Boost Derived Hybrid Converter for Simultaneous AC and DC Loads

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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. Such multioutput converters with better power processing density and reliability can be well suited for systems with simultaneous dc and ac loads, e.g., nanogrid 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. A suitable pulse width modulation (PWM) control strategy, based upon SVPWM, is described. The dsPIC30f4011 controller was used to implement this hybrid converter topology.

Keywords: Hybrid converter, Boost derived hybrid converter, Voltage Source Inverter, SVPWM,dsPIC30f4011.

I. INTRODUCTION

NANOGRID architectures are being increasingly incorporated in modern smart residential electrical power systems. These systems involve different load types—dc as well as ac—efficiently interfaced with different kinds of energy sources (conventional or non-conventional) using power electronic converters. Fig.1.1 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.1.1(a) uses separate power converters for each conversion type (dc–dc and dc–ac) while Fig.1.1(b) utilizes a single power converter stage to perform both the conversions. The latter converter, referred to as a hybrid converter, 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.

Smart residential systems are often connected to nonconventional 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 or in cascade, supplying dc and ac outputs at *v*dcout and *v*acout, respectively. Depending upon the requirements, topologies providing higher gains may be required to achieve step-up operation.

II. LITERATURE REVIEW

A. Power electronics as efficient interface in dispersed power generation systems

The traditional power systems are changing globally, a large number of dispersed generation (DG) units, including both renewable and non-renewable energy sources such as wind turbines, photovoltaic (PV) generators, fuel cells, small hydro, wave generators, and gas/steam powered combined heat and power stations, are being integrated into power systems at distribution level. Power electronic, the technology of efficiently processing electric power, plays an essential part in the integration of the dispersed generation units for good efficiency and high performance of the power systems. This paper reviews the applications of power electronics in the integration of DG units, in particularly, wind power, fuel cells and PV generators.

B. Maximum Boost Control Of The Z-Source Inverter

two control methods to obtain maximum voltage gain of the Z-source inverter. The method maximizes the shoot through period without effecting the active states by turning all zero states into the shoot through zero state, thus maximum output voltage can be obtained for a given modulation index. In turn, maximum modulation index can be used to obtain any desired output voltage, thus, minimizing the voltage stress across the switches. Third harmonic injection can also be used to extend the modulation index range. The relationship of the voltage gain versus modulation index was analyzed, and the relationship between minimum voltage stress of the switches and voltage gain was given. Simulation and experiments were conducted to verify the control methods and analysis.

C. Dead Time Compensation Method For Voltage-Fed PWM Inverter

A new dead time compensation method for a pulse width modulation (PWM) inverter is proposed. In the PWM inverter, voltage distortion due to the dead time effects produces fifth and seventh harmonics in the phase currents of the stationary reference frame, and a sixth harmonic in the d- and q-axis currents of the synchronous reference frame, respectively. In this paper, the sixth harmonic of the integrator output of the synchronous d-axis proportional–integral (PI) current regulator is used to compensate the output voltage distortion due to the dead time effects, since the integrator output has ripple corresponding to six times the stator fundamental frequency. The proposed method can be easily implemented by feed forwardly adding compensation voltages to the output reference voltage of the synchronous PI current regulator. The proposed method, therefore, has some significant advantages such as simple implementation without additional hardware, easy mathematical computation, no offline experimental measurements, and application in both the steady state and the transient state. The validity of the proposed compensation algorithm is shown through several experiments.

D. Extended-boost Z-source inverters

The Z-source inverter has gained popularity as a single-stage buck–boost inverter topology among many researchers. However, its boosting capability could be limited, and therefore, it may not be suitable for some applications requiring very high boost demand of cascading other dc–dc boost converters. This could lose the efficiency and demand more sensing for controlling the added new stages. This paper is proposing a new family of extended-boost quasi Z-source inverter (ZSI) to fill the research gap left in the development of ZSI. These new topologies can be operated with same modulation methods that were developed for original ZSI. Also, they have the same number of active switches as original ZSI preserving the single-stage nature of ZSI. Proposed topologies are analyzed in the steady state and their performances are validated using simulated results obtained in MATLAB/Simulink. Furthermore, they are experimentally validated with results obtained from a prototype developed in the laboratory.

III. SYSTEM DESIGN

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 con- verter 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

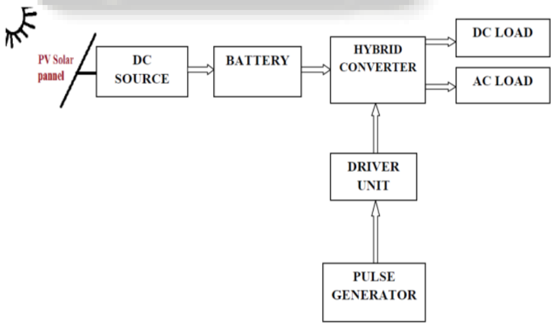

Fig. 1: Block diagram of proposed system

IV. OPERATING PRINCIPLE

The BDHC has three distinct switching intervals as described in the following.

A. 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 Q1–Q4 or Q3–Q2) of any particular leg are turned on at the same time. The duration of the shoot-through interval decides the boost converter duty cycle (Dst). The diode "D" is reverse biased during this period. The inverter output current circulates within the bridge network switches. Thus, BDHC allows ad- ditional switching states which are strictly forbidden in a VSI.

B. 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 (vsn) is equal to the vdcout (neglecting the diode voltage drop). In this interval, either Q1–Q2 or Q3–Q4 is turned on.

C. 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" con- ducts during this interval. Fig. 5(c) shows the equivalent circuit for this interval.

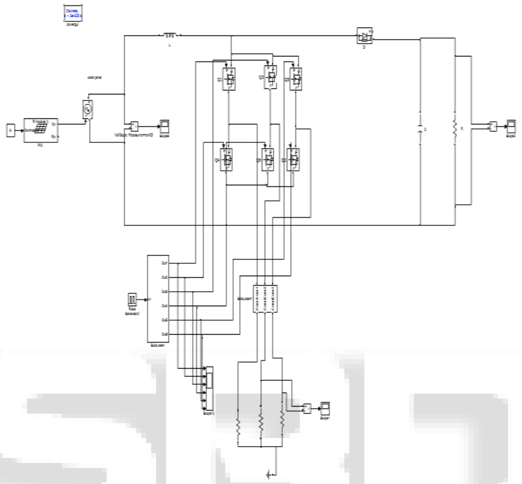

Fig.:2 simulation circuit diagram for proposed method

V. CONTROL STRATEGY

A. Space Vector Modulation for BDHC

The structure of a typical three-phase VSI is shown in Figure 2. As shown below, V_a, V_b and V_c are the output voltages of the inverter. Q_1 through Q_6 are the six power MOSFETS that shape the output, which are controlled by a, a', b, b', c and c'. When an upper transistor is switched on (i.e., when a, b or c is 1), the corresponding lower transistor is switched off (i.e., the corresponding a', b' or c' is 0).The on and off states of the upper transistors, Q_1, Q_3 and Q_5, or equivalently, the state of a, b and c, are sufficient to evaluate the output voltage for the purpose of this discussion.

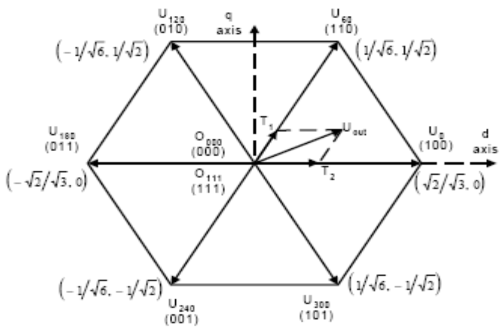

Fig. 3: The Basic Space Vectors (Normalized w.r.t. V_{dc}) and Switching States

There are eight possible combinations of on and off states for the three upper power transistors. The eight combinations and the derived output line-to-line and phase voltages in terms of DC supply voltage V_{dc}

a	b	c	V_a	V_b	V_c	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0	1	1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

Table 1: Device On/Off States and Corresponding Outputs of a Three-Phase VSI

As shown in table 1, there are eight possible combinations of on and off states for the three upper power transistor.SV PWM refers to a special way of determining the switching sequence of the upper three power transistors of a three-phase VSI. It has been shown to generate less harmonic distortion in the output voltages and or currents in the windings of the motor load and provides more efficient use of DC supply voltage, in comparison to direct sinusoidal modulation technique.

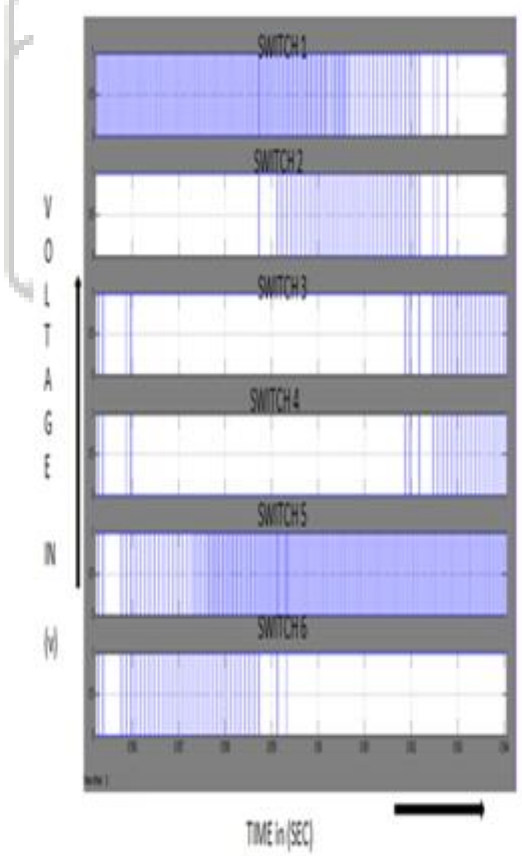

Fig. 4: SV PWM output waveform of proposed BDHC

VI. EXPERIMENTAL VERIFICATION

The controller of the prototype is implemented using the dsPIC30F4011. A complete list of parameters Values for the prototype are given in Table 2. Fig. 5 shows the photograph of the experimental setup. Table 3 lists the components used for building the BDHC prototype.

Parameters	Attributes
Power Rating	5 W
Input Voltage	12 V
DC Output Voltage	50 V
AC Output Voltage	50 V
DC Load	2 KΩ
AC Load	2 KΩ

Table 2:Design Example Specifications of The BDHC

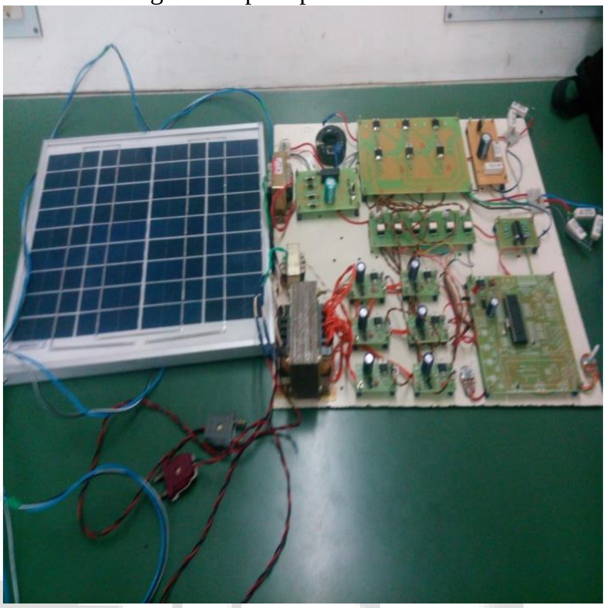

Fig. 5: Photograph of the MOSFET-based laboratory prototype of the BDHC.

Component	Manufacturer
Gate Driver	Toshiba TLP250
Controller	dsPIC30F4011
Switches	MOSFET IRF540

Table 3:Component List

VII. RESULT AND VERIFICATION

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 VSI. Extend the proposed philosophy to higher order boost converters in order to achieve a higher conversion ratio. Due to less number of switches hence switching loss also reduced. The harmonic distortion was minimized as much as possible. Hence resulting hybrid converter topology which has minimum, reduced shoot-through, and high conversion ratio.

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 on inverse 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 switched boost 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.

[13] R. Adda, O. Ray, S.Mishra, and A. Joshi, "Synchronous-reference-frame based 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, "Modelling 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.