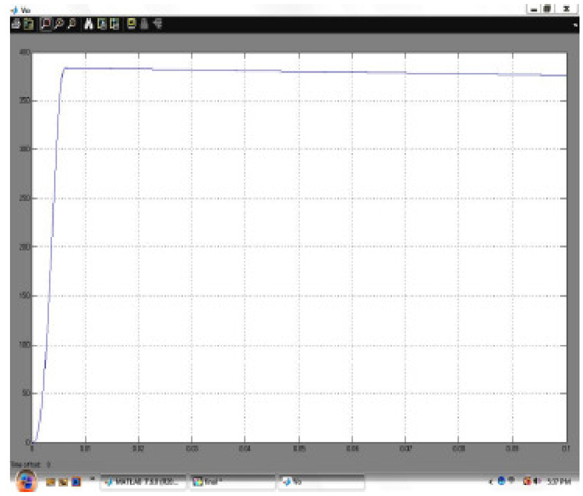

Fig 7(c): Measured dc output voltage waveforms of bridgeless PFC boost rectifier operating at 85-Vrms line voltages. Vout = 384Vdc

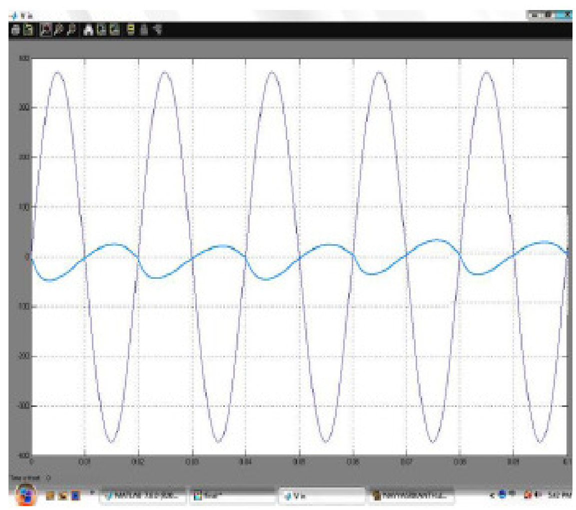

Fig 7(d) : Measured line voltage and line current waveforms of bridgeless PFC boost rectifier operating at 264-Vrms line voltage.

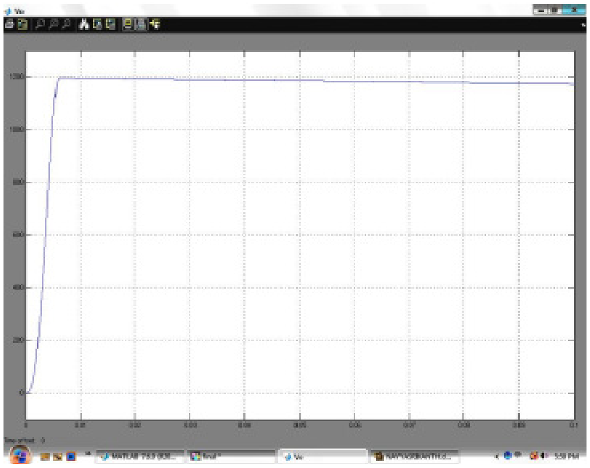

Fig 7(e): Measured dc output voltage waveforms of bridgeless PFC boost rectifier operating at 264-Vrms line voltages. Vout=1200 Vdc

VII (b) EXPERIMENTAL RESULTS

The proposed rectifier prototype was built to verify the operation; the critical relationships of voltage boost and simulation results are presented. Experimental results are verified and demonstrated promising the features and the Controller waveform at power factor correction. It should be noted that the power factor is improved up to the expected level and working for a frequency of 50Hz successfully. Fig. 8 shows the experimental setup.

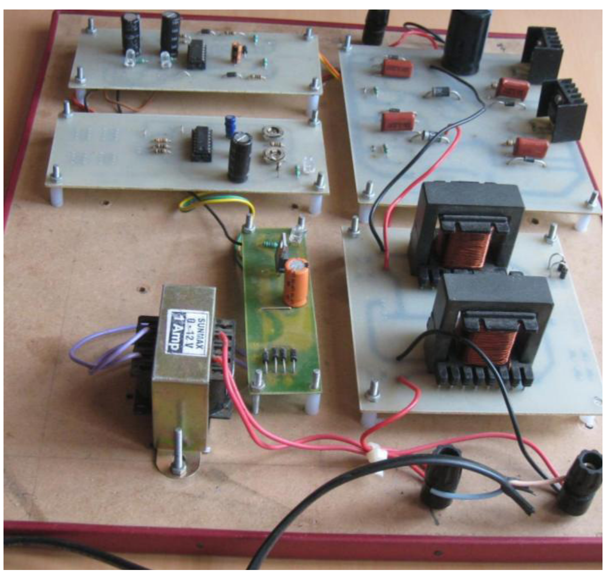

Fig. 8 Photo of Experimental Set up

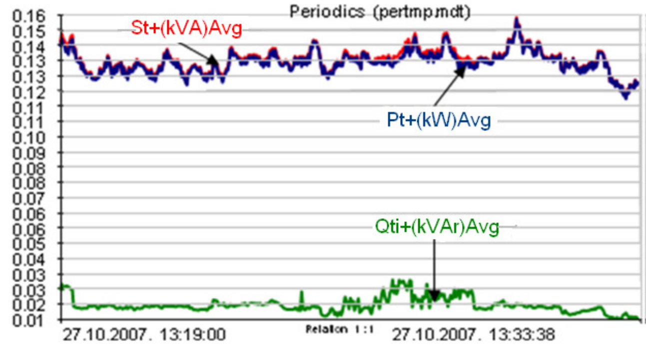

Fig 9(a): Power wave forms

Experimental results of the prototype is presented input voltage and output voltage waveforms of bridgeless PFC boost rectifier are shown in figure 9(d) and 7(e) respectively. It can be seen that the power factor is improved shown in Figs 9(b) and 9(c) respectively.

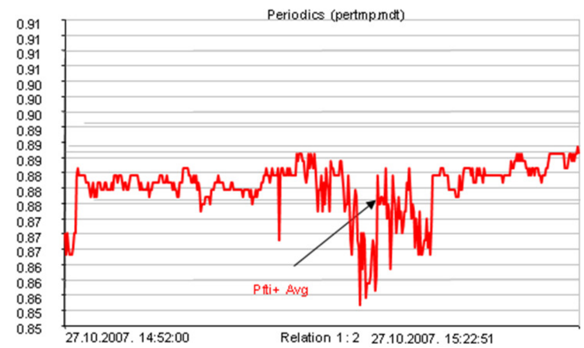

Fig 9(b): Power factor without PFC

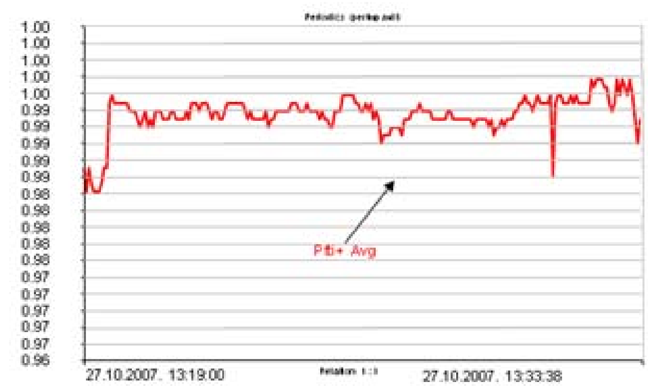

Fig 9(C): Power factor with PFC

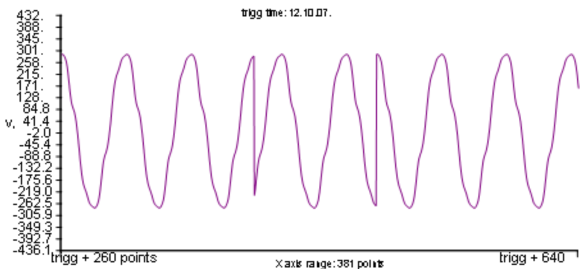

Fig 9(d) : Measured line voltage and line current waveforms of bridgeless PFC boost rectifier

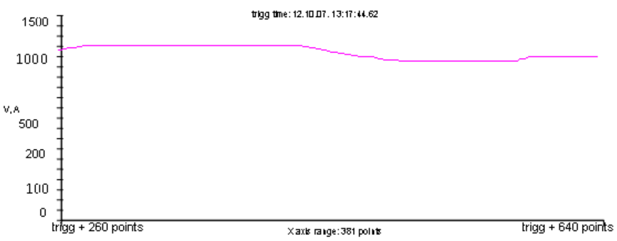

Fig 9(e): Measured dc output voltage waveforms of bridgeless PFC boost rectifier

CONCLUSION:

A novel single-phase PFC boost rectifiers is presented The bridgeless PFC boost rectifier, also called the dual-boost PFC rectifiers, compared to the conventional PFC boost rectifier, generally, improves the efficiency of the front-end PFC stage by eliminating one diode forward-voltage drop in the line-current path. The basic bridgeless PFC boost rectifier is not a practical solution because it has significantly larger common mode noise than the conventional PFC boost rectifier. In this paper, the bridgeless PFC boost rectifier with two dc/dc boost circuits is selected as a representative member of the bridgeless PFC boost rectifier family for performance comparison with the conventional PFC boost rectifier.

REFERENCES

[1] T. Ernö and M. Frisch, "Second generation of PFC solutions," *PowerElectronics Europe,Issue,* pp. 33-35, 2004.

[2] Crbone,A.Scappatura: "A high efficiency power factor corrector for single phase bridge diode rectifier". IEEE Conf. ESC 4 June 2004,Aachen, Germany.

[3] R. Carbone, P. Corsonello, M. Fantauzzi, A. Scappatura: "Power Factor Correctors for Single-phase Rectifiers: a Comparative Performance Analysis" 3th IASTED Intern. Conf. EUROPES 2003,September 3-5,2003, Marbella, Spain.

[4] R. Carbone: " Single-Phase Controlled Rectifier with Unity Power Factor" 8th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '08), 21-23 November 2008, Venice, Italy.

[5] R. Carbone, P. Corsonello: "A new passive power factor corrector for single phase bridge diode rectifier". IEEE Power Electronic Specialist Conference (PESC 03), June 15-19 2003,

[6] R. Redl: "An Economical Single-Phase Passive Power-Factor-Corrected Rectifier: Topology, Operation, Extensions, and Design for Compliance". IEEE Applied Power Electronics Conf. (APEC), Feb. 98, pp.454-460.

[7] Huber, L.; Jovanovic, M.M.: "Single-stage single- switch input-current shaping technique with fast- output-voltage regulation" IEEE trans. On Power Electronics, vol.13, May 1998. pp. 476-486.

[8] C.M. Wang, "A novel zero-voltage switching PWM boost rectifier with high power factor and low conduction losses," *International Telecommunication Energy Conf. (INTELEC) Proc*., pp. 224-229, Oct. 2003.

[9] J. Liu, W. Chen, J. Zhang, D. Xu, and F.C. Lee, "Evaluation of power losses in different CCM mode single-phase boost PFC converters via simulation tool," *IEEE Industry Applications Conf. (IAS) Record*, Session: High frequency power conversion, Paper 4, Sep. 2001.

[10] L. Rossetto, G. Spiazzi, and P. Tenti, "Boost PFC with 100-Hz switching frequency providing output voltage stabilization and compliance with EMC standards," *IEEE Trans. Ind. Applicat* .vol.3 6, pp.188–193,Jan./Feb.2000.

[11] U. Moriconi, "A bridgeless PFC configuration based on L4981 PFC controller," Application Note AN 1606, ST Microelectronics, 1/18-18/18,Nov.2002.

[12] H. Ye, Z. Yang, J. Dai, C. Yan, X. Xin, and J. Ying, "Common mode noise modeling and analysis of dual PFC circuit," I*nternational Telecommunication Energy Conf. (INTELEC) Proc*., pp. 575-582, Sep.2004.

[13] L. Rossetto, S. Buso, G. Spiazzi: "Conducted EMI Issues in a 600W Boost PFC Design".IEEE Transaction on Industry Applications, vol.36, n.2, March/April,2000,pp.578-585.

[14] F. Muzi, L. Passacantando: "Improvements in Power Quality and Efficiency with a new AC/DC High Current Converter" WSEAS Transactions on Circuit and Systems, Issue 5, Volume 7, May 2008.

[15] Jinrong Qian; Lee, F.C.Y.: " High-efficiency single- stage single-switch high-power-factor AC/DC converter with universal input" IEEE Transactions on Power Electronics.

[16] F. Souza and I. Barbi, "A new ZVS semi resonant high power factor rectifier with reduced conduction losses," *IEEE Trans. Industrial Electronics*, vol. 46, No.1, pp. 82- 90, Feb. 1999.

[17] B. Lu, R. Brown, and M. Soldano, "Bridgeless PFC implementation using one cycle control technique," *IEEE Applied Power Electronics (APEC) Conf. Proc.*, pp. 812-817, Mar. 2005.

[18] Ismail Daut, Rosnazri Ali and Soib Taib "Design of a Single-Phase Rectifier with Improved Power Factor and Low THD using Boost Converter Technique" American Journal of Applied Sciences 3 7): 1902-1904, 2006.

[19] Maswood A. I and LiuF. : A unity power factor front end rectifier with hysteresis current control, IEEE transactions on Energy Conversion, vol. 21, no.1, pp.153-160.