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ORIGINAL ARTICLE

Studying the effect of over-modulation on the output voltage of three-phase single-stage grid-connected boost inverter

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Abstract Voltage boosting is very essential issue in renewable-energy fed applications. The classical two-stage power conversion process is typically used to interface the renewable energy sources to the grid. For better efficiency, single-stage inverters are recommended. In this paper, the performance of single-stage three-phase grid-connected boost inverter is investigated when its gain is extended by employing over-modulation technique. Using of over-modulation is compared with the employment of third order harmonic injection. The latter method can increase the inverter gain by 15% without distorting the inverter output voltage. The performance of extended gain grid-connected boost inverter is also tested during normal operation as well as in the presence of grid side disturbances. Simulation and experimental results are satisfactory.
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1. Introduction

A number of power conversion circuits have been based on extensions of the three primitive single-stage power converters, namely, the buck, boost, and buck–boost converters. The voltage source inverter can be categorized as a buck converter extension, since its output voltage is less than its input. The current source inverter can be categorized as a boost extension since it boosts the input DC voltage without an additional boosting stage. The buck–boost inverter proposed in [1] can both buck and boost the input voltage; hence, it can be classified as an extension of the primitive buck–boost converter. Applications of this topology may include the start-up and shut-down of drive systems, where the buck capability would be of use. Its buck–boost capability can be used in applications such as dynamic voltage restorers or V/F control of drive systems. The boost capability may benefit the grid connection of limited output voltage renewable energy sources. Extending the boost inverter's boost capability is the main emphasis of this work.

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The voltage source inverter (VSI), current source inverter (CSI), and Z-source inverter are the prevalent converter topologies proposed for grid-connected renewable energy systems. The voltage source inverter (VSI) is the workhorse of the power converter industry. Its widespread use and versatile applications span most industrial and commercial sectors. One of the characteristics of the topology is the stepped down nature of its output voltage. If one is to consider the application of this topology in grid-connected renewable energy applications, such a characteristic emerges as an important design factor. In such applications, the low output voltage typical of renewable sources such as photovoltaic and fuel cell systems requires proper boosting in order to meet grid interface requirements. A two-stage power conversion process is thus typically used. Using an intermediate DC–DC boost converter is one means of achieving the required voltage boost. This adds significant complexity and hardware to the power conversion system [2–8]. Alternatively, a bulky low frequency output transformer to boost the inverter output voltage may be used.

A CSI boosts the input DC voltage to the AC voltage without the boost DC–DC converter stage. The converter power switches should have a reverse voltage blocking capability or series connected diodes with the switches. These semiconductor devices should be able to carry the full input DC current [8–10]. Ref. [11] provides a detailed comparative evaluation of VSIs and CSIs for grid interfaces in distributed and renewable energy systems.

The Z-source inverter is considered a combination of the VSI and the CSI. It can be employed to achieve inverting and buck/boost function in only a single stage. With a specific impedance network of capacitors and inductors, the Z-Source inverter employs the shoot-through states by gating both upper and lower switches in the same phase legs to boost the DC voltage without adding a DC–DC converter [12–15]. Buck–boost capability, intrinsic short circuit protection due to the Z-source arrangement, and improved EMI are considered advantages of the ZSI over the CSI and VSI.

Single-phase DC–AC boost converters [16–18] can also be used to connect renewable energy sources to the grid. In [16], a new single-phase voltage source inverter was described. It can generate an output AC voltage larger than the input DC voltage depending on the reference duty cycle [16,17]. Fig. 1a shows a block diagram of the single-phase boost inverter. Blocks A and B represent DC–DC converters. These converters produce a dc-biased sine wave output so that each block only produces a unipolar voltage. The modulation of each converter is 180° out of phase with the other, which maximizes the voltage excursion across the load. The load is connected differentially across the converters. Thus, whereas a dc bias appears at each end of the load with respect to ground, the differential DC voltage across the load is zero.

A single-stage three-phase boost inverter is proposed in [18] with reference to its possible use in distributed power generation and emphasizing its impact on the overall power quality and dynamic performance. It provides both DC to three-phase conversion and voltage boost; moreover, it is comparatively lower in cost than alternative solutions, is compact, and does not need switching devices with reverse voltage blocking capability nor a power transformer [18]. The system consists of three DC to DC bi-directional boost converters with a common point as shown in Fig. 1b. These converters produce a DC-biased sine wave output. The AC component of each converter is 120° out of phase with the other. The main advantages are the use of only six IGBTs, and its low reactive element requirements to generate an output AC voltage larger than the input DC voltage.

Conventional three-phase VSIs have utilized third harmonic injection to extend the inverter gain by approximately 15% without an additional boosting stage [19–22]. In earlier work [23], employment of third harmonic injection to extend the gain of single-stage three-phase grid-connected boost inverter is proposed. Over-modulation technique may be used to extend the inverter gain as well. In this work, the effect of using over-modulation on the output voltage of the boost inverter is studied. The main contributions in this paper can be summarized in the following bullets:

- A study of the effect of modulation index on the THD of the boost inverter output voltage has been presented.
- A study on the effect of over-modulation on the inverter's output voltage has been presented.
- The performance of grid-connected inverter with extended gain is tested during normal operation as well as in the presence of grid side disturbances.

2. Boost inverter principle of operation

Each phase in the three-phase boost inverter consists of two IGBTs, one inductor, and one capacitor as shown in Fig. 1. There is a common point for the capacitors (*O*), which is connected to the negative terminal of the DC supply. The load is

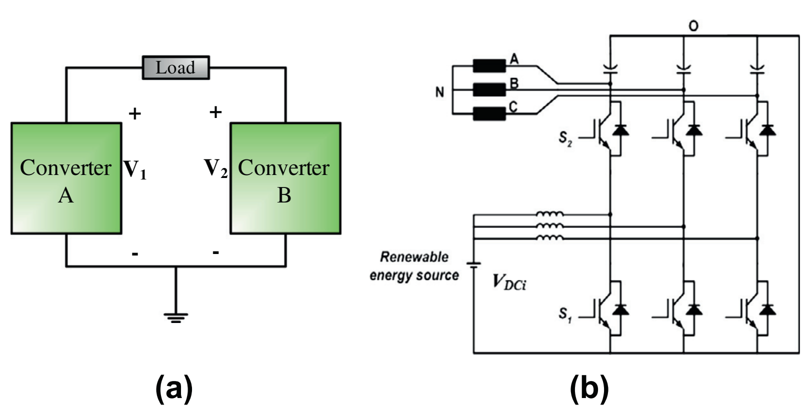

Figure 1 (a) Single-phase boost inverter block diagram and (b) three-phase boost inverter.

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