

Utilizing a Resistance Compression Network for a High Efficiency Resonant dc/dc Converter

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Abstract— This paper presents a new topology for a high efficiency dc/dc resonant power converter that utilizes a resistance compression network to provide instantaneous zero voltage switching and near zero current switching across a wide range of input voltage, output voltage and power levels. The resistance compression network (RCN) maintains desired current waveforms over a wide range of voltage operating conditions. The use of on/off control in conjunction with narrowband frequency control enables high efficiency to be maintained across a wide range of power levels. The converter performance provides galvanic isolation and enables large (greater than 1:10) voltage adaptation ratios, making the system suitable for large step-up conversion in applications such as distributed photovoltaic converters..

Index Terms- dc/dc converter, resonant converter, on-off control, high efficiency power converter, resistance compression network

1. Introduction

High-voltage-gain dc/dc converters are found in a variety of applications. For example, to connect photovoltaic panels to the grid, interface circuitry is needed. Some architecture for this purpose incorporates dc/dc converters to boost voltage of individual photovoltaic panels to a high dc-link voltage, with follow-on electronics for converting dc to ac (e.g., [1], [4]). The step-up dc/dc converter is a critical part of this system, and must operate efficiently for a large voltage step-up and for a wide voltage range (e.g., at the converter input and/or output depending upon the system). Furthermore, to be compact it must operate at high switching frequencies. In conventional hard-switched power converters, the overlap of current and voltage is large during switching, resulting in significant power loss, especially at high frequencies. Soft switched resonant converter topologies providing zero voltage switching (ZVS) or zero current switching (ZCS) can greatly reduce loss at the switching transitions, enabling high efficiency at high frequencies. Unfortunately, while many soft-switched resonant designs achieve excellent performance for nominal operating conditions, performance can degrade quickly with variation in input and output voltages and power levels.

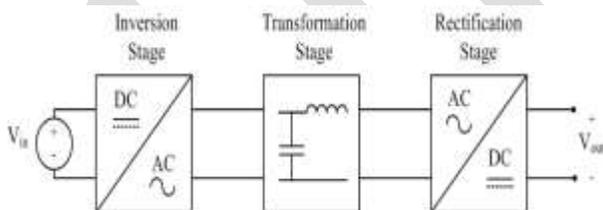


Fig. 1 Architecture of proposed dc/dc converter

This paper introduces a new high efficiency resonant dc/dc converter topology, the Resistance Compression Network (RCN) converter, which seeks to overcome the abovementioned challenges. This converter operates with simultaneous zero voltage switching (ZVS) and near zero current switching (ZCS) across a wide range of input voltage, output voltage and power levels, resulting in low switching losses.

II. RCN CONVERTER TOPOLOGY AND CONTROL

The dc/dc converter proposed here consists of an inversion stage, a transformation stage and a rectification stage, as shown in Fig. 1. The inversion and rectification stages use standard designs. However, the transformation stage and the control of the converter

are new. The topology of the proposed Resistance Compression Network (RCN) converter is shown in Fig. 2. The converter as shown is designed to step-up voltage. The transformation stage consists of a matching network, a transformer, and a resistance compression network (RCN). The Fig. 1: Architecture of proposed dc/dc converter. Matching network composed of L_{rp} and C_{rp} 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 parasitic. The 1:N transformer provides additional voltage gain and isolation. The resistance compression network (composed of L_s and C_s) 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 it 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 here, the RCN also includes a series resonant tank (composed of L_r and C_r). Its purpose is to provide additional filtering.

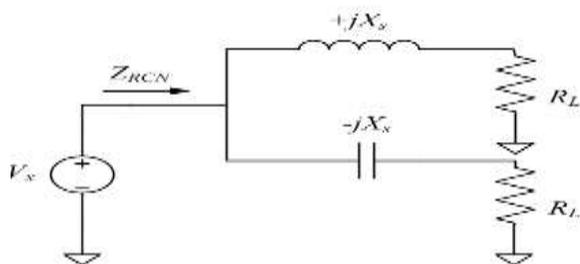


Fig. 2: Fundamental frequency model of the resistance compression network (RCN) and the rectifiers.

The inverter stage is simply a full-bridge inverter (composed of switches S1 - S4). A full-bridge is used instead of a half-bridge to reduce the voltage gain requirement from the matching network and the transformer. The rectification stage is composed of two half bridge rectifiers. The capacitors C_{in} and C_{out} are for input and output filtering, respectively, and the two capacitors marked as CDC are for dc blocking purposes.

III. ANALYSIS AND DESIGN METHODOLOGY

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

$$R_L = 4V_{out}^2 / \pi^2 P_{out}; \quad (1)$$

Where V_{out} is the converter output voltage and P_{out} is the switching-cycle-average output power. As shown in Fig. 2, one of the branches of the RCN comprises a blocking capacitor CDC and an RCN inductor L_s . The other branch comprises a series LC tank tuned to be net capacitive at the switching frequency (net equivalent capacitance C_s). This branch may be modeled as a series resonant tank (with components L_r and C_r) tuned to the switching frequency for filtering, in series with an additional RCN capacitance C_s . Since the series LC tank appears as a short circuit at the switching frequency, it is treated as such in Fig. 2 and in the following analysis. Hence, at the switching frequency the input impedance of the RCN looks purely resistive and is given by:

$$Z_{RCN} = X_s^2 + R^2 L / 2RL \quad (2)$$

where X_s is the magnitude of impedance of the RCN elements (L_s and C_s) at the switching frequency. The use of the resistance compression network reduces the change in impedance seen by the inverter as the effective rectifier resistance (R_L) changes due to variations in output voltage and output power

IV. PROTOTYPE CONVERTER DESIGN

A prototype of the RCN dc/dc converter of Fig. 6 has been designed and built. The designed dc/dc converter is meant for large-step-up applications such as the two-stage photovoltaic-to-grid conversion system shown in Fig. 7. The RCN dc/dc converter can be used to convert the low (widely varying) output voltage of a photovoltaic panel into a high dc link voltage, for example. The design specifications for this prototype are given in Table I. The converter is required to operate over an input voltage range of 25-40 V, an output voltage range of 250-400 V and over a wide output power range of 20-200 W. The switching frequency of the converter was selected as 500 kHz. This frequency minimized the total losses in the magnetic (assuming 3F3 magnetic material and RM cores) and the transistors as shown in Fig. 8. Given that the architecture provides relatively low transistor switching losses, selection of a different magnetic material could enable significantly higher frequencies to be utilized.

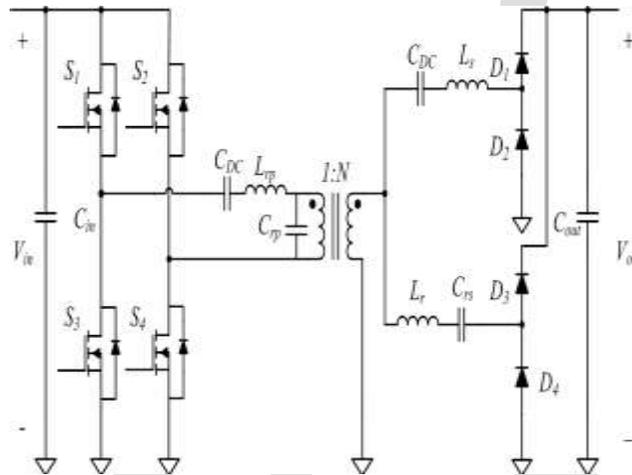


Fig. 5 Implementation of the proposed Resistance Compression Network (RCN) dc/dc converter

For the transformation stage, the reactive elements values were chosen considering the trade-offs between the losses in the parasitic of the transformer, the matching network and the RCN. If the total gain provided by the transformer and matching network is increased, the magnitude of impedance of the RCN also has to be increased. This helps in reducing the increase in output power at higher output voltages, which in turn helps maintain high efficiencies at the higher output voltages. If more gain is provided by the matching network the value of the matching network inductance increases, and thus the matching network loss also increases. However, this results in a decrease in the required gain of the transformer which can result in a decrease in transformer loss

A trade-off of the losses in the transformer and matching network was considered to determine the value of the gain of these elements. For the matching network, an achievable inductor Q was selected, and the results of [17] were used to compute the loss of the matching network for a range of matching network gain values. Each matching network gain results in a specified transformer gain. A computer search routine was then used to identify the best transformer design for each specified gain. Transformers were designed by searching fully across a set of specified cores and wire/foil configurations to minimize transformer loss (the code provided in, which uses the power loss equations given in the appendix, was used estimate these losses). The split of gains (between matching network and transformer) and the transformer design leading to the lowest total computed loss were then selected. For available cores and wires, the transformer turns ratio (N) was chosen to be 6 and the gain of the matching network (G) was chosen to be 1.67, for a total gain of approximately 10. It is noted that more sophisticated optimizations could yield better results. This could include fully optimizing the design of the matching network inductor as part of the search to co-optimize the transformer/matching-network system (e.g., to maximize the achievable overall efficiency in a given volume). Likewise, introduction of more sophisticated loss models could be expected to provide refined results. Nevertheless, the method utilized is efficient and yields good results.

V. SIMULATION RESULTS

The prototype RCN dc/dc converter has been tested using a dc power supply and a resistive load. The tests were carried out with different input voltages (in the 25-40 V range) and different output voltages (in the 250-400 V range). Figure 11 shows current and voltage waveforms for the converter over two switching periods, when operated at an input voltage of 25 V. In particular, it shows the current through the inductor of the matching network, which is also the output current the inverter, the gate drive voltages of the inverter switches S1 and S3, and the drain-source voltage of the switch S3.

As expected, the current through the inductor of the matching network is approximately sinusoidal. Also, the switches achieve zero-voltage switching (ZVS) and near-zero-current switching (ZCS), as can be seen from Fig. 12. Even with the slight distortion in currents that occur owing to limited tank Q, ZVS and near ZCS are still achieved as predicted with sinusoidal approximations. This owes in part to the fact that even with moderate damping of the resonant oscillation owing to the rectifier network, the current waveform still tends towards zero (at a reduced slope) for the next switching transition. Figure 12(a) shows a zoomed in view of the turnoff transition of switch S3. The current through switch S3 at turn-off is small compared to both the peak and average of the current it carries (turn-off current is 15.7% of peak current and 27.5% of average current). Figure 12(b) shows the turn-on transition of switch S3. Notice that the switch turns

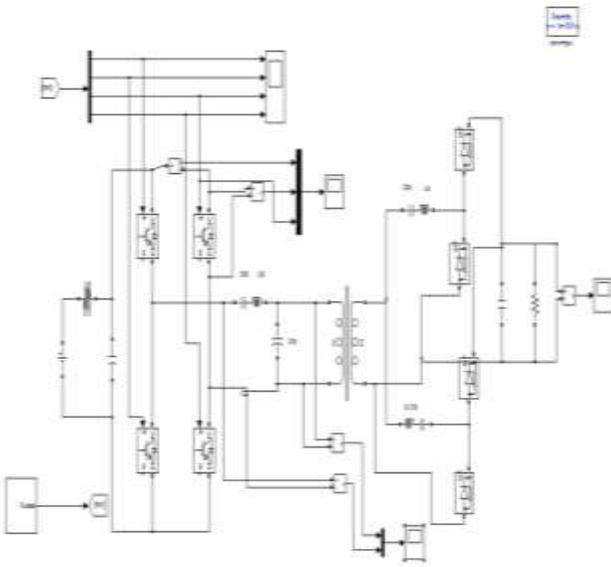


Fig 6 simulation circuit of resonant dc/dc converter

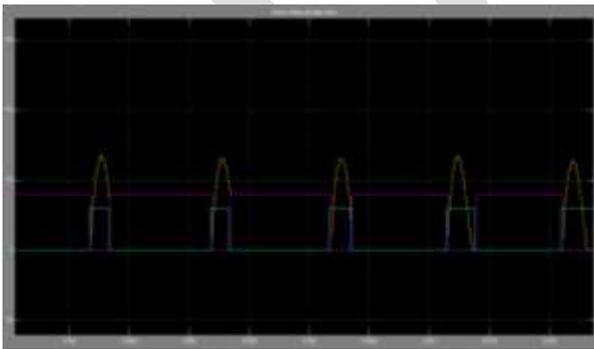


Fig 7 simulation waveforms of voltage and pulse

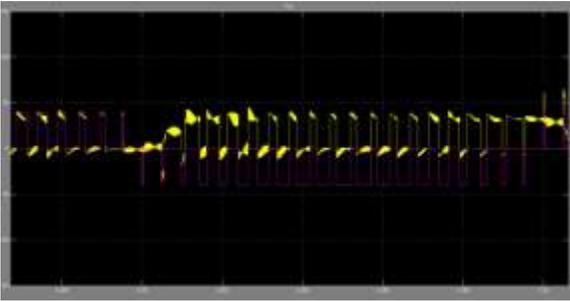


Fig 8 simulation wave form of input voltage

VI. CONCLUSION

This paper presents a new resonant dc/dc converter topology that uses a resistance compression network and a combination of on/off control and narrowband frequency control. The converter implementation provides galvanic isolation and enables large (greater than 1:10) voltage conversion ratios. The proposed converter achieves very high efficiency by maintaining ZVS and near ZCS over a wide input voltage, output voltage and power range.

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