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Hybrid Converter with Simultaneous AC and DC Output for Nano-Grid Applications with Residential System

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Abstract: Grid architectures are preferred in modern smart residential electrical power systems. These types of systems engage various load types like DC as well as AC interfaced with sources using power electronic converters. This type of architecture has separate power converters for AC to DC conversion and DC to DC conversion. This study projects a converter which can feed DC and AC loads simultaneously from a single DC input. The projected converter is realized with a VSI bridge network instead of the control switch used in single-switch boost converters. The consequential hybrid converter obtained, requires less switches to give both forms of output showing more reliability. It provides shoot-through protection and has improved power processing. The switches are triggered by efficient SVM method to suppress the harmonics present in the output voltage. The simulation results depict AC and DC outputs that verify the credibility of the proposed converter.

Key words: Hybrid converter, residential system, space vector modulation, DC nano-grid, SVM method, power processing, harmonics

INTRODUCTION

Nano-grid architectures have been widely used in modern power system. Conventional designs for smart residential systems involves usage of two converters to meet AC and DC load requirements. For achieving step-up voltage operation, higher gain topologies would be required (Ray *et al*., 2012). A Z-Source Inverter (ZSI) that mitigates shoot-through caused due to electromagnetic interference is proposed (Peng, 2003). Then, extended boost topology of ZSI was proposed (Gajanayake *et al*., 2010) in which gain was higher. Quasi Z source inverters with shoot-through capability were proposed with reduced harmonics (Santhoshi *et al*., 2014, 2015). The ability to supply both AC and DC loads was still a researcher's challenge as ZSIs or Q-ZSIs could not satisfy the criteria. Later, a hybrid converter that had similar functionality of ZSIs and ability to supply AC and DC loads simultaneously was proposed (Mishra *et al*., 2012). This converter was derived from a four-switch topology. Tymerski and Vorperian (1986) recent research on hybrid converters improvised in usage of different topologies to AChieve simultaneous outputs and compare them (Ray and Mishra, 2014).

The current VSI of a hybrid converter involves the use of dead time circuitry in order to evade the shoot-through. Also, switches damage is common due to which mitigation of turn on of switches takes place. It is difficult to achieve high boost gain in the conventional topology. Also, shoot through state causes instability in the circuit leading to undesirable output. The projected converter is a hybrid form of converter which is derived from a conventional boost type of topology. With the proposed converter, DC and AC loads are supplied by single DC source using efficient power electronic converters.

MATERIALS AND METHODS

Proposed converter

Block diagram: Conventionally a boost circuit consists of two switches. A controllable switch is used to control the duty cycle and another diode is used as the second switch.. A hybrid converter is realized using a voltage source inverter instead of a controllable switch. The block and circuit diagrams of the projected converter are shown in Fig. 1 and 2, respectively. It can be observed that both AC and DC loads are being supplied by the proposed circuit model.

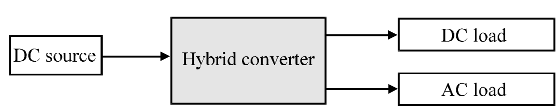

Fig. 1: Proposed converter-block diagram

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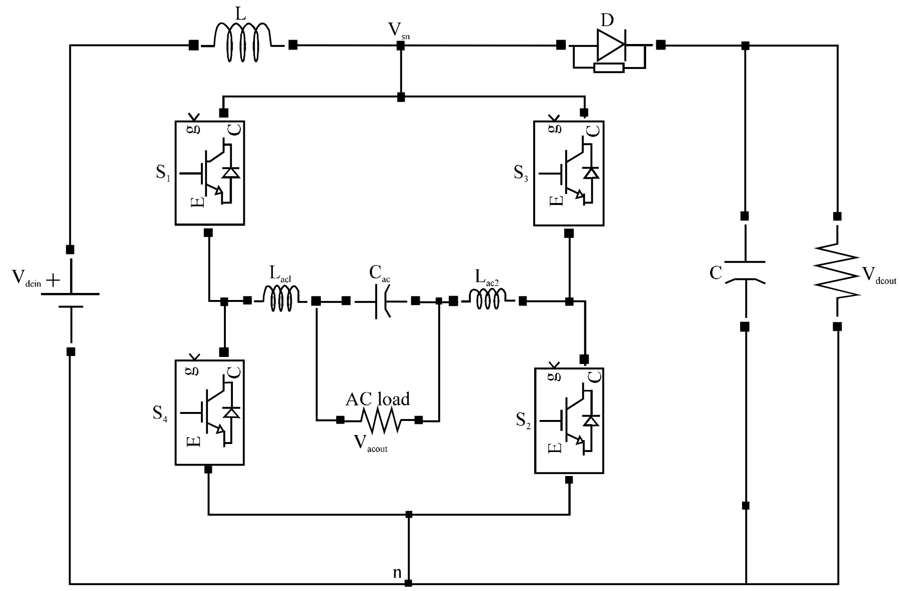

Fig. 2: Proposed converter-circuit diagram

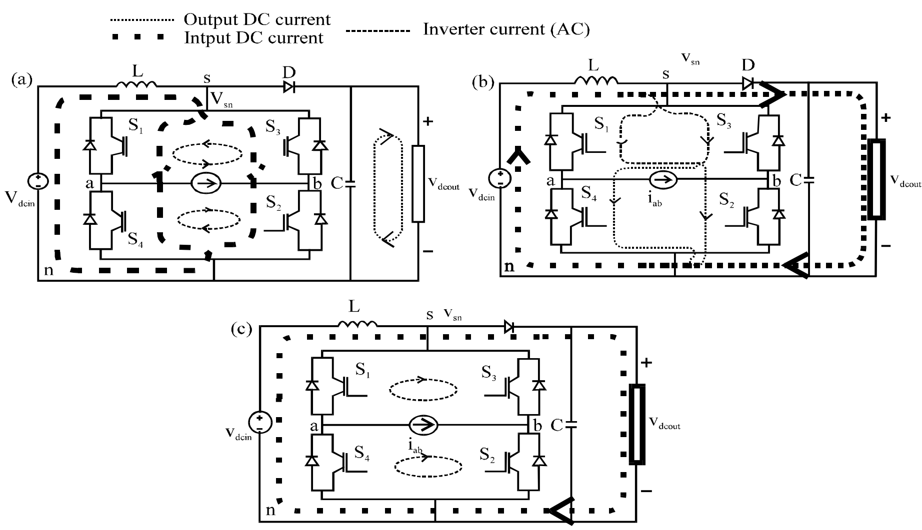

Fig. 3: a) Shoot through interval; b) Power interval and c) Zero interval

Modes of operation: The operation of the proposed converter involves usage of four switches for control of AC and DC output power. Hence, the following challenges are involved in the operation: For boost and inverter operation, duty cycle and modulation index need to be defined. Voltages and currents through various components of the circuit have to be defined. The input power should be controlled and channelized to AC and DC loads. The proposed converter constitutes to three unique switching intervals namely shoot-through, power and zero intervals.

Mode 1; Shoot-through stage: During the shoot-through interval, two of the switches in the same leg (either S_1-S_4 or S_3-S_2) are on. The duration at which shoot-through occurs determines the duty cycle of the converter. The circuit of the proposed converter during this stage is shown in Fig. 3a. Here, the reverse biased diode is to be noted. The inverter output current circulates between the switches. This additional stage is not present in conventional VSIs.

Mode 2; Power stage: During the power interval, either S_1-S_2 or S_3-S_4 is turned on. The diode conducts and

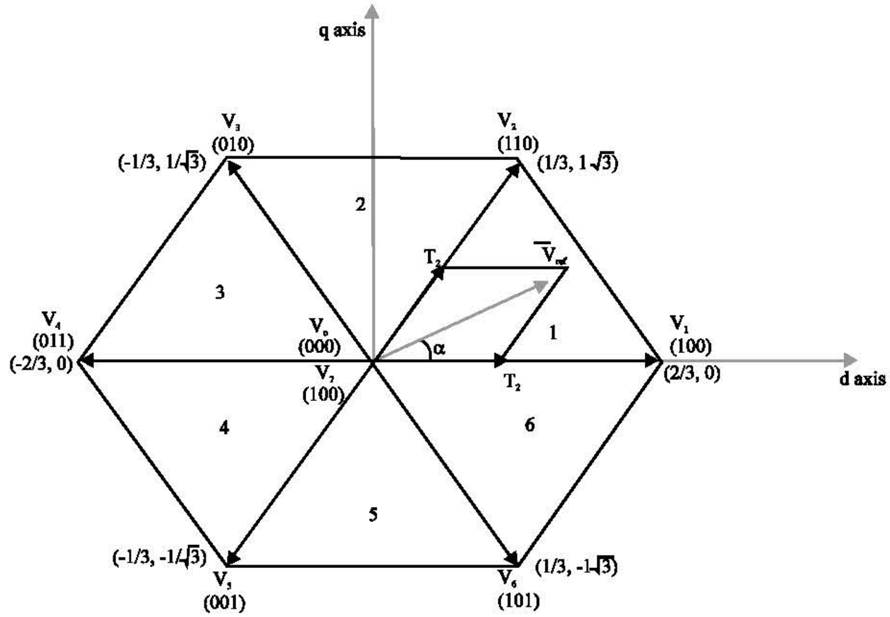

Fig. 4: Basic switching vectors and sectors

hence, the voltage at the nodes is the voltage at that node excluding the voltage drop across the diode. This is the most prominent mode of operation of VSIs. The circuit of the proposed converter during this stage is shown in Fig. 3b.

Mode 3; Zero stage: During the zero interval, S_1-S_3 or S_2-S_4. The diode conducts and current flows between the switches. The circuit of the proposed converter during this stage is shown in Fig. 3c. In the figures, the lines denote.

Output power: The expression for output power delivered by hybrid converter:

$$P_{dc} = V_{dcin}^{2}/R_{dc}*(1-D_{st})^2$$
$$P_{ac} = 0.5*V_{dcin}^{2}*M_a^{2}/R_{ac}*(1-D_{st})^2$$

where P_{dC} is the DC output power and P_{ac} is the AC output power respectively. It can be noticed that output power from DC is dependant only on the duty cycle, D_{st} whereas AC, power output depends on duty cycle, D_{st} and modulation index, M_a.

Control strategy: Space vector modulation controls the switches of the proposed converter. It considers the sinusoidal voltage to be a constant amplitude vector that rotates at an unvarying frequency. The most prominent benefit of using this technique is reduction of harmonics.

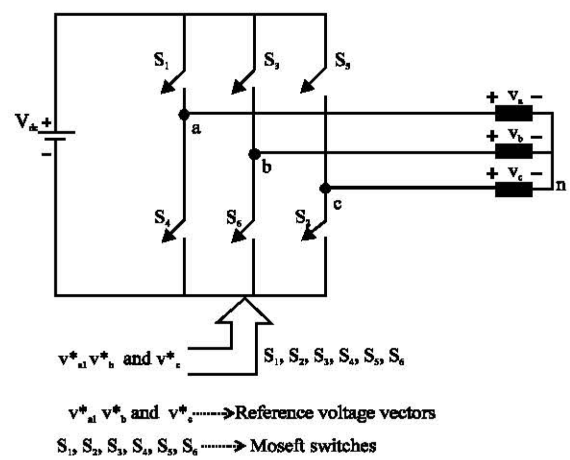

Fig. 5: Realization of SVM for a three phase inverter

In space vector modulation, non-zero state vectors (V1-V6) and zero state vectors (V_0 and V_7) are possible. Nonzero vectors will a hexagon as revealed in Fig. 4. They will supply electric power to the load. About 60° phase difference is formed between two non-zero vectors. The two zero vectors will be at origin. They will not supply any voltage to the load. SVM will approximate V_{ref} (reference voltage vector) with the use of eight switching patterns. The realization of SVM technique after axes transformation is shown in Fig. 5 and the switching time table at each sector is shown in Table 1.

Table: Switching time table at each sector in SVM

Sectors	Upper switches (S_1, S_3, S_5)	Lower switches (S_4, S_6, S_2)
1	$S_1 = T_1+T_2+T_0/2$	$S_4 = T_0/2$
	$S_3 = T_2+T_0/2$	$S_6 = T_1+T_0/2$
	$S_5 = T_0/2$	$S_2 = T_1+T_2+T_0/2$
2	$S_1 = T_1+T_0/2$	$S_4 = T_2+T_0/2$
	$S_3 = T_1+T_2+T_0/2$	$S_6 = T_0/2$
	$S_5 = T_0/2$	$S_2 = T_1+T_2+T_0/2$
3	$S_1 = T_0/2$	$S_4 = T_1+T_2+T_0/2$
	$S_3 = T_1+T_2+T_0/2$	$S_6 = T_0/2$
	$S_5 = T_2+T_0/2$	$S2 = T_1+T_0/2$
4	$S_1 = T_0/2$	$S_4 = T_1+T_2+T_0/2$
	$S_3 = T_1+T_0/2$	$S_6 = T_2+T_0/2$
	$S5 = T_1+T_2+T_0/2$	$S_2 = T_0/2$
5	$S_0 = T_2+T_0/2$	$S_4 = T_1+T_0/2$
	$S_3 = T_0/2$	$S_6 = T_1+T_2+T_0/2$
	$S_5 = T_1+T_2+T_0/2$	$S_2 = T_0/2$
6	$S_1 = T_1+T_2+T_0/2$	$S_4 = T_0/2$
	$S_3 = T_0/2$	$S_6 = T_1+T_2+T_0/2$
	$S_5 = T_1+T_0/2$	$S_2 = T_2+T_0/2$

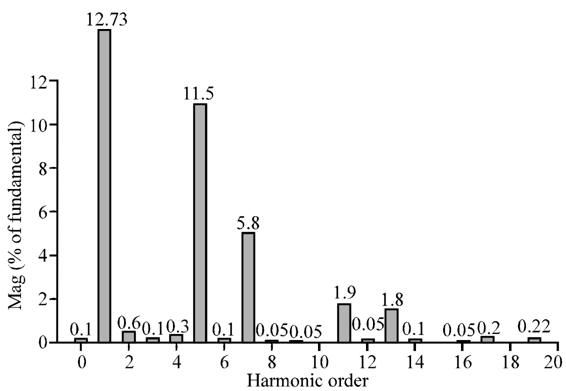

Fig. 6: THD in output current; Fundamental (50 Hz) = 3.132: THD = 12.73%

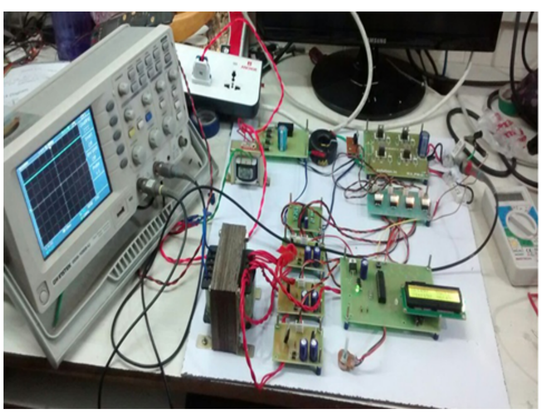

Fig. 7: Hardware setup of the proposed converter

RESULTS AND DISCUSSION

The MATLAB Simulation tool was used to test the circuit. The proposed converter could supply AC and DC loads with an output voltage of about 230 and 220 V, respectively. The THD vin output current is shown in Fig. 6. It measured about 12.73%. The hardware setup is shown in Fig. 7.

CONCLUSION

The proposed research presents a hybrid converter to supply AC and DC loads respectively. The inverter and DC-DC converter will operate simultaneously based on the PWM technique. Topologies using sine PWM have more harmonics compared to the ones using space vector modulation. Reduced THD content is AChieved due to space vector modulation technique used in the proposed research. High boost gain and high utilization factor are achieved. Instability of the load is eliminated. Simplified components structure is developed, since, separate converter for boost operation is avoided. The components utilized in the circuitry are simple and more than one load can be supplied simultaneously. These type of converters are increasingly used in nano-grid applications.

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