

Soft-Switching Boost Converters for Photovoltaic Systems

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Abstract—In this paper, four different topologies of soft-switching boost converter using a simple auxiliary resonant circuit for solar power system are reviewed. These converters have simple structure, low cost and ease of control and are applicable for photovoltaic applications. Also, these topologies raise efficiency and, minimize switching losses by adopting soft-switching method using resonance. As we know efficiency, number of components and, voltage and current stresses are effective in selecting the converter for different applications. Therefore we need to choose the optimal boost converter considering above indexes. Efficiency, number of components and voltage and current stresses of these soft-switching boost converters have been compared in this paper to choose the optimal converter for photovoltaic application.

Index Terms— Soft-switching, boost converter, photovoltaic, comparison.

I. INTRODUCTION

Recently, Photovoltaic (PV) energy has attracted interest as a next generation energy source. It is capable of solving the problems of global warming and energy exhaustion caused by increasing energy consumption. The output voltage and power of the solar cell is easily changed by the surrounding conditions such as irradiation and temperature. So, a switching mode converter usually is used maximum power point tracking between solar cells and output inverter. Boost is the most simple and popular topology. Nonisolated DC-DC conversion applications like photovoltaic (PV) grid-connected power systems, electric vehicles (EV), fuel cells, uninterruptible power supplies (UPS), and high-intensity-discharge (HID) lamps for automobile headlamps call for high-performance step-up techniques [1, 2]. The common approach to these applications is a classical boost converter having simple structure, continuous input current, and clamped switch voltage stress to the output voltage.

Several kinds of soft-switching PWM converters, have been proposed in recent years trying to reduce switching losses, diode reverse recovery current, and the electromagnetic interference (EMI) noise of the pulse width modulation (PWM) controlled converters [3], [4]. Passive methods use only resonant inductors, capacitors, and diodes to achieve soft switching at turn-on and turn-off of the

switches. Active methods use resonant inductors, capacitors, diodes, and auxiliary active switches to reduce switching loss due to main power switches. Recently, zero-voltage/current transition (ZVT/ZCT) PWM converters are proposed in addition to traditional zero voltage/current switching (ZVS/ZCS), which diminish voltage/current stresses of the main switch and achieve the soft switching of the main switch [5], [6].

However, the auxiliary circuit for resonance increases the complexity of the circuit, as well as its cost. For some resonant converters with an auxiliary switch, the main switch enables soft-switching, while the auxiliary switch performs hard switching. These converters cannot improve the whole system's efficiency owing to the switching losses of the auxiliary switch [7].

Since power converter are one of most important part of PV systems, an overview to four soft-switching boost converters are given here. This aim is very important for design and construction of PV power generators. All of selected converters have high efficiency, low cost, and ease of control. To selecting optimal soft-switching converter, it should be noted to the cost, complexity and reliability in addition to high efficiency. The brief operations of selected converters, which perfectly explain in [8]-[11], are given in section 2. Discussion about the converters is given in section 3 and section 4 is summary of the paper.

II. OPERATION OF SELECTED SOFT-SWITCHING BOOST CONVERTERS

A. Case A

Fig. 1, shows a soft-switching boost converter with an auxiliary switch and resonant circuit which is presented in [8]. The resonant circuit consist of a resonant inductor (L_r), two resonant capacitors (C_r and C_{r2}), two diodes (D_1 and D_2), and an auxiliary switch (S_2). These resonant components make a partial resonant path for the main switch to perform soft switching under the zero-voltage condition using the resonant circuit. The operational principle of the proposed converter can be divided into nine modes. After turning on the auxiliary switch, the resonant inductor current begins to increase linearly and the main inductor current decreases. Immediately after the resonant inductor current and main inductor current have equalized, the main diode is turn off.

Then the resonant capacitor (C_r) and the resonant inductor start their resonance. After finishing the resonance, the resonant capacitor voltage is equal to zero, and the body diode of main switch is turn on naturally. The main switch turns on under zero-voltage condition and auxiliary switch is turned off. Then the resonant inductor and second resonant capacitor (C_{r2}) start their resonance.

After the quarter-wave resonance of L_r and C_{r2} , C_{r2} has been fully charged, and the current flows the resonant inductor reverses. When the C_{r2} voltage has reached to zero by resonance, the body diode of the auxiliary switch is turned on. The main switch is turned off under the zero-voltage condition and the resonant capacitor C_r has been charged by the sum of the two inductor currents to output voltage. Then, the main diode turns on under the zero-voltage condition and the resonant inductor current decreases linearly toward zero. Measured efficiency is about 96% in full load.

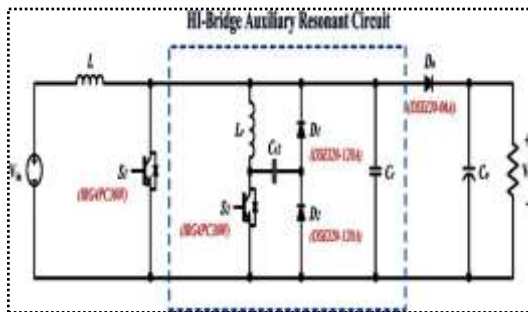


Fig. 1. Schematic of the soft-switching boost converter with an HI-bridge auxiliary resonant Circuit in [8]

B. Case B

Fig. 2, shows another soft-switching boost converter for photovoltaic power generation system [9]. One inductor (L_2), two capacitor (C_{r1} and C_{r2}) and two diodes (D_1 and D_2) are added to the conventional boost converter circuit. On/Off control is done by one switch and the switching loss can be reduced by switching at zero-current and voltage made by L_2 and C_{r2} resonance. This converter can be analyzed as seven modes according to the operation conditions.

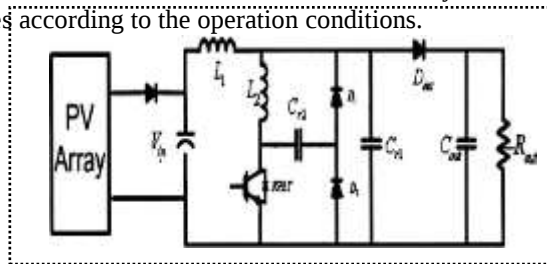


Fig. 2. Proposed soft switching boost converter in [9]

After turning on the switch under ZCS condition, the resonant inductor current increases linearly and main diode current decreases. If this current becomes the same as the current of the main inductor L_1 , the current of the output side diode becomes zero and turns off. Then the auxiliary resonant inductor L_2 and the auxiliary capacitor C_{r1} resonate and the voltage of C_{r1} falls to zero and two auxiliary diodes D_1 and D_2 turn on naturally. After turning off the switch under zero-voltage condition, the voltage of the auxiliary resonant capacitor C_{r1} increases linearly from zero to the output voltage and the second resonance takes place. The energy stored at L_2 moves to C_{r2} . The current of L_2 becomes zero and

of this converter is about 96.85% at full load.

C. Case C

Third case of soft-switching boost converter is shown in Fig. 3, which provides ZCS turn-off of the main switch without additional conduction loss and current stress [10]. The auxiliary circuit consists of one switch (S_a), one diode (D_a), one resonant inductor (L_r) and one resonant capacitor (C_r). It provides ZCS turn-off of all active switches and the resonant inductor, L_r can minimize the reverse recovery problem of the main diode D_f , and also helps the soft turn-on of the main switch. This converter operates in eight modes. By turning on the main switch S , the current through the resonant inductor L_r , and the main diode D_f , reduces linearly to zero and then the main diode D_f is turned off softly. After this period the auxiliary switch is softly turned on under ZCS by resonant inductor, and then the resonance between the resonant inductor and the resonant capacitor starts. After the half of the resonant period, the resonant capacitor voltage reverses its polarity so the auxiliary diode starts conduction and the resonant inductor current flows oppositely.

The resonant inductor current is increased to negative sinusoidal value and the main switch current is reduced to zero and then the anti-parallel diode of the main switch starts conduction. The main switch and the auxiliary switch are turned off at the same time under ZCS to simplify the control design. The resonant capacitor voltage is charged to the output voltage by the input current and then the main diode turns on under ZVS condition and starts conduction. Finally the main switch is turned on again, and the switching cycle is repeated. This soft-switching boost converter is easy to control because the two switches are controlled by the same PWM signal. The measured efficiency of the proposed ZCT converter is measured about 95.2% at full load.

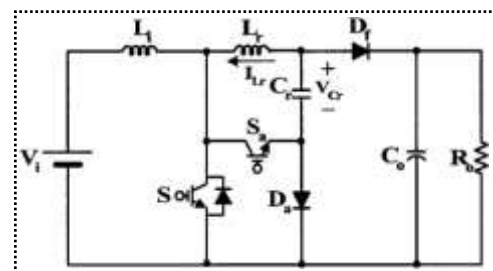


Fig. 3. ZCT boost converter in [10]

D. Case D

the voltage of C_{r2} becomes the maximum value.

After this period the voltage of C_{r2} decreases to zero and the current of L_2 flows reversely and the anti-parallel diode of the switch turns on. The two currents of main inductor and auxiliary inductor transmit the energy to the output through main diode and decrease linearly. Finally the current of the auxiliary resonant inductor L_2 becomes zero. The efficiency

The circuit scheme of the last case is ZVT-PWM boost converter which is presented in [11] and shown in Fig. 4. The active snubber cell basically consists of an auxiliary resonant inductor (L_r), a resonant capacitor (C_B), an auxiliary transistor (T_2), and two auxiliary diodes (D_1 and D_2). In the proposed converter, the capacitor C_r in parallel with T_1 is not required, and the diode D_{T1} in anti parallel with T_1 may not be used. Seven stages occur in the steady state operation of the proposed converter over one switching cycle. When the auxiliary switch T_2 turns on, the resonant inductor current increases and the main diode current falls to zero and turned off under zero-voltage condition. Then a parallel resonance between L_r and C_r starts. After resonance period the voltage of C_r becomes zero and the anti parallel diode D_{T1} of the main switch is turned on. The main switch is turned on under

TABLE I: COMPARISON OF PROPOSED BOOST CONVERTERS

		Number of auxiliary circuit component				Voltage And Current Stresses					
	Eff. [%]	Sw	D	Resonant Inductor $\mu\text{H/watt}$	Resonant Capacitor nf/watt	Main switch [V],[A]		Aux. Switch [V],[A]		Main diode [V],[A]	
						V_p	I_p	V_p	I_p	V_p	I_p
CASE A	96	1	2	$L_r = 33.3$	$C_r = 5.6$ $C_r2 = 50$	400	6	400	10	400	3.5
CASE B	96.85	-	2	$L_2 = 42.2$	$C_{r1} = 83.3$ $C_{r2} = 8.3$	650	12	-	-	400	12
CASE C	95.2	1	1	$L_r = 12.4$	$C_r = 10$	338	7.6	341	9	665	7.7
CASE D	97	1	2	$L_r = 7.5$	$C_B = 11$	440	12	400	18	400	14

zero-voltage condition and the auxiliary diode is turned off under near zero-voltage condition. Then L_r and C_r start their resonance. After resonance period the resonant inductor (L_r) current decreases and the resonance capacitor (C_B) is charged from zero to exactly the output voltage by L_r current. As soon as resonant inductor current drops to zero, D_r and D_1 are turned off under near zero-current condition. So, the main switch T_1 is turned off and the auxiliary diode D_2 is turned on with ZVS by the capacitor (C_B). During this stage when C_r voltage reaches the output voltage V_o and the auxiliary resonant capacitor (C_B) voltage falls to zero simultaneously, the main diode D_f is turned on with ZVS and the auxiliary diode D_2 is turned off under zero-voltage condition. Finally the main diode continues conducting the input current and the snubber circuit is not active.

In this converter all of the semiconductor devices are both turned on and off under exact or near ZVS and/or ZCS. The converter has a simple structure, low cost, ease of control and high efficiency. At full output power in the proposed soft-switching boost converter, the main switch loss is about 27% and the total circuit loss is about 36% of that in its counterpart hard switching converter, and so the overall efficiency, which is about 91% in the hard switching case, increases to about 97% [11].

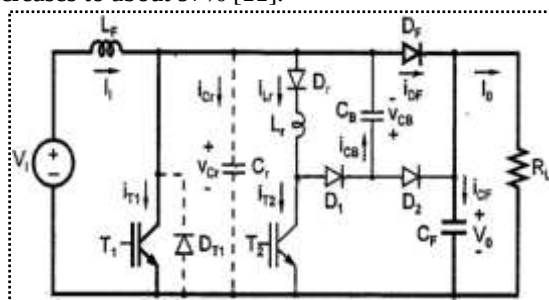


Fig. 4. Circuit scheme of the ZVT boost converter in [11]

III. DISCUSSION AND COMPARISON

Efficiency (Eff.), number of auxiliary switch (sw), diode (D), resonant inductor (L) and capacitor (C) beside their amount and voltage and current stresses of main switch,

auxiliary switch and main diode of these four soft-switching

boost converters system have been summarized in TABLE .

TABLE , shows the efficiency of each converter. We can see that the converter in CASE C has the minimum efficiency and the converter in CASE D has the maximum efficiency. So, the converter in CASE D is more appropriate for PV application from this aspect.

TABLE , also shows the number of auxiliary components that have been used in auxiliary resonant circuit of each soft-switching boost converter. The number of devices and the value of resonant capacitor and resonant inductor are effective on the cost of the converter. However the number of components is more, the converter will be more expensive.

We can see that the boost converter in CASE C has the minimum auxiliary components and the converters in CASE A, D have the maximum auxiliary components. Therefore the converter in CASE C will be more economically.

The current/voltage stresses of main switch, auxiliary switch, and main diode of the proposed converters have been shown in TABLE . The converter in CASE B has the maximum voltage and current stresses on main switch. The converter in CASE D has the maximum current stress on auxiliary switch while the converter in CASE C has the minimum current stress on auxiliary switch. Finally we can see that the converter in CASE C has the maximum voltage stress on main diode and the converter in CASE B has maximum current stress on main diode.

IV. CONCLUSION

In this paper four different kind of soft switching boost converters with auxiliary resonant circuit for photovoltaic applications have been reviewed. Through this auxiliary resonant circuit, all of the switching devices perform soft-switching under zero-voltage and zero-current conditions. These boost converters have high efficiency, low cost, and ease of control. The efficiency of these boost converters is more than 95% and are useful for photovoltaic application. The operation principle of these converters was expressed briefly. As we know in addition to efficiency, number of auxiliary components and current /voltage stresses are effective in selecting the optimal converter for

photovoltaic applications. Therefore we must look to these factors. So, efficiency, number of auxiliary components and current/voltage stresses of these converters have been compared in this paper.

(EMI), electrical machines and drives.

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