A HIGH VOLTAGE GAIN FLYBACK CONVERTER WITH SOFT SWICHING FOR SOLAR APPLICATIONS

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Abstract - ***This paper presents an isolated step up flyback converter using an active-clamp circuit with a series resonant voltage doubler. The active-clamp circuit provides zero-voltage switching (ZVS) turn-on, and limits switch voltage stress. Further, to remove the reverse-recovery problem of the rectifier diodes, a series-resonant voltage doubler is used. Using pi controller the output voltage Vd is maintained constant for load variations and input voltage variations. Thus, the converter has the structure to minimize power losses. A 400watt flyback converter is designed and simulated to conform the validity.***

Key Words**: *voltage doubler, active-clamp, zero-voltage switching.***

1. INTRODUCTION

The increasing energy shortages and the exhaustion of global resources, leads the current researchers to concentrate on renewable energy [1]. Despite the fact that PV energy is known as one of the great alternative sources, the PV system costs more. Therefore, the cost and energy efficiency of the PV system and the extracted power from the PV panel should be improved. Thus, it is essential for a PV system to have the high-efficiency inverter and the maximum power point tracking (MPPT) control technique, which extracts the maximum power from the PV panel. Based on the connection method of PV modules, the PV system is classified into the centralized system, the string system, and the microinverter [2]. Among them, the microinverter offers high efficiency of MPPT according to the individual module control. But, it is still costly to be used widely. Therefore, in order to reduce cost and improve efficiency of the microinverter, various studies are being carried out [3]-[5]. The output voltage of a PV panel is generally supplied by a low-level dc voltage, so a high voltage gain inverter is needed to meet high voltage loads. The simple boost converter has been proved to be insufficient in providing high step-up ratios in an efficient way, due to the high current and voltage stress on the switch and the severe diode reverse recovery losses, when operating in continuous conduction mode. Thus, the PV inverter topology with galvanic isolation is preferred for the microinverter. The flyback topology [6] of the conventional microinverter is typically provides relative simplicity of the circuit structure, ease of control, and minimal number of switching devices compared to other topologies. However, there are drawbacks such as switching losses of the switch and reverse-recovery losses of the diodes. Furthermore, the high turn ratio of the transformer increases the leakage inductance of the transformer, and its large inductance deteriorates the system efficiency. Due to the lower utilization of the transformer, the flyback topology is limited for low wattages. Thus, the increased power rating of the microinverter is required to cope with large power rating of the PV panel and to lower the cost per watt of the microinverter.

This paper presents an isolated step up flyback converter using an active-clamp circuit with a series resonant voltage doubler. The active-clamp circuit provides zero-voltage switching (ZVS) turn-on, and limits switch voltage stress. Further, to remove the reverse-recovery problem of the rectifier diodes, a series-resonant voltage doubler is used. Using pi controller the output voltage Vd is maintained constant for load variations and input voltage variations. Thus, the converter has the structure to minimize power losses. A 400watt flyback converter is designed and simulated to conform the validity.

2. ANALYSIS OF PROPOSED CONVERTER:

The circuit configuration of the dc–dc stage is shown in Fig 2. The dc–dc stage consists of an active-clamp circuit in the primary side and the series-resonant voltage doubler in the secondary side of the transformer $T1$. The active-clamp circuit is composed of a switch $S1$, a switch $S2$, and a clamp capacitor Cc. This circuit limits the voltage across the switch $S1$ and regenerates the energy stored in the leakage inductance Llk. Then, the switches $S1$ and $S2$ are operated complementarily with the zero-voltage switching (ZVS) turn-on. In the secondary side of the transformer $T1$, rectifier diodes *Dr*1 and *Dr*2 and a resonant capacitor *Cr* represent the series-resonant voltage doubler. This circuit provides the resonant-current paths of the power transfer, regardless of the main switch state. In particular, the resonant current formed by leakage inductance of the transformer and the resonant capacitor removes the reverse-recovery problem of the secondary rectifier diodes *Dr*1, *Dr*2. Fig 2. Shows the equivalent circuit of the dc–dc stage. Its theoretical waveforms and for each interval in the steady state are depicted in Figs. 3. The active-clamp circuit and the series-resonant voltage doubler can be analyzed in the six operation modes, according to the conduction states of the switches and diodes during one switching period *Ts,*dc.

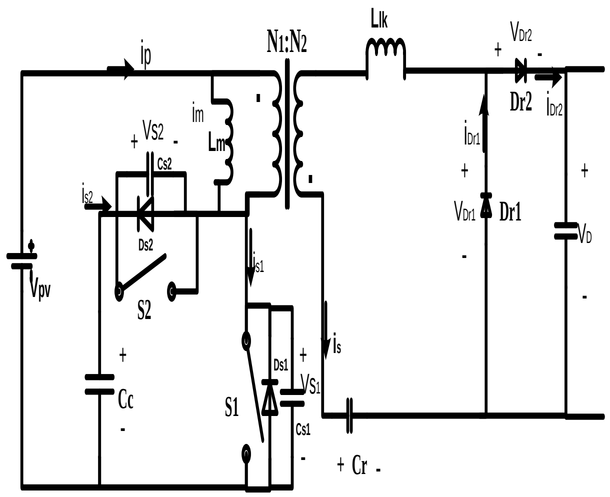

Fig 1: Equivalent circuit of fly back converter

Mode (i): When switch S1 is closed at time t1, the voltage *Vs1* across the switch S1 becomes zero, and the primary current *ip* of the transformer flows. When, the input voltage *Vpv* equals the voltage across magnetizing inductance *Lm*, the magnetizing current *iLm* increases linearly. In addition, the series resonance occurs between the capacitor *Cr* and the leakage inductance *L*lk of the transformer. The voltage across the leakage inductance *L*lk is the difference between the secondary voltage *nV*PV and the resonant capacitor voltage *Vcr*. Thus, the secondary current *is* of the transformer flows through the rectifier diode *Dr*1 with the resonance of the positive current

Mode (ii): At time t2 secondary current *is* becomes zero, such that primary current is equal to magnetizing current *iLm*. Therefore *ip* increases linearly.

Mode (iii): The rectifier diode *Dr*1 and the switch *S*1 are turned off. Since the secondary current i_{Dr1} is already zero in *Mode2*, the reverse-recovery loss of the rectifier diode D_{r1} is removed. At the same time, the output capacitor C_{s1} of the switch *S*1 is charged, and the output capacitor C_{s2} of the switch *S*2 is discharged.

Mode (iv): At the end of *Mode3*, the voltage V_{s2} across the switch *S*2 is zero, and the primary current *ip* flows through the antiparallel diode of the switch *S*2. Thus, the ZVS turn-on of the switch *S*2 is achieved. Then, the voltage across magnetizing inductance *Lm* equals *V*PV − *Vc*, and the magnetizing current *iLm* decreases linearly. At the same time, the rectifier diode D_{r2} is in the on-state. The effect of the active-clamp capacitor *Cc* cannot be ignored because $C_c/_{n^2}$ is smaller than the resonant capacitor *Cr*. Thus, the resonance of the secondary current i_s occurs among *Cr*, $C_c/_{n^2}$ and *L*lk. The secondary current *is* flowing through the rectifier diode D_{r2}.

Mode (v): Since the secondary current i_{Dr2} is already zero in *Mode 4,* the reverse-recovery loss of the rectifier diode *Dr*2 is removed. Similar to *Mode 3*, the rectifier diode *Dr*2 achieves the zero-current switching (ZCS) turn-off. As the secondary current i_s becomes zero, the primary current i_p and the magnetizing current i_{Lm} are linearly decreased.

Mode (vi): The switch *S*2 and the secondary side diodes *Dr*1 and *Dr*2 of the transformer are in the off-state. The output capacitor *CS*1 of the switch *S*1 and the output capacitor *CS*2 of the switch *S*2 are discharged and charged, respectively. At the end of *mode6*, the voltage *vS*1 across the switch *S*1 is zero, and the primary current *ip* flows through the antiparallel diode of the switch *S*1.Thus, the ZVS turn-on of the switch *S*1 can be achieved in mode 1.

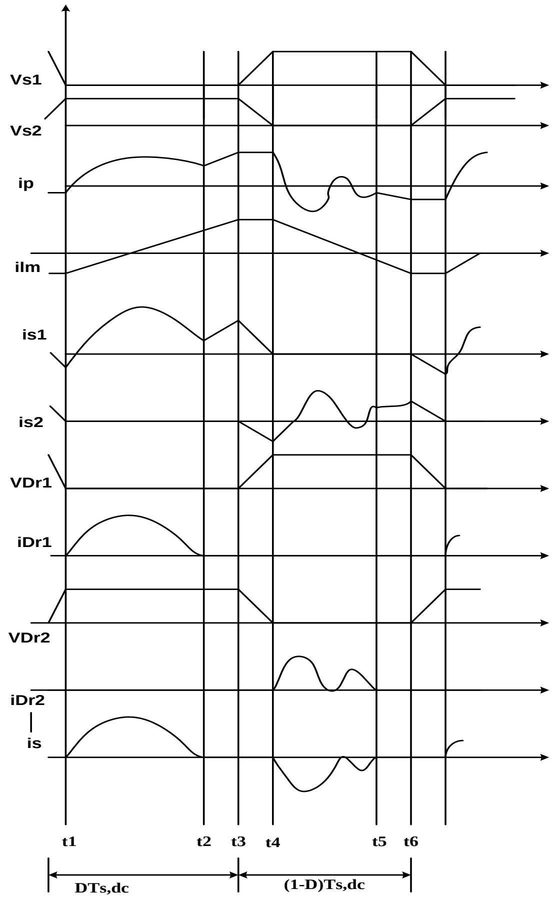

Fig 2: Theoritical waveforms of fly back converter

3. DESIGN CONSIDERATIONS

1. Magnetizing inductance Lm: Writing the average inductor current equation for total time period and solving for Lm, gets as follows

$$Lm = \frac{(1-D)^2 R}{2f}\left(\frac{N1}{N2}\right)^2$$

An additional dead-time period is introduced between the turn on and turn off transitions of Q1 and Q2. During the dead-time, primary current flow remains continuous through the body-diode of the P-channel AUX MOSFET, Q2, or the main MOSFET, Q1. This is commonly known as the resonant period in which the conditions are set for zero voltage switching (ZVS).

$$Tdelay = \frac{\pi}{2}\sqrt{L_{eq} \times 2 \times C_{ds}}$$

2. Leakage inductance Llk & Resonant capacitor Cr: The series resonance occurs between the capacitor *Cr* and the leakage inductance *L*lk of the transformer. The voltage across the leakage inductance *L*lk is the difference between the secondary voltage *nV*PV and the resonant capacitor voltage *V*cr. Thus, the secondary current *is* of the transformer flows through the rectifier diode *Dr*1 with the resonance of the positive current as follows:

$$\frac{di_s}{dt} = \frac{nV_{PV} - V_{cr}}{L_{lk}}$$

$$i_s = C_r \frac{dV_{cr}}{dt}$$

Where the turn ratio *n* is *N*2/*N*1.The secondary current is calculated as

$$i_s(t) = \frac{nV_{PV} - V_{cr}}{Z_{r1}} \sin \omega_{r1}(t - t1)$$

Where *V*cr is the average voltage across the resonant capacitor *Cr*. The resonant angular frequency *ωr*1 and the impedance *Zr*1 of the resonant circuit are given by

$$Z_{r1} = \sqrt{\frac{L_{lk}}{C_r}}$$

$$\omega_{r1} = \frac{1}{\sqrt{L_{LK} C_r}}$$

Since the resonant sinusoidal value sin (*ωr*1*DT,* dc) at the on-time *Ts,dc* must be negative to achieve for the ZCS turn-off of the rectifier diodes, the following equation is obtained as

$$\omega_{r1} DT_{s,dc} > \pi$$

Thus, the resonant capacitor *Cr* of the series-resonant voltage doubler is given by

$$C_r < \frac{D^2 T_{s,dc}^2}{\pi^2 L_{lk}}$$

3. Dmax and Dmin: From the steady state output equation of the converter, we can get approximate values for Dmax, Dmin as follow

$$Dmax \cong \frac{Vo}{Vmin(N_{ratio}) + Vo}$$

$$Dmin \cong \frac{Vo}{Vmax(N_{ratio}) + Vo}$$

4. Clamp capacitor Ccl: A simplified method for approximating Ccl is to solve for Ccl, such that the resonant time constant is much greater than the maximum off-time.

$$2 \times P \times f\sqrt{Lm \times Ccl} > 10 \times t_{off\,(max)}$$

Where Lm is transformer magnetizing inductance and $t_{off\,(max)}$ is the maximum off-time. By dividing both sides of by the total period, T, and solving for Cc in terms of known design parameters as follows

$$Ccl > \frac{10 \times (1 - Dmin)^2}{Lm \times (2\pi f)^2}$$

4. SIMULATION RESULTS

A 400-W microinverter was designed and simulated in MATLAB/SIMULINK software with the component values obtained from the design procedure aforementioned are listed in Table I. Fig.3 shows that flyback converter boosts the input voltage 65v to 350v .Fig 4 shows that at time t=22usec gate pulse for switch S1 is turned on, but voltage across switch is reached to zero. Similarly at time t=0.634msec gate pulse for switch S2 is turned on, but voltage across switch is zero at that instant. It is shown that, during the turn ON, the gating voltage for the primary switches is applied only after voltage has become zero Thus ZVS turn on is achieved. An active clamp circuit is used to reduce the voltage spikes observed across the primary switches during turn OFF in the simulations. Fig 5 shows that rectifier diodes have no reverse-recovery problem due to ZCS turn-off

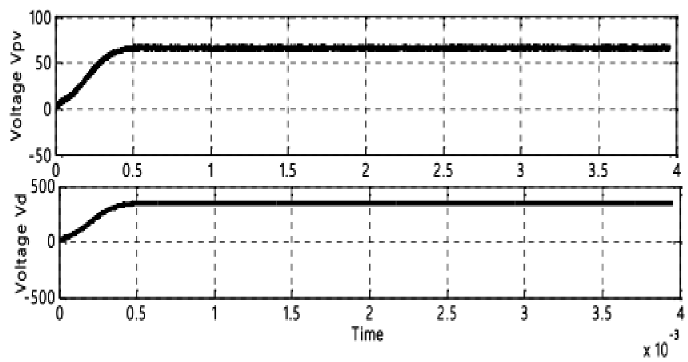

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Fig3: simulated waveforms showing boosting of input voltage

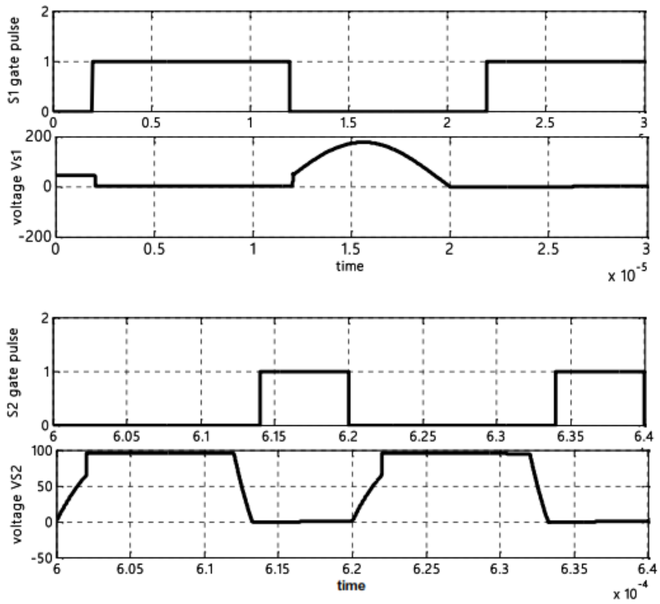

Fig 4: simulated waveforms for zvs turn on of switches

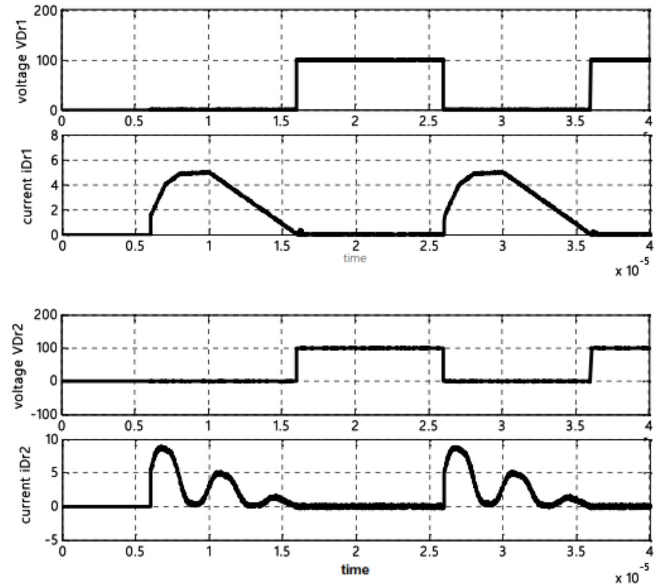

Fig 5: simulated waveforms for zcs turn off of secondary diodes

TABLE I

Specifications of the proposed microinverter

PARAMETERS	Values
Input voltage	65volts
Rated power	400watt
Switching frequency of DC-DC stage	50khz
Clamp capacitor	2.2uF
Resonant capacitor	2.4uF
Turns ratio	1:4
Magnetizing inductance	20uH

5. CONCLUSION

This paper illustrates a flyback converter with soft-switching. The active-clamp circuit offers the soft switching of the primary-side switches and reduces the voltage stress by clamping the voltage spike across the switches. Its series-resonant voltage doubler provides the ZCS turn-off of the rectifier diodes.Hence switching power losses is minimized. A 400 watt flyback converter is designed and simulated to conform the validity.

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