ZVT Boost Converter Employing Auxiliary Resonant Circuit in PV Energy Systems

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ABSTRACT : *In this thesis, a boost converter operating all the switching devices under ZVT is studied and a model converter is used in the Solar Energy systems using PV array and MPPT algorithm. Generally photovoltaic (PV) energy systems are gaining popularity because the systems are being developed to extract maximum energy from the sun in most efficient way and feed it to the loads without affecting their performance. The efficiency of a single PV cell is very low. In the proposed converter topology, a part of the circuit resonates for a small period of the switching cycle of the converter, known as the auxiliary resonant circuit that provides the soft transition from ON state to OFF state and vice versa, thus by reducing the losses that occur due to hard switching of the switches converter efficiency can be improved. Due to reduced losses during switching transitions heating effect of MOSFETs is reduced and have a longer life. The comparative study between the proposed topology and conventional hard switching converter can be analyzed in terms of reduction of switching losses and the improvement of efficiency.*
Keywords - *ZCT, Boost Converter, PV Array, MPPT.*

I. INTRODUCTION

India is the world's third largest electricity producer and consumer of electricity after the United States and China; however, the electrical infrastructure is generally considered unreliable. Nearly all electronic goods require DC power to run and it is easy to produce from AC-DC converters. However, after that process another DC-DC converter is required for fast and easy Control with high reliability. Fast control needs high switching frequency for the converter. High switching frequency also causes electromagnetic interference (EMI) and extra switching losses [1]. Normally current and voltage waveforms overlap in every switching action which is called hard switching. Addition to overlap power loss at hard switching, reverse recovery loss of diodes and parasitic capacitance discharge loss of the main switch is taken into account for general power loss in switching process. Nowadays, to overcome these drawbacks, soft switching techniques are used. Soft switching techniques provide high efficiency due to lowered or destroyed current or voltage stresses.

The efficiency of the PV energy system solely depends on the PV panels, power converter and the Maximum Power Point Tracking system. The efficiency of a single PV cell is very low. The efficiency of hard switching converters is low. So they can be replaced by the soft switching converters that have very less losses and high efficiency. Use of good and efficient MPPT algorithm also improves the system efficiency. In this thesis, improvement of converter efficiency is most focused on.

II. HIGH SWITCHING FREQUENCY OPERATION

A power electronic converter has energy storage elements such as inductors, capacitors and transformers that account for much of its overall size. These components are used to store and transfer energy as part of the power conversion process. As a converter's switching frequency is increased, the component values of its energy storage elements Decrease, as do their physical size and weight, due to the shorter time they are required to store voltage or current. As a result, the higher the switching frequency a converter operates with, the smaller its energy storage elements (and thus its overall size) will be.

There are, however, drawbacks to operating a switch-mode power electronic converter with high switching frequency, the key one being that doing so increases the converter's switching losses. Unlike an ideal switch that would be able to turn on and off Instantaneously without any overlap between the voltage across it and the current flowing through it, a real switch does have these overlaps in voltage and current whenever a switching transition from on to off or vice versa is made.

Since power is dependent on the product of voltage and current, the fact that there is voltage/current overlap during switching transitions means that there are power losses during these times. These losses are referred to as switching losses in the power Electronics literature and the higher the switching frequency that a power converter operates with, the more switching losses it will have.

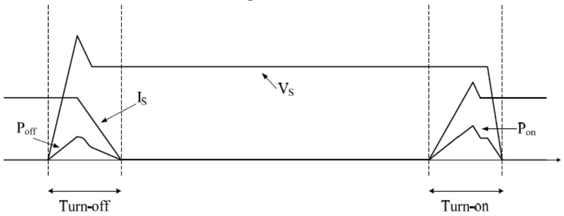


Fig 1: Typical switch voltage and current waveforms

III. POWER LOSSES IN HARD-SWITCHING CONVERTERS

In the switching converters, when the switching device is in ON state, as the voltage blocked by the switch is zero, the power losses are zero. When the switch remains in the off state, as the current allowed by the switch is zero, the power losses are zero. But during the transition of the switch from both ON state to OFF state and OFF state to ON state, if there is no mechanism to make either voltage or current zero, power losses occur. This is in the case of hard-switching converters.

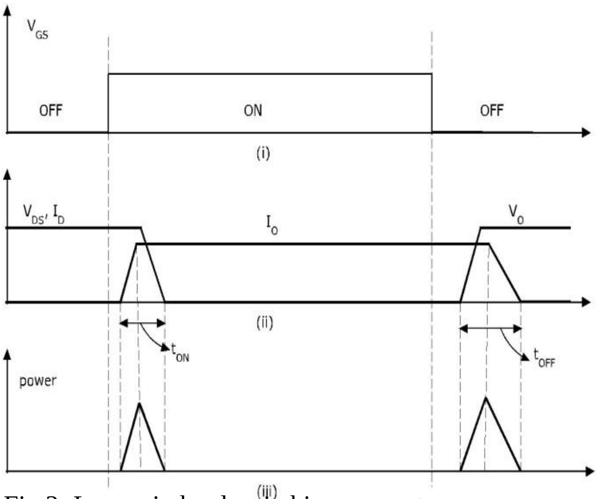


Fig 2: Losses in hard switching converters.

In the hard switching converters, power losses will occur when there will be a simultaneous non-zero voltage applied across and non-zero current flowing through the switch. When the switching device turns ON or OFF, the device voltage and current are high in simultaneous cases resulting in high losses. This is shown as waveforms in figure 2 (i) showing control pulse given to the switching device, (ii) the device voltage and current and (iii) power losses per switching cycle.

The switching losses in one switching cycle can be denoted as

$$Psw = VsIsfs\left(\frac{Ton + Toff}{2}\right)$$

From the equation of switching losses, it can be observed that the switching losses can be reduced in 2 ways, (1) by reducing the delay times during turn ON and turn OFF, by using faster and more efficient switches in converter. (2) By making the voltage across or current through the switch zero before turning it ON/OFF, the concept of soft switching converters.

IV. SOFT SWITCHING

A power converter can be operated with high switching frequencies only if the problems of switching losses can be overcome; this can be done using "soft-switching" techniques. This term "soft-switching" refers to various techniques that make the switching transitions more gradual than just simply turning a switch on or off (which is referred to as "hard-switching" in the power electronics literature) and that force either the voltage or current to be zero while the switching transition is being made. Switching losses are reduced as there is no overlap of switch voltage and switch current during a switching transition as one of the two is zero during this time.

V. SOFT SWITCHING TECHNIQUES

There are two basic methods to attain soft switching, zero current switching (ZCS) and zero voltage switching (ZVS).

A) ZERO CURRENT SWITCHING

A switch operating with ZCS has an inductor and a blocking diode in series with it. The switch turns ON under ZCS as the rate of rise of current after the voltage becomes zero is controlled by the inductor. As the inductor does not allow sudden change in current, it rises linearly from zero.

When a negative voltage is made to appear across the combination of inductor and switch using a resonant circuit, the current flowing through the switch is naturally reduced to zero which results in the turn OFF of the switch under ZCS.

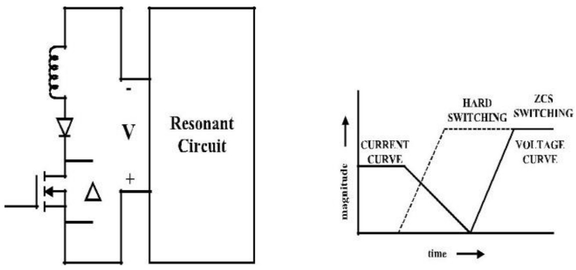
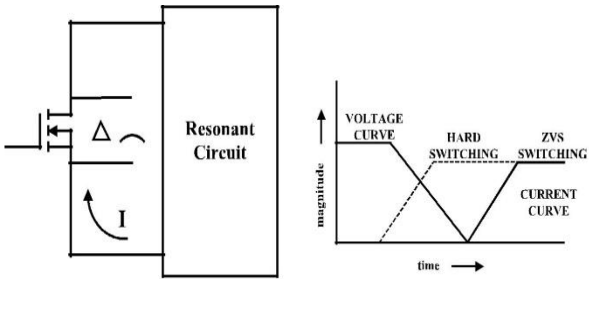


Fig 3: (a) ZCS turn OFF using negative voltage.
(b) Switching waveforms of hard switching and ZCS during turn OFF.

B) ZERO VOLTAGE SWITCHIING

A switch operating with ZVS has an anti-parallel diode and a capacitor across it. During turn OFF as the current reduces to zero, the rate of voltage rise that takes place across the switch is controlled by the capacitor. As the capacitor does not allow sudden change in voltage, it rises linearly from zero.

The turn OFF characteristics of the switch are controlled by a capacitor connected across it. This capacitor reduces the voltage rise rate as current flow reduces to zero.



(a) (b)

Fig 4: (a) ZVS turn ON using negative current. (b) Switching waveforms of hard switching and soft switching

VI. ZVT CONVERTERS

The ZVT converters accomplish zero voltage switching during both turn-ON and turn-OFF transitions of the primary or boost switch.

By introducing a resonant circuit in parallel with the switches, the converter can achieve ZVS for both power switch and diode without significantly increasing their voltage and current Stresses. The converter consists of a main switch S and an auxiliary Switch S2. It can be seen that the voltage and current waveforms of the switches are square-wave-like except during turn-on and turn-off switching intervals, where ZVT takes place. The main switch and the output diode are under ZVS and are subjected to low voltage and current stresses. The auxiliary switch is under ZCS, resulting in low switching loss.

The concept of ZVT can be extended to other PWM circuits by adding the resonant circuit.

The turn ON transition in zero voltage switching is accomplished by discharging the capacitor connected in parallel by making use of the energy stored in a magnetic circuit element like a transformer winding or an inductor coil. The switch is turned ON after the parallel diode enters into the state of conduction. This ensures a zero voltage across the switch during transition.

VII. PROPOSED ZVT BOOST CONVERTER

The circuit scheme of the proposed ZVT-PWM boost converter, *Vi* is input voltage source, *Vo* is output voltage, L_{in} is main inductor, *CF* is output filter capacitor, *S1* is main switch and *D1* is main diode. The main switch consist of a main transistor *T*1and its body diode *D*5. The snubber circuit shown with dashed line is formed by snubber inductor *Lr* , a snubber capacitor C_r and auxiliary switch *S*2 . *T*2 and *D*5 are the transistor and its body diode of the auxiliary switch, respectively. The capacitor *Cr* is assumed to be the sum of the parasitic capacitor of *S*1 and the other parasitic capacitors incorporating it. In the proposed converter, it is not required to use an additional *Cr* capacitor.

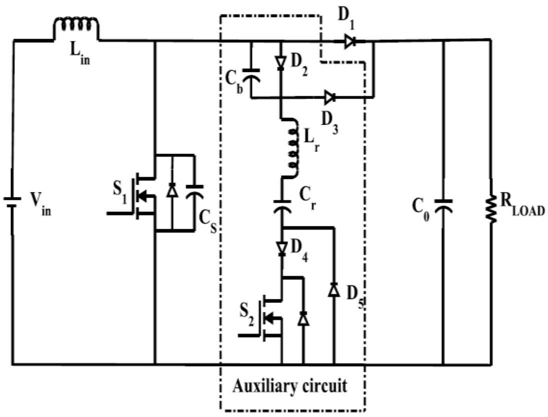


Fig 5: Schematic Diagram of ZVT DC-DC Boost Converter.

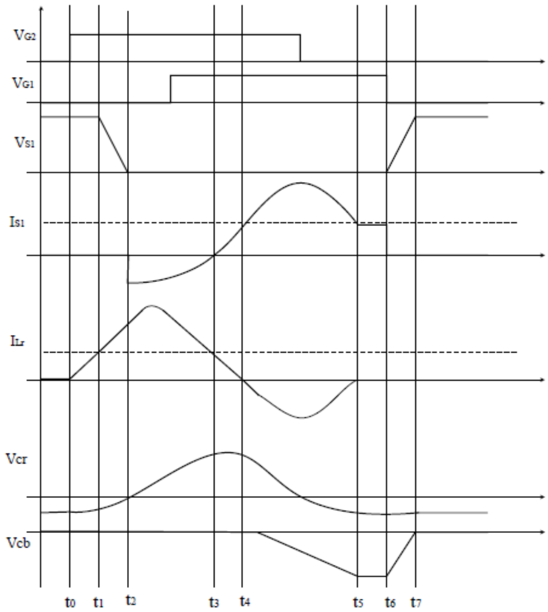


Fig 6: Hypothetical waveforms of the Converter.

VIII. BOOST CONVERTER FOR PV ENERGY SYSTEM

The PV array's conditioned by the ZVT DC-DC boost converter and output is supplied to the load after being The switching of the MOSFETs constituting the circuit is controlled by a maximum power point tracking (MPPT) algorithm which tracks that operating point of the PV array that meets the DC load line (including the effect of converter).

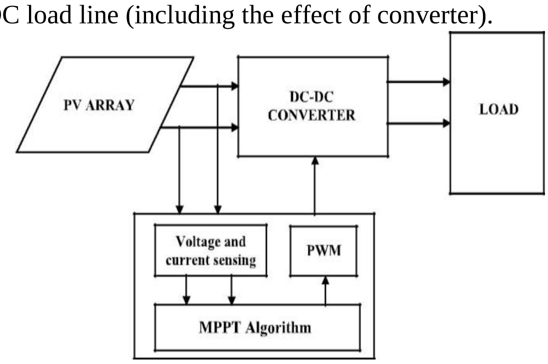


Fig 7: Block diagram of DC-DC converter with PV energy system.

IX. MAXIMUM POWER POINT TRACKING (MPPT)

The relationship between output voltage and current from the PV module is a function of solar irradiation, module temperature, and amount of partial shadow, as seen in Figure 1.4. According to its *I-V* curve, there is a point where the PV module generates the most power. This point is called the Maximum Power Point (MPP), and the corresponding current and voltage are denoted as I_{MPP} and V_{MPP}. The MPP is different as the PV module's I - V curve changes with irradiance and module temperature. Sometimes it changes rapidly due to fast changes in the weather conditions such as partial cloudy day; otherwise it is almost constant in a sunny day without clouds. Because of this characteristic of MPP, some proper algorithms are required for Maximum Power Point Tracking (MPPT). Many researches are conducted of Different MPPT techniques. There are three main methods, which are the most widely used Perturb and Observe (P&O); Incremental Conductance (INC) and Constant Voltage (CV). The first two are essentially "hill-climbing" methods because they share the same scenario.

X. SIMULATION AND RESULTS

The simulation model for ZVT PWM boost converter is given in Fig. 8 the circuit consists of a boost inductor, a MOSFET switch, boost diode and a output capacitor. The input current is assumed to be constant and input voltage is 200V DC. The pulse to gate of MOSFET switch is given from the pulse generator block. Scope displays the different waveforms of the PWM boost converter. The MOSFET switch operates at a frequency of 100 KHz.

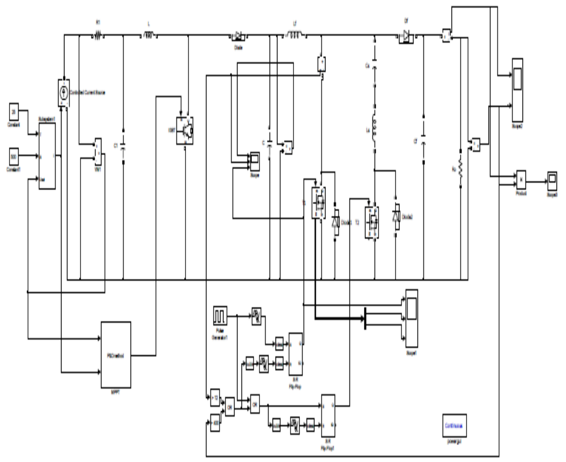


Fig 8: Simulink Model of Proposed ZVT Boost Converter.

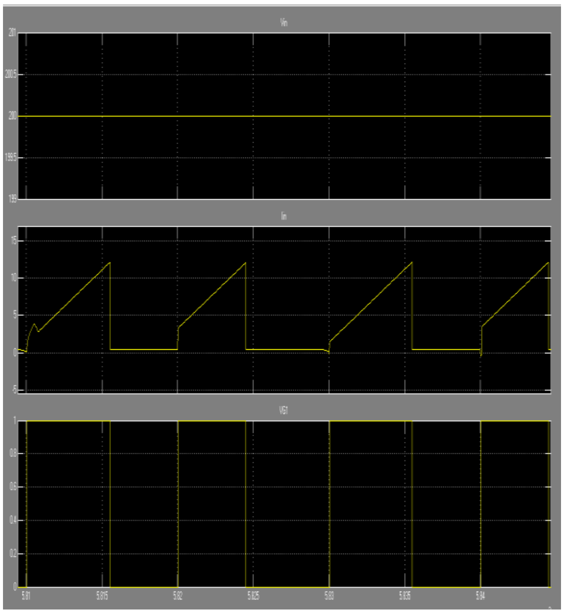


Fig 9: Input voltage and Current for corresponding pulses.

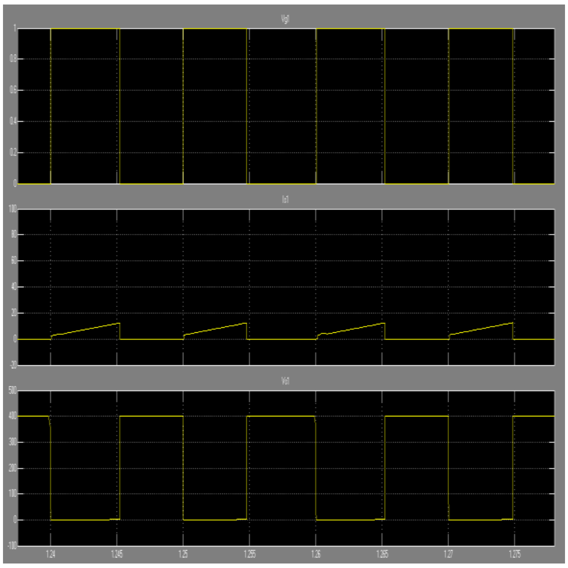


Fig 10: Voltage and Current across the Main Switch illustrating ZVT

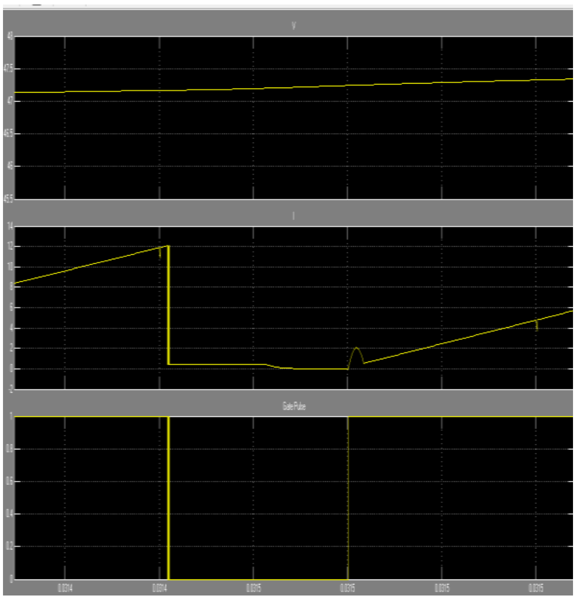


Fig 11: Voltage and Current across the Main Switch illustrating ZCT

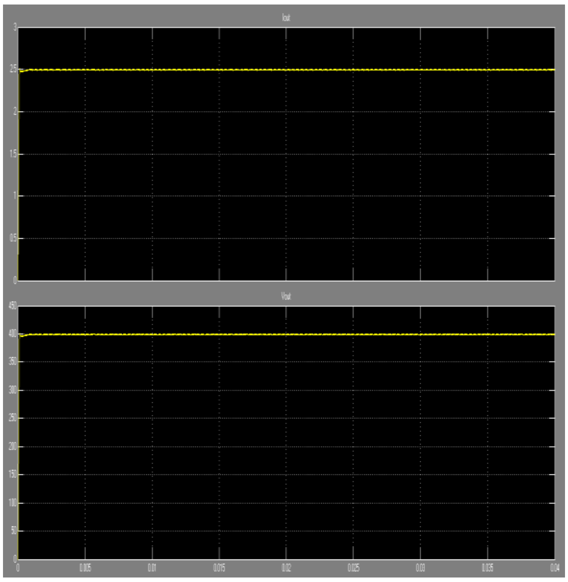


Fig 12: Voltage and Current across the Load.

XI. CONCLUSIONS

In this study, a PWM boost converter with a novel active snubber cell has been analyzed in detail. This active snubber cell provides ZVT turn on and ZCT turn OFF together for the main switch of the converter. Also, the proposed snubber cell is implemented by using only one quasi-resonant circuit without an important increase in cost and complexity.

In this paper 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.

REFERENCES

[1] C. P. Sai Kiran , M. Vishnu Vardhan, "High Frequerncy soft switching of PWM Boost Converter Using Auxiliary Resonant Circuit",Vol. 4- Issue 10 (October-2014), International Journal of Engineering research and Applications(IJERA), ISSN:2248-9622

[2] B. Abdi, A. Safaei, J. S. Moghani, and H. Askarian Abyaneh, "An Overview to Soft-Switching Boost Converters for Photovoltaic," International Journal of Computer and Electrical Engineering vol. 5, no. 1, pp. 18-21, 2013.

[3] Huang, G. Moschopoulos, "A New Family of Zero Voltage Transition PWM Converters With Dual Active Auxiliary Circuits" IEEE Transactions on Power Electronics, vol. 21, pp. 370-379, March 2006

[4] Nihan Altintas,, A. Faruk Bakan, and Ismail Aksoy "A Novel ZVT-ZCT-PWM Boost Converter" IEEE transactions on power electronics, vol.29, no. 1, January 2014.

[5] Bodur and A. F. Bakan, "A New ZVT-PWM DC-DC Converter," IEEE Transactions on Power Electronics, vol. 17, pp. 40-47, Jan. 2002.

[6] Aksoy, I.; Bodur, H.; Bakan, A.F.; , "A New ZVT-ZCT-PWM DC–DC Converter," Power Electronics, IEEE Transactions on , vol.25, no.8, pp.2093-2105, Aug. 2010

[7] H. Bodur, and A.F. Bakan, "A New ZVT-ZCT-PWM DC-DC Converter," IEEE Transactions on Power Electronics, vol. 19, pp. 676-684, May. 2004.

[8] E. Adib and H. Farzanehfard, "Family of zero-voltage transition pulse width modulation converters with low auxiliary switch voltage stress," IET Power Electron., vol. 4, pp. 447–453, Apr. 2011.

[9] Y. Lee, M. K. Lee, D. S. Hyun, and I. Choy, "New zero-current transition PWM DC/DC converters without current stress," IEEE Trans.Power Electron., vol. 18, no. 1, pp. 95–104, Jan. 2003.

[10] H. Mao, F. C. Lee, X. Zhou, H. Dai, M. Cosan, and D. Boroyevich, "Improved zero-current-transition converters for high-power applications,"IEEE Trans. Appl., vol. 33, no. 5, pp. 1220–1232, Sep./Oct. 1997.

[11] G. Hua, C. S. Leu, Y. Jiang, and F. C. Lee,"Novel Zero-Voltage-Transition PWM Converters," IEEE Transactions on Power Electronics, vol. 9, pp. 213-219, Mar. 1994.

[12] R. L. Lin, Y. Zhao, F.C. Lee, "Improved Soft-Switching ZVT Converters with Active Snubber", Applied Power Electronics Conference and Exposition IEEE, vol. 2, pp. 1063 – 1069, Feb. 1998.

[13] G. Hua, E. X. Yang, Y. Jiang, and F. C. Lee, "Novel Zero-Current-Transition PWM Converters," IEEE Transactions on Power Electronics, vol. 9, pp. 601-606, Nov. 1994.

[14] Nikhil Jain, Praveen K.Jain and Geza Joos, "A Zero Voltage Transition Boost Converter Employing a Soft Switching Auxiliay Circuit With Reduced Conduction Losses," in IEEE Transactions on power electronics, vol.19, no.1, January 2004.

[15] Sang-Hoon Park, Gil-Ro Cha, Yong-Chae Jung and Chung-Yuen Won, "Design and Application for PV Generation System Using a Soft-Switching Boost Converter with SARC," IEEE Transactions on Industrial Electronics, vol.57, no.2, February 2010.

[16] A. F. Bakan, H. Bodur, and I. Aksoy, "A novel ZVT-ZCT PWM DC-DC converter," in *Proc. 11th Eur. Conf. Power Electron. Appl.*, Dresden, Sep.2005, pp. 1–8.

[17] A. F. Bakan, "A new LVI assisted PSFB PWM DC-DC converter,"in Proc. 6th Int. Conf. Electr. Electron. Eng. (ELECO), Bursa, Turkey, Nov.5–8, 2009, pp. 230–233