Simultaneous DC and three phase output using hybrid converter

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Abstract This Paper introduces new hybrid converter topologies which can supply simultaneously three phase 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 numberof switches as compared with conventional design having separate converter for supplying three phase AC and DC loads, provide DC and three AC outputs with an increased reliability, resulting from the inherent shoot through protection in the inverter stage. The proposed converter, studied in this paper, is called Boost-Derived Hybrid Converter (BDHC) as it is obtained from the conventional boost topology. A DSPIC based feedback controller is designed to regulate the DC as well as AC outputs. The proposed Converter can supply DC and AC loads at 95 V and 35 V (line to ground) respectively from a 48 V DC source.

1. Introduction
In modern smart residential electric power systems NANOGRID architectures are increasingly used [1]. The loads can be DC as well as AC, interfaced with a DC energy source using power electronic controllers [2]. Fig.1 shows the system, DC source can be – a solar panel, battery, fuel cell etc. Fig. 1(a) is the existing system which has two separate converters for each conversion (DC – DC and DC – AC), where as fig. 1(b) is the system proposed in this paper which incorporates a single power converter for both the conversions named as Hybrid Converter, which has high power processing density and improved reliability.
The operation of Conventional VSIs in hybrid converters would involve the use of dead-time circuitry to prevent shoot through. In addition, due to 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 compactness of the overall conversion system, the generation of spurious noise may be a commonplace. Thus, the VSIs in such applications need to be highly reliable with appropriate measures against EMI induced misgating. Depending upon the requirements, topologies providing higher gains may be required to achieve step-up operation [3]. The paper investigates the use of single boost stage architecture to supply hybrid loads. Z-Source Inverter (ZSI), proposed in [4], can mitigate the problem of shoot-through due to EMI in a VSI. The use of a unique impedance network at the input of the ZSI allows a 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 ZSource topology [5]. However ZSI cannot supply both DC as well as 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].

2. Converter

A. Existing system- Complementary switch pairs are present in a Boost converter, one of which is a control switch which controls the duty cycle. The conventional consist of two converters (a boost converter and a VSI) hence the control circuit is also more, which makes the number of required switches high.

B. Hybrid Converter - The control switch of the boost converter is replaced with a VSI. Hence the number of control switches is reduced. Both the VSI and Boost Converter are controlled using the same bridge configuration, thus reducing control circuit.
3. Operation
In this paper, continuous conduction mode (CCM) of operation has been assumed (the boost inductor current \( I_L \) never goes to zero).

A. Operating principle: The hybrid converter consist of six bi-directional switches. And each is a combination of a switch \( S_i \) (i=1, 2...6) and a diode \( D_i \) (i=1, 2...6).

The boost operation can be realized by turning ON of both switches of any particular leg. 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. The duration of shoot-through interval decides the boost converter duty cycle \( D_{st} \).

The ac output of the hybrid converter is controlled using a modified version of unipolar sine-PWM switching scheme. The BDHC, during inverter operation, has the same circuit states as a conventional VSI. The switch node voltage \( V_{sn} \) acts as the input to the inverter; it switches between the voltage levels- \( V_{DC \ out} \) 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 \( V_{DC \ out} \).

B. Simulation model: For simulation of the proposed hybrid converter Parameters of the different circuit components are taken as: Input inductor \( (L) =10\text{mH} \), DC capacitor \( (C) =3000\text{µH} \), DC load \( R_{dc} = 1\text{KΩ} \), AC load \( R_{ac} = 500 \text{Ω} \) and Switching frequency is taken as 20 KHz.

The control scheme of hybrid converter is based on PWM technique based upon the switching scheme proposed in [10]. 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 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. This scheme has been proposed in [11-12], and the concept is illustrated using Fig.4.

![Figure 4: Control signals to switches S1 to S6](image)

The PWM scheme is realized by providing the signals S1-S6 to the gates of the controlled switches. $V_{ST}(t)$, a DC signal, controls the shoot-through period and hence the duty ratio ($D_{st}$) for the DC output of the Boost converter and $V_m(t)$ controls modulation index (Ma) for the inverter. The nature of the gate signals for a positive value of reference signal $V_m(t)$. This switching strategy constraint is taken care of by the controller used.

C. DC output: In this fig.5 time is taken as x-axis and corresponding DC output voltage of BDHC is taken as y-axis. Fig.23 shows the DC voltage output waveform for input 48V and DC load $R_{dc} = 1K\Omega$. DC voltage gain can be achieved by BDHC is equivalent to boost converter. For 48V input BDHC gives 95V output.

![Figure 5: DC voltage output waveform](image)
D. Three Phase AC output: In this fig. 6 time is taken as x-axis and corresponding three phase AC output voltage of BDHC is taken as y-axis. Fig. 24 shows each phase line to ground voltage waveform for a DC input of 48V for a AC load $R_{ac} = 500\Omega$. The BDHC converts 48V DC into 35V three phase AC voltage.

![Figure 6: Three Phase AC voltage output waveform](image)

4. Advantages
The proposed Boost-Derived Hybrid Converter has the following advantages:
1. Inherent Shoot-through protection: The problems associated with misgating-on of the two complementary switches of each inverter leg due to EMI or other spurious noise has been eliminated by the proposed topology. Shoot-through condition does not cause problems in the operation of the circuit and hence improves the reliability of the system. On the contrary, having a Shoot-through is necessary for Boost converter cascaded VSI operation.
2. Implementation of dead-time is not essential for this topology. This improves the nature of the inverter output with respect to its harmonic content [14]. In traditional PWM inverters dead-time compensation circuitry may be needed to compensate the distortion in output voltage due to dead-time circuit.
3. The number of controllable switches is reduced when compared to a Boost cascaded inverter topology (Fig. 2 (b)); both the VSI and Boost Converter are controlled using the same bridge configuration, thus reducing control circuit.
4. In this topology, the duty ratio and modulation index of the DC and AC structure can be independently controlled. In contrast to a ZSI or SBI [6], the maximum duty cycle for DC-DC conversion is not limited to 0.5. Thus, when the BDHC is not used for DC-AC operation, the converter can be solely used for Boost operation.
5. The current during boost interval of the Boost converter alternates between the two legs of the inverter. This enables use of higher switching frequency for the boost converter thus reducing magnetic size and improving the dynamics of the system.
6. The converter can supply both AC as well as DC loads from a single DC input supply. 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.
5. Conclusion
This paper proposes new Hybrid converter topologies which can supply simultaneously both DC and AC loads from a single DC supply. The hybrid converter topologies discussed in this paper are Boost Derived Hybrid Converter (BDHC). The proposed hybrid converters has the following advantages, shoot-through condition does not cause any problem 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. Limitations on voltage gain obtained by a BDHC can be achieved by BBDHC topology. In case of BDHC, for an input Voltage of 48V, maximum DC output voltage obtained is 95V. Maximum AC voltage obtained as same as input voltage i.e. 48V. In order to obtain AC voltage levels higher than the input voltage a step up transformer need to be interfaced with the hybrid converter.

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