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Comparison of Basic Soft Switching Techniques in DC-DC Boost Converters used in solar PV Panels

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Abstract – DC-DC boost converters are usually used so as to increase voltage in battery charging of electrical vehicles, power factor correction circuits and solar photo voltaic panels etc. applications. The control of these converter types is realized with Pulse Width Modulation (PWM) owing to its high power density, fast dynamic response and easy control. The high switching frequency is needed to provide these features. However, the switching losses and electromagnetic interference (EMI) increase if the switching frequency is increased. The efficiency and performance of the converter decrease in this case. So, the soft switching techniques are improved to minimize the switching losses and increase the efficiency DC-DC boost converters are commonly in photovoltaic panels to reduce the cost and increase the power density by increasing the switching frequency. It is also necessary to use soft switching techniques in order to the switching power losses and electromagnetic interference noises as a result of increased switching frequency. In this study, soft switching techniques, which are very popular in recent years and frequently used in the industry, are described. After discussing the advantages and disadvantages of applying each of the techniques described, the results are compared and simulated with PSIM program.

Keywords –Soft switching, boost converter, hard switching, pulse width modulation, solar photovoltaic panel.

I. Introduction

Recently, energy demand and conservation of conventional fuel reserves increases rapidly. Due to these renewable energies draws the attention of researchers recently. Solar power technology is one of the fastest growing and popular among existing renewable energies. Solar photovoltaic (PV) systems are the most sought after renewable energy source due to the universal availability of the solar irradiation and the flexibility to install the PV panel at the consumer end. In order to improve the efficiency of the PV system by overcoming the losses due to the partial shading and module mismatches, modular PV systems are preferred for low power applications. To meet the requirements of various solar PV applications, high performance converters with improved efficiency and power density are needed. [1-4].

The solar cell has nonlinear V –I and P–V characteristics, which depend on the irradiance, the operating temperature and load condition of the cell. Therefore, the dc–dc converter for a PV system has to control the variation of the maximum power point of the solar cell output. In other words, modulation of the duty ratio of the dc–dc converter controls maximum power point tracking [5-7].

To increase the power density and efficiency in PV systems, the high frequency switching DC-DC boost converters topologies have been considered and discussed for solar PV applications. However, the high switching frequency leads to the switching losses and EMI noises. So, the soft switching (SS) techniques are improved to solve these issues. The basic SS techniques are zero voltage transition (ZVT) and zero current transition (ZCT).

In ZVT SS technique, the voltage of main switch is reduced to zero by aid of an active snubber cell while the main switch is at off state. Then, a control signal is applied to the gate of the main transistor while its voltage is zero. Thus, the main switch turns on without loss under ZVT [8]. In ZCT SS technique, firstly the current of main switch is dropped to zero by aid of an active snubber cell while the main switch is at on state. The control signal of the main switch is removed while its current is zero. So, the main switch turns off under ZCT [9].

The turning off without the switching loss is provided owing to ZCT while the turning on without switching loss is provided owing to ZVT. Many studies have been made to eliminate disadvantages in ZVT and ZCT techniques [10-14].

Boost converters are used to boost the input voltage. The output voltage will be higher than the input voltage. But there is a power loss across the switching device. This can be eliminated by operating the switch either at zero voltage or at zero current. Thus the converter efficiency is improved. This is the necessity of a boost converter with soft- switching [15]. In this paper, two example soft - switched boost converter are examined and compared from a solar panel. One of the converters provides ZVT soft switching other than ZCT soft switching. So, these SS techniques are compared for solar PV panel.

II. Switching Methods

In the power electronics converter, the semiconductor elements can be operated two switching methods. These methods are hard switching method and soft switching method.

A. Hard Switching

Hard switching is a switch made without using any additional circuitry to reduce or eliminate the switching losses of semiconductor power elements. The hard switching operation causes the reverse recovery losses of the diodes. Also, the electromagnetic interference (EMI) noises occur in the semiconductor elements since the current and voltage rise speed is high in the hard switching operation. To overcome these problems, the soft switching method is improved.

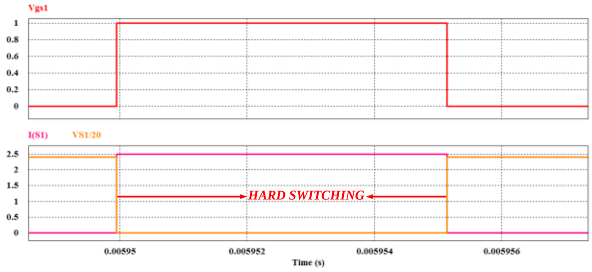

Fig. 1 The voltage and current shapes in hard switching method

B. *Soft Switching*

Soft switching is a switching method used to minimize or eliminate the switching losses and EMI noises with additional circuits or minimizing. The additional circuits developed for soft switching are called snubber cells. The purpose of the soft switching method is to increase the power density of the circuit.

III. Soft Switching Techniques

The basic soft switching techniques are ZCS, ZVS, ZVT and ZCT. ZVT and ZCT are modern SS techniques. In the modern techniques, the switching losses are completely eliminated but the losses are minimized in the classical techniques (ZCS and ZVS).

A. *Zero Voltage Switching*

Zero voltage switching (ZVS) is a soft switching technique implemented in the turning-off process. In this technique, basically a small-value capacitor is connected in parallel to the power switch, limiting the rate of voltage rise of the element. Thus, the overcurrent of the current and the voltage is reduced, the switching energy loss is reduced and the switching energy is transferred to the capacitor. This energy in the capacitor is recovered in modern cells.

The switching energy loss in ZCS and ZVS techniques is not completely eliminated. For this reason, these techniques are also called ZCS and ZVS techniques. Normally, the series inductance causes an additional voltage stress on the power element and the parallel capacitor causes an additional current stress.

B. *Zero Current Switching*

Zero current switching (ZCS) is a soft-switching technique implemented in the process of turning-on. In this technique, a low-valued inductance is connected in series to the power switch, limiting the rate at which the current flows through the element. Thus, the overcurrent of the current and the voltage and the loss of switching energy are reduced. In fact, the switching energy is transferred to the inductance. This inductive energy is consumed in a resistance in classical cells, but is recovered by transferring a voltage source or load with a short-time partial resonance in modern cells.

C. *Zero Voltage Transition*

Zero voltage transition (ZVT) is an advanced soft switching technique applied in the turning-on process of the semiconductor power switches. In this technique, the voltage of the power switch is reduced to zero by a short-time partial resonance and the control signal is applied while this voltage is held at zero. Thus, switching energy loss is completely eliminated. This technique, in which the switching energy is recovered, can be obtained with modern cells and requires an additional power switch.

Additionally, the discharge energy loss of the parasitic capacitor of the power switch is eliminated and this energy is recovered in this technique. This soft switching technique is of importance for MOSFET power components with high parasitic capacitors. In Fig. 2, an example ZVT PWM DC-DC boost converter is shown [13].

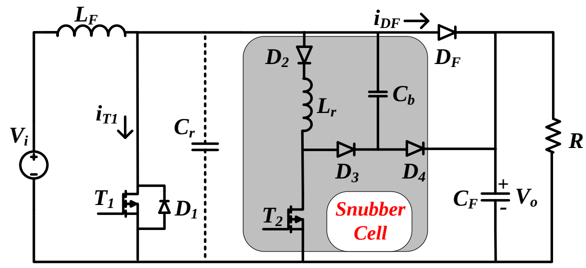

Fig. 2 An example ZVT PWM DC-DC boost converter [13]

D. *Zero Current Transition*

Zero current transition (ZCT) is an advanced soft-switching technique performed in the turning-off process. In this technique, the current passing through the power switch is reduced to zero by a short-time partial resonance and the control signal is cut off while the current is kept at zero. Thus, the overcurrent of the current and the voltage and the loss of switching energy are completely eliminated. This technique, in which the switching power is recovered, can only be achieved with modern cells and requires an auxiliary or additional semiconductor switch. In Fig. 3, an example ZCT PWM DC-DC boost converter is shown [14].

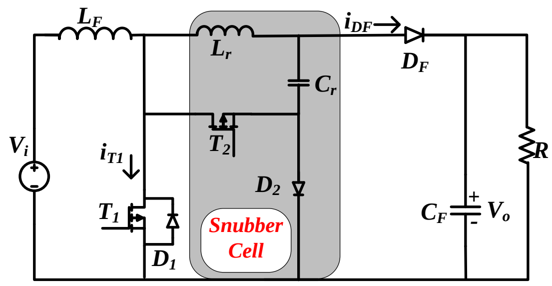

Fig. 3 An example ZCT PWM DC-DC boost converter [14]

IV. Simulation Results

An example ZVT and ZCT converters mentioned above are simulated by 50 W and 100 kHz in PSIM 9.1.1 simulation program. In the simulation operation, the input voltages of the converters are obtained from a photovoltaic solar panel and its value is 15 V. The input voltage is increased with boost converter until 48 V in order to charge a battery.

Fig. 4 shows example ZVT boost converter scheme in PSIM programme. In here, the input voltage is obtained with solar PV panel and its value is 15 V. This converter is operated 100 kHz switching frequency and 50 W output power. The simulation results are given Fig. 5 and Fig. 6.

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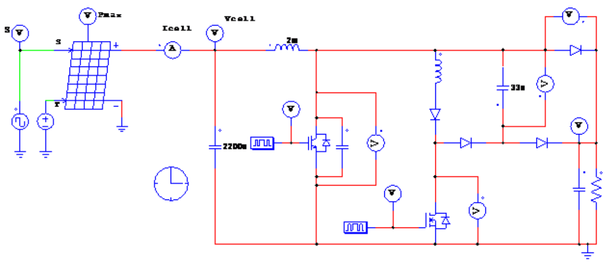

Fig. 4 Example ZVT boost converter with solar PV panel input

In Fig. 5, the current and voltage waveforms of the solar solar PV panel and the output voltage are given. It can be seen that solar PV panel provides the constant input voltage for the boost converter.

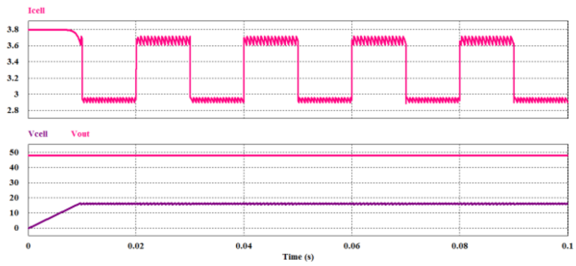

Fig. 5 The simulation results of the solar solar PV panel

In Fig. 6, the voltage and current waveforms of the main switch, the auxiliary switch and the main diode of the example ZVT boost converter are given. As shown in figure, the main switch turns on under ZVT due to the snubber cell and turns off under ZVS due to the snubber capacitor. The auxiliary switch turns on under ZCS and turns off under ZVS. Also, the main diode turns on under ZVS and turns off under ZCS. There is no additional current or voltage stress on the semiconductor elements.

In this converter, the parasitic capacitors are charged to the output voltage while the MOSFET element is off-mode. The parasitic capacitor value in the MOSFET switch has the greatest value compared to other switches. The discharge of the C_r capacitor over the switch means that an energy of $1/(2CV_{out}^2)$ is lost every cycle. Therefore, the energy that accumulates in the C_r capacitor must be recovered. The structures with ZVT snubber cells are applied to switch MOSFET semiconductor elements.

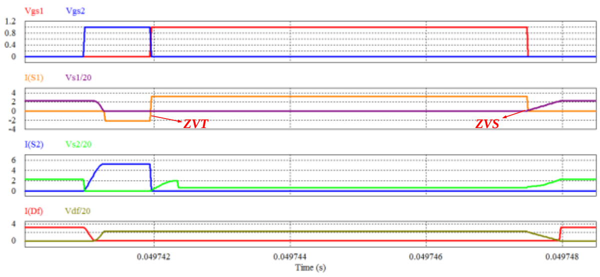

Fig. 6 The simulation results of the example ZVT PWM DC-DC boost converter.

Fig. 7 shows example ZCT boost converter scheme in PSIM programme. In here, the input voltage is obtained with solar PV panel and its value is 15 V. This converter is operated 100 kHz switching frequency and 50 W output power. The simulation results are given Fig. 8.

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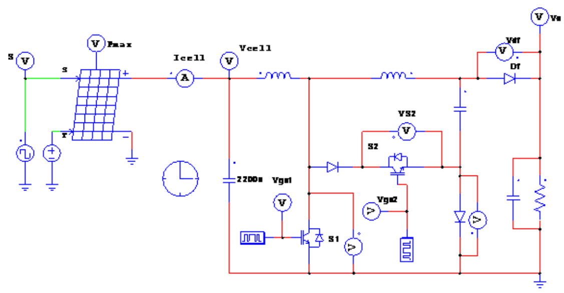

Fig. 7 Example ZCT boost converter with solar PV panel input

In Fig. 8, the voltage and current waveforms of the main switch, the auxiliary switch and the main diode of the example ZCT boost converter are given. As shown in figure, the main switch turns on under ZCS and turns off under ZCT due to the snubber cell. The auxiliary switch turns on under ZCS and turns off under ZVS-ZCS. Also, the main diode turns on under ZVS and turns off under ZCS. Just there is an additional voltage stress on the main diode.

In this converter, it is desirable to have no active or passive auxiliary elements on the main current paths in a well-designed snubber cell. Because the elements on this main current path cause the loss due to their internal resistance, they reduce the efficiency. It also increases the cost of cooling by causing heating problems. In this converter, the sunbber inductance is a disadvantage that the inductance is on the main current path. Because the losses caused by the internal resistance of the inductance reduce the amount of transformer efficiency. Another problem of the snubber cell is that the voltage stress of $2V_{out}$ times occurs in the main diode. Furthermore, the energy of the parasitic capacitor of the main transistor cannot be recovered.

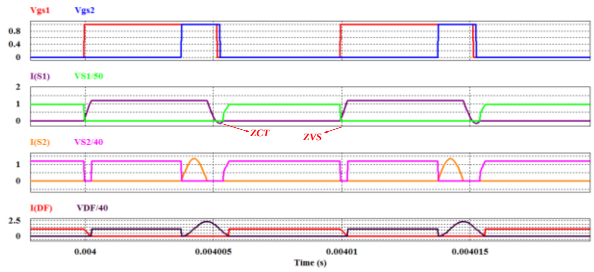

Fig. 8 The simulation results of the example ZVT PWM DC-DC boost converter.

Consequently, the ZVT boost converter is suitable to boost the voltage of solar solar PV panel system. If the ZVT switching method is used, the switching power losses are eliminated without the additional losses or stresses.

V. CONCLUSION

In this paper, the solar PV panel voltage is boosted with a soft switching boost converter. The soft switching method ensures the reducing the switching power losses, EMI noises and reverse recovery losses and it provides that the efficiency and the power density are increased. For this reason, the most important soft switching techniques ZVT and ZCT techniques are examined with example topologies in the simulation operation. Finally, ZVT and ZCT boost converters are operated by minimizing the switching power losses.

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