Electrical Power and Energy Systems 43 (2012) 280–289

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Advanced power conditioner using sinewave modulated buck–boost converter cascaded polarity changing inverter

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ARTICLE INFO

Article history:
Received 12 January 2012
Received in revised form 28 April 2012
Accepted 1 May 2012
Available online 23 June 2012

Keywords:
Sinusoidal absolute value tracking
Buck–boost converter
Full-bridge inverter
Polarity changing inverter
Soft switching

ABSTRACT

This paper presents an advanced power converter employs a sinusoidal voltage absolute value tracking buck–boost DC–DC converter in the first power processing stage and a polarity changing full-bridge inverter in the second stage. The proposed power conversion system has the capability of delivering good quantitative and qualitative sinusoidal output current and voltage waveforms with good output voltage regulation. Consequently, the complete voltage regulator system, which is mainly suitable for new energy generation systems as well as energy storage systems, can be constructed compactly and inexpensively without DC link electrolytic capacitor. Also, the paper presents an auxiliary passive resonant circuit for soft switching operation. Simulation results using PSIM software are presented to verify the operation principles and feasibility of the proposed power conversion system. Finally, these results are verified by means of an experimental prototype.

1. Introduction

With increasing demands worldwide for more electrical energy and the desire to reduce greenhouse-gas emissions, increasing attention is directed at sources of renewable energy, such as photovoltaic, wind and fuel cell, the development of clean distributed generation becomes increasingly important. The electric power output from such sources is small and DC. Connecting such systems to a constant voltage and frequency grid or feeding residential power utilizations requires two stages of energy conversion: DC–DC and DC–AC [1]. Coupled with these increasing demands for renewable energy sources, energy conversion systems are also growing to meet the challenge.

The DC–DC converter and the inverter are the main parts of the energy conversion system for the renewable energy source. They are the heart of the system, the most complex component and the most likely part to fail [2,3]. Their task is to track and convert the direct current from the source to a usable form of standard utility grid AC power; pure, noise free sinewave power at a fixed frequency and voltage. Therefore, it is important to optimize the control circuits and to choose a topology with the lowest possible power dissipation and cost effective requirements [4–7]. This paper focuses on the design of such system and its overall control for the efficient, cost effective and reliable injection of energy into a grid.

The main design target points are often high power density and high efficiency [8]. There is few number of literatures available considering this power range and a new performance criterion should be applied. Ohashi proposed the new concept of "Power density" [9,10], and he showed the trend of the continuous growth of power density in various applications of power electronics. A variety of high performance DC–DC power converter topologies have been proposed for increasing power density and efficiency [11–14]. Kolar listed four key items which strongly influence final converter design, which are efficiency (loss), volume, weight and cost. These items are closely coupled together and the total optimization procedure is discussed in [15].

The conventional utility-connected power conversion systems are schematically classified into three different types; isolated low frequency transformer AC link, isolated high frequency transformer AC link, and transformer-less direct AC link. The topologies of low frequency AC link and high frequency AC link have the advantage of safety due to the function of electrical isolation. On the other hand, the transformer-less AC link topology has the main advantages of low cost and small physical size [16–19].

The main limiting components inside the power conversion circuit are the decoupling capacitors used for power decoupling between the renewable energy source and the single-phase grid [19,20]. An electrolytic capacitor of large capacitance is required on the DC input bus in order to decouple the power pulsation caused by the renewable energy source. This capacitor is bulky, expensive and its lifetime expectancy is much shorter than that of any other semiconductor components in the power conversion system. Hence, the lifetime of the conversion system is shortened,

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http://dx.doi.org/10.1016/j.ijepes.2012.05.002

because the electrolytic capacitor has a drastically shortened life, especially when used in a high-temperature environment. In addition, significant practical problems as low power conversion efficiency, volumetric physical size and reliability have been appeared due to the use of the electrolytic capacitors. Due to these cost and reliability issues, there have been significant efforts to eliminate or reduce the capacitance of the electrolytic capacitor and tendency to use small film capacitors instead [18–28].

To overcome these defects, a dual mode time sharing power conversion system without electrolytic capacitor, as shown in Fig. 2a, has been proposed in [25]. It offers high efficiency and relatively low price. However, a bypass high switching diode and sharing of operation functionalities appear in this topology reduces the control circuit flexibility and simplicity. This paper proposes an extended version of previously proposed utility interactive power conversion topology suitable for renewable energy generation systems, which of course, offers the most flexible control freedom and simplifying the control circuit for producing a specified input-to-output transfer gain. The proposed power conversion circuit also enables realization of small volume, lightweight and stable ac current injection into the utility line. A control method suitable for the proposed inverter is also proposed. The effectiveness of the proposed inverter is verified thorough PSIM simulation on a 5 kW prototype.

2. Topologies and operation principles

2.1. Conventional power conversion circuit

System configuration of the conventional power conversion system is shown in Fig. 1a, which couples a DC–DC boost converter to the conventional full-bridge (FB) single-phase voltage source inverter (VSI) with no sharing of components or operation functionalities. For comparison, its principle of operation is briefly described here, and it is depicted in Fig. 1b that the inverter uses a voltage boost circuitry to boost its DC input voltage by controlling the conductive duty cycle of the switch SW_c. Mathematically, by performing state-space averaging, it can easily be shown that the DC bus voltage V_{dc} and peak ac output voltage V_o of the inverter can explicitly be expressed as [2,3]

$$V_{dc} = \frac{1}{1-D} V_{in} \quad (1)$$

$$V_o = \frac{M}{2(1-D)} V_{in} \quad (2)$$

where D refers to the conductive duty ratio of SW_c, M represents the modulation index commonly linked to traditional inverter control, and $1/(1-D)$ is defined as the voltage boost factor. Clearly, the inverter ac output voltage can be stepped down or up, with respect to the applied input voltage, by tuning D and M accordingly, which will also affect the voltage stresses appearing across switches SW and (SW_1–SW_4). The boost converter in the first stage is used to boost the low and unregulated DC voltage up to a constant output voltage. The active power switch SW_c always operates at high switching frequency. The output side of this boost converter needs a bulk and large-volumetric electrolytic DC capacitor to keep constant DC voltage. The FB inverter in the second stage operates also at all time to produces the required AC voltage for residential applications or utility interactive AC power grid under sinewave carrier-based high frequency PWM control. Consequently, the total system efficiency is very poor.

2.2. Previously proposed conversion circuit

The circuit topology of the previously proposed time-sharing sinewave controlled power conversion system is depicted in Fig. 2a [25]. This system composed of time-sharing absolute sinewave voltage tracking boost DC–DC converter with bypass diode D_b and FB VSI. The PWM DC–DC converter with bypass diode is

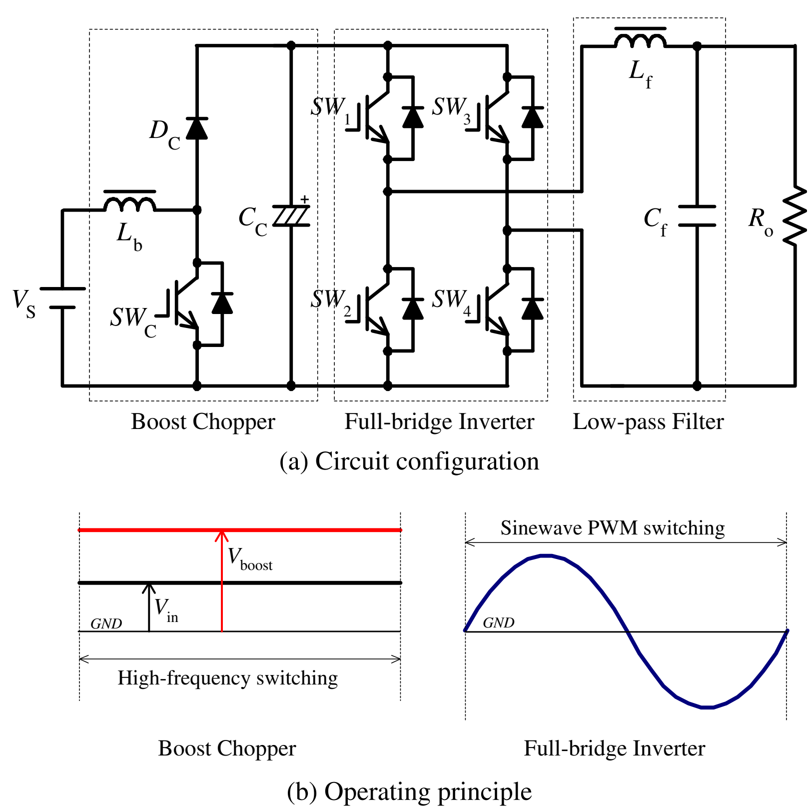

Fig. 1. Conventional single-phase power conversion circuit.