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Design and Implementation of DC-DC-AC Converter

[1] Tonsy Tony, [2] Sipin Paul, [3] Sharika Raj C

Abstract: - **Due to wide-range low dc output voltage, the renewable energy sources cannot support the ac or dc electrical appliances directly. Consequently, a step-up converter is required. Currently using photovoltaic systems has several energy conversion stages. As the conversion stages increases power loss, switching loss and harmonics increases. So as to overcome these disadvantages, a new DC-DC-AC converter has been proposed in this paper which exhibits several advantages, the most important of which is the ability to generate both DC and AC outputs higher than the DC source voltage in a single stage with reduced number of switches. So the DC-DC-AC converter can connect the renewable energy sources directly to AC and DC equipment's. The proposed technology has wide range of applications including industrial, domestic, agricultural, marine etc. The simulations were done in MATLAB/Simulink and both the DC as well as AC output voltages obtained from DC-DC-AC converter were verified.**

Key words: DC-DC-AC Converter, Differential Boost Inverter (DBI), Interleaved Boost Converter (IBC)

INTRODUCTION

Power electronic converters are a family of electrical circuits which convert electrical energy from one level of voltage, current, or frequency to another using power switching components. In all power converter families, energy conversion is a function of different switching states. The process of switching the power devices in power converter topologies from one state to another is called modulation [1]. Regarding different applications, various families of power converters with optimum modulation technique should be used to deliver the desired electrical energy to the load with maximum efficiency and minimum cost. Three main families of power converters are DC-DC converter, DC-AC converter, AC-DC converter

The electrical conversion according to the different family of power converters used in renewable energy systems was explained here. In renewable energy systems, sources can be either AC or DC such as Wind Turbine (WT) or PV systems, respectively. However, due to load requirements, the power may be changed to DC or AC. Therefore, based on different applications, proper combination and control of above power converters can supply a load. In residential applications or grid connected systems where the variable voltage of renewable energy systems should be converted to achieve desirable AC voltage and frequency, AC-DC, DC-DC and DC-AC converters may be needed. On the other hand, when the input voltage is variable DC source such as a PV or FC systems, DC-DC converter combined with DC-AC converter may be used to have a regulated AC waveform for residential or grid connected systems.

Converters like Buck, Boost and Buck-Boost converters are popularly used for photovoltaic systems [2]. But these converters are limited to low power applications. The main attribute of the boost inverter or boost DC-AC converter topology is the fact that it generates an AC output voltage larger than the DC input one, depending on the instantaneous duty -cycle [3]. This property is not found in the classical voltage source inverter which produces an AC output instantaneous voltage always lower than the DC input voltage [4]. As a consequence, when an output voltage larger than the input one is needed, a boost DC-DC converter must be used between the DC source and inverter [5]. Boost DC-AC inverter naturally generates an AC voltage in a single stage whose peak value can be lower or greater than the DC input voltage. The main drawback of this structure deals with its control. Boost inverter consists of Boost DC-AC converters that have to be controlled in a variable-operation point condition [6]. The conversion of DC power into AC power through a single phase inverter will typically introduce a low-frequency current ripple (at twice the AC output voltage frequency) at the DC input side of the power conversion system. Differential inverters have been widely applied to AC applications powered by DC sources, e.g., in renewable energy systems, due to its advantages of high efficiency, reduced size, and low cost [7].

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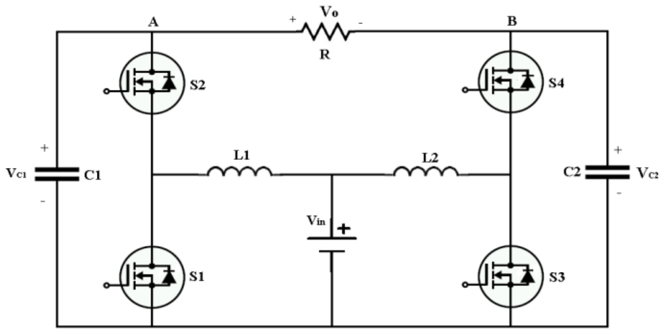

Fig.1. DC-DC-AC converter

Differential inverters are inverters made up of two identical bidirectional DC-DC (i.e., buck, boost or buck–boost) converters, either a boost, a buck, or a buck–boost operation together with the voltage inversion function to deliver the output in a single stage. Based upon the DC-DC converter type each converter will generate a DC biased AC output voltage that is higher or lower than the renewable source voltage of which when the outputs of the two DC-DCconverters are combined, only a pure AC output voltage is generated.

II. DC-DC-AC CONVERTER

A. Overview

This paper proposes a new breed of voltage source inverter referred to as DC-DC-AC converter. Differential inverter is modified to develop a new DC-DC-AC converter which can drive both AC and DC equipment's. DC-DC-AC converter is a combination of two identical boost converters to generate DC or AC output higher than the DC source voltage in a single stage with reduced number of switches. This is a single input dual output converter. It has two modes of operations, Differential Boost Inverter (DBI) mode for inverting the DC to generate boosted AC output, and Interleaved Boost Converter (IBC) mode for converting low voltage DC to high voltage ripple reduced DC. The main attribute of the new converter topology is the fact that it is a combined converter-inverter system, depending on the selected mode of operation it act as a boost DC-AC inverter (DBI) or boost DC-DC (IBC) converter. The two identical boost converters are combined in series and parallel for DBI mode and IBC mode of operations respectively.

B. Design

The assumptons and eqations for the desgn of DC

DC-DC-AC converter are exactly similar to the design of a conventional boost converter circuit. Fig. 1 shows the circuit diagram of a DC-DC-AC converter which is a combination of 180° phase shifted two identical boost converters. It consist of two inductors L1, L2 two output capacitors C1, C2 four switches S1-S4 and load resistance R. V_inbe the source voltage of the converter. The output voltage and current of the converter are depicted as V_0 and I_0 respectively. V_C1and V_C2 are the voltages of the converter output capacitors C1 and C2, respectively. Design equations used for designing various components and selecting different factors are shown below

$$R = V_0/I_0 \quad (1)$$

$$Dutycycle, D = 1 - V_{in}/V_0 \quad (2)$$

$$Capacitor, C = I_0 D/f_s \Delta V_0 \quad (3)$$

$$Inductor, L = V_{in} D/f_s \Delta I_L \quad (4)$$

Where f_s and I_L are the supply frequency and inductor current respectively.

B. Operation

Differential Boost Inverter (DBI) mode:

The principle purpose of the boost converters which are connected in series for DBI mode is to produce the respective capacitor voltages as faithfully as possible a sinusoidal reference. Boost converters produce a DC-biased sine wave output, so that each source produces only a unipolar voltage. The modulation of each converter is 180° out of phase with the other, which maximizes the voltage deviation across the load. The load is connected differentially across the converters [8].

Assume all the components are ideal and that the converter operates in a continuous conduction mode with two topological modes for a period of operation. Initially switch S1 is closed and S2 is open for 180°, the inductor current I_{L1} raises quite linearly, diode D2 is reversed biased. At that time capacitor C1 supplies energy to the load and as a result Voltage V_{C1} decreases. For next 180° of conduction switch S1 is open and S2 is closed, the inductor current I_{L1} flows through capacitor C1 and load. The current I_{L1} decreases while capacitor C1 is recharged. The output of the DC-DC-AC converter is controlled by varying the duty cycle D of the boost converters such that each converter will generate a DC biased AC output voltage that is higher than the photovoltaic voltage of which when the difference between the outputs of the two DC-DC converters and a DC component of voltage appears at each end of the load with respect to ground is taken, only a pure AC output voltage is generated. But the differential DC voltage across the load is zero. The output voltage of each converter and their combined output voltage will be, respectively

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$$V_{C1} = V_d + [V_{max}Sin(\omega t)/2] \quad (5)$$

$$V_{C2} = V_d + [V_{max}Sin(\omega t - \pi)/2] \quad (6)$$

$$V_0 = V_{C1} - V_{C2} = V_{max}Sin(\omega t) \quad (7)$$

Where V_{C1} and V_{C2} are the output voltages of the two DC-DC converters, V_{max} is the amplitude of the output voltage V_0, ω is the line frequency and V_d is the DC-biased voltage of V_{C1} and V_{C2}. From (7), it can be observed that the required output is as desired, i.e.,comprising only the ac component.

ii. Interleaved Boost Converter (IBC) mode:

Interleaved boost converter mainly used for renewable energy sources has a number of boost converters connected in parallel which have the same frequency and phase shift. The boost converters are connected in parallel by shorting the output terminals A and B, to accomplish the IBC mode operation of DC-DC-AC converter. Assume all the components are ideal and that the converter operates in continuous conduction mode for high power applications due to lower input peak current and reduced conduction losses. By dividing the output current into 'n' paths higher efficiency is achieved and eventually reducing the copper losses and the inductor losses.

When the switch S1 is turned on, the current in the inductor I_L1 increases linearly. During this period energy is stored in the inductor L1. When S1 is turned off, diode D1 conducts and the energy stored in the inductor decreases in a shape resembling the ramp waveform, with a slope which is based on the difference between the input and output voltage. The inductor starts to discharge and transfer the current through the diode to the load. After a half switching cycle of S1, S2 is also turned on completing the same cycle of events [9].

Since the terminals A and B are shorted for IBC mode, both the power channels are combined at the output capacitors C1 & C2, the effective ripple frequency is twice than that of a single-phase boost converter. The amplitude of the input current ripple is small. The gating pulses [10], of the two devices are shifted by a phase difference of 360/n, where n is the number of parallel boost converters connected in parallel. For a two-phase interleaved boost converter n=2, so the two devices are phase shifted by 180 degrees, the input current ripple produced is the smallest [11]. This advantage makes this topology very attractive for the renewable sources of energy [12].

IV. SIMULATION AND EXPERIMENTAL RESULTS

The optimum component values of L1, L2, C1 and C2 are obtained from the design and fine-tuned based on simulation results. The simulation of the complete system is carried out in the MATLAB/Simulink environment. Fig. 3 shows the simulink model of photovoltaic fed battery charging system. In this mode of operation the DC-DC-AC converter acts as an interleaved boost converter. The switching pulse for the IBC is generated by MPPT algorithm under this mode of operation. Fig. 4 shows the simulink model of combined photovoltaic and battery fed induction motor drive. In this mode of operation the DC-DC-AC converter acts as differential boost inverter. The switching pulse for the DBI is generated by PWM technique. The overall system works automatically according to the MATLAB code created in the MATLAB function block. When a value greater than zero is given to mode selector block, then DC-DC-AC converter acts as IBC for battery charging and the corresponding switching pulses are automatically generated from Embedded MATLAB function block by executing the MATLAB coded program. Similarly, when a value less than zero is given then the DC-DC-AC converter acts as DBI.

The PV panel is modeled by using the solar cells taken from Simscape/SimElectronics/Sources in the Simulink Library Bowser. The MPPT block is modeled by using Perturb and Observe Algorithm (P & O). The parallel connection of boost converters for high-power applications is a popular technique. Its main advantage stems from the fact that sharing the input current among the parallel converters allows smoothing some of the design constraints of the switching cells. While comparing with other conventional boosters such as boost, buck-boost, series resonant full-bridge and push-pull converters, the IBC has several advantages because others add objectionable

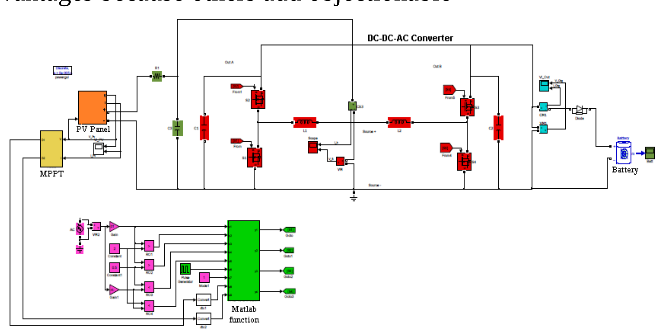

Fig.3.MATLAB/Simulink Model of Photovoltaic Fed Battery Charging System Using DC-DC-AC Converter

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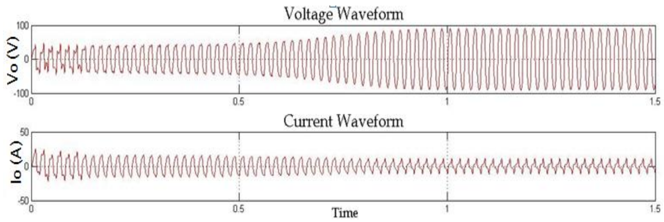

Fig.5. DC-DC-AC converter Output Voltage and Current WaveformsDuring DBI Mode

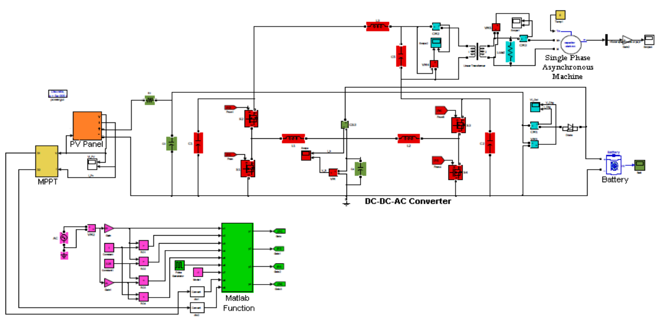

Fig.4.MATLAB/Simulink Model of Combined Photovoltaic and Battery Fed Induction Motor Drive Using DC-DC-AC Converter

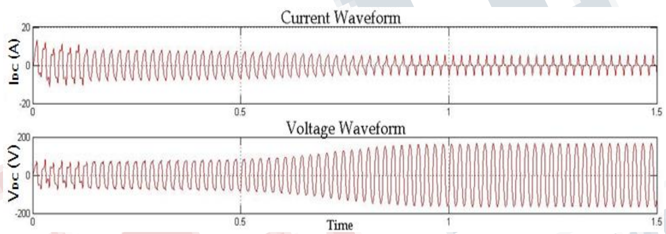

Fig.6. Single PhaseInduction Motor Output Voltage and Current Waveforms

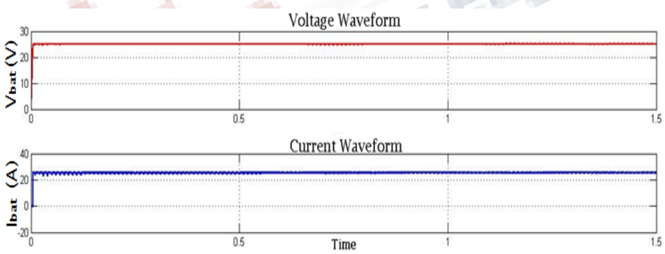

Fig.7. Battery Charging Voltage and Current Waveforms At 1000W/m^2 IrradianceDuring IBC mode

ripples in the current owing out of the PV cell. To minimize the ripples, an IBC is used for the converter mode operation as a suitable interface for the renewable source.

TABLE I
DC-DC-AC CONVERTER SIMULATION RESULT ANALYSIS

DC-DC-AC Converter Outputs			
DBI Mode AC Output		IBC Mode DC Output	
Input	Output	Input	Output
36V PV Panel and 12V, 7Ahr Lead Acid Battery	90V, 20A sinusoidal AC voltage	12V PV Panel	24V DC voltage

software and both the DC as well as AC output voltages obtained from DC-DC-AC converter was verified. The simulation results shows that the proposed PV fed Induction motor drive using a DC-DC-AC converter was conceived to be a commercially viable solution having low cost, high efficiency and robustness. From the simulation results of comparative study, it is clear that the ripple voltage can be reduced by replacing boost converters by IBC. DC-DC-AC converter is a promising solution for renewable energy systems as it has the ability to generate DC or AC output higher than the DC source voltage in a single stage with reduced number of switches. The proposed technology can be extend to develop a three phase DC-DC-AC converterby adding one more boost converter for driving three phase AC motors such as BLDC, PMSM etc.

CONCLUSION

A new breed of energy converter was designed and studied both theoretically and experimentally. The simulations were done in MATLAB/Simulink

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