Novel Soft-Switching High Gain Transformerless DC-DC Converters without Auxiliary Switches for Renewable Energy Systems

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Abstract — This paper presents new soft-switching transformerless DC-DC converters without auxiliary switches. The soft-switching operation is achieved with the aid of simple resonant cell, which comprises of an inductor, a capacitor and a diode. In addition to the auxiliary cell, a voltage multiplier cell also included in order to ensure high voltage conversion ratio. The major advantages of the proposed converters are reduced turn on/turnd off losses, high conversion ratio and very simple auxiliary circuitry. A resonant cell is incorporated in this converter which is used to turn on the main switching devices at zero current and turn them off at zero current. The zero current switching operation is achieved with a simple auxiliary cell. This paper describes the operation principles and the design simulations of proposed converters. The theoretical analysis of the proposed converters is validated by the simulation analysis on 12V/60V/1kW converter systems.

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I. INTRODUCTION

Transformerless DC-DC converters are plays a significant role to improve the voltage conversion ratios in applications such as battery energy storage systems (BESS) and renewable energy conversion systems (fuel cell, solar cell and photovoltaic cells). However, due to inherent low voltage characteristics of the renewable energy sources, a high gain, high efficient DC-DC converter is necessary for industry demands. In the initial days of research, DC-DC converter [1] without a transformer is introduced on boost converter in addition to the voltage dividers which are capable to operate under small duty ratios and high switching frequencies. On the other hand a transformerless step-up converter [2] with switched capacitor circuits has been introduced to obtain required voltage conversion ratios. Without using large duty ratios on the main switches, another high step-up converter [3] has been developed with dual voltage lift cells. However, this converter achieved high voltage conversion ratio at low output power level. In addition to reducing the volume and cost, other literature is focused on reduced voltage and current stresses in their switching devices that are mitigated through hybrid converters [4], which are realized with different combinations of switched capacitor/switched inductor structures. Instead of input inductors, the switched inductors were utilized to increase the voltage gain. However, the usage of switched inductors [5] resulted in increased volume and cost of the overall configuration. Furthermore, voltage stresses of switches and diodes are reduced by a voltage quadrupler in high step-up converters [6]. In other literature, to increase gain factor >10, two multiplier cells are introduced [7] in a transformerless converter (TLC). Then, in order to reduce the extreme duty ratios to the main switches in TLC, an extra switch and diodes are used [8-9]. To achieve better efficiency in TLCs, the soft-switching operation of the main switches is the alternate solution. The zero current switching (ZCS) operation is achieved in a TLC with the help of additional auxiliary circuit [10].

The main aim of this paper is to achieve soft-switching operation without using auxiliary switches and to obtain gain factor in TCLs, which is more than 20. The previously existed converters [3] [9] [10] are operated at low power with a gain factor just under 10. The proposed topologies in this paper are targeted to operate at high power levels and achieve gain factor well over 20. This paper proposes soft-switching TCLs with simple auxiliary cells and a multiplier at the output side. The auxiliary cell can provide soft-switching operations to all switching devices and multiplier cell impose an increased gain factor. The proposed converter system can be applicable for high power applications. This paper presented two topologies, first one with 12V/214V/450 W system and second topology with 12V/600V/1.3 kW. The proposed converter description and its operation principles are discussed in section II and section III presents simulation evaluations of proposed converters.

II. PROPOSED TRANSFORMERLESS CONVERTER DESCRIPTION AND ITS OPERATION PRINCIPLES

The proposed converter topologies are illustrated in Fig.1 and Fig.2. Fig.1 is derived from conventional transformerless converters [3] and Topology II is the
extended version of [8] shown in Fig.2. Both the topologies are introduced with an additional auxiliary cell and a multiplier at output side. Topology I consists of the main IGBTs $S_1$, $S_2$ and input inductors $L_1$, $L_3$. The auxiliary cell comprises of three elements such as an inductor $L_m$, a diode $D_m$ and a capacitor $C_m$. The voltage multiplier consists two diodes $D_p$, $D_q$ and two capacitors $C_p$, $C_q$.

The operation of $S_m$ For simplicity, the topology-II operation is not exhibited.

A. Topology - I

The operation of the proposed topology is divided into four intervals from $t_0$-$t_4$. At $t_0$, the switches $S_1$, $S_2$ are turned on. The inductor $L_a$ current increases linearly and $C_2$ is discharged to the level of half of the output voltage. The output power is delivered by the previously energy stored in charged $C_p$ and $C_q$.

Figure 1. Proposed transformerless converter topology-I

Figure 2. Proposed transformerless converter topology-II

Figure 3. Proposed transformerless converter topology-III

The auxiliary cell used in these topologies mitigates soft-switching operation and multiplier cell provides high conversion ratio as compared with existing versions [3]. Topology II comprises of three switches $S_1$, $S_2$ and $S_4$. To obtain soft-switching to $S_1$, $S_2$, an additional auxiliary cell is assisted with an inductor $L_m$, a diode $D_m$ and a capacitor $C_m$. The IGBT $S_4$ is also self-assisted with an additional resonant elements $L_a$, $C_a$ and a diode, $D_a$ as shown in Fig.3. The topology-I can have gain <20 and topology-II and topology-III, exhibits gain more than 20. The operation of topology-I is divided in to four intervals $t_0$-$t_4$, which is shown in Fig.4. The operation of topology-III is explained with the help of key waveform shown in Fig.5. Topology II operation similar to Topology-III except the soft-switching.

During the interval $t_1$-$t_5$, the energy will be accumulating by $L_1$, $L_2$. The interval, $t_1$-$t_3$, is a short resonant time interval in which the current through the $S_1$, $S_2$ falls to zero, therefore the ZCS condition is achieved for both the IGBTs $S_1$, $S_2$. The capacitor $C_2$ charges to the level of output voltage and direction of $L_a$ current changes, which linearly decreases to zero at $t_3$. The body diodes of $S_2$, $S_4$ conducts to create a path for resonant current until $t_3$. During the interval $t_3$-$t_4$, the $S_1$, $S_4$ are turned off and the load is fed by the previously accumulated energy by $L_1$, $L_2$.

Figure 4. Key waveform : Topology-I

Figure 5. Key waveform : Topology-III
B. Topology-III

The operation of topology-III is divided into five intervals, t₀-t₅. Its equivalent current flow schematics are shown in Fig.6. At t₀, S₁, S₂ are turned on. Throughout this interval, energy is accumulated by L₁, L₃. The capacitor C₆ is discharged from the level 2V₀ and inductor L₉ is at -Lₙ. At time t₁, the IGBT S₃ is turned on and S₁, S₂ are turned off, since the currents reached zero. Then the body diodes of S₁, S₂ start conducting. Thus, the ZCS condition is achieved for S₁, S₂. At the beginning of this interval t₁-t₂, the L₉, C₆ are resonating each other and diode Dₙ conducts for a short duration. Then i₃n, V_C₆ are maintained at constant and diode Dₙ stops conducting. During the interval t₂-t₃, the IGBT S₃ will be conducting. At t₃, the IGBT S₃ current decreases to zero and then body diode conducts till t₄. Therefore, the ZCS turn off condition achieved. From t₄-t₅, all switches are in turned off, since there

III. SIMULATION EVALUATIONS

The designs are simulated on MATLAB simulink for the proposed topologies. The simulation parameters used for the Topology I are as follows: Vₛ = 12 V; switching frequency fₛ = 50 kHz; output voltage Vₒ = 214 V; output power = 450 W; Lₙ = 1 μH; Cₖ = 3 nF; L₁, L₃ = 100 μH; C₆ = 100 μF. Fig.7 shows the obtained simulated voltage and current waveforms of S₁, S₂. It is observed from the obtained results, the IGBTs S₁, S₂ are turned off with zero current switching (ZCS). Thus, the voltage and current stresses are significantly reduced. Fig.8 shows the voltage and current waveforms of Cₖ, Lₙ, Dₙ, Dₚ and Dₗ. The peak voltage across Cₖ is Vₒ, current through the Dₙ is 0.2A and currents through Dₚ, Dₗ are nearby half of the input current. The overall gain of the proposed topology I is exactly 18 as compare with the existing versions have <10 [3] [7-9]. However, the existed topologies [8] [9] are operated under 200 W output power, whereas the proposed topology is operated 450W without increasing additional switching losses.
In similar way, the simulations are performed for proposed topology III. The parameters used in the design is as follows: $V_{in}=12 \text{ V}$; $V_{out}=360\text{ V}$; $P_{in}=1.3 \text{ kW}$; $f=50kHz$; $L_{m}=0.1\mu \text{H}$; $C_{m}=3 \text{ nF}$; $L_{s}=0.5 \mu \text{H}$; $C_{s}=10 \text{ nF}$. Fig.9 shows the voltage and current waveforms of $S_{1}$, $S_{6}$ and $D_{a}$. It can be seen that, the ZCS turn-off condition is achieved for all the switches. Fig.10 shows the voltage and current waveforms of $C_{m}$, $C_{s}$, $L_{m}$, $L_{s}$ and $D_{m}$. Fig.11 shows the current waveforms of diodes $D_{p}$, $D_{q}$ and $D_{a}$. The overall gain obtained for topology is >25 as compare with existing converters.

[3] [7-9], as the gain factors of existing versions are below 20 and output power is below 500 W. The proposed topology can be operated at 1.3 kW with the aid of multiplier cell and soft-switching, obtained by a simple auxiliary cell.

IV. CONCLUSION

This paper proposes soft-switching transformerless converters for renewable energy conversion systems. The simulations analysis performed on two topologies, the first topology with 12V-214V system operated at 450W output power and second topology with 12V-360V-1.3kW system. The proposed topologies are incorporate with an additional simple auxiliary cell and a multiplier at the output side. Auxiliary cell provides soft-switching characteristics to the IGBTs and multiplier cell enhances the conversion ratios well over the existing topologies. The gain factor of the proposed topologies I is just below 20 and for the other, it is above 20. The proposed soft-switching transformerless converters will be the alternate solution for increased conversion ratios and high output powers with higher efficiencies.

REFERENCES


