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Grid Connected Single Stage ZCS AC-DC Converter For PFC Application

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Abstract - The devices generally used in industrial, commercial and residential applications need to undergo rectification for their proper functioning and operation. They are connected to the grid comprising of non-linear loads and thus have non-linear input characteristics, which results in production of non-sinusoidal line current. Also, current comprising of frequency components at multiples of line frequency is observed which lead to line harmonics. Due to the increasing demand of these devices, the line current harmonics pose a major problem by degrading the power factor of the system thus affecting the performance of the devices. Hence there is a need to reduce the line current harmonics so as to improve the power factor of the system. This has led to designing of Power Factor Correction circuits.

A new interleaved single-stage ac–dc converter is proposed in this paper to reduce line current harmonics while achieving power factor correction (PFC). The proposed rectifier can produce input currents that do not have dead band regions with high PFC, operate with a continuous output current, and minimize the input electromagnetic interference filter size. Zero Current Switching technique is usedin this paper. In this paper, the operation of the new converter is explained, its features and design are discussed in results, and its operation is confirmed with experimental results obtained from a prototype.

I. INTRODUCTION

Over the years as the portable electronics industry progressed, different requirements evolved such as increased battery lifetime, small and cheap systems, brighter, full-color displays and a demand for increased talk-time in cellular phones. An ever increasing demand from power systems has placed power consumption at a premium. To keep up with these demands engineers have worked towards developing efficient conversion techniques and also have resulted in the subsequent formal growth of an interdisciplinary field of Power Electronics. However it comes as no surprise that this new field has offered challenges owing to the unique combination of three major disciplines of electrical engineering: electronics, power and control.

The objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. This objective is complicated by the fact that there are loads on the system that produce harmonic currents. These currents result in distorted voltages and currents that can adversely impact the system performance in different ways. The performance of the system depends on the load also. Typical examples of non-linear loads include rectifiers (power supplies, UPS units, discharge lighting), adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment. Typical examples of linear loads include motors, heaters and incandescent lamps.

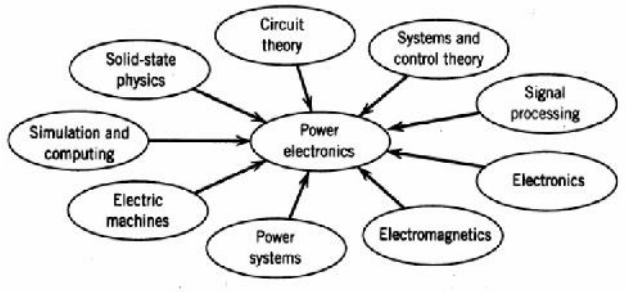

Fig : Need of Power Electronics.

POWER FACTOR

The inductive or the capacitive loads are generally termed as the reactive loads. The significance of these different types of loads is that the active (or true or useful) power can only be consumed in the resistive portion of the load, where the current and the voltage are in phase. The reactive component of the load only consumes (watt less or) reactive power which is necessary for energizing the magnetic circuit of the equipment (and is thus not available for any useful work). Inductive loads require two forms of power - Working/Active power (measured in kW) to perform the actual work of creating heat, light, motion, machine output, etc., and Reactive power (measured in kVAr) to sustain the electromagnetic field. To understand it better, we need to consider that there maybe two currents running through a circuit. One of these currents contains watts (watts produce work) and the other current contains no watts. Why do we need current with no watts (also referred to as watt-less current)? The answer is simple. The current known as watt-less current is required to produce the magnetic field around an electric motor. If there was no watt-less current then an electric motor would not turn. The problems arise due to the fact that we can sometimes have too much watt-less current, in those cases we need to remove some of it.

The vector combination of these two power components (active and reactive) is termed as Apparent Power (measured in kVA), the value of which varies considerably for the same active power depending upon the reactive power drawn by the equipment. The ratio of the active power (kW) of the load to the apparent power (kVA) of the load is known as the power factor of the load.

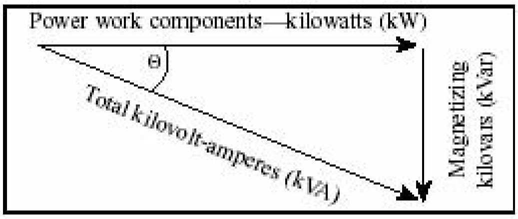

Fig : Power Factor

$$\text{Power Factor} = \frac{\text{Active Power (kW)}}{\text{Apparent Power (kVA)}}$$

Thus when the nature of the load is purely resistive the kVAr or the reactive component will be nil and thus the angle φ will be equal to 0 degrees and the power factor will be equal to unity. For a purely inductive load the power factor will be 0.0 lagging and for a purely capacitive load the power factor will be 0.0 leading. Thus, it is evident from above that, more the power factor departs from unity the more will be the kVA demand for the same kW load. Since most of the HT tariffs include kVA Demand charges along with the Energy Charges, the more the kVA demand for the same kW load the more shall be the electricity bill of the consumer. To say it otherwise, the customers with a low power factor will pay more for their useful electrical power. (The Billing demand for the month is generally taken to be the actual maximum kVA demand of the consumer during the month or a fixed percentage of the contract demand or a fixed kVA value, whichever is higher, based on the type of the consumer and the tariff structure of the utility.)

II. LITERATURE SURVEY

Every year, millions and millions of notebook computers, LCD monitors and LCD televisions are produced. With such a fast growing number of these and other electronic devices using more and more power, actions must to be taken to ensure the functionality of the nationwide power grid.

Implementing power factor correction (PFC) into switch mode power supplies will maximize:

- The power handling capability of the power supply
- Current handling capacities of power distribution networks

Many studies employ a three-phase rectifier with single-phase PFC modules.

Different PFC modules are using different types of rectifiers. They are Buck, Boost, and Fly back rectifiers. Each rectifier module has its capabilities to give reliable operation. But these rectifiers are using switches for its operation.

Why Single – Stage Scheme …..?

Power factor correction (PFC) is needed in ac–dc power supplies for them to comply with harmonic standards such as IEC 1000-3-2 [1]–[3]. Although it is possible to satisfy these standards by adding passive filter elements to the traditional passive diode rectifier/*LC* filter input combination, the resulting converter would be very bulky and heavy due to the size of the low-frequency inductors and capacitors. The most common approach to PFC is to use two-stage power conversion schemes.

These two-stage schemes use a front-end ac–dc converter stage to perform ac–dc conversion with PFC with the output of the front-end converter fed to a back-end dc–dc converter stage that produces the desired isolated dc output voltage [4]. Using two converter stages in this manner, however, increases the cost, size, and complexity of the overall ac–dc converter, and this has led to the emergence of single-stage power-factor-corrected converters.

In order to reduce the cost, size, and complexity associated with two-stage ac–dc power conversion and PFC, researchers have tried to propose single-stage converters that integrate the functions of PFC and isolated dc–dc conversion in a single power converter. Several single-phase [5]–[11] and three-phase [4], [12]–[24] converters have been proposed in the literature, with three-phase converters being preferred over single-phase converters for higher power applications.

Previously proposed three-phase single-stage ac–dc converters, however, have at least one of the following drawbacks that have limited their widespread use.

1) They are implemented with three separate ac–dc single stage modules [13]–[15].

2) The converter components are exposed to very high dc bus voltages so that switches and bulk capacitors with very high voltage ratings are required [17], [18], [22], [23].

3) The input currents are distorted and contain a significant amount of low-frequency harmonics because the converter has difficulty performing PFC and dc–dc conversion simultaneously [16].

4) The converter must be controlled using very sophisticated techniques and/or nonstandard techniques [5]–[11]. This is particularly true for resonant-type converters that need variable-switching-frequency control methods to operate.

5) The output inductance must be very low, which makes the output current to be discontinuous. This results in a very high output ripple so that secondary diodes with high peak current ratings and large output capacitors to filter the ripple are needed [13]–[20].

6) Most of them are in discontinuous conduction mode at the input and need to have a large input filter to filter out large high-frequency harmonics [4], [13]–[15], [17], [18], [22]–[24].

The authors proposed a three-phase single-stage three-level converter to mitigate these drawbacks in [24]. Although the converter proposed in that paper was an advance over previously proposed three-phase single-stage converters, it still suffered from the need to have a discontinuous output inductor current at light-load conditions to keep the dc bus capacitor voltage < 450 V, and it needed to operate with discontinuous input current, which resulted in high component current stress and the need for significant input filtering due to the large amount of ripple.

This paper presents a new interleaved three-phase single stage rectifier that does not have any of these drawbacks. The work presented in this paper can be considered to be a follow-up work in relation to what was presented in [24]. In comparison to the converter presented in [24], the converter presented in this paper has an interleaved structure, requires two fewer diodes in the dc bus, has an output current which is continuous for all load ranges, has a dc bus voltage that is less than 450 V for all load conditions, and has a much better input current harmonic content. In this paper, the operation of the new converter is explained, its features and design are discussed in results, and its operation is confirmed with experimental results obtained from a prototype.

III. PROPOSED METHOD AND RESULTS

Grid Connected single stage ZCS AC-DC converter for PFC application

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

"Another very important aspect of the systems connected to the grid is to select a proper power factor according to the grid demands: active or reactive power. The most efficient systems are those which allow variation in the active and reactive power injected into the grid, depending on the power grid requirements".

In any basic switched power supply consists of five standard components:

- Pulse-width modulating controller
- Transistor switch (active switch)
- Inductor
- Capacitor
- Diode (passive switch)

Switch

In its crudest form a switch can be a toggle switch which switches between supply voltage and ground. But for all practical applications which we shall consider we will deal with transistors. Transistors chosen for use in switching power supplies must have fast switching times and should be able to withstand the voltage spikes produced by the inductor. The input on the gate of the transistor is normally a Pulse Width Modulated (PWM) signal which will determine the ON and OFF time. Sizing of the power switch is determined by the load current and off-state voltage capability. The power switch (transistor) can either 32 be a MOSFET, IGBT, JFET or a BJT. Power MOSFETs are the key elements of high frequency power systems such as high-density power supplies. Therefore MOSFETs have now replaced BTJ's in new designs operating at much higher frequencies but at lower voltages. At high voltages MOSFETs still have their limitations. The intrinsic characteristics of the MOSFET produce a large on-resistance which increases excessively when the devices breakdown voltage is raised. Therefore the power MOSFET is only useful up to voltage ratings of 500V and so is restricted to low voltage applications or in two-transistor forward converters and bridge circuits operating off-line. At high breakdown voltages (>200V) the on-state voltage drop of the power MOSFET becomes higher than that of a similar size bipolar device with similar voltage rating. This makes it more attractive to use the bipolar power transistor at the expense of worse high frequency performance. As improvements in fabrication techniques, new materials, device characteristics take place than MOSFETs are likely to replace BJTs.

Operating Frequency:

The operating frequency determines the performance of the switch. Switching frequency selection is typically determined by efficiency requirements. There is now a growing trend in research work and new power supply designs in increasing the switching frequencies. The higher is the switching frequency, the smaller the physical size and component value. The reason for this is to reduce even further the overall size of the power supply in line with miniaturization trends in electronic and computer systems. However there is an upper frequency limit where either magnetic losses in the inductor or switching losses in the regulator circuit and power MOSFET reduce efficiency to an impractical level. Higher frequency also reduces the size of the output capacitor. E.g. the capacitance required is 67μF at 500 KHz, but only 33μF at 1MHz.The ripple current specification remains unchanged.

Inductor:

The function of the inductor is to limit the current slew rate (limit the current in rush) through the power switch when the circuit is ON. The current through the inductor cannot change suddenly. When the current through an inductor tends to fall, the inductor tends to maintain the current by acting as a source. This limits the otherwise highpeak current that would be limited by the switch resistance alone. The key advantage is when the inductor is used to drop voltage, it stores energy. Also the inductor controls the percent of 33 the ripple and determines whether or not the circuit is operating in the continuous mode. Peak current through the inductor determines the inductor's required saturation current rating, which in turn dictates the approximate size of the inductor. Saturating the inductor core decreases the converter efficiency, while increasing the temperature of the inductor, the MOSFET and the diode. The size of the inductor and capacitor can be reduced by the implementation of high switching frequency, multiphase interleaved topology, and a fast hysteric controller. A smaller inductor value enables a faster transient response; it also results in larger current ripple which causes higher conduction losses in the switches, inductor and parasitic resistances. The smaller inductor also requires a larger filter capacitor to decrease the output voltage ripple. Inductors used in switched supplies are sometimes wound on toroidal cores, often made of ferrite or powdered iron core with distributed air-gap to store energy. A DC-DC converter transfers energy at a controlled rate from an input source to an output load, and as the switching frequency increases, the time available for this energy transfer decreases. For example, consider a buck converter operating at 500 kHz with a 10 μH inductor. For most

DC-DC converters, changing the frequency to 1 MHz allows use of exactly one half the inductance, or 5µH.

Capacitor:

Capacitor provides the filtering action by providing a path for the harmonic currents away from the load. Output capacitance (across the load) is required to minimize the voltage overshoot and ripple present at the output of a step-down converter. The capacitor is large enough so that its voltage does not have any noticeable change during the time the switch is off. Large overshoots are caused by insufficient output capacitance, and large voltage ripple is caused by insufficient capacitance as well as a high equivalent-series resistance (ESR) in the output capacitor. The maximum allowed output-voltage overshoot and ripple are usually specified at the time of design. Thus, to meet the ripple specification for a step-down converter circuit, we must include an output capacitor with ample capacitance and low ESR. The problem of overshoot, in which the output-voltage overshoots its regulated value when a full load is suddenly removed from the output, requires that the output capacitor be large enough to prevent stored inductor energy from launching the output above the specified maximum output voltage. Since switched power regulators are usually used in high current, high performance power supplies, the capacitor should be chosen for 34 minimum loss. Loss in a capacitor occurs because of its internal series resistance and inductance. Capacitors for switched regulators are partly chosen on the basis of Effective Series Resistance (ESR). Solid tantalum capacitors are the best in this respect. For very high performance power supplies, sometimes it is necessary to use parallel capacitors to get a low enough effective series resistance.

Freewheeling Diode:

Since the current in the inductor cannot change suddenly; a path must exist for the inductor current when the switch is off (open). This path is provided by the freewheeling diode (or catch diode).The purpose of this diode is not to rectify, but to direct current flow in the circuit and to ensure that there is always a path for the current to flow into the inductor. It is also necessary that this diode should be able to turn off relatively fast. Thus the diode enables the converter to convert stored energy in the inductor to the load. This is a reason why we have higher efficiency in a DC-DC Converter as compared to a linear regulator. When the switch closes, the current rises linearly (exponentially if resistance is also present). When the switch opens, the freewheeling diode causes a linear decrease in current. At steady state we have a saw tooth response with an average value of the current.

8.2: Why ZCS …. ?

The control switches in all the PWM dc-dc converter topologies, operate in a switch mode, in which they turn whole load current on and off during each switching. This switch-mode operation subjects the control switches to high switching stress and high switching power losses. To maximize the performance of switch-mode power electronic conversion systems, the switching frequency of the power semiconductor devices needs to be increased, but this results in increased switching losses and electromagnetic interference (EMI). To eradicate these problems, Zero voltage switching (ZVS) technique and zero current switching (ZCS) technique are two conventionally employed soft switching methods. These techniques lead to either zero voltage or zero current during switching transition, significantly decreasing the switching losses and increasing the reliability for the converters. The ZVS technique eliminates capacitive turn-on losses, and decreases the turnoff switching losses by slowing down the voltage rise, thereby lowering the overlap between the switch voltage and the switch current. However, a large external resonant capacitor is needed to lower the turn-off switching loss effectively for ZVS. Conversely, ZCS eliminates the voltage and current overlap by forcing the switch current to zero before the switch voltage rises, making it more effective than ZVS in reducing switching losses, especially for slow switching power devices. For high efficiency power conversion, the ZCS topologies are most frequently adopted. Variable frequency control can achieve output regulation of the resonant converters in both traditional ZCS and ZVS approaches. Traditional ZCS converters operate with constant on-time control, while the traditional ZVS converters operate with constant off-time control. Both approaches need to operate with a wide switching frequency range when given a wide input source and load range, making the filter circuit design difficult to optimize. Many high efficiency converter topologies with ZCS have been explored and proposed. The primary design feature of novel ZCS/ZVS PWM power converters is the incorporation of an auxiliary switch in the traditional quasi-resonant circuit. The resonance of the novel converters is dominated by the auxiliary switch, which generates resonance and temporarily stops a period that can be regulated, thus circumventing the disadvantages of fixed conduction or cut-off time in a traditional quasi-resonant power converter.

Simulink model

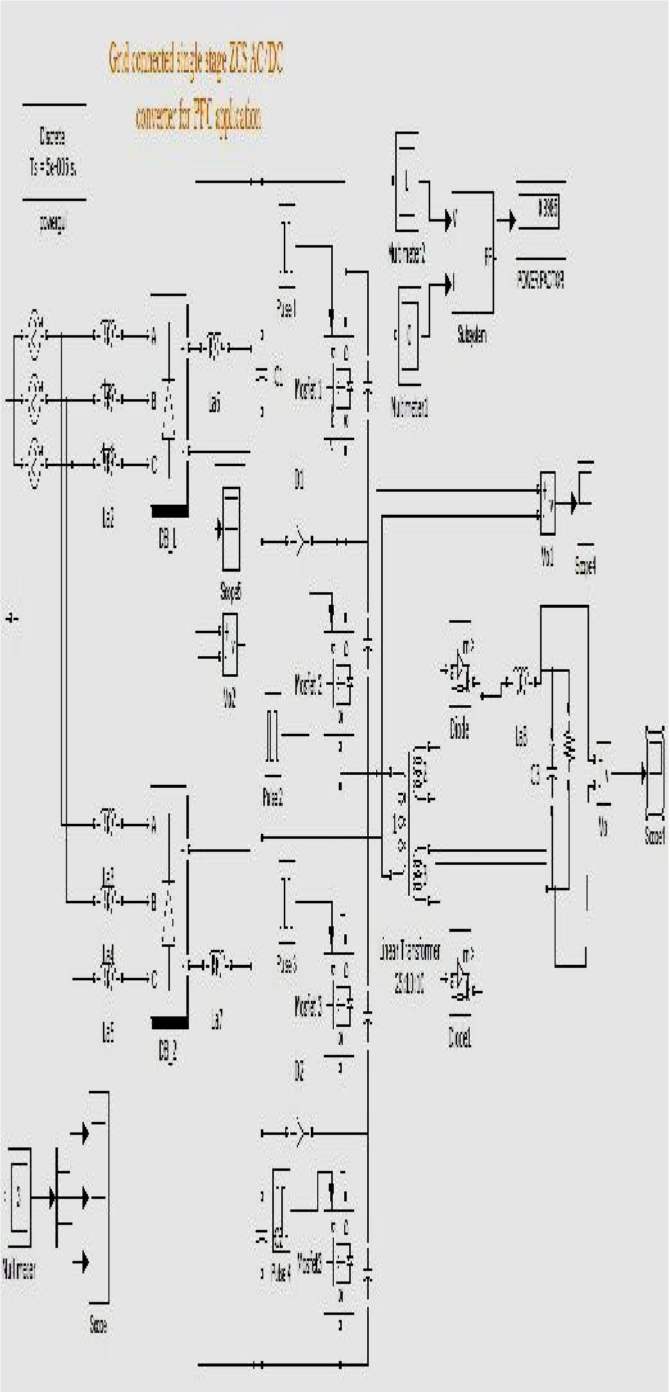

Fig: Simulink model of single stage ZCS AC-DC converter for PFC application.

:Simulink Results

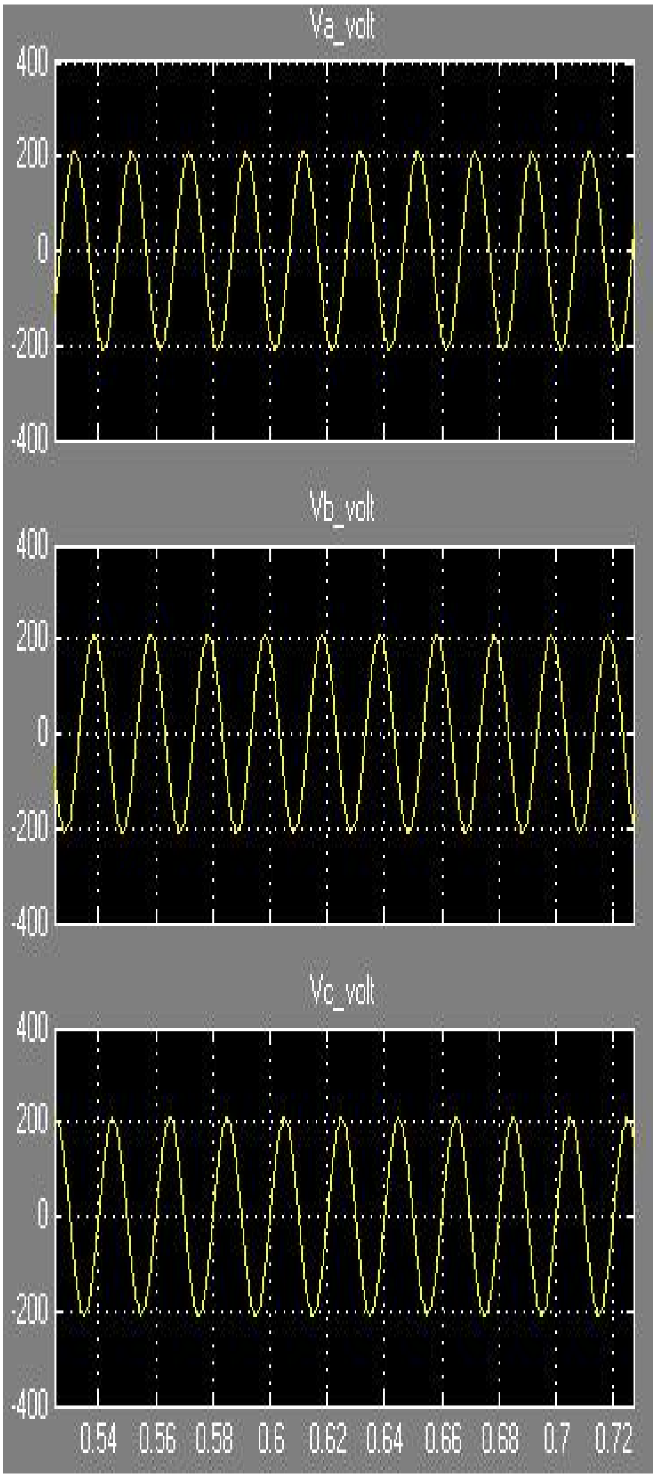

Fig: Input voltages

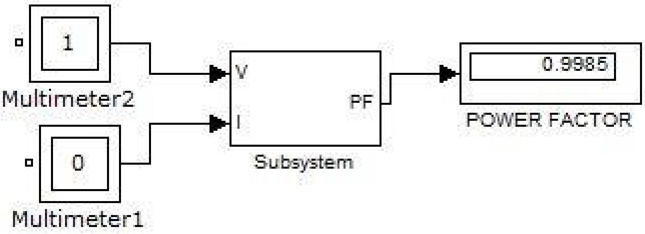

Fig: Power Factor from Simulink Model

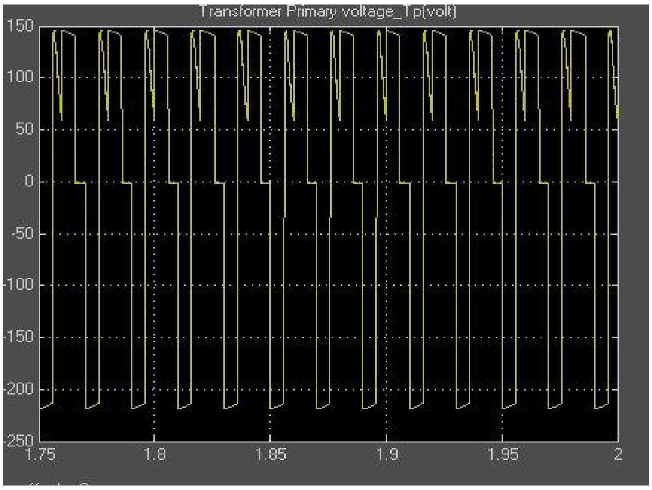

Fig: Primary voltage of the Main Transformer.

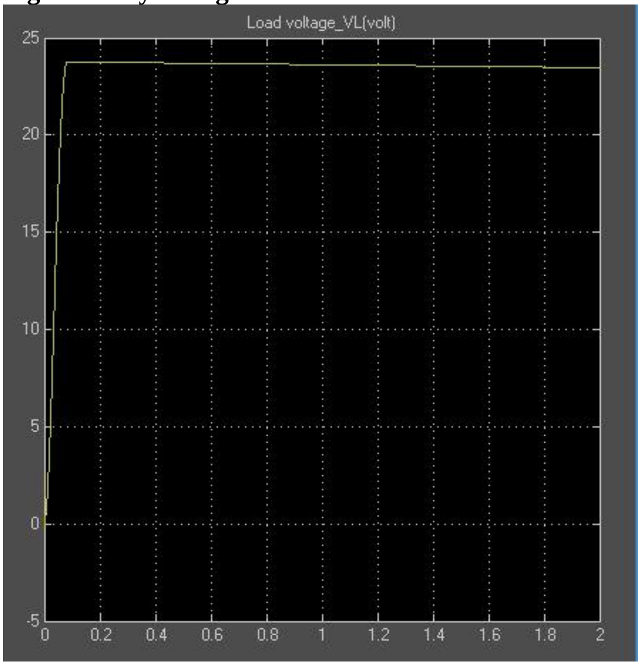

Fig: Output Inductor Current

CONCLUSION

A new three-phase three-level single-stage power-factor corrected ac–dc converter with interleaved input has been proposed in this paper. The converter operates with a single controller to regulate the output voltage and uses auxiliary windings taken from its power transformer as magnetic switches to cancel the dc bus voltage so that the input section operates like a boost converter. The proposed converter has the following features.

1) The proposed converter can operate with lower peak voltage stresses across its switches and the dc bus capacitors as it is a three-level converter. This allows for greater flexibility in the design of the converter and ultimately improved performance.

2) The proposed converter can operate with an input current harmonic content that meets the EN61000-3-2 Class A standard with reduced input filter due to the interleaved structure.

3) The output inductor of the proposed converter can be designed to work in continuous conduction mode over a wide range of load variation and input voltage. This results in a lower output inductor current ripple than that found in previously proposed converters which helps reduce secondary component stresses and filtering.

4) The aforementioned features are all an improvement on the original non-interleaved converter that was presented in [24]. Moreover, the proposed interleaved converter operates with greater efficiency than the converter proposed in [24] because it has fewer diodes in the dc bus and it has less turn-on losses.

REFERENCES

[1] Limits for Harmonic Current Emission (Equipment Input Current >16 A per Phase), IEC1000-3-2 Int. Std., 1995.

[2] Limits for Harmonic Current Emission (Equipment Input Current >16 A per Phase), IEC1000-3-4 Int. Std., 1998.

[3] IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, IEEE Std. 519-1992, Apr. 1993.

[4] B. Tamyurek and D. A. Torrey, “A three-phase unity power factor single stage AC–DC converter based on an interleaved flyback topology,” IEEE Trans. Power Electron., vol. 26, no. 1, pp. 308–318, Jan. 2011.

[5] J. M. Kwon, W. Y. Choi, and B. H. Kwon, “Single-stage quasi-resonant flyback converter for a cost-effective PDP sustain power module,” IEEE Trans. Ind. Electron., vol. 58, no. 6, pp. 2372–2377, Jun. 2011.

[6] H. L. Cheng, Y. C. Hsieh, and C. S. Lin, “A novel single-stage high-power factor AC/DC converter featuring high circuit efficiency,” IEEE Trans. Ind. Electron., vol. 58, no. 2, pp. 524–532, Feb. 2011.

[7] S. K. Ki and D. D.-C. Lu, “Implementation of an efficient transformer-less single-stage single-switch AC/DC converter,” IEEE Trans. Ind. Electron., vol. 57, no. 12, pp. 4095–4105, Dec. 2010.

[8] H. Ma, Y. Ji, and Y. Xu, “Design and analysis of single-stage power factor correction converter with a feedback winding,” IEEE Trans. Power Electron., vol. 25, no. 6, pp. 1460–1470, Jun. 2010.

[9] H. J. Chiu, Y. K. Lo, H. C. Lee, S. J. Cheng, Y. C. Yan, C. Y. Lin, T. H. Wang, and S. C. Mou, “A single-stage soft-switching flyback converter for power-factor-correction applications,” IEEE Trans. Ind. Electron., vol. 57, no. 6, pp. 2187–2190, Jun. 2010.

[10] J. Zhang, D. D.-C. Lu, and T. Sun, “Flyback-based single-stage power factor correction scheme with time-multiplexing control,” IEEE Trans. Ind. Electron., vol. 57, no. 3, pp. 1041–1049, Mar. 2010.

[11] H. S. Ribeiro and B. V. Borges, “New optimized full-bridge single-stage AC/DC converters,” IEEE Trans. Ind. Electron., vol. 58, no. 6, pp. 2397– 2409, Jun. 2011.

[12] P. Barbosa, F. Canales, J.-C. Crebier, and F. C. Lee, “Interleaved threephase boost rectifiers operated in the discontinuous conduction mode: Analysis, design considerations and experimentation,” IEEE Trans. Power Electron., vol. 16, no. 5, pp. 724–734, Sep. 2001.

[13] H. M. Suraywanshi, M. R. Ramteke, K. L. Thakre, and V. B. Borghate, “Unity-power-factor operation of three phase AC–DC soft switched converter based on boost active clamp topology in modular approach,” IEEE Trans. Power Electron., vol. 23, no. 1, pp. 229–236, Jan. 2008.

[14] U. Kamnarn and V. Chunkag, “Analysis and design of a modular threephase AC-to-DC converter using CUK rectifier module with nearly unity power factor and fast dynamic

response," IEEE Trans. Power Electron., vol. 24, no. 8, pp. 2000–2012, Aug. 2009.

[15] U. Kamnarn and V. Chunkag, "A power balance control technique for operating a three-phase AC to DC converter using single-phase CUK rectifier modules," in Proc. IEEE Conf. Ind. Electron. Appl., 2006, pp. 1–6.

[16] J. Contreas and I. Barbi, "A three-phase high power factor PWM ZVS power supply with a single power stage," in Proc. IEEE PESC, 1994, pp. 356–362.

[17] F. Cannales, P. Barbosa, C. Aguilar, and F. C. Lee, "A quasi-integrated AC/DC three-phase dual-bridge converter," in Proc. IEEE PESC, 2001, pp. 1893–1898.

[18] F. S. Hamdad and A. K. S. Bhat, "A novel soft-switching high-frequency transformer isolated three-phase AC-to-DC converter with low harmonic distortion," IEEE Trans. Power Electron., vol. 19, no. 1, pp. 35–45, Jan. 2004.

[19] C. M. Wang, "A novel single-stage high-power-factor electronic ballast with symmetrical half-bridge topology," IEEE Trans. Ind. Electron., vol. 55, no. 2, pp. 969–972, Feb. 2008.

[20] D. Wang, H. Ben, and T. Meng, "A novel three-phase power factor correction converter based on active clamp technique," in Conf. Rec. ICEMS, 2008, pp. 1896–1901.

[16] S. Rajakaruna and L. Jayawickrama, "Steady-state analysis and designing impedance network of Z-source inverters," *IEEE Trans. Ind. Electron.*, vol. 57, no. 7, pp. 2483–2491, Jul. 2010.

[17] J. B. Liu, J. G. Hu, and L. Y. Xu, "Dynamic modeling and analysis of Z-source converter—Derivation of AC small signal model and designoriented analysis," *IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 1786– 1796, Sep. 2007.

[18] M. S. Shen, Q. S. Tang, and F. Z. Peng, "Modeling and controller design of the Z-source inverter with inductive load," in *Proc. IEEE PESC*, 2007, pp. 1804–1809.

[19] P. C. Loh, D. M. Vilathgamuwa, C. J. Gajanayake, Y. R. Li, and C. W. Teo, "Transient modeling and analysis of pulse-width modulated Z-source inverter," *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 498– 507, Mar. 2007.

[20] Q. V. Tran, T. W. Chun, J. R. Ahn, and H. H. Lee, "Algorithms for controlling both the DC boost and AC output voltage of Z-source inverter," *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2745–2750, Oct. 2007.