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Design of Isolated Power System -Based Boost Converter with Simultaneous DC and AC Outputs

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Abstract: This paper proposes a family of hybrid converter topologies which can supply simultaneous dc and ac loads from a single dc input. These topologies are realized by replacing the controlled switch of single-switch boost converters with a voltage-source-inverter bridge network. The resulting hybrid converters require lesser number of switches to provide dc and ac outputs with an increased reliability, resulting from its inherent shoot-through protection in the inverter stage. Such multi output converters with better power processing density and reliability can be well suited for systems with simultaneous dc and ac loads, e.g., nano grids in residential applications. The proposed converter, studied in this paper, is called boost-derived hybrid converter (BDHC) as it is obtained from the conventional boost topology. The steady-state behaviour of the BDHC has been studied in this paper, and it is compared with conventional designs. A suitable pulse width modulation (PWM) control strategy, based upon unipolar sine-PWM, is described. A DSP-based feedback controller is de-signed to regulate the dc as well as ac outputs. A 600-W laboratory prototype is used to validate the operation of the converter. The proposed converter is able to supply dc and ac loads at 100 V and 110 V (rms), respectively, from a 48-V dc input. The performance of the converter is demonstrated with inductive and nonlinear loads. The converter exhibits superior cross-regulation properties to dynamic load-change events. The proposed concept has been extended to quadratic boost converters to achieve higher gains.

Keywords: Boost-Derived Hybrid Converter (BDHC), Dc Nanogrid, Pulsewidth-Modulated Inverters.

I. INTRODUCTION

Nano grid architectures are being increasingly incorporated in modern smart residential electrical power systems [1]. These systems involve different load types—dc as well as ac—efficiently interfaced with different kinds of energy sources (conventional or nonconventional) using power electronic converters [2]. Fig. 1 shows the schematic of a system, where a single dc source (v_{dcin}) (e.g., solar panel, battery, fuel cell, etc.) supplies both dc (v_{dcout}) and ac (v_{acout}) loads. The architecture of Fig. 1(a) uses separate power converters for each conversion type (dc–dc and dc–ac) while Fig. 1(b) utilizes a single power converter stage to perform both the conversions. The latter converter, referred to as a hybrid converter in this paper, has higher power processing density and improved reliability (resulting from the inherent shoot-through protection capability). These qualities make them suitable for use in compact systems with both dc and ac loads. For example, an application of a hybrid converter can be to power an ac fan and a LED lamp both at the same time from a solitary dc input in a single stage.

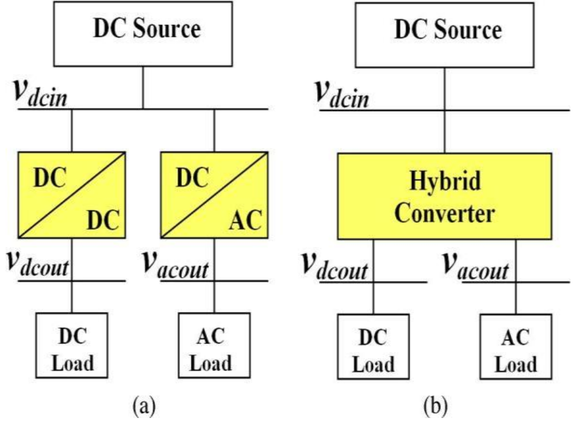
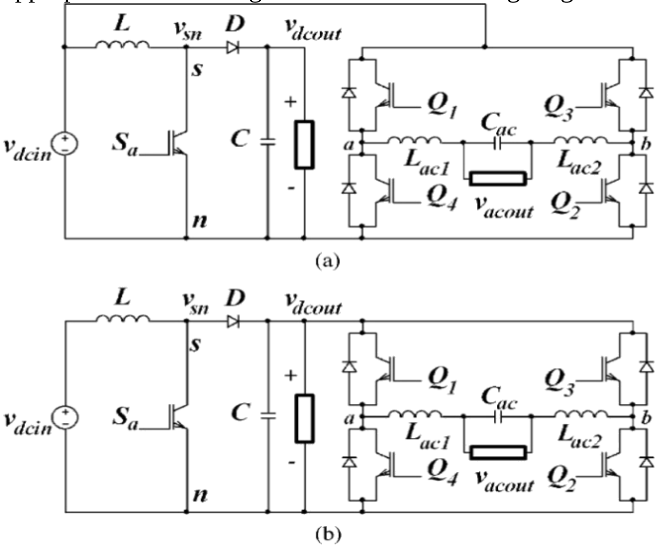


Fig. 1. Representative schematic of a nanogrid architecture with a single dc input and simultaneous dc and ac outputs. (a) Dedicated power converter-based architecture. (b) Hybrid converter-based architecture.

Smart residential systems are often connected to non conventional energy sources to provide cleaner energy. Due to space constraints, these dedicated energy sources are highly localized and have low terminal voltage and power ratings (typically, on the order of a hundred watts). Conventional designs involve two separate converters, a dc–dc converter (e.g., boost) and a voltage source inverter (VSI), connected either in parallel [as shown in Fig. 2(a)] or in cascade [Fig. 2(b)], supplying dc and ac outputs at Vdcout and Vacout, respectively. Depending upon the requirements, topologies providing higher gains may be required to achieve step-up operation [3]. This paper investigates the use of single boost-stage architecture to supply hybrid loads. The operation of conventional VSIs in hybrid converters would involve the use of deadtime circuitry to prevent shoot-through. In addition, due to electromagnetic interference (EMI) or other spurious noise, misgating turn-on of the inverter leg switches may take place, resulting in damage to the switches. In residential applications, due to the compactness of the overall conversion system, the generation of spurious noise may be commonplace. Thus, the VSIs in such applications need to be highly reliable with appropriate measures against EMI-induced misgating.



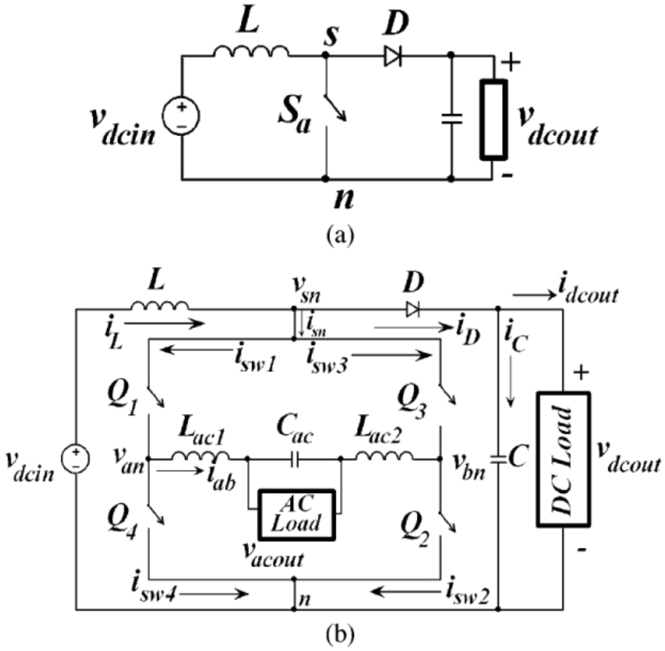
(a)

(b)

Fig. 2. Schematic of power converter topologies with simultaneous dc and ac loads. A conventional boost converter and a VSI have been used to implement the system. System (a) when both are connected in parallel and (b) when connected in cascade.

The Z-source inverter (ZSI), proposed in [4], can mitigate the problem of shoot-through due to the EMI in a VSI. The use of a unique impedance network at the input of the ZSI allows shoot-through state in which both the switches of an inverter leg can be turned on simultaneously. Extended boost ZSI has been proposed where a higher gain is achieved utilizing this Z-source topology [5]. However, ZSI cannot supply both dc and ac loads simultaneously. This is due to the fact that it has two capacitors which have to be matched with equal loads across them. Unmatched loads on the capacitors might lead to dynamic instability [6]. The switched boost inverter (SBI), proposed in [7], is a hybrid converter topology, which can achieve similar advantages as a ZSI with lesser number of passive components and supply simultaneous dc and ac loads. This inverse Watkins–Johnson (IWJ) converter-derived topology [8] is a converter based upon the first-order four-switch converter cell [9]. The proposed hybrid converter is derived from a two-switch converter cell-based step-up converter, such as the boost converter. There-fore, it involves lesser component count compared to the IWJ converter. The proposed converter is denoted as boost-derived hybrid converter (BDHC). The objectives of this paper are the following: 1) to introduce a family of hybrid converter topologies capable of simultaneously supplying ac and dc loads; 2) to characterize the steady-state behaviour of the BDHC topology; 3) to develop a PWM control scheme for the BDHC; 4) to compare the performance of the BDHC with conventional designs; 5) to validate the static and dynamic performance of the BDHC using an experimental prototype; and 6) to extend the proposed philosophy to higher order boost converters in order to achieve a higher conversion ratio. This paper is organized as follows. The proposed circuit modification principle is described next in Section II, and its application to a boost converter is shown.

The steady-state characterization of the converter is given in Section III. The PWM control strategy and the closed-loop implementation to regulate both ac and dc outputs are described in Section IV, followed by a comparative study of the BDHC in Section V. Section VI extends the circuit modification principle to higher order boost converters. The converter and its control strategy have been validated using an experimental prototype in Section VII.



(a)

(b)

Fig.3. (a) Conventional boost converter. (b) Proposed BDHC obtained by replacing S_a with a single-phase bridge network. The switch realization for the bridge can be done using bidirectional switches—either IGBTs with antiparallel diodes or MOSFETs.

II. BDHC

A. Proposed Circuit Modification

Boost converters comprise complementary switch pairs, one of which is the control switch (controls the duty cycle) and the other capable of being implemented using a diode. Hybrid converter topologies can be synthesized by replacing the controlled switch with an inverter bridge network, either a single-phase or three-phase one. The proposed circuit modification principle, applied to a boost converter, is illustrated in the next section. The resulting converter, called BDHC, is the prime focus area of this paper. Section VI extends this principle to higher order converters.

B. Derivation of BDHC Topology

The control switch S_a of a conventional boost converter [shown in Fig. 3(a)] has been replaced by the bidirectional single-phase bridge network switches (Q_1–Q_4) to obtain the BDHC topology [shown in Fig. 3(b)]. This proposed converter provides simultaneous ac output (v_{acout}) in addition to the dc output (v_{dcout}) provided by the boost converter. For the BDHC, the hybrid (dc as well as ac) outputs have to be controlled using the same set of four controlled switches Q_1–Q_4. Thus, the challenges involved in the operation of BDHC are the following: 1) defining the duty cycle (D_{st}) for boost operation and the modulation index (M_a) for inverter operation; 2) determination of voltage stresses and currents through different circuit components and their design; and 3) control and channelization of total input power to both ac and dc loads. In the subsequent sections, all the aforementioned challenges will be discussed.

III. OPERATION OF BDHC

A. Operating Principle

Each of the four bidirectional switches (Q_1–Q_4) of BDHC comprises the combination of a switch S_i and an antiparallel diode D_i (i = 1 to 4). The boost operation of the proposed converter can be realized by turning on both switches of any particular leg (either S_1–S_4 or S_3–S_2) simultaneously. This is equivalent to shoot-through switching condition as far as VSI operation is concerned, and it is strictly forbidden in the case of a conventional VSI. However, for the proposed modification, this operation is equivalent to the switching "on" of the switch "S_a" of the conventional boost converter [see Fig. 3(a)]. The ac output of the BDHC is controlled using a modified version of unipolar sine-PWM switching scheme, described in Section IV. The BDHC, during inverter operation, has the same circuit states as a conventional VSI. The reason for this is as follows: For conventional VSIs (shown in Fig. 2), although the input to the bridge is a voltage stiff dc bus, the input dc voltage is required only during the power intervals, i.e., when there is a power transfer with the source. In the other intervals, the current freewheels among the inverter switches and these states do not require the input to be at a fixed dc value and hence can be zero. In the BDHC, the switch node voltage (v_{sn}) acts as the input to the inverter; it switches between the voltage levels—v_{dcout} and zero. The switching scheme should ensure that the interval for power transfer with the source occurs only when v_{sn} is positive, i.e., when v_{sn} is clamped to the dc output voltage v_{dcout}. Fig. 4 illustrates this concept. The BDHC has three distinct switching intervals as described in the following.

1. Interval I: Shoot-through interval: The equivalent circuit schematic of the BDHC during the shoot-through interval is shown in Fig. 5(a). The shoot-through interval occurs when both the switches (either Q_1–Q_4 or Q_3–Q_2) of any particular leg are turned on at the same time. The duration of the shoot-through interval decides the boost converter duty cycle (D_{st}). The diode "D" is reverse biased during this period. The inverter output current circulates within the bridge network switches. Thus, BDHC allows additional switching states which are strictly forbidden in a VSI.

2. Interval II: Power interval: The power interval, shown in Fig. 5(b), occurs when the inverter current enters or leaves the bridge network at the switch node "s." The diode "D" conducts during this period, and the voltage at the switch node (v_{sn}) is equal to the v_{dcout} (neglecting the diode voltage drop). In this interval, either Q_1–Q_2 or Q_3–Q_4 is turned on.

3. Interval III: Zero interval: The zero interval occurs when the inverter current circulates among the bridge network switches and is not sourced or sunk. The diode "D" conducts during this interval. Fig. 5(c) shows the equivalent circuit for this interval.

Table I shows the expressions for diode current (i_D), capacitor current (i_C), inverter output voltage (v_{ab}), and boost switch node voltage (v_{sn}) for different operating modes. All these expressions have been defined in Fig. 3(b).

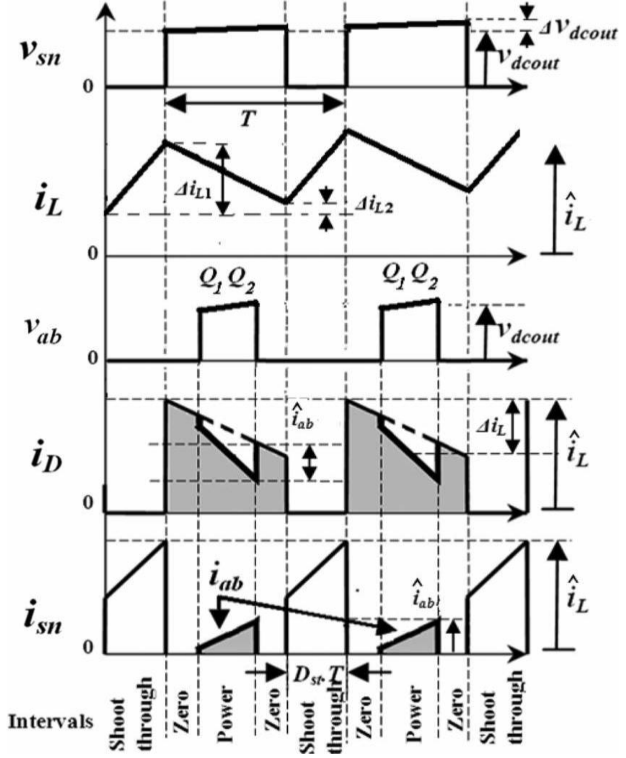


Fig. 4. Switch node voltage (v_{sn}), inductor current (i_L), inverter output voltage (v_{ab}), diode current (i_D), and inverter input current (i_{sn}) for a positive inverter output current.

The reference directions for the voltages and currents have been shown in Fig. 3(b). The figure shows that the inductor current has a low-frequency component (at twice the power frequency) as described in Section III.

B. Steady-State Analysis Gain Expression for DC and AC Outputs

Similar to conventional boost converters, the dc output of the BDHC can be regulated using the duty cycle, denoted by

Dst, and is defined as the shoot-through time interval in a switching cycle, as shown in Fig. 4. For the purpose of analysis, we assume that the output dc capacitor voltage and the input inductor current have small ripple compared to their dc values.

IV. CONTROL STRATEGY

A. Modified Unipolar PWM Strategy for BDHC

The fundamental principle behind the operation of BDHC is based upon the fact that the inverter bridge input must be connected to a positive voltage during the power interval only. This means that the inverter output has to be modulated when vsn _= 0and boost operation occurs when vab = 0. The inverter output voltage assumes three different values, and hence, the PWM modulation strategy used is based upon unipolar sine- PWM scheme, which provides three voltage levels for output. The PWM control scheme for the BDHC is based upon the switching scheme proposed in [10]. In this scheme, shown in Fig. 6(a), the shoot-through is realized by gating-on both the switches of a single leg at the same time. The switching strategy involves turning on only one leg at a time in order to achieve shoot-through. Another alternative is to turn on all the switches during shoot-through.

V. SIMULATION RESULTS

The behaviour of hybrid converters, described in this paper, has been validated using a laboratory prototype. A 600-W IGBT-based laboratory prototype has been used to demonstrate the characteristics of the BDHC. For the purpose of designing the passive components, the ripple contents (both high- and low-frequency components) in the inductor current and the capacitor voltage have been taken to be 25% and 3%, respectively, at the rated power.

A. Steady-State Behaviour of BDHC

Fig. 10 shows the gate control signals for the BDHC switches and the resulting switch node voltage (vsn) (referring to Figs. 3(b) and 8). The control schematic described in Section IV has been used for the generation of the gate signals. The waveforms validate that, whenever the switches S1 and S4 or S2 and S3 are “on” at the same time, vsn = 0. This interval refers to shoot-through, and it controls the dc output. The ac output is modulated using the reference signal vm(t). Fig. 9(a) and (b) shows the steady-state open-loop behavior of the BDHC. For an input voltage of 48 V dc, the output dc voltages achieved are 75.4 V and 108 V dc for duty cycles of 0.4 and 0.6, respectively. The ac output is 30 V (rms) for modulation indices of 0.6 and 0.4, respectively. From these results, it is validated that, when the equality condition of relation (3) is maintained, for any value of duty (Dst), the magnitude of the ac output voltage is always 0.707 times the input voltage. Here, the dc and ac loads are 30 and 9 Ω, respectively. Hence, the prototype serves 390-W dc and 110-W ac loads approximately. From (4) and (5), the ratio of dc power to ac power is equal to 2Rac/M2a .Rdc, i.e., 3.75 (for Dst = 0.6 and Ma = 0.4). Thus, the theoretically calculated power relationship closely matches the experimentally observed values.

B. Variation of Gain with Duty Cycle

The dc as well as ac voltage gains of the experimental prototype have been plotted against the duty cycle (Dst) and shown in Fig. 10(a) and (b). A 48-V dc input is used to obtain the experimental data points. In order to achieve the highest ac gain, the modulation index satisfies the equality condition of relation (3). The results have been compared with theoretical gains of conventional architectures such as separate boost converter and VSI, boost cascaded VSI, BDHC, and QBDHC. For the purpose of analysis, it has been assumed that the modulation index for traditional VSI is 0.8, in order to achieve a practical value of high ac output. Clearly, a boost cascaded VSI achieves a higher ac conversion ratio compared to the proposed converter at the cost of reduced EMI immunity. However, for a higher ac or dc conversion ratio, a QBDHC can be used.

C. Cross-Regulation of BDHC

The closed-loop schematic, described in Section IV, has been used to regulate both dc and ac outputs. The dc as well as the ac outputs can be controlled independently using the two control parameters “Dst” and “Ma”, respectively, so long as relation (3) is satisfied. The cross-regulation behavior of the converter has been shown in Fig. 11. These results show that both the dc and ac outputs are well regulated, even during a step change in loads in either outputs. The converter efficiency has been measured to be 86.12% for a total output of 370 W (dc power of 334 W and ac power of 36 W) and 88.1% at the total output power of 564 W (dc power of 492 W and ac power of 72 W).

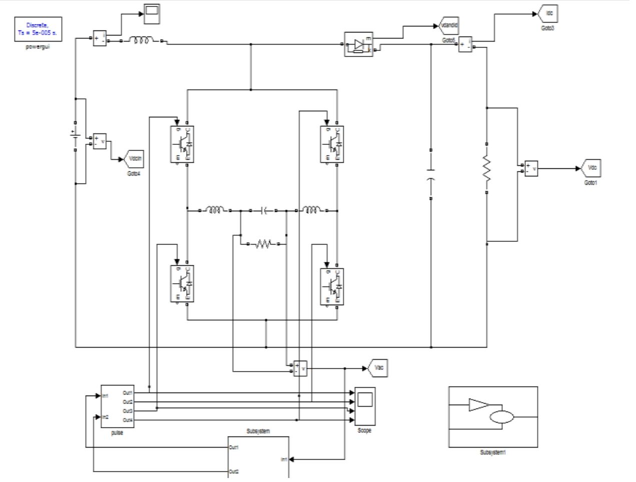


Fig.5. Circuit diagram of proposed design.

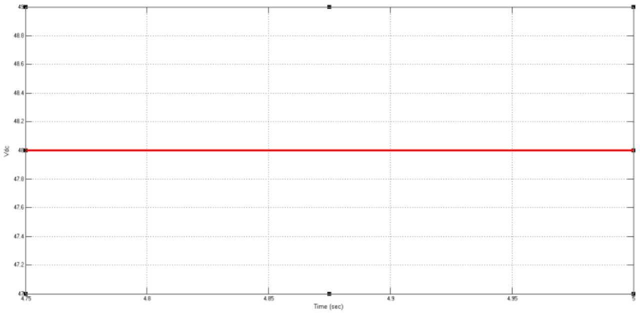


Fig.6. Dc voltage for proposed design.

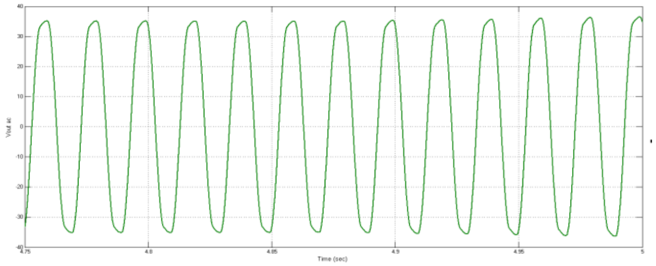


Fig.7. Output ac voltage.

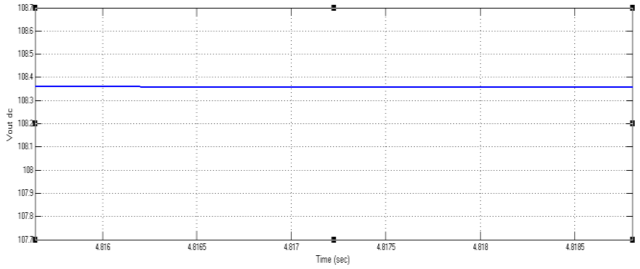
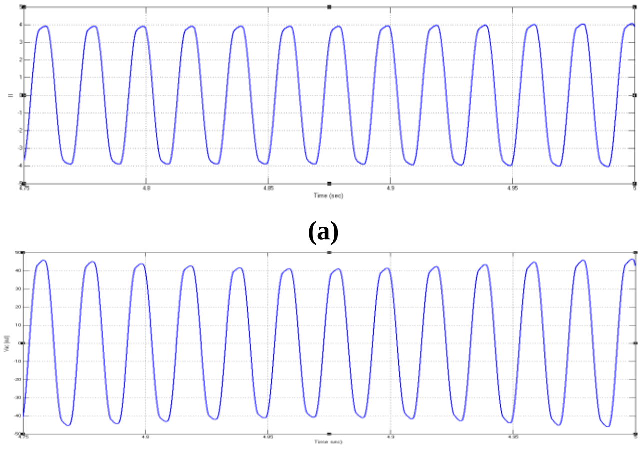


Fig.8. Output dc voltage.



(a)

(b)

Fig.9. Steady-state behavior of the BDHC in open loop. The converter produces a dc output (vdcout) as well as an ac output (vacout) from an input voltage (vdcin) of 48 V dc (Ch. 1). (a) DC output of 75.4 V (Ch. 4) and ac output of 30V(rms) (Ch. 2) for Dst=0.4 andMa=0.6. (b) DC output of 108Vdc (Ch. 4) and ac output of 30 V (rms) (Ch. 2) for Dst=0.6 and Ma=0.4.

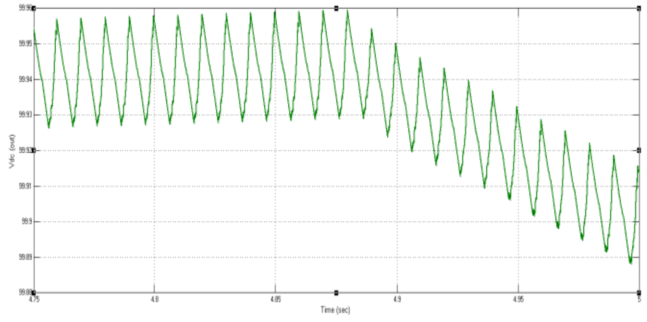
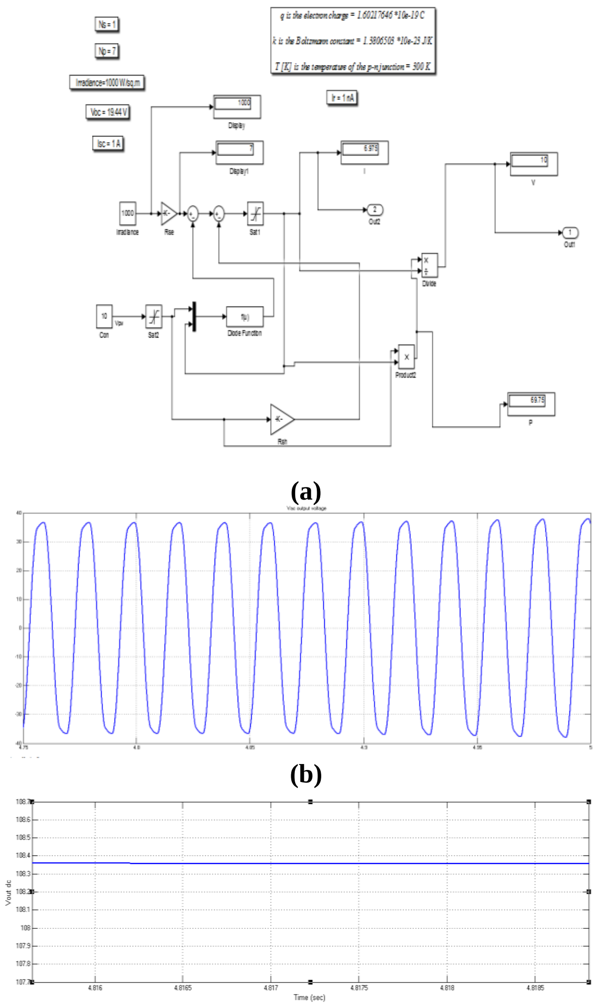


Fig.10.Cross-regulation behavior of the BDHC when subjected to step change in loads (dc as well as ac).



(a)

(b)

(c)

Fig.11. Transformer (1 : 5) coupled BDHC with 110-V ac loads. Response of the prototype to (a) resistive ac load of 110 Ω, (b) inductive load of 0.75 (lag) power factor load, and (c) nonlinear load.

VI. CONCLUSION

This paper has proposed hybrid power converter topologies which can supply simultaneous dc and ac loads from a single dc input. The various advantages of using this single converter stage like shoot-through protection have been described and compared to traditional VSIs. It has been shown that a class of converters can be achieved by describing the BDHC and QBDHC. Experimental results verify the operation of the BDHC in an open loop. The cross-regulation behavior of the converter has been studied along with its behavior to different load types.

VII. REFERENCES

[1] D. Boroyevich, I. Cvetkovic, D. Dong, R. Burgos, F. Wang, and F. Lee, “Future electronic power distribution systems—A contemplative view,” in Proc. 12th Int. Conf. OPTIM Elect. Electron. Equip., Brasov, Romania, May 20–22, 2010, pp. 1369–1380.

[2] F. Blaabjerg, Z. Chen, and S. B. Kjaer, “Power electronics as efficient interface in dispersed power generation systems,” IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1184–1194, Sep. 2004.

[3] O. Ray, S. Mishra, A. Joshi, V. Pradeep, and A. Tiwari, “Implementation and control of a bidirectional high-gain transformer-less standalone inverter,” in Proc. IEEE Energy Convers. Congr. Expo., Raleigh, NC, USA, Sep. 2012, pp. 3233–3240.

[4] F. Z. Peng, “Z-source inverter,” IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.

[5] C. J. Gajanayake, F. L. Luo, H. B. Gooi, P. L. So, and L. K. Siow, “Extended-boost Z-source inverters,” IEEE Trans. Power Electron., vol. 25, no. 10, pp. 2642–2652, Oct. 2010.

[6] S. Upadhyay, R. Adda, S. Mishra, and A. Joshi, “Derivation and characterization of switched-boost inverter,” in Proc. 14th Eur. Conf. Power Electron. Appl.—EPE, Birmingham, U.K., Aug. 2011, pp. 1–10.

[7] S. Mishra, R. Adda, and A. Joshi, “Inverse Watkins-Johnson topology based inverter,” IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1066– 1070, Mar. 2012.

[8] S. Mishra, R. Adda, and A. Joshi, “Switched-boost inverter based oninverse Watkins-Johnson topology,” in Proc. IEEE ECCE, Phoenix, AZ, USA, Sep. 2011, pp. 4208–4211.

[9] R. Tymerski and V. Vorperian, “Generation, classification and analysis of switched-mode dc-to-dc converters by the use of switched-inductor-cells,” in Proc. Int. Telecommun. Energy Conf., Oct. 1986, pp. 181–195.

[10] R. Adda, S. Mishra, and A. Joshi, “A PWM control strategy for switchedboost inverter,” in Proc. IEEE ECCE, Phoenix, AZ, USA, Sep. 2011, pp. 991–996.

[11] F. Z. Peng, M. Shen, and Z. Qian, “Maximum boost control of the Z-source inverter,” IEEE Trans. Power Electron., vol. 20, no. 4, pp. 833– 838, Jul. 2005.

[12] M. Shen, J. Wang, A. Joseph, F. Z. Peng, L. M. Tolbert, and D. J. Adams, “Constant boost control of the Z-source inverter to minimize current ripple and voltage stress,” IEEE Trans. Ind. Appl., vol. 42, no. 3, pp. 770–778, May/Jun. 2006.

[13R. Adda, O. Ray, S.Mishra, and A. Joshi, “Synchronous-reference-framebased control of switched boost inverter for standalone dc nanogrid applications,” IEEE Trans. Power Electron., vol. 28, no. 3, pp. 1219–1233,Mar. 2013.

[14] S. H. Hwang and J. M. Kim, “Dead time compensation method for voltage-fed PWM inverter,” IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 1–10, Mar. 2010.

[15] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 2nd ed. New York, NY, USA: Springer-Verlag, 2001.

[16] J. A. Morales-Saldaña, R. Galarza-Quirino, J. Leyva-Ramos, E. E. Carbajal-Gutierrez, and M. G. Ortiz-Lopez, “Modeling and control of a cascade boost converter with a single switch,” in Proc. IEEE IECON, Paris, France, Nov. 7–10, 2006, pp. 591–596.

[17] B.-R. Lin, J.-J. Chen, and F.-Y. Hsieh, “Analysis and implementation of a bidirectional converter with high conversion ratio,” in Proc. IEEE ICIT, 2008, pp. 1–6.

[18] D. Maksimovic and S. Cuk, “Switching converters with wide dc conversion range,” IEEE Trans. Power Electron., vol. 6, no. 1, pp. 151–157,Jan. 1991.