ANALYSIS OF MULTIPORT DC-DC CONVERTER IN RENEWABLE ENERGY SOURCES

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Abstract

Multi-port DC-DC converter has attracted special interest in applications where multiple energy sources are used. In this project, a three-port converter with three active full bridges, two LCC resonant tanks, and a three-winding transformer is proposed. It uses a single power conversion stage with high-frequency link to control power flow between batteries, load, and a renewable source such as solar cell. The converter has capabilities of bidirectional power flow in the battery and the load port. The converter has high efficiency due to soft-switching operation in all three bridges. Design procedure for the three-port converter is explained and experimental results are presented.

Index Terms— *Bidirectional power, phase-shift control at constant switching frequency, soft-switching operation, three-port converter, LCC resonant converter, three-winding transformer.*

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1. INTRODUCTION

Future power conversion systems need to be interfaced with alternative energy sources such as fuel cells, photovoltaic, along with energy storage devices such as batteries, super capacitors. Multiport converter, a promising concept for alternative energy systems, has attracted increasing research interest recently [1]. Compared with the conventional approach that uses multiple converters, a multiport converter promises cost-effective, flexible, and more efficient energy processing by utilizing only a single power stage

For dc-dc power conversion, the dual-active-bridge (DAB) has attractive features such as low device stresses, bidirectional power flow, fixed-frequency operation, and utilization of the transformer leakage inductance as the energy transfer element [2]. The main drawback of the DAB converter, however, is that it cannot handle a wide input voltage range. In such a case the soft-switching region of operation will be significantly reduced. To extend the soft-switching operation range in case of port voltage variations, duty-cycle control along with phase shift control.

Duty ratio control was also used for adjusting the amplitude of the fundamental component, but not explicitly for extending ZVS range. In addition, a phase shift plus pulse-width-modulation control was applied to the DAB converter, where the converter uses two half-bridges to generate asymmetrical in order to deal with the voltage variation. However, for the multiport topologies, with this method only one port may [3] have a wide operating voltage because all the bridges operate at the same duty ratio? Front-end boost converter is use to solve the port voltage variation [4].

To increase the power –handling capacity of the converter, three-phase version is proposed in [5]. A high power converter to interface batteries and ultra-capacitors to a high voltage dc has been demonstrated using half bridge. The selection of switching frequency is not independent of the value of inductance [6]. A series-resonant converter has more freedom in choosing realizable inductance values and the switching frequency, independent of each other. Such a converter can operate at higher switching frequencies for medium and high-power converters.

Other circuit topologies are suggested for a three-port converter such as the current-fed topologies that have more number of magnetic and fly back converter topologies that are not bidirectional [7]. A constant-frequency phase-controlled parallel resonant converter was proposed, which uses phase shift between input bridges to control the ac-link bus voltage, and also between input and output bridge to control the output dc voltage. Such high-frequency ac-link systems using resonant converters have been extensively explored for space applications and telecommunications applications.

2. THREE-PORT TOPOLOGY

The proposed three-port converter with duty ratio control method is not ideally suited for the two-port DAB converter because it not guarantees ZVS over the full range of operation. However, ZVS condition can be achieved in the three-port triple active bridge converter. The proposed duty ratio control method, ZVS conditions is achieved over the entire phase shift region. The three port bidirectional converter having the following features, all ports are bidirectional, including load port for application, Centralized control of power flow, reduced switching losses due to soft-switching operation.

High frequency three-winding transformer is proposed to provide the isolation between the three Ports. Due to single-stage power conversion, the converter has a centralized control for regulating the output voltage. The converter naturally yields to bi-directional power flow in all ports. One method of building a single-stage power converter circuit interfacing multiple energy sources and the load is to emulate a multiple bus power system. HF transformers have small size, light weight, and low cost compared to bulky line frequency transformers.

All of these topologies use inductors as the main power transfer and storage element. Another method of building a single stage power converter circuit is to use time-sharing principle i.e., at any time instant only one of the sources will be connected to the load. These converters employ square-wave pulse width modulation to achieve voltage regulation. The average output voltage is varied by varying the duty cycle of the power semiconductor switch.

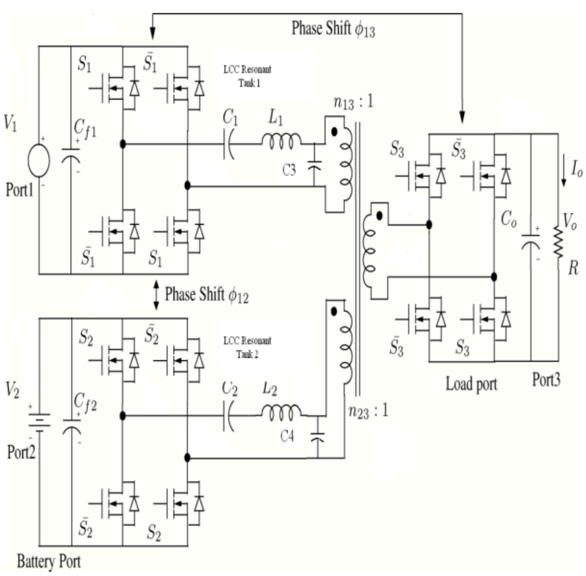

Fig.1 Three-port DC-DC converter

An LCC resonance converter shares the advantages of other resonance converters, when the switching frequency is lower than the resonant frequency [8], and Zero voltage switching suitable for MOSFETs when the switching frequency is higher than the resonant frequency. These characteristics make the LCC resonant converter a potential candidate for high power and high frequency application.

Besides the above features, the LCC resonance converter offers additional merits when compared with series resonant converter (SRCs) and parallel resonance converter (PRCs). First the series capacitor the equivalent at light load end. This is because the tank capacitances smaller, this results in an increase of the characteristics impedance of the resonant tank, and is helpful to limit the circulating current. Secondly, the voltage conversion characteristics allow the converter to operate in a wide load range (from full load to no load),where PRCs may lose regulation at full load end SRCs may lose regulation LCC resonance converter behaves more like a PRCs under light load, and an SRCs under full load. Therefore, the circulating energy at light load is minimized. Thirdly the LCC converter has inherent short circuit protection.

3. DESIGN

The proposed circuit is shown in Fig.1. It has two LCC resonant tanks formed by L1, C1 and C3, L2, C2 and C4, respectively. The input filters capacitor for port 1 and port 2 are Cf1 and Cf2, respectively. Two phase shift variables $\varphi 13$ *and* $\varphi 12$ are considered as shown in Fig.1. They control the phase shift between the square wave outputs of the bridges. The phase shift $\varphi 13$ *and* $\varphi 12$ are considered positive.

The transformer is a core component. It provides isolation and voltage matching. The selection of the transformer turns ratio using the formula.

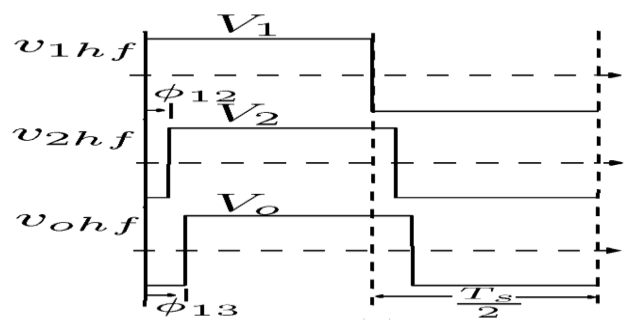

Fig.2 PWM waveform with definitions of phase-shift variables $\varphi 13$ *and* $\varphi 12$

$$\frac{N_1}{V_1} = \frac{N_2}{V_2} = \ldots\ldots\ldots = \frac{N_N}{V_N} \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

Where N1, N2 are the winding turn’s number and V1, V2 are the port voltages. The power throughput of the transformer should be the maximum of all the possible situations. When switching frequency is fixed, the power flow through the transformer is related to phase shifts and leakage inductances. For instance, in a two winding situation, the power flow p is giver by,.

$$P = \frac{N_1V_1V_2}{2\pi N_2F_SL_S}\varphi\left(\frac{\varphi}{\pi}\right) \quad ....(2)$$

Where Fs are the switching frequency, Ls is the total inductance referred to the primary. A small leakage inductance leads to a smaller leakage inductance leads to a smaller phase shift while transferring the same amount power. In the design, it is assumed that the source connected to port 1 is unidirectional but, bidirectional power flow can be enabled in this port also.

The requirements on the region of operation for the three-port converter are the following:

1) To supply the load power independently from each of the sources;
2) Share the load between the sources;
3) At reduced load, the main source is to supply the load and charge the battery;
4) When the load is regenerative, the power is used to charge the battery.

When power flow from the poet 1 to port 3, the converter works in boost mode to keep the port 3 at a desired high value. In the other direction of power flow, the converter works in buck mode to charge the energy storage element.

Table 1 Three-Port Converter Parameter

Converter parameter	value
Resonant inductor	9 µf
Resonant capacitor	0.5 µf
Port 1 voltage	24v
Port 2 voltage	24v
Output voltage	96v
Turns ratio	0.25
Duty cycle	0.5
Filter capacitor	10 µf

4. SIMULATION RESULTS

The three-port dc-dc converter was simulated with MATLAB. The parameters for simulation are listed in TABLE I. The simulation waveforms of the voltage and power at the switching frequency of 25KHZ and the duty ratio of 0.5% The ratio of switching frequency to resonant frequency as 1.1 The port 1 power does not vary with load as long as output voltage is maintained constant.

A large filter capacitor is required since it needs to supply a large charging/discharging current during operation and maintain a constant voltages The parameter used for simulation is C0=10µf.

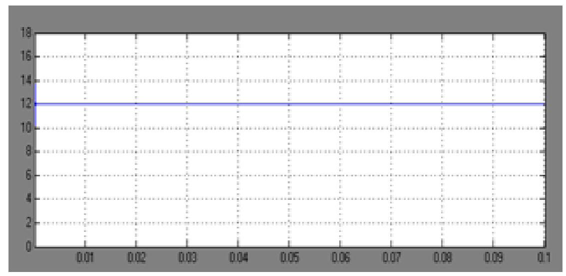

Fig.3 Port 1 DC input voltage

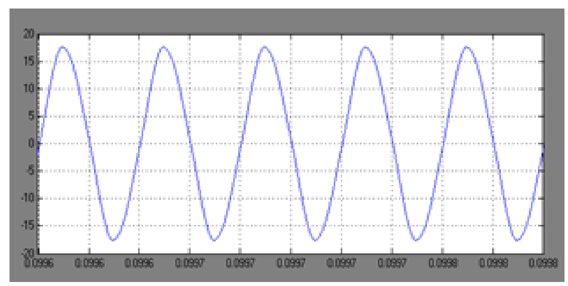

Fig.4 Transformer secondary voltage

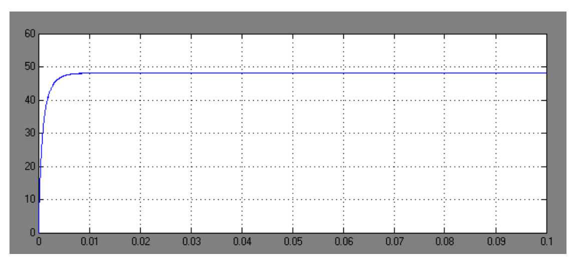

Fig.5 Port 3 Dc output voltage

The efficiency of the whole system is around 90%. The efficiency of this system is increases comparing to the existing three-port series resonant dc-dc converter the fig 7 shows.

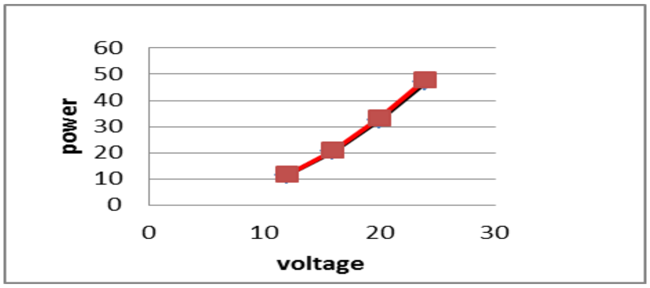

Fig.6 Graph between input voltage and power

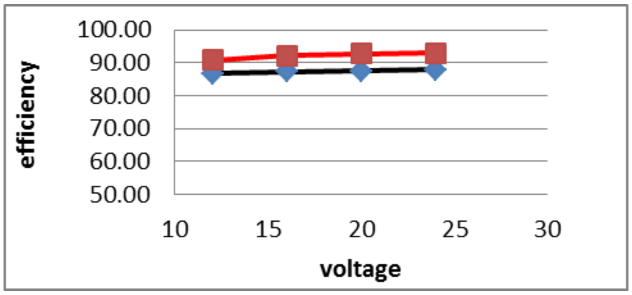

Fig.7 Graph between input voltage and efficiency for existing and proposed circuit.

CONCLUSIONS

In this paper, a three-port dc-dc converter was introduced to interface renewable energy sources and the load, along with the energy storage. It was proven by analysis and experimental results that power flow between the ports in either direction. This converter can reverse the direction of flow of current, and thereby power, while maintaining the voltage polarity unchanged. A design procedure with normalized variables, which can be used for various power and port voltage levels, was presented. Experimental results verify the functionality of the three-port converter.

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