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High Efficiency DC-DC Converter for Low PV Voltage Sources

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Abstract **-** A high efficiency DC-DC converter for low PV voltage sources has been proposed in this paper. The proposed converter converts the low dc voltage to a high dc voltage with a high-efficiency. The proposed converter uses the active clamping circuit and voltage doubler rectifier in order to achieve a high step-up ratio and soft switching operation. The output diodes are turned off at zero-current, which can significantly reduce the switching power losses at high output voltage applications. A high-efficiency of 97.5 % is achieved to generate 350V high output voltage from 36 V low PV module voltages which can be connected to grid tie for ac application.

Keywords - *High Efficiency, High Step-up Ratio, Soft Switching, Zero Current.*

I. INTRODUCTION

The great necessity in several areas, particularly the industrial sector, for switch mode power converters with larger power ratings was the starting point for the appearance dc–dc converter. With the increasing threat of the fast depletion of conventional resources, people seek renewable energy sources, such as solar, wind, geothermal, and hydraulic energies. For these systems, different power converter topologies can be used for the power electronic interface between them and the load. Basically, low-voltage high-current structures are needed because of its electrical characteristics. In these systems, a boost converter is often selected as a possible converter. However, a boost converter will be limited when the power increases (greater than 4.5 kW) or for higher step-up ratios (greater than two times). For low voltage dc energy sources, a power conditioning system (PCS) is required to convert the energy sources to a high dc voltage before making it to ac for grid-tie applications [1], [2]. A step-up dc-dc converter is needed with a high step up ratio and high-efficiency. The intention of this paper is to propose a high-efficiency dc-dc converter for the photovoltaic module integrated converter (PV-MIC) system [3], [4] where a high step-up dc-dc converter and low power inverter are attached at the back of each panel.

For a power level around 250 W in the PV-MIC system applications, several high step-up dc-dc converters are proposed for the power conversion from low dc voltage to high dc voltage. The current-type source push-pull converter [5] allows the use of non-isolated gate driver and requires only two switches. A high step-up ratio is achieved, and wide input voltage range is adapted. However, the current source requires higher voltage rating switches and a large inductor size so; voltage-type source step-up dc-dc converter is more attractive for PV-MIC system applications due to less cost and small size. However, for energy applications where the efficiency is most concerned, the conventional flyback or forward converters are not suitable because switching losses are significant owing to the hard-switching operation. Although several soft-switched flyback or forward converters were proposed in [6], [7], they does not have a high step-up voltage conversion ratio, thus requiring a high turns ratio. High turns ratio is not favorable as secondary has large leakage inductance at secondary causing high switching loss at output diode.

II. OPERATING THEORY

In this paper, high efficiency dc-dc converter with high step-up gain is proposed. The proposed converter uses the active-clamping circuit [8] and the voltage-doubler rectifier [9] in order to achieve a high step-up ratio and soft-switching operation. The output diodes in the proposed converter can be turned off at zero-current, which reduces switching power losses at high output voltage applications. The leakage inductance of the transformer and the resonant capacitor of the voltage doubler rectifier utilized to achieve zero-current switching of the output diodes.

III. OPERATION

Figure 1 shows the circuit diagram of the proposed converter. The step-up dc-dc converter consists of a boost type of an active-clamping circuit (C_c, S_1, S_2), a transformer (T), and a Voltage-Doubler rectifier (L_{lk}, C_r, Do1, Do2). D_{S1} and D_{S2} are the diodes of S_1 and S_2, respectively. C_{S1} and C_{S2} are the output capacitors of S_1 and S_2, respectively. L_m is the magnetizing inductor of T. L_{lk} is the leakage inductor of T. C_r is the resonant capacitor. Do1 and Do2 are the output diodes. Figure 2 shows the corresponding circuit diagram for each operating mode.

1) Mode 1 [t_0, t_1] : At t = t_0, S_1 is turned on. Since VL_m = V_{pv}, the magnetizing inductor current iL_m increases linearly. When nV_{pv} is applied across the secondary winding of T, Do1 is turned on. A series-resonant circuit consisting of L_{lk} and C_r is formed at the secondary side.

2) Mode 2 [t_1, t_2] : At t = t_1, the half-resonant period of the output diode current iDo1 is finished. The output diode current iDo1 is zero before Do1 is turned off. Zero-current switching of Do1 is achieved.

3) Mode 3 [t_2, t_3] : At t = t_2, S_1 is turned off. The current i_{pv} charges C_{S1} and discharges C_{S2}. The voltage V_{S1} across S_1 increases from zero to the clamping capacitor voltage V_c.

4) Mode 4 [t_3, t_4]: At t = t_3, the voltage V_{S2} across S_2 is zero. The voltage V_{S1} across S_1 is clamped at V_c. The current i_p begins to flow the body diode D_{S2} of S_2. S_2 is turned on at zero-voltage.

Since, $VL_m = -(V_c - V_{pv})$, the magnetizing inductor current iL_m decreases linearly. When $n(V_{pv} - V_c)$ is applied reversely across the secondary winding of T, Do2 is turned on.

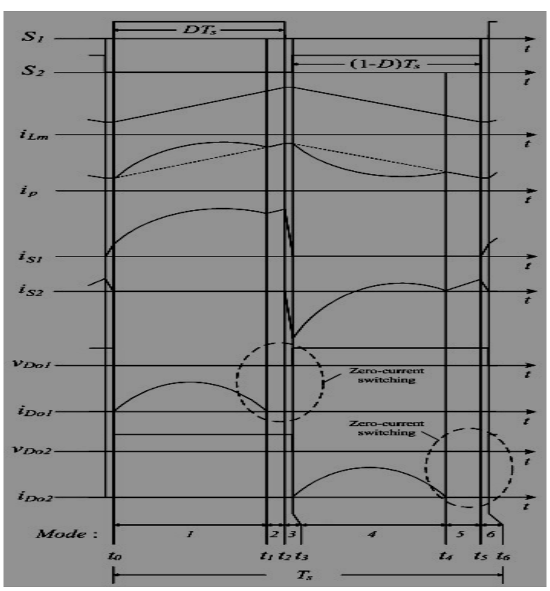

Fig. 2: Theoretical waveforms of the proposed converter

5) Mode 5 [t_4, t_5] : At t = t_4, the half-resonant period of the output diode current iDo2 is finished. The output diode current iDo2 is zero before Do2 is turned off. Zero-current switching of Do2 is achieved.

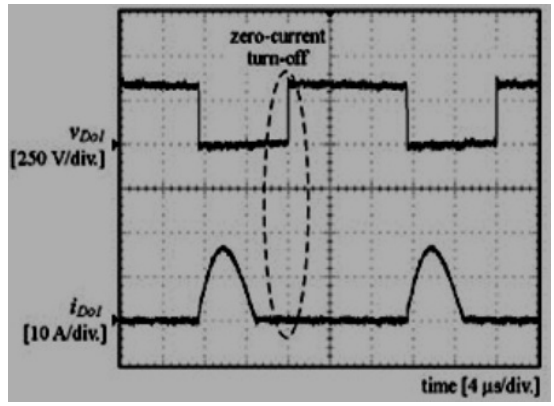

Fig. 3 : Voltage and current waveforms of Do1

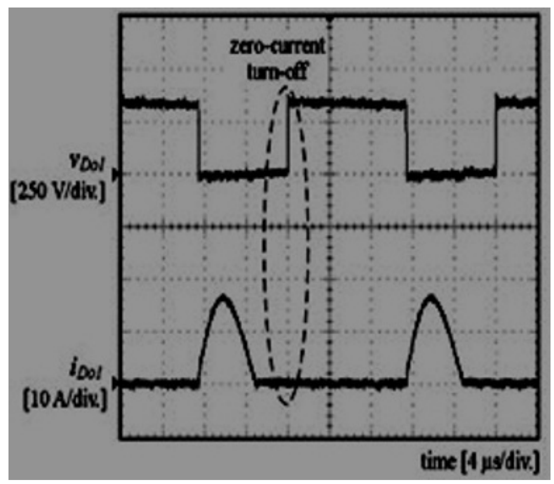

Fig. 4: Voltage and current waveforms of Do2

6) Mode 6 [t_5, t_6] : At t = t_5, S_2 is turned off. The current i_p discharges C_{S1} and charges C_{S2}. The voltage V_{S1} across S_1 decreases from the clamping voltage V_c to zero. The next switching cycle begins when S_1 is turned on again.

The balance on the secondary winding of T, the resonant capacitor voltage VC_r is obtained as: $VC_r = (1 - D)V_d$. By calculating the average output power P_d and using the relation of $P_d = V_d I_d$ where I_d is the average output current, the voltage conversion ratio of the proposed converter is obtained as $\frac{V_d}{V_{pv}} = \frac{n}{1-D}$

IV. EXPERIMENTAL RESULT

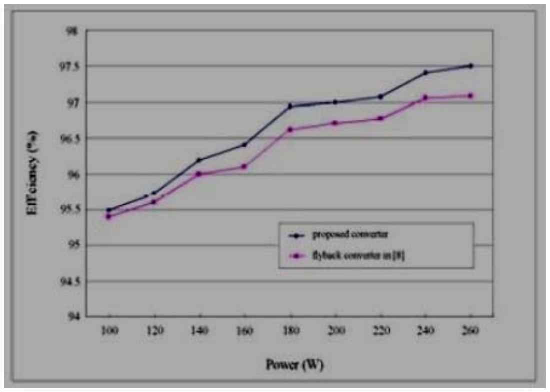

Fig. 5: Measured efficiencies

Figure 5 shows the measured efficiencies of the flyback converter in and the proposed converter.

V. CONCLUSION

The proposed converter achieves an efficiency of 97.5 % and improves the efficiency by 0.4 % compared to the flyback converter in for 260 W output power. The proposed converter is expected to be a promising high step-up dc-dc converter for low-voltage dc energy source applications like PV MIC system

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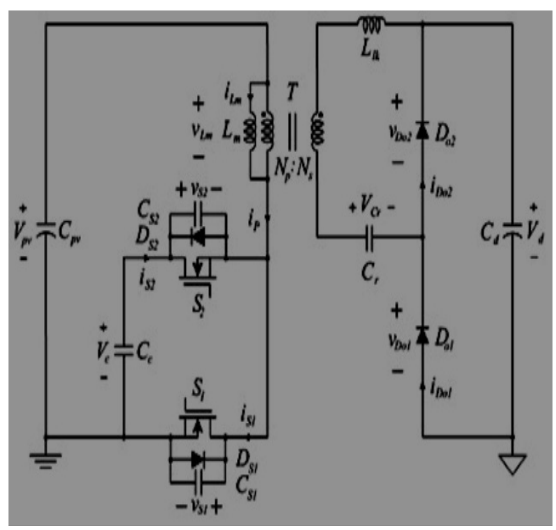

Fig. 1: Circuit diagram of the proposed converter

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