Analysis of a Soft Switching High Voltage Gain DC/DC Boost Converter for PV Systems

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Abstract- This paper presents an analysis of a non-isolated soft switching high voltage gain DC/DC boost converter by using a coupled inductor, voltage quadrupler and active clamp circuit for Photovoltaic (PV) systems. The main advantage of this converter, coupled inductor with voltage quadrupler circuit is used to decrease voltage stress in semiconductor switches and providing high voltage gain. Therefore, low voltage valued and low on-resistance $R_{DS(ON)}$ MOSFETs can be used to decrease on-state losses. The reverse recovery and high frequency turn off losses is reduced for achieving Zero-Current Switching (ZCS) in all diodes. Voltage spike caused by leakage inductance of the coupled inductor is minimized by means of the active clamp circuit. Thus, Zero-Voltage Switching (ZVS) turn on of all MOSFET switches are achieved. The Perturb and Observe (P&O) method is utilized in this study to obtain maximum power from the PV system. In order to show the effectiveness of the converter, PSIM simulations are realized under various irradiance cases. The conversion efficiency is obtained about 95.97% at full load from the simulation results.

Keywords DC/DC converter, high voltage gain, coupled inductor, voltage quadrupler, ZCS, ZVS, PV system.

1. Introduction

In the past few decades, distributed generation with renewable energy sources have rapidly developed [1]. Much research has been carried out on renewable energy to get maximum power with high efficiency among renewable energy resources like wind, Photovoltaic (PV), etc. The output PV panel voltage is very low between (25-50 V) due to safety factors and for various applications is required boosting large voltage [2]. Maximum Power Point Tracking (MPPT) methods are commonly used with PV systems to maximize power extraction [3]. The Perturb and Observe (P&O) [4], [5] and the incremental conductance [6] MPPT algorithms are frequently used in the PV systems. These algorithms depend on the voltage-power characteristic, if $(\frac{dP}{dV} < 0)$ right of the maximum power point MPP, while the left of the MPP when $(\frac{dP}{dV} > 0)$ [7].

In conventional boost converters, high losses are found on input side due to large peak current which adverse effects on the magnetic components. Because the large voltage across the switch, the switch conduction losses are increased $(R_{DS(ON)} \propto {V_{DS}}^2)$. The inductor and capacitor resistances increase the losses due to large duty cycle. In addition, diode reverse recovery problem is a disadvantage [8]. For these reasons, the conventional boost converters are not appropriate to use for high voltage gain application. To get a high voltage gain without a high duty cycle, there are several proposed topologies. Among them, the coupled inductor is commonly used [9]. Although achieving high voltage gain with large turns ratio, its leakage inductance cause power losses and high voltage stress on the MOSFETs [10]. Therefore, passive or active clamp techniques are used to recycle leakage energy from the coupled inductor. Passive clamp circuits reform voltage gain, but cause high voltage stress on output diode. Utilizing active clamp circuit, Zero-

Voltage Switching (ZVS) turn on with power switches are obtained [11].

In this paper, coupled inductor based high voltage gain soft switching DC-DC boost converter is analyzed and controlled for PV systems. This converter [11] has main advantages; firstly, the voltage quadrupler circuit is combined with secondary of the coupled inductor to produce high voltage gain. Secondly, at turn on for a MOSFET, coupled inductor transfers the energy to the voltage multiplier circuit. Thus, smaller magnetic component can be used with this converter. Thirdly, all diodes turned off at Zero-Current Switching (ZCS) and therefore reverse recovery losses, high frequency turn off losses are reduced and high voltage spike is eliminated.

2. Proposed System Overview

The proposed system, including soft switching, high voltage gain converter is illustrated in Fig. 1. It involves of an input voltage (V_{PV}) and current (I_{PV}) from PV panel, input capacitor (C_{PV}), a coupled inductor primary side denotes (L_m and L_{kp}) and secondary side denotes (L_{ks}), a clamp circuit (auxiliary switch S_2 and out capacitor C_{o3}), a resonant voltage quadrupler circuit (consist of the diodes D_1, D_2, D_{o1}, and D_{o2} along with capacitors C_1, C_2, C_{o1}, and C_{o2}), parasitic capacitors of MOSFETs (C_{r1} and C_{r2}) and output DC load (R_o). The converter key waveforms as indicated in Fig. 2 and the nine operation interval are briefly described in [11].

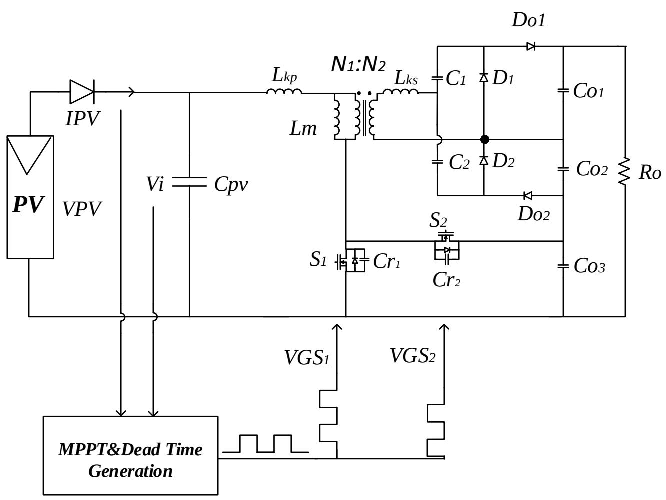

Fig. 1. The proposed system block diagram.

The conversion ratio (M) of the converter is calculated from equation (1). The turn ratio of coupled inductor can be increased without increase MOSFET's voltage stress.

$$M = \frac{V_o}{V_{in}} = \frac{1+2N}{1-D} \quad (1)$$

Soft switching operation of the converter is achieved as the following:

i) For achieving ZVS turn on of MOSFET S_1 there are two conditions: First, the stored magnetizing inductance energy is greater enough to discharge C_{r1} of MOSFET S_1 and charge C_{r2} of MOSFET S_2. Second, the dead time (ΔT) is enough for charge and discharge the MOSFET parasitic capacitor. For getting ZVS of MOSFETs, magnetizing inductance $(L_{m_{max}})$ is obtained from equation (2).

$$L_{m_{max}} < \frac{V_{in} D_{\max}(1-D_{\max})}{2(1+2N) I_o f_s} \quad (2)$$

In this study, the magnetizing inductance (L_m) is selected as 9μH, and dead time (ΔT) is determined from equation (3).

$$\Delta T \geq \sqrt{L_m (C_{r1} + C_{r2})} \quad (3)$$

ii) The ZCS turn off of diodes D_1, D_2, D_{o1} and D_{o2} is achieved if the minimum time to turn on MOSFET S_1 is greater than the one-half of resonant period. Therefore, the capacitors C_1 and C_2 are obtained as equation (4).

$$C_1, C_2 < \left(\frac{D_{min}^2 T_s^2}{\pi^2 L_{ks}}, \frac{(1-D_{max})^2 T_s^2}{\pi^2 L_{ks}} \right) \quad (4)$$

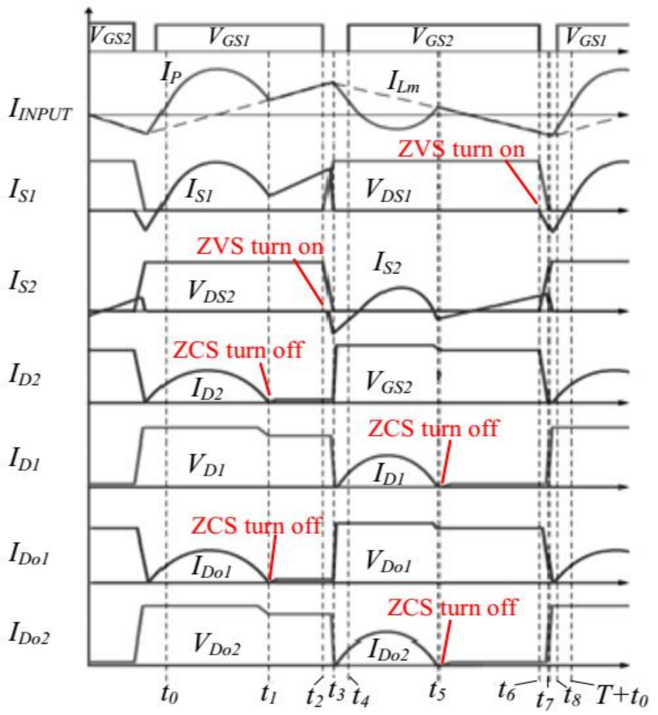

Fig. 2. The converter key waveforms.

In the paper, high voltage gain is obtained without using high duty cycle or large magnetic components, which are main advantages over the conventional converter as indicated in Table 3.

Table 3. Comparison of conventional and analyzed boost converter.

Parameter	Conventional boost converter	Analyzed boost converter
Voltage gain	$\frac{1}{1-D}$	$\frac{1+2N}{1-D}$
Voltage stress of MOSFETs	V_o	$\frac{V_o}{1+2N}$
Voltage stress of diodes	V_o	$\frac{NV_o}{1+2N}$

3. Simulation Results

PSIM based proposed system block diagram is seen in Fig. 3. The Perlight Solar PLM-250M PV panel is used as the input source. The PV panel parameters are given in Table 1. Current-voltage (I-V) curves of the PV panel at different irradiation cases are illustrated in Fig. 4. The ratings of the P_{MPP} values are depicted in this figure under the solar irradiation decreases from 1000 W/m^2 to 200 W/m^2 at constant temperature 25˚C. The sensed PV voltage and current are given to MPPT inputs and then Pulse Width Modulated (PWM) signal outputs are obtained to gate signal for main and auxiliary MOSFET switches. The P&O MPPT algorithm is used due to simple operation, tracking efficiency and high reliability. For achieving ZVS for main and auxiliary switches, the time delay between to gate signals is adjusted properly by using dead time generator. The converter specifications are given in Table 2.

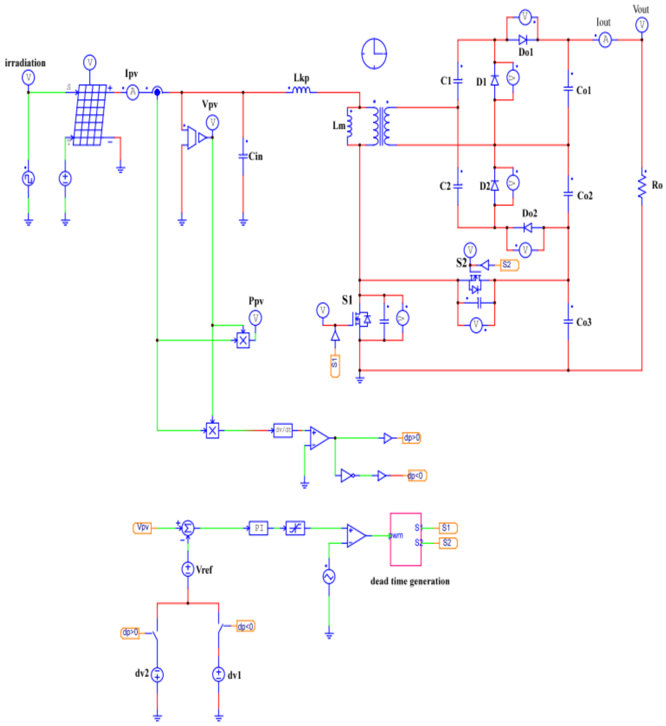

Fig. 3. PSIM based proposed system block diagram.

Table 1. PV panel parameters.

Parameter	Value
PV panel model	PLM-250M
Maximum power (P_m)	250 W
Number of cells (N_s)	60
Maximum power current (I_{pm})	8.20 A
Short circuit current (I_{sc})	8.78 A
Maximum power voltage (V_{pm})	30.50 V
Open circuit voltage (V_{oc})	38 V

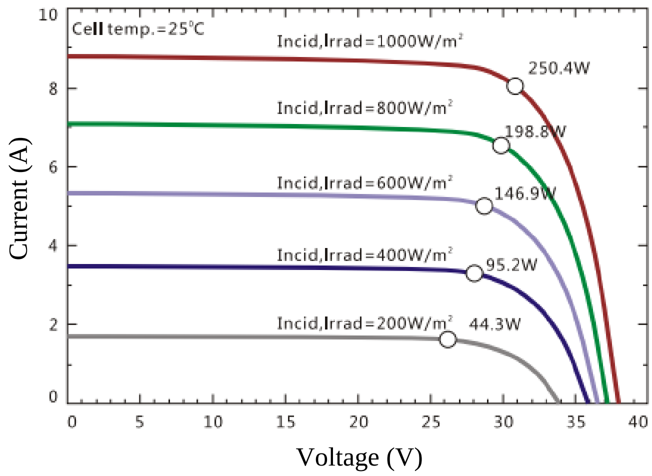

Fig. 4. I-V curves under different solar irradiation.

Table 2. The converter specifications.

Components	Value
Output voltage (V_o)	340 V
Switching frequency (f_{sw})	60 kHz
Power (P)	250 W
Turns ratio (N)	1:2.4
MOSFETs (S_1, S_2)	IRFP4227pbf
Diodes (D_1 , D_2, D_{o1}, D_{o2})	MUR1560
Capacitors (C_1, C_2)	2 μF
Output capacitors (C_{o1}, C_{o2}, C_{o3})	100 μF
Magnetizing Inductance (L_m)	9 μH
Leakage Inductance (L_{kp}, L_{ks})	0.174 μH, 1 μH

The simulation results for the proposed system are obtained at full load condition. Also, for evaluation performance of the MPPT method, the solar irradiation are changed instantly from 1000 W/m^2 to 600 W/m^2. Figure 5 shows ZVS turn on of the MOSFETs S_1, S_2 with input signals (V_{GS1}), (V_{GS2}) and primary and magnetizing current of the coupled inductor. In this figure, ZVS turn on of all MOSFETs is clearly depicted. Figure 6 shows ZCS turn off of the diodes D_1, D_2, D_{o1} and D_{o2}. Thus the losses of the diodes caused by the reverse recovery issue is decreased. The ZVS and ZCS soft switching process improves the conversion efficiency of the converter.

The PV panel current (I_{PV}), voltage (V_{PV}) and the converter output current (I_{out}), voltage (V_{out}) waveforms obtained by PSIM simulation are shown in Fig. 7. The range of input and output voltage of the converter is 30 V-340 V. It can be observed that the converter with coupled inductor and resonant voltage multiplier circuit provides high output voltage under different irradiation conditions. The performance of the MPPT method in rapidly changing solar irradiation is confirmed.

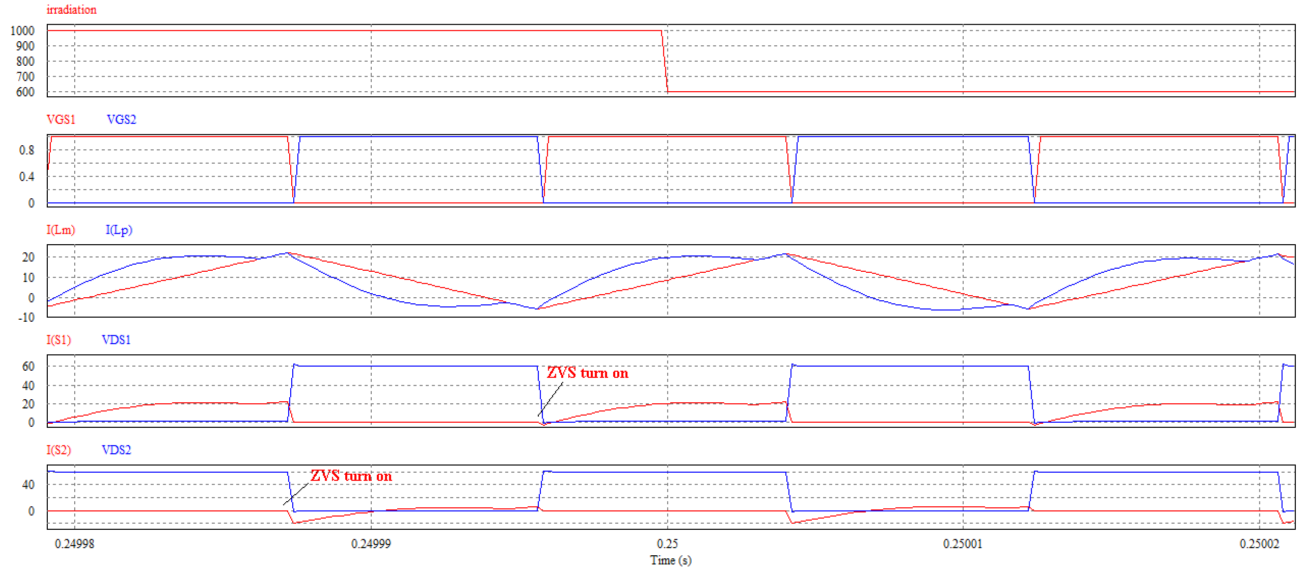

Fig. 5. ZVS turn on of the MOSFETs S_1, S_2 with V_{GS1}, V_{GS2} and inductor magnetizing and primary current.

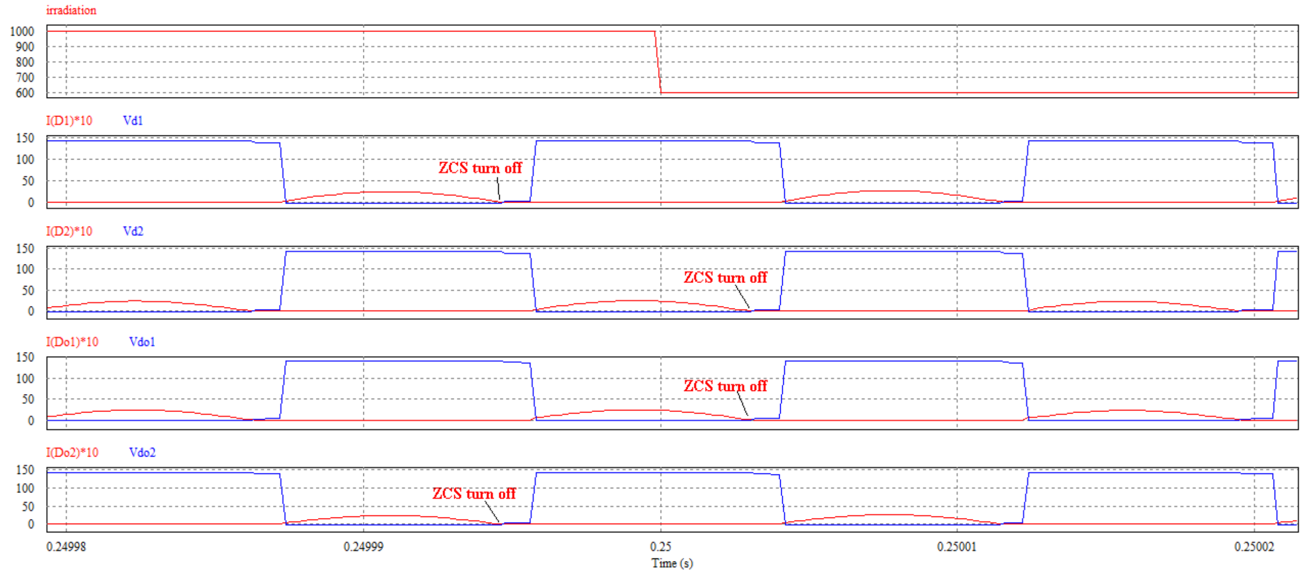

Fig. 6. ZCS turn off of the diodes D_1, D_2, D_{o1} and D_{o2}.

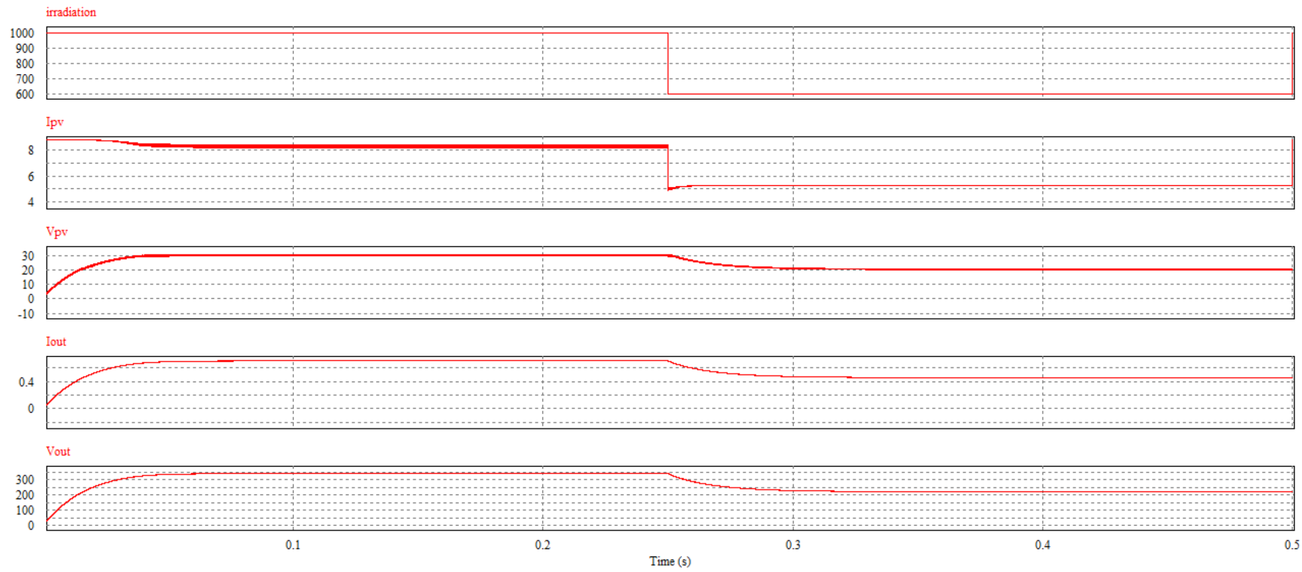

Fig. 7. PV panel I_{PV}, V_{PV} and converter I_{out}, V_{out} waveforms under solar irradiation change.

4. Conclusion

In this paper, the non-isolated high voltage gain DC/DC boost converter with coupled inductor and resonant quadrupler circuit for PV systems is analyzed. The PSIM simulations are realized to confirm the soft switching process of the converter. The high voltage gain is realized without utilizing high duty cycle or large magnetic components which a main advantage over the conventional converters. Thus, the efficiency is improved by the low on-state resistance $R_{DS(\mathrm{ON})}$ MOSFETs and the ZVS turn on of the all MOSFETs. The reverse recovery losses are decreased and the quasi-resonant quadrupler circuit provides the ZCS turn off of all diodes. Therefore, the proposed system is a proper choice for the PV systems.

References

[1] J. M. Guerrero, F. Blaabjerg, T. Zhelev, K. Hemmes, E. Monmasson, S. Jemei, M. P. Comech, R. Granadino, J. I. Frau, "Distributed generation: toward a new energy paradigm", IEEE Industrial Electronics Magazine, vol. 4, no. 1, pp. 52-64, March 2010.

[2] S. Hema, A. Arulmathy, V. Saranya and S. Yugapriya, "High voltage gain soft switching converter for solar energy AC and DC applications", International Conference on Power and Embedded Drive Control (ICPEDC), Chennai, 2017, pp. 326-332.

[3] E. Mamarelis, G. Petrone and G. Spagnuolo, "Design of a sliding-mode-controlled SEPIC for PV MPPT applications", IEEE Transactions on Industrial Electronics, vol. 61, no. 7, pp. 3387-3398, July 2014.

[4] C. W. Tan, T. C. Green and C. A. Hernandez-Aramburo, "Analysis of perturb and observe maximum power point tracking algorithm for photovoltaic applications", IEEE 2nd International Power and Energy Conference, Johor Bahru, 2008, pp. 237-242.

[5] F. Boico and B. Lehman, "Study of different implementation approaches for a maximum power point tracker", IEEE Workshops on Computers in Power Electronics, Troy, NY, 2006, pp. 15-21.

[6] B. Liu, S. Duan, F. Liu and P. Xu, "Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array", 7th International Conference on Power Electronics and Drive Systems, Bangkok, 2007, pp. 637-641.

[7] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru and R. Teodorescu, "On the perturb-and-observe and incremental conductance MPPT methods for PV systems", IEEE Journal of Photovoltaics, vol. 3, no. 3, pp. 1070-1078, July 2013.

[8] M. Das and V. Agarwal, "A novel, high efficiency, high gain, front end DC-DC converter for low input voltage solar photovoltaic applications", IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, 2012, pp. 5744-5749.

[9] S. Sathyan, H. M. Suryawanshi, M. S. Ballal and A. B. Shitole, "Soft-switching DC–DC Converter for distributed energy sources with high step-up voltage capability", IEEE Transactions on Industrial Electronics, vol. 62, no. 11, pp. 7039-7050, Nov. 2015.

[10] S. Sathyan, H. M. Suryawanshi, A. B. Shitole and G. G. Talapur, "Soft switched high voltage gain boost integrated flyback converter", IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Trivandrum, 2016, pp. 1-6.

[11] S. Sathyan, H. M. Suryawanshi, B. Singh, C. Chakraborty, V. Verma and M. S. Ballal, "ZVS–ZCS high voltage gain integrated boost converter for DC microgrid", IEEE Transactions on Industrial Electronics, vol. 63, no. 11, pp. 6898-6908, Nov. 2016.