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Improved Hybrid Converter with Simultaneous DC and AC Outputs

Sarath Prasad K S[1], T Valsalan[2], Dr. P Vijayakumar[3]

[1]Electrical and Electronics, Engineering Department, Government College of Engineering Kannur

[2]Research Scholar, Electrical Engineering, Karpagam University, Coimbatore

[3]Department of Electrical Engineering, Karpagam College of Engineering, Coimbatore

Abstract: ***This Paper introduces new hybrid converter topologies which can supply simultaneously AC as well as DC from a single DC source. The new Hybrid Converter is derived from the single switch controlled Boost converter by replacing the controlled switch with voltage source inverter (VSI). This new hybrid converter has the advantages like reduced number of switches as compared with conventional design and provides DC as well as AC outputs with an increased reliability resulting from the inherent shoot through protection in the inverter stage. For controlling switches, PWM control based upon unipolar Sine-PWM is described. Simulink model is used to validate the operation of the converter. The proposed Converter can supply DC and AC loads at 220 V and 230V (rms) respectively from a 12V DC source.. A 50 W laboratory prototype is used to validate the operation of the converter.***

Keywords: DC Nanogrid, Voltage source inverter(VSI), Boost-Derived Hybrid Converter(BDHC), Unipolar PWM.

1. Introduction

Nanogrid architectures have a great role to play in modern power system [1]. This paper presents both DC and AC loads supplied by different kinds of energy sources efficiently by power electronic converters. Fig.1 shows the schematic of the system in which single DC source supplies both AC and DC loads. The architecture involving the hybrid converter in which both the operations are performed by a single converter [2]-[4]. Because of the inherent shoot through protection, the hybrid converter has higher power processing capability and improved reliability. The use of single boost stage architecture is discussed in this paper.

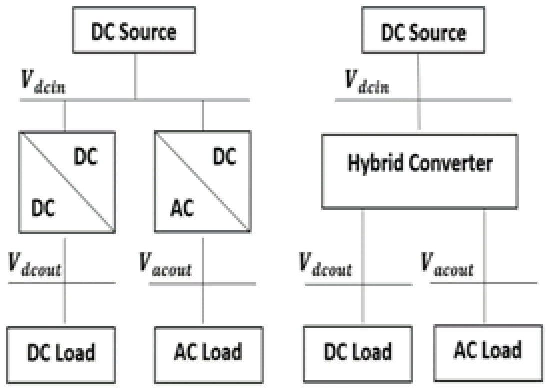

Figure 1: Schematic diagram of the system providing both AC and DC from single DC source.

Simulation results are provided to validate the performance. The decrease in converter size along with output voltage ripple and reduction in switch voltage stress can be analyzed from the results. Conventional boost circuit is having two switches, one is a controllable switch (controls the duty cycle) and other can be implemented using a diode. Replacing the controllable switch in the boost circuit either with a single phase or three phase VSI leads to the realization of hybrid converter[5-7].

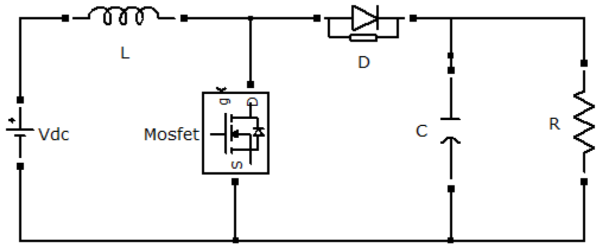

Figure 2: Conventional boost converter

The boost derived hybrid converter is obtained by replacing the control switch of a boost converter by single phase bridge network switches(S_1-S_4) as shown in Fig.3.So difficulties faced in the operation of BDHC are,(a) defining duty cycle (D_{st}) for boost operation and modulation index (M_a) for inverter operation (b) control and channelization of input DC power to DC as well as AC loads (c) Determination of voltage and current stresses various switches[8-9].

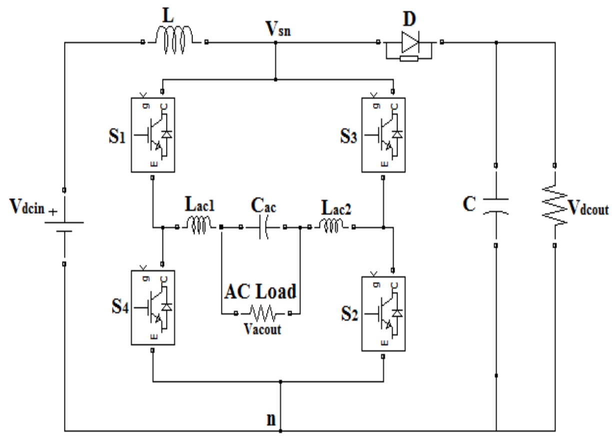

Figure 3: Boost-Derived Hybrid converter obtained by replacing Sa with a single phase bridge network

2. Proposed Circuit Modification of Boost Derived Hybrid Converter (BDHC)

A. Proposed Circuit modification

The proposed modification is explained by the circuit diagram shown in Fig. 4. DC input of 12V is stepped up using a boost converter and output of single phase inverter is given to a step up transformer giving a 230V AC output and a 220V DC output simultaneously. The PIC microcontroller output is given to a MOSFET driver whose output is given to turn on the switches of single phase inverter.

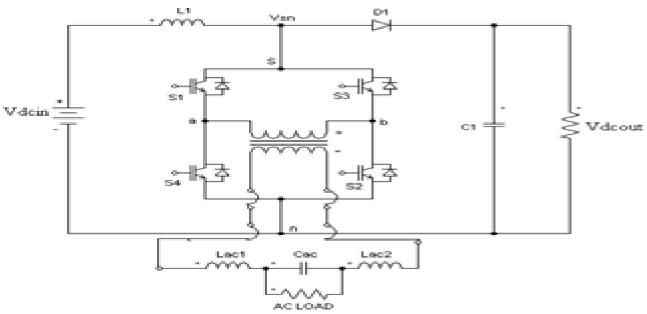

Figure 4: Circuit diagram of proposed converter

The block diagram of proposed circuit is explained in fig.5,It includes DC input, boost converter, single phase inverter, and step up transformer. From the block diagram it is clear that we get a simultaneous DC and AC output. Here PIC controller is used and switches used for the circuit is MOSFET.

B. Operation of proposed BDHC

The switches (S1-*S*4 or S3-*S*2) of same leg carry out the operation of Boost. As we know the same leg switching is similar to shoot through of VSI. For the hybrid converter this is similar to the conventional boost operation in which the

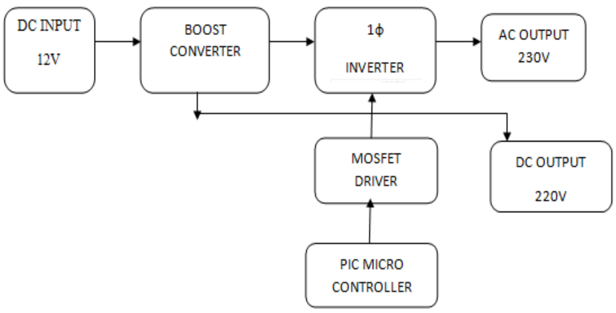

Figure 5: Block diagram for proposed hybrid converter

controllable switch is replaced by switches (S1-*S*4 or S3-*S*2).The unipolar sinusoidal PWM technique is used to control ac output [4]. The different types of switching states are explained below. It consists of three stages**:**

a. Interval 1:Shoot-Through interval

Fig.6shows the circuit diagram during shoot-through interval. This interval is similar to boost operation, it determines the duty ratio of the converter.The operation is carried out by switching of same legs at the same time. For this interval Diode D is reverse biased.

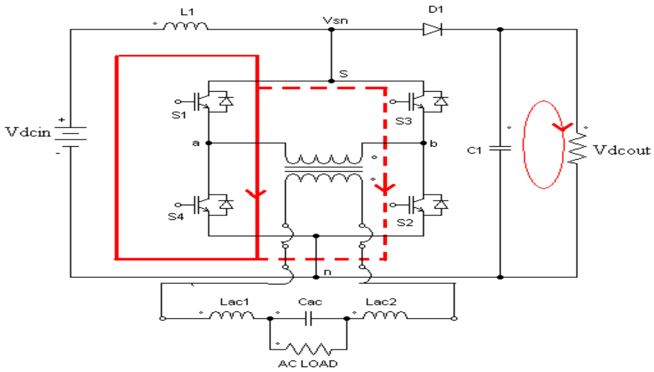

Figure 6: Circuit diagram of shoot through interval

b. Interval 2: Power interval

Fig.7 shows the circuit diagram during power interval. For this interval the Switches *S*1-*S*2 or *S*3-*S*4 turned on. During this interval diode is forward biased. Power transfer to both DC and AC loads are done in this interval.

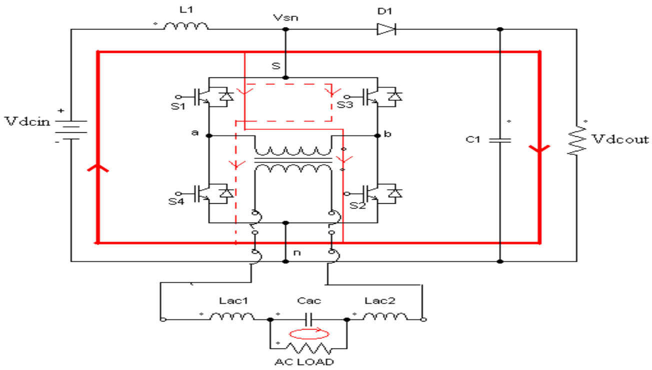

Figure 7: Circuit diagram of power interval

c. Interval 3: Zero interval

Fig.8 shows circuit diagram during zero interval. Here diode is in forward biased condition. In this interval power transfer is only to DC load. The bridge switches allows the circulation of inverter current.

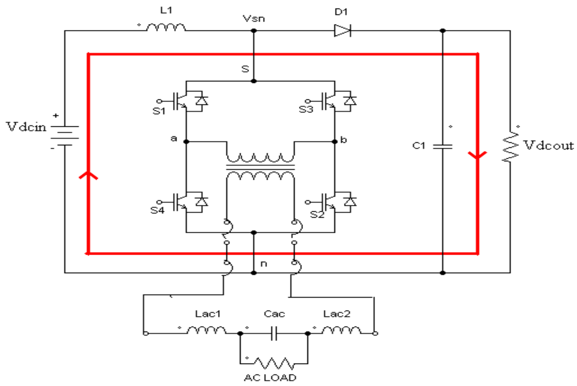

Figure 8: Circuit diagram of proposed converter.

C. Implementation and Control of BDHC

A positive voltage must be given to the inverter bridge during the power stages forms the basic principle of BDHC.This means that the inverter output has to be modulated when $v_{sn} \neq 0$ and boost operation occurs when $v_{ab} = 0$. The PWM modulation strategy is based upon unipolar sine-PWM scheme providing three output voltage levels since the inverter output has three output voltage levels as shown in Fig.9.

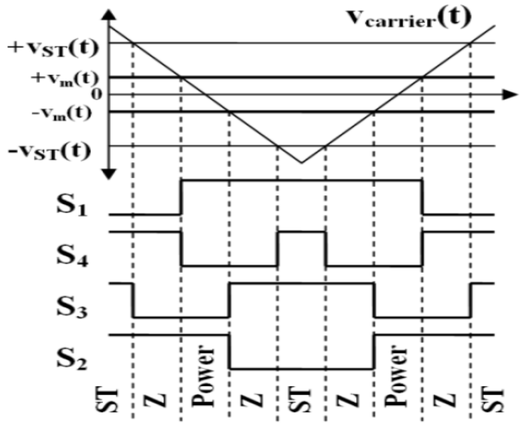

Figure 9: Generation of Gate signals for a positive value of reference signal (vm(t)) using PWM scheme

D. Operation with step-up transformer

When the BDHC is operated from a 48V input voltage, the AC output voltage needs to be stepped up by using a transformer to achieve practical voltage levels. The result shows an output of AC loads at 230 V AC (rms)can be achieved. There is limitation on the maximum D_{st} or M_a possible as for both DC and AC outputs, same set of controls are applied to the switches. The switching strategy must satisfy the following constraint.:

$$M_a + D_{st} \leq 1 \quad (1)$$

$$\frac{V_{acout}}{V_{dcin}} = \frac{M_a}{1-D_{st}} \quad (2)$$

Maximum value of ac gain is achieved at equality condition of relation (1)

At equality condition, $V_{acout} = V_{dcin}$

From (1) and (2), the expressions for output DC as well as AC power can be derived as:

$$P_{dc} = \frac{V_{dcin}^{\ 2}}{R_{dc} \times (1 - D_{st})^2} \quad (3)$$

$$P_{ac} = \frac{0.5 \times M_a^2 \times V_{dcin}^{\ 2}}{R_{dc} \times (1 - D_s)^2} \quad (4)$$

where R_{dc} and R_{ac} are the DC and AC output resistances respectively. D_{st} determines the DC output power and D_{st} along with M_a determines the AC output power. The amount of ripple in the inductor and capacitor voltage determines the selection of L and C.

$$v_{ab} = v_{an} - v_{bn} = v_{ab} \sin(\omega t) \quad (5)$$

$$i_{ab} = i_{ab} \sin(\omega t - \varphi) \quad (6)$$

where φ is the phase difference between fundamental components of inverter output voltage and current. We have power balance equation

$$\widehat{p_{ab}} = \frac{d\left(\frac{1}{2} L i_L^2(t) + \frac{1}{2} C v_{dcout}^2(t)\right)}{dt} = 0.5 V_{ab}\, i_{ab} \cos(2\omega t - \varphi) \quad (7)$$

$$i_L = \frac{P_{dc} + P_{ac}}{V_{dcin}} = \frac{V_{dcout}\, i_{dcout} + 0.5 V_{ab}\, i_{ab} \cos(\varphi)}{V_{dcin}} \quad (8)$$

Where $\widehat{p_{ab}}$ is the double frequency power component of input power to the inverter bridge and i_L is the average input inductor current.

3. Modeling and Simulation Study

MATLAB model of open loop BDHC has been developed for input voltage of 12V. The power rating is selected as 500W. PWM signals for the VSI is developed. DC output voltage of 190V and AC output voltage of 230V was obtained simultaneously. For simulation of the proposed hybrid converter Parameters of the different circuit components are taken as: Input inductor (L) =5mH, DC capacitor (C) =1 mH, AC filter inductor ($L_{ac}=L_{ac1}+L_{ac2}$) =500μH, AC filter capacitor (C_{ac}) =10μF, DC load R_{dc} = 100Ω, AC load R_{ac}=500 Ω and Switching frequency is taken as 10 kHz. Simulink model is shown in fig.10.

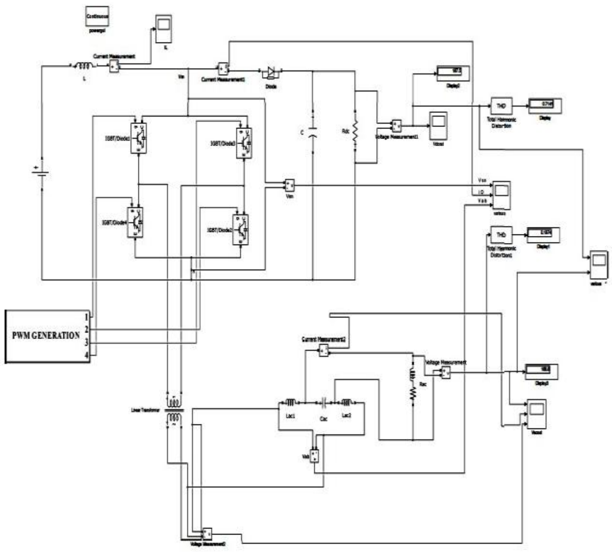

Figure 10: Simulink Model of improved BDHC

The signals shown in Fig.11 provided to gates of the controllable switches S_1-S_4. Fig.12 shows the Simulink model for the modified unipolar PWM control strategy. $V_{st}(t)$ is the dc signal controls the duration of shoot-through interval, hence adjust the duty cycle for the boost operation. $V_m(t)$ Controls the modulation index for inverter operation. Fig.13shows the DC output voltage and Fig.14 shows the AC output voltage waveform and output current waveform. Dc voltage gain can be achieved by BDHC is equivalent to boost converter, and is around four to five [7-9]. Maximum value of ac voltage is equal to voltage at the output of single phase inverter.

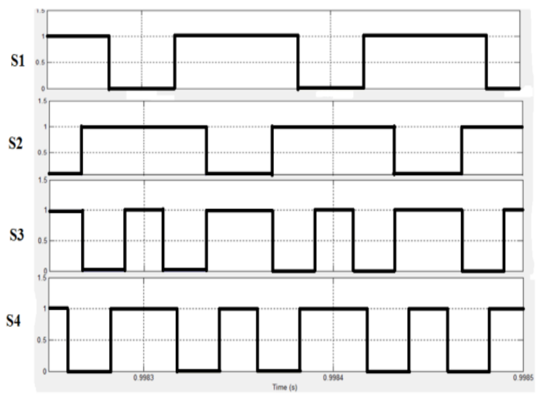

Figure 11: Control signals to the switches **S1**-**S4**.

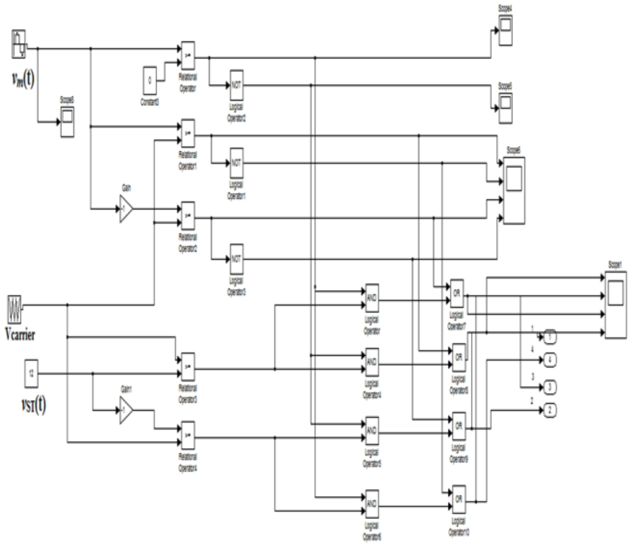

Figure 12: Simulink model of PWM generation.

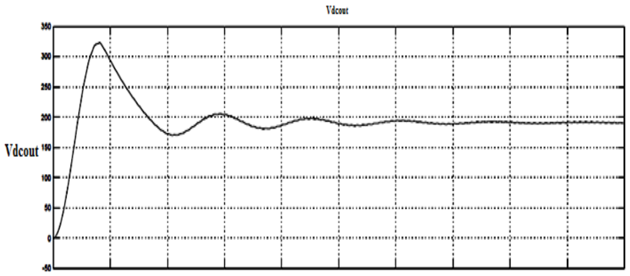

Figure 13: Output DC voltage waveform

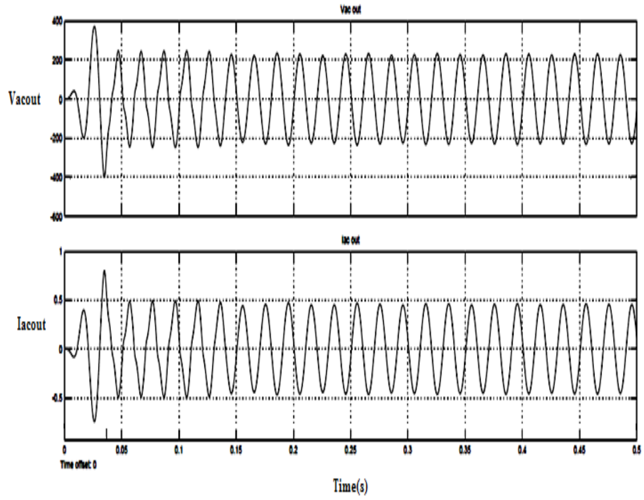

Figure 14: Output AC voltage waveform, output ac current

Table 1: Output For Different Values of V_{st}

V_{in} (V)	V_{st}(V)	V_{dcout}(V)	THD	V_{acout} (V)	THD
48	5	200	0.966	230	0.4567
48	6	158.2	0.8788	230	0.3342
48	8	119.1	0.8579	230	0.2628
48	10	95.28	1.277	230	0.2428

TABLEI shows output values of DC and AC for different values of Vst, where V_{mpeak} =12V and $V_{carrierpeak}$=20V.

4. Hardware Implementation

The behavior of hybrid converters, described in this paper, has been validated using a laboratory prototype(fig 15). A 50 W MOSFET based laboratory prototype has been used todemonstrate the characteristics of the BDHC.Fig. 16 shows the switching waveforms of the BDHC from microcontroller.For an input voltage of 12V DC,fig 17 shows the output DC voltage achieved is190V for duty cycles of 0.48. Fig 18 shows the AC output is 154 V (rms) for modulation indices of 0.52 respectively. From these results, it is validated that, when the equality condition of relation (1) is maintained, for any value of duty (D_{st}), the magnitude of the AC output voltage is always 0.707 times the input voltage.

Figure 15: Hardware setup for BDHC

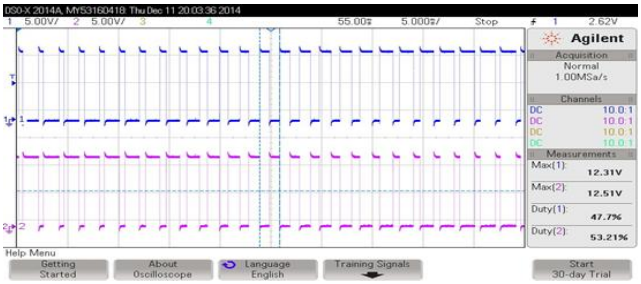

Figure 16: Pulses from Microcontroller

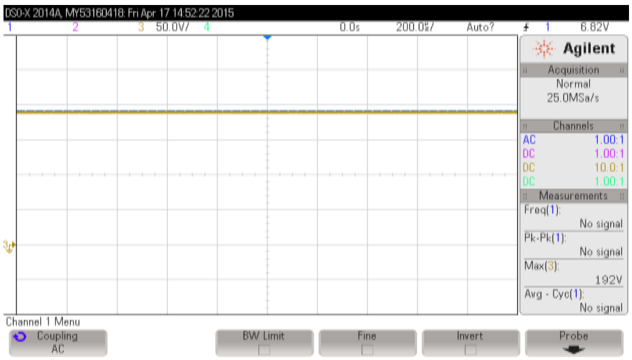

Figure 17: Output waveform for DC Voltage

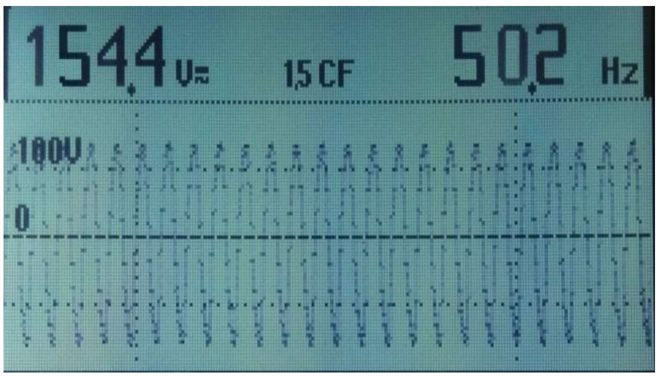

Figure 18: Output waveform for AC Voltage

5. Summary and Conclusions

A pic based boost hybrid converter is proposed and a comparative study with conventional converter is done to validate the performance of the modified converter. This paper proposes new Hybrid converter topologies which can supply simultaneously both DC and AC loads from a single DC supply.

The proposed hybrid converter has the following advantages, shoot-through condition does not cause anyproblem on working of the circuit hence improves the reliability of the system, Implementation of dead time circuitry is not needed, Independent control over AC and DC output and the converter can also be adapted to generate AC outputs at frequencies other than line frequencies by a suitable choice of the reference carrier waveform.

In case of BDHC, for an input Voltage of 12V, maximum dc output voltage obtained is 220V (Maximum ACvoltage obtained as same as 230V AC (rms). In order to obtain ac voltage levels higher than the input voltage is made possible by step up transformer is interfaced with the hybrid converter.

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