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Research Paper

RESONANT DC-DC CONVERTER USING RESISTANCE COMPRESSION NETWORK

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This paper aims at developing a flyback based high step up dc-dc converter with high efficiency which reduces the number of switches used and thereby reducing the gate pulse requirement. Thus it reduces the complexity. In applications like photovoltaic systems the low voltage output of solar panels (typically 12 Volts) has to be boosted to high voltage (typically up to 400V) and then inverted to 230 V standard ac supply. This project presents a new topology for an increased efficiency in dc/dc resonant power converter that uses a flyback converter and a resistance compression network (RCN) to provide simultaneous zero-voltage switching and near-zero-current switching across a wide range of input voltage, output voltage, and power levels. The flyback converter, a transformer-isolated version of the buck-boost converter with galvanic isolation between the input and any outputs, is used to increase the efficiency. The RCN maintains desired current waveforms over a wide range of voltage operating conditions. The converter implementation provides galvanic isolation and enables large (greater than 1:10) voltage conversion ratios, making the system suitable for large step-up conversion.

Keywords: DC/DC converter, Flyback converter, High-efficiency power converter, Photovoltaic systems, Resistance compression network (RCN), Resonant converter

INTRODUCTION

The power electronics community is constantly striving towards developing higher efficiency converters. High efficiency is achieved by utilizing switching topologies with ideally lossless passive components. In order to have high efficiency a trade-off between conduction and switching loss has to be made in order to minimize the total loss. The ideal dc-dc converter exhibits 100% efficiency; in practice, efficiencies of 70% to 95% are typically obtained. This is achieved using switched-mode, or chopper, circuits whose elements dissipate negligible power.

Resonant converter, can achieve very low switching loss thus enable resonant topologies to operate at high switching frequency. In resonant topologies, Series Resonant Converter (SRC), Parallel Resonant Converter (PRC) and Series Parallel Resonant Converter (SPRC, also called LCC resonant converter) are the three most popular topologies. Unfortunately, all three converters suffered from wide input range

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problem. As frequency increases in SRC, the impedance of the resonant tank is increased. This means more and more energy is circulating in the resonant tank instead of transferred to output. So SRC is expected to handle wide input range but with impedance problem.

So as to deal with impedance, new topology is introduced in this paper. Impedance problem can be resolved using the new concept, resistance compression effect. It matches input and output impedance with a varying load condition.

Previous work (Inam *et al.*, 2013) deals with the resonant dc-dc converter that makes use of full bridge inverter. A full bridge inverter comprises of four switches which has its respective losses.

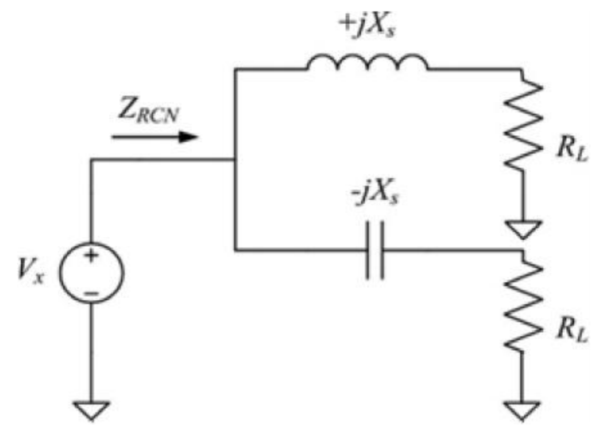
The DC to DC converters, that converts unregulated dc input voltage to regulated dc output voltage, are designed as forward converter and flyback converter. Forward converters include buck converter, boost converter and buck-boost converter. The flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation. It also make use of single switch.

The remainder of this paper is organized as follows: Section II describes the resistance compression network. The methodology of the proposed resonant dc-dc converter is analyzed is presented in Section III. Section IV describes the operation of the RCN dc/dc converter. The result from the simulated design is presented and discussed in Section V. Finally, Section VI summarizes the conclusion of the paper.

RESISTANCE COMPRESSION NETWORK

Load variations are a known problem for resonant conversion systems. With a wide range of variations, each requires a significant change in the switching frequency, complicating EMI compatibility design, and efficiency that would reduce especially in light load conditions. The load variation problem can be significantly reduced with use of dedicated circuitry that would "compress" the variation of the load resistance into a smaller range. Current effort in the scientific community examines a structure that utilizes a passive, lossless network with the combination of passive rectifiers.

Figure 1: Fundamental Frequency Model of the RCN and the Rectifiers



Although the structure (called resistance compression network) is simple and significant suppression of the load variations is possible, the structure is only applicable to DC-DC conversion systems, where the same effect could be achieved if the active solution had been pursued instead. Compression networks ideally act without loss, such that all energy provided at the input port is transformed and transferred to the resistive load. In effect, the load resistance range appears compressed when looking through a resistance compression network.

IMPEDANCE MATCHING

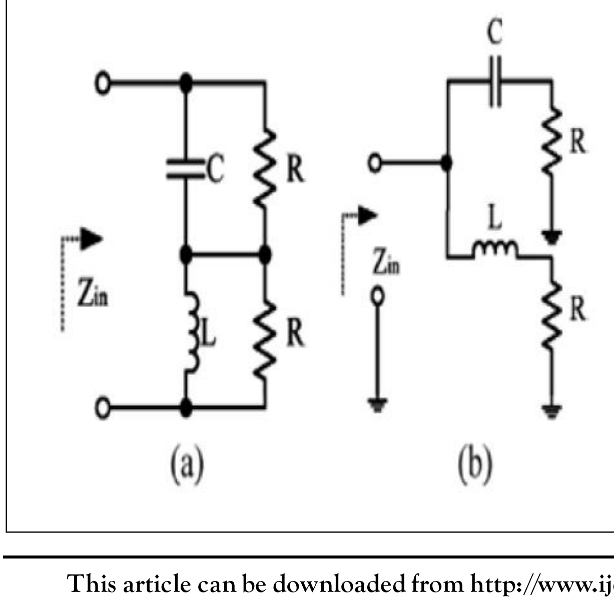
Two simple linear circuits of this class that exhibit resistance compression characteristics are illustrated in Figure 1. When either of these circuits is driven at the resonant frequency, of its LC tank, it presents resistive input impedance that varies only a small amount as the matched load resistances vary across a wide range. For example, for the circuit of Figure 2(a), the input resistance is:

$$R_{in} = \frac{2R}{1+\left(\frac{R}{Z_0}\right)^2}$$

where $Z_0 = \sqrt{L/C}$ is the characteristic impedance of the tank. For the circuit of Figure 2 (b), the input resistance at resonance is

$$R_{in} = \frac{Z_0^2}{2R}\left[1+\left(\frac{R}{Z_0}\right)^2\right]$$

Figure 2: Resistance Compression Circuits



Using fundamental frequency analysis, at the switching frequency the half-bridge rectifiers can be modeled as resistors, as illustrated in Figure 1. The effective resistance of these rectifiers is given by

$$R_L = \frac{4V_{out}^2}{®^2 P_{out}}$$

Hence, at the switching frequency the input impedance of the RCN looks purely resistive.

$$Z_{RCN} = \frac{X_s^2 + R_L^2}{2R_L}$$

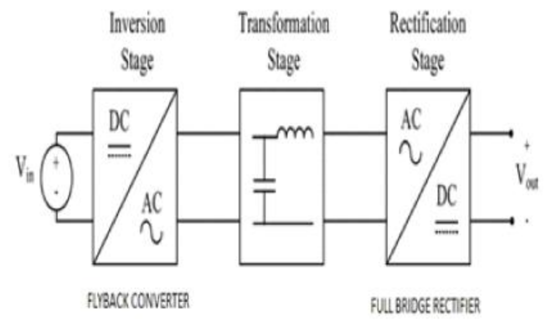
where Xs is the magnitude of impedance of the RCN elements (Ls and Cs) at the switching frequency. The value of RL will be greater than ZRCN. Thus the load resistance is reduced by the use of resistance compression network.

This helps achieve ZVS and near-ZCS of the inverter switches across a wide range of output and input voltages. The RCN also serves to limit the instantaneous output power across the full operating range by providing a specified loading characteristic to the inverter. The value of Xs is selected in such a way so as to limit the output power to the maximum value required across the range of output voltages at the minimum input voltage. Since the power delivery capability of the converter increases with input voltage, this ensures that the converter can deliver the maximum required power across its entire input voltage range. It is also noted that the power characteristic across output voltage is quite flat at the minimum input voltage, owing to the effect of the RCN.

PROPOSED CONVERTER TOPOLOGY

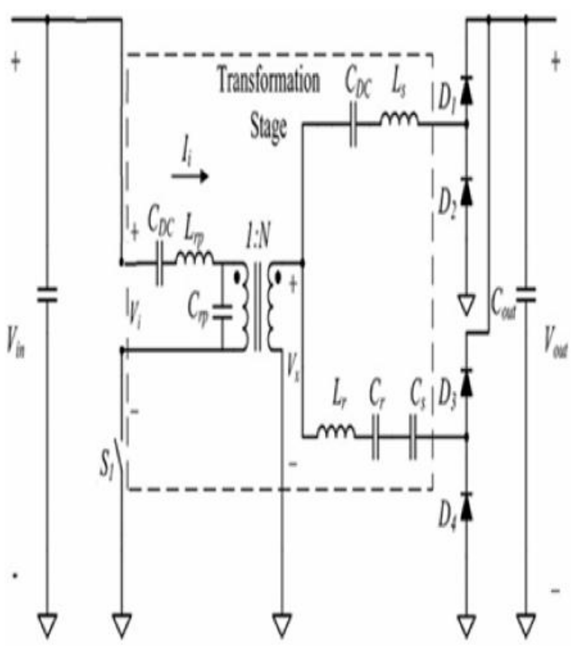
The resonant dc/dc converter, proposed in this project, consists of an inversion stage, a transformation stage, and a rectification stage, as shown in Figure 3. The rectification and transformation stages use standard designs (Inam *et al.*, 2013). The inversion stage of the converter is new. The converter is designed to step-up input voltage.

Figure 3: Architecture of the Proposed dc/dc Converter



The inversion stage is designed using a fly back converter. Proposed converter design is shown in Figure 4. It consists of a dc supply from a battery source. It is given to a flyback converter

Figure 4: Topology of the Proposed DC/DC converter



which consists of a MOSFET switch and a flyback transformer. The transformation stage includes a resistance compression network (RCN) and filters. Then followed by a two half bridge diode rectifier. This rectifier supplies the load. The operation explains the working design of the converter.

OPERATION OF THE PROPOSED RESONANT DC-DC CONVERTER

The inverter stage is a proposed flyback converter (composed of only one switch S1). A flyback converter is used instead of a half bridge or full bridge to reduce the number of switch requirement. The flyback converter is based on the buck-boost converter. Although the two-winding magnetic device is represented using the same symbol as the transformer, a more descriptive name is “two winding inductor.” This device is sometimes also called a “flyback transformer.” Unlike the ideal transformer, current does not flow simultaneously in both windings of the flyback transformer. Rather, the flyback transformer magnetizing inductance assumes the role of the inductor of the buck-boost converter. The magnetizing current is switched between the primary and secondary windings.

The transformation stage consists of a matching network, a transformer, and an RCN. The matching network composed of Lrp and Crp acts as a filter and provides a voltage gain, hence reducing the transformer turns ratio requirement. One issue with high-turns-ratio step-up transformers that exists in many topologies is that the parasitic leakage inductance of the transformer can undesirably ring with its secondary side winding capacitance at the switching transitions. This creates large ringing in the current and voltage waveforms, and high-frequency losses. The matching network also eliminates this ringing by absorbing the transformer parasitics.

The 1:N transformer provides additional voltage gain and isolation. The RCN (composed of Ls and Cs) is a special single input, multi output matching network that provides desirable impedance control characteristics. The RCN technique was originally proposed and applied for radio-frequency (RF) applications, such as very-high-frequency dc/dc converter systems and RF power amplifiers; here, we exploit if for high efficiency power conversion. The function of the RCN is to automatically regulate the converter operating power and waveforms in a desirable manner as the input and output voltages vary. As applied, the RCN also includes a series resonant tank (composed of Lr and Cr). Its purpose is to provide additional filtering.

The rectification stage is composed of two half-bridge rectifiers. The capacitors Cin and Cout are for input and output filtering, respectively, and the two capacitors marked as CDC are for dc blocking purposes.

EXPERIMENTAL RESULT

The concept of proposed converter is evaluated by using MATLAB simulink models. Finally the results are presented. The converter model was simulated for 267.5 V/20 W to 434.4 V/200 W dc output with 25 V to 40 V dc input voltage ranges, respectively. The switching frequency, fs = 500 kHz

Figure 5: Simulation Diagram of Resonant DC - DC Converter Using Resistance Compression Network

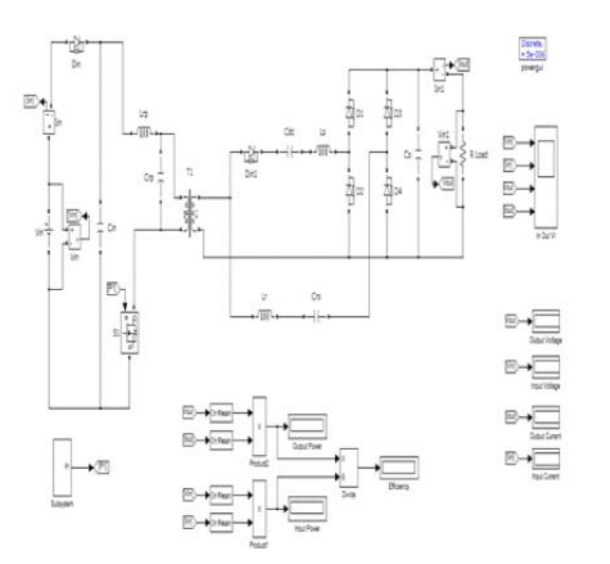
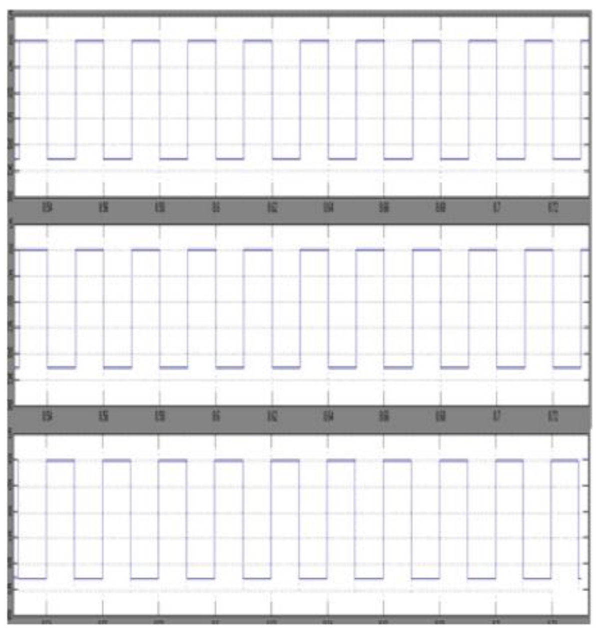


Figure 6: ZVS (dia. 3) and ZCS (dia. 2) Across the MOSFET Switch with Respect to the Gate Pulse (dia. 1)



The zero voltage switching (ZVS) and zero current switching (ZCS) is achieved in the MOSFET switch with respect the input pulse by using ON-OFF control. The simulated current and voltage and its corresponding efficiency is tabulated below.

The efficiency of the proposed converter is higher than the efficiency of the previous designed converter that makes use of a full bridge inverter in the inversion stage of the design [2].

Input volt 1	Input current 1	Output volt 2	Output Current 2	Efficiency
25 V	6.32 A	230 V	0.535 A	94.96 %
40 V	10.2 A	460 V	0.868 A	96.47 %

CONCLUSION

This paper presents a new resonant dc/dc converter topology that uses an RCN in combination with a flyback converter. This implementation reduces the number of switches used, which in turn reduces the gate pulse requirement. Thereby reducing the complexity. The converter implementation provides galvanic isolation and enables large (greater than 1:10) voltage conversion ratios and an increased efficiency. The proposed converter achieves very high efficiency by maintaining ZVS and near-ZCS over a wide input voltage, output voltage. The experimental results for 200 W shows that the converter maintains an efficiency of over 96.47% across its entire 25–40 V input voltage range at the designed output voltage of 460 V; an efficiency of over 94.96% as output voltage is reduced down to 230 V; and an efficiency of over 94.96% even as output power is reduced to 20 W.

FUTURE WORK

In future analysis can be extended for hardware and their performance is analyzed under varying input conditions. Further work is needed to assess the impact of the converters in other applications than in photovoltaic system.

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