

Analysis and Design of A Zero Voltage Transition Dc-Dc Boost Converter

Genesia C Tavares

Electrical and Electronics Engineering Department
Goa college of Engineering, Farmagudi,
Ponda, Goa – 403401

Noah Dias

Electrical and Electronics Engineering Department
Goa college of Engineering, Farmagudi,
Ponda, Goa – 403401

Abstract— In the last few years, there is an enormous growth in Renewable energy sources. During the extraction of electric power from renewable sources, dc-dc converters play a very significant role. This paper, proposes a boost converter wherein the switching of the main switch is done under Zero Voltage Transition. Here the proposed converter is modeled for a load of 250W. The auxiliary circuit which aids in the soft-switching resonates for a small portion of the switching cycle of the converter and enables the soft transition of the switch from ON state to OFF state and vice versa. This will thus help in improving the converter efficiency by reducing the losses that occur due to hard transition of the switches. The converter is modeled in MATLAB simulink.

Keywords—Boost converter, Auxilliary circuit, Zero voltage switching, Zero current switching.

I. INTRODUCTION

The conduction losses are very low in conventional hard switching converters, but the efficiency is low due to high switching losses [1] [2]. Thus, in order to make the switching transitions at either zero-voltage condition or zero current condition the technique of soft switching is introduced, so that the main portion of losses can also be reduced and the efficiency of the converters can be highly improved [2].

In Power Electronic converters, switching in any case when the converter is ON, the power losses are zero. During the OFF state the current will not pass through the switch hence there will not be any power losses. Whenever the switch goes from ON state to OFF state and OFF state to ON state power losses will occur if we do not have any way to reduce either the current or voltage to zero [1]. This happens in hard-switching converters and power losses will occur if there will be a voltage applied across and a current flowing through the switch. When the switching device turns ON or OFF, the voltage and current are huge and it will result in high losses. [2]

The power losses that occur when switching are the product of the voltage appearing across the terminals of the switch and the current which flows through the switch. The entire loss is the product of energy lost and the switching frequency. These losses are referred to as switching losses.

II. SOFT SWITCHING TECHNIQUES

A. Methods of Soft Switching

There are two methods for soft switching techniques to attain zero losses switching where either the voltage or current through the device is made zero during switching.

1. Zero current switching (ZCS)

Zero Current Switching is achieved with a switch having an inductor and a blocking diode in series [2]. The switch turns ON under ZCS as the rate of increase of current after the voltage turns zero is controlled by the inductor. The inductor does not allow sudden change in current, and hence it rises linearly. When a negative voltage appears across the combination of inductor and switch with a resonant circuit, the current flowing through the switch is automatically reduced to zero which turns OFF the switch under zero current switching.

2. Zero voltage switching (ZVS)

A switch which operates at ZVS will have an anti-parallel diode and a capacitor across it [2]. During turn OFF since the current goes to zero, the capacitor controls the rate of voltage increase taking place across the switch. Since the capacitor does not allow sudden changes in voltage, it will rise linearly. The turn OFF characteristics of the switch is controlled by a capacitor. This capacitor reduces the voltage rise as current flow reduces to zero.

B. Proposed Soft-Switching Boost Converter configuration

The zero-voltage DC-DC boost converter diagram is described in fig 1. It is basically a boost converter with a diode D1, input inductor L_{in} , main switch S1 and output capacitor C_o with a load R_{ld} . This circuit also contains additional circuit called the auxiliary circuit that will resonate for a small portion of time. This circuit consists of an inductor L_r , capacitor C_r , diodes D2 to D5 and a capacitor C_b which will feed the resonant energy to the load. The capacitance C_s is the parasitic capacitance of the switch S1 and not any external capacitance.

Zero Voltage Transition works on the principle that the auxiliary circuit will carry a current much higher than of the input current [1][4][5], but for a small period of the switching cycle so as to attain the soft switching in the converter. The main switch is perfectly turned on under ZVS and near ZCS by ZVT with a parallel resonance, the main switch is perfectly turned off under ZCS and ZVS by ZCT with a serial

resonance. The auxiliary switch is turned on with near ZCS [5].

Zero Voltage Transition converters have higher efficiency unlike the hard-switching converters due to the decreased switching loss.

This circuit reduces the conduction losses of all the switches; main and the auxiliary ones and also all the diodes. This can be done using a capacitor which will control the turn-off characteristics of the main switch, whose resonant energy will be dissipated into the load [1]. The capacitor C_b is the feed-forward capacitor that controls the turn-off of the main switch. The energy retained by this capacitor will be discharged fully to the load through the diodes D1 or D3. The rms current of the auxiliary circuit is considerably decreased hence the conduction power losses will be reduced too.

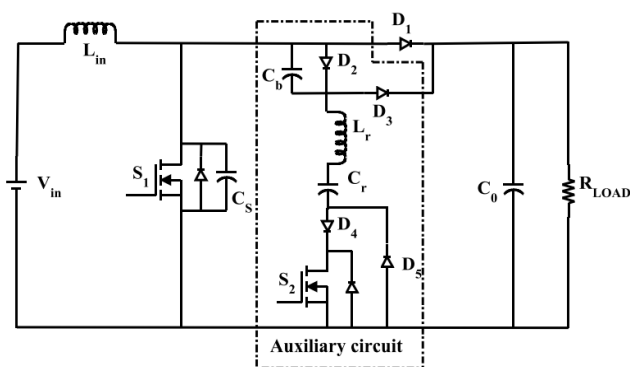


Fig. 1. Schematic of the proposed ZVT DC-DC Boost Converter

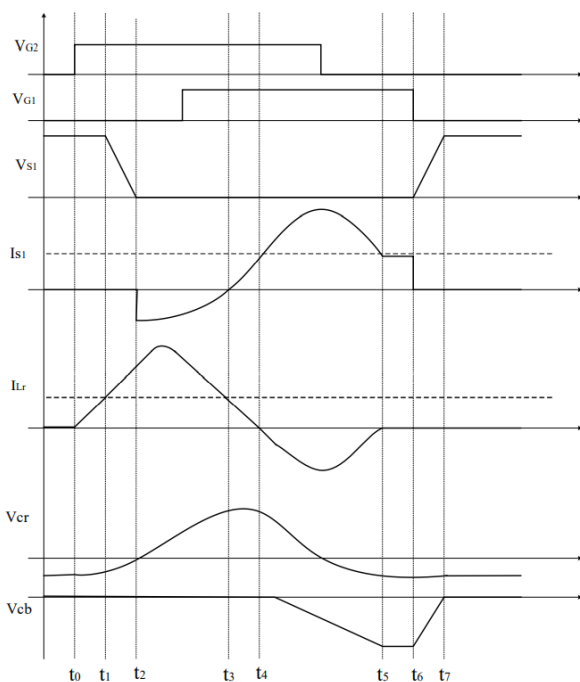


Fig. 2. Waveforms of the different modes of the DC-DC Boost converter

C. Modes of operation of the above converter.

We shall look at the circuit operation for one complete switching cycle, which is divided into seven parts. Each of these parts is explained with its equivalent circuit for that particular interval.

In the beginning the diode D1 supplies the output current and the circuit acts as a simple PWM boost converter. Under this condition circuit is shown in fig 3

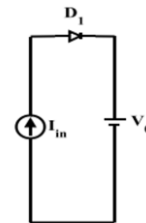


Fig. 3. Schematic of circuit in simple Boost mode

Mode 1[t0-t1]:

At t_0 switch S_2 is turned ON with Zero Current Transition due to the presence of auxiliary resonant inductor which is connected serially to it. The current will start to move slowly from the diode D1. The resonant inductor present will decrease the turn-off current rate through D1 that turns off under ZCS. Now the auxiliary current flowing through the inductor equals to the input current. The circuit for this interval is explained in fig 4.

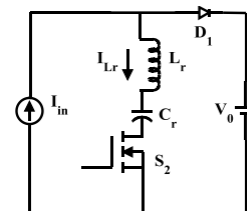


Fig. 4. Schematic of circuit for Mode 1

Mode 2[t1-t2]:

The auxiliary circuit current will keep on increasing here. The input current supplied shall be assumed to be constant since the input inductance will not allow sudden change in the current. Hence the capacitance C_s of the main switch S_1 will start to discharge into the auxiliary circuit to supply for the increased portion of the auxiliary current. In this interval the capacitance discharges completely. The equivalent circuit for this mode is explained in fig 5.

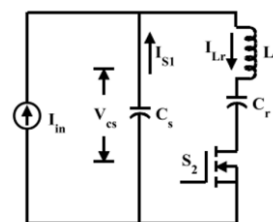


Fig. 5. Schematic of circuit for Mode 2

Mode 3[t2-t3]:

After t_2 the diode present in the main switch which is connected in anti-parallel to it starts conducting, which will make the voltage blocked by switch S_1 to be zero. This is the Zero Voltage period during which the switch S_1 must be supplied with the trigger. End of this interval the current carried by the auxiliary circuit equals the input supply current and the main switch is in a condition to start conduction. The equivalent circuit of the converter for this mode is explained in fig 6.

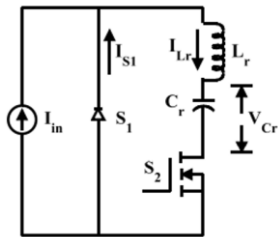


Fig. 6. Schematic of circuit for Mode 3

Mode 4[t3-t4]:

The auxiliary current stops the input supply current and the remaining of the input supply current starts flowing through the switch S_1 . During the end of this interval the current in the auxiliary circuit becomes zero. The equivalent circuit of the converter for this mode is explained in fig 7

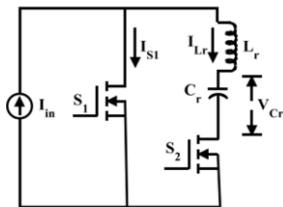


Fig. 7. Schematic of circuit for Mode 4

Mode 5[t4-t5]:

The direction of current flow in the auxiliary circuit changes and the negative portion of the resonant cycle will start during this interval. Diode D_4 in series with the switch makes the branch unidirectional and will not allow the switch S_2 to conduct and this current passes through the diode D_5 resulting in a Zero Voltage turn-off condition for S_2 . The current from the diode D_2 will pass to the capacitor C_b hence charging it. The equivalent circuit for this interval is explained in fig 8.

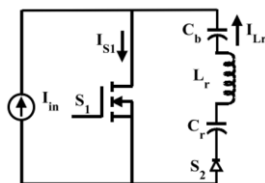


Fig. 8. Schematic of circuit for Mode 5

Mode 6[t5-t6]:

During the start of this interval, the auxiliary current will turn zero and the resonant cycle shall end here. The circuit will run as an equivalent PWM boost converter during its charging state. The equivalent circuit of the converter in this interval is explained in fig 9.

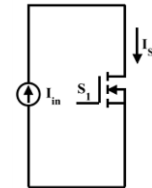


Fig. 9. Schematic of circuit for Mode 6

Mode 7[t6-t7]:

At t_6 during this interval S_1 is turned-off. The feed forward capacitor C_b will cause for the slow voltage rise across S_1 . Voltage across the capacitor C_b will reverse bias the diode D_1 and hence it will not conduct. The energy present in the capacitor C_b during the cycle discharges through the diode D_3 and when this voltage will be zero the diode D_1 starts conducting and the next switching cycle gets started. The equivalent circuit of the converter for this mode is explained in fig 10.

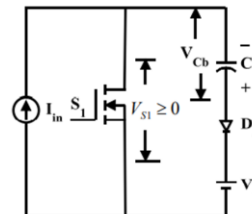


Fig. 10. Schematic of circuit for Mode 7

III. CONVERTER DESIGN

Design specifications:

The specifications for the design of the converter are given in Table I for a load of 250W.

Sr NO	Parameter	Specification	Value
1	Output power	P_{out}	250W
2	Output voltage	V_{out}	400V
3	Input voltage	V_{in}	90-265V
4	Switching frequency	F_{sw}	100kHz
5	Output voltage ripple	V_{rp}	1%
6	Input current peak ripple	ΔI_{rpp}	20%

Table I

Find Rload:

$$R_{Load} = V_{out}^2 / P_{out} = 640 \Omega; \quad (1)$$

For a conventional boost converter:

$$V_{out} / V_{in} = 1 / (1-D) \quad (2)$$

Hence D = 33.75%

Let D_{main} = 30% and D_{aux} = 3.75%

Output Capacitor:

The peak charging current of the capacitor is:

$$I_{chg_pk} = \frac{P_{Out}}{V_{Out}} = \frac{250}{400} = 0.625A \quad (3)$$

The voltage ripple across C₀ is:

$$V_{chg_pk} = \frac{I_{chg_pk}}{2 \cdot \pi \cdot f_r \cdot C_0} \quad (4)$$

$$C_0 = \frac{I_{chg_pk}}{2 \cdot \pi \cdot f_r \cdot V_{chg_pk}} = \frac{0.625}{2 \cdot \pi \cdot 120Hz \cdot (0.01 \cdot 400)} \quad (5)$$

$$= 207 \mu F$$

Input Inductor:

The maximum peak-peak ripple current is

$$\Delta I_{rpp} = I_{pk_max} \cdot \Delta I = \frac{\sqrt{2} P_{Out}}{\eta} \times 20\% = 0.827A \quad (6)$$

The maximum peak input current with ripple is

$$I_{rpk_max} = I_{pk_max} + \frac{\Delta I_{rpp}}{2} = 4.135 + \frac{0.827}{2} \quad (7)$$

$$= 4.55A$$

The duty ratio of the converter when maximum current occurs is

$$D_{pk} = 1 - \frac{\sqrt{2} \cdot V_{in_min}}{V_0} = 1 - \frac{\sqrt{2} \cdot 90}{400} = 0.682 \quad (8)$$

The input inductor value is calculated as follows

$$L_{in} = \frac{\sqrt{2} \cdot V_{in_min} \cdot D_{pk}}{\Delta I_{rpp} \cdot F_{sw}} = \frac{\sqrt{2} \cdot 90 \cdot 0.682}{0.827 \cdot 100kHz} \quad (9)$$

$$= 1050 \mu H$$

Resonant Inductor:

Assuming the value of $t_{rr} = 30ns$

$$L_r = \frac{3 \cdot t_{rr} \cdot V_{s2_pk}}{I_b} = \frac{3 \cdot 30ns \cdot (0.7 \cdot 400)}{3.700} \quad (10)$$

$$= 5.8 \mu H \approx 6 \mu H$$

Resonant Capacitor:

Assume Z_r = 0.21 pu

$$Z_r = \sqrt{\frac{L_r}{C_r}} \Rightarrow C_r = \frac{L_r}{Z_r^2} \quad (11)$$

$$Z_r = Z_{r_pu} \cdot Z_{rb} = 0.21 \times 107.469 = 22.568 \Omega \quad (12)$$

$$\therefore C_r = 11nF$$

Auxiliary capacitor C_b:

For proper design we select the curve K=3

$$K = \frac{C_r}{C_b} = 3 \quad (13)$$

$$C_b = \frac{C_r}{K} = 3.66nF \quad (14)$$

IV. SIMULATION DETAILS

A. Design parameters of the Boost converter

The converter circuit is simulated in MATLAB Simulink for a switching frequency of 100kHz, with the design parameters in Table II.

Sr NO	Parameter	Specification	Value
1	Resonant inductor	L _r	6μH
2	Resonant capacitor	C _r	11nF
3	Feed-forward capacitor	C _b	3.66nF
4	Boost inductor	L _{in}	1050μH
5	Output capacitor	C _o	470nF
6	Input voltage	V _{in}	265V
7	Switching frequency	F _{sw}	100kHz

Table II

B. PWM Signals of the main and auxiliary switch

For zero-voltage switching, delay is required in the PWM signal of the main switch, during which the auxiliary switch is turned ON [11]. The PWM signals of both switches is shown in fig 11.

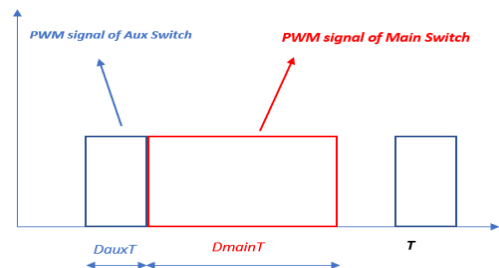


Fig 11. PWM signals S1 and S2

C. Simulink Circuit

Below fig 12 is the circuit design in MATLAB Simulink wherein the output voltage of 400V is obtained for 265V input.

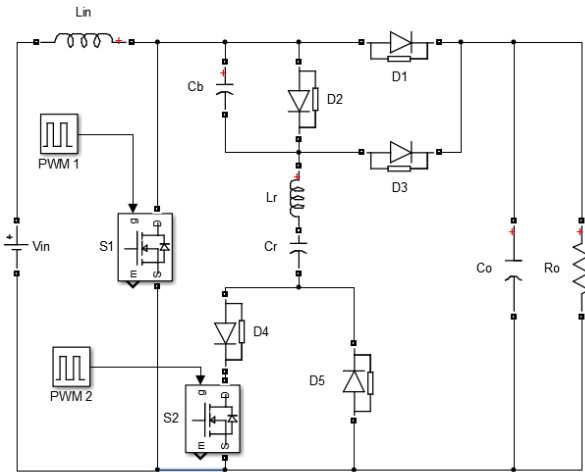
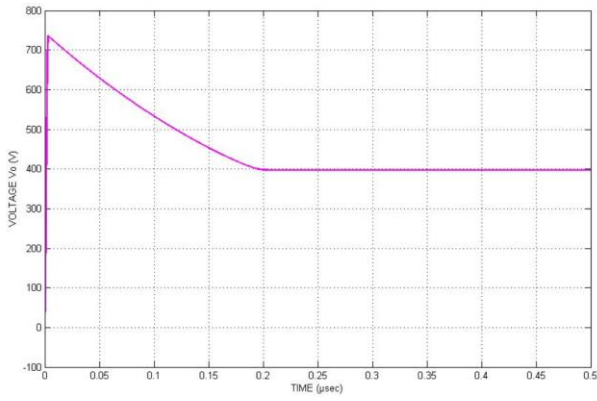
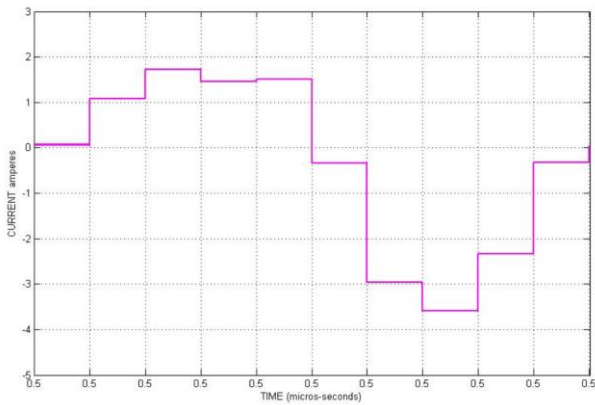


Fig 12. Simulation circuit

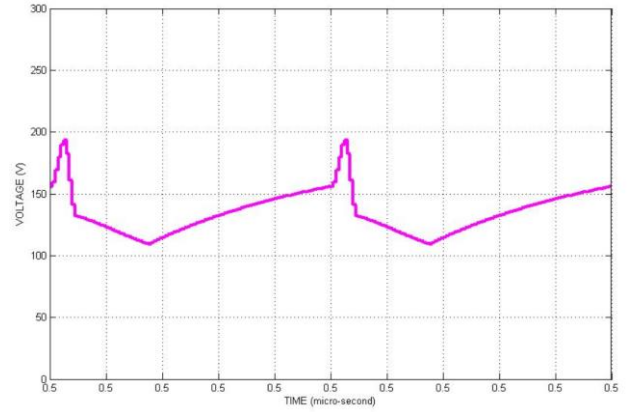
D. Simulation results



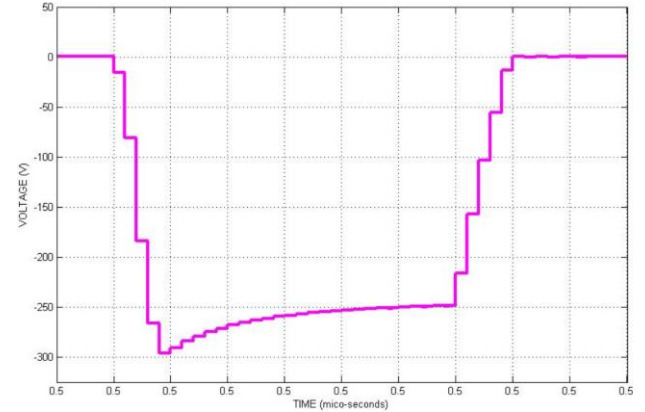
(a) Output Voltage = 400V



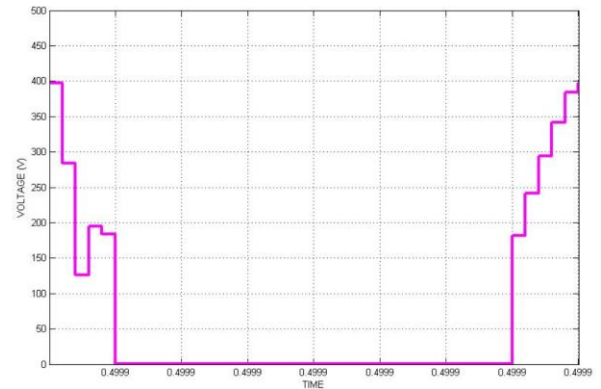
(b) Auxiliary Inductor Current



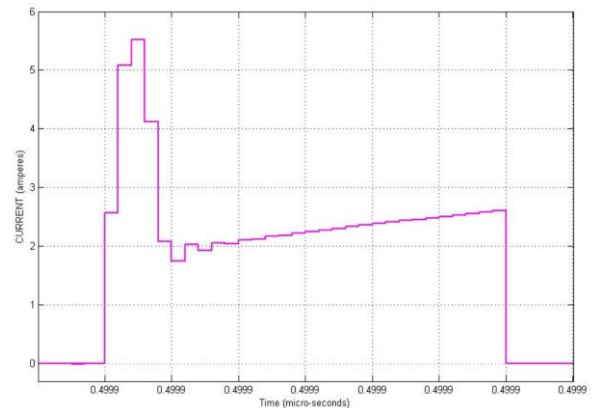
(c) Auxiliary Capacitor Voltage



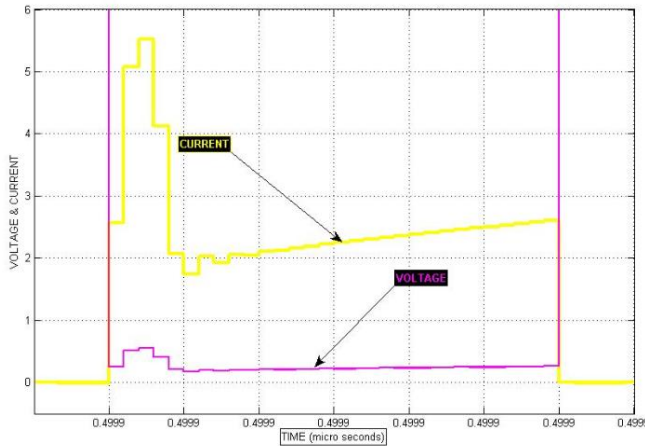
(d) Feed Forward Capacitor Voltage



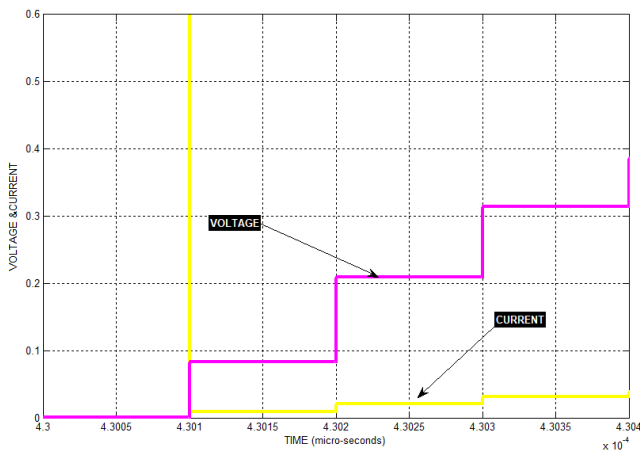
(e) Main Switch S1 Voltage



(f) Main Switch S1 Current



(g) ZVS ON of Main Switch S1



(h) ZCS ON of S2

CONCLUSION

In this paper a DC-DC Boost converter with soft switching techniques is designed and analyzed. The proposed converter decreases the switching losses and increases the efficiency of the converter. The converter uses an auxiliary resonant circuit in order to achieve ZVS. The detailed design and analysis are discussed. MATLAB Simulink is used to verify the operation and performance of the proposed converter.

REFERENCES

- [1] Nikhil Jain, Praveen K. Jain, Fellow, IEEE, and Géza Joós, Senior Member, IEEE
- [2] Analysis and design of a zero voltage transition DC-DC boost converter for photovoltaic energy system. By Anusha, V (2014) MTEch thesis.
- [3] Song, I., Jung, D., Ji, Y., Choi, S., Jung, Y., & Won, C. (2011). A soft switching boost converter using an auxiliary resonant circuit for a PV system. 8th International Conference on Power Electronics - ECCE Asia. doi:10.1109/icpe.2011.5944781
- [4] G.Moschopoulos, P.Jain, Y.Liu and Geza Joos, "A Zero Voltage Switched PWM Boost Converter with an Energy Feedforward Auxiliary Circuit," IEEE Transactions on Power Electronics, vol.14, paper 653-662, July 1999.

- [5] Hacı Bodur and A. Faruk Bakan, "A new ZVT-PWM DCDC converter," IEEE Trans. on Power Electronics, vol. 17, no. 1, pp. 40-47, January 2002.
- [6] Zhao, R., Pan, J., & Hui, J. (2007). :A Novel Soft-Switching Boost PFC with a Passive Snubber". 2007 2nd IEEE Conference on Industrial Electronics and Applications. doi:10.1109/iciea.2007.4318651.
- [7] K. M. Smith and K. M. Smedley, "A comparison of voltage mode soft switching methods for PWM converters," IEEE Trans. Power Electron., vol. 12, pp. 376-386, Mar. 1994.
- [8] L. Yang and C. Q. Lee, "Analysis and design of boost zero-voltage-transition PWM converter," in IEEE Appl. Power Elec. Conf. Rec., 1993, pp. 707-713
- [9] G. Hua, C.-S. Lieu, Y. Jiang, and F. C. Lee, "Novel zero-voltage-transition PWM converters," IEEE Trans. Power Electron., vol. 9, pp. 213-219, Mar. 1994.
- [10] Sang-Hoon Park, Gil-Ro Cha, Yong-Chae Jung and Chung-Yuen Won, "Design and Application fro PV Generation System Using a Soft-Switching Boost Converter with SARC," IEEE Transactions on Industrial Electronics, vol.57, no.2, February 2010.
- [11] John Bazinet and John A.O'Connor, "Analysis and Design of a Zero Voltage Transition Power Factor Correction Circuit," Unitode Integrated Circuits Merrimack, NH 03054.
- [12] Husev, O., Liivik, L., Blaabjerg, F., Chub, A., Vinnikov, D., & Roasto, I. (2015). Galvanically Isolated Quasi-Z-Source DC-DC Converter With a Novel ZVS and ZCS Technique. IEEE Transactions on Industrial Electronics, 62(12), 7547-7556.
- [13] Bano, M. J., & Kowser, F. (2014). Soft-switching boost converter with an auxiliary resonant circuit. 2014 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014].