International Journal of Applied Power Engineering (IJAPE)
Vol. 10, No. 1, March 2021, pp. 68~79
ISSN: 2252-8792, DOI: 10.11591/ijape.v10.i1.pp68-79

Single switch Z-source/quasi Z-source DC-DC converters

V. Saravanan[1], M. Sabitha[2], V. Bindu[3], Venkatachalam K M[4], M. Arumugam[5]
Department of Electrical and Electronics Engineering, Arunai Engineering College, Anna University, Tamil Nadu, India

Article Info

Article history:

Received Apr 23, 2020
Revised Jun 7, 2020
Accepted Oct 16, 2020

Keywords:

DC-DC power conversion
Photovoltaic
Voltage boosting ability
Voltage gain
Z-source converter

ABSTRACT

This paper analyzes a family of high step up single switch switched capacitor boost converters and Z-source/quasi Z-source dc-dc converters to provide high output dc voltage gain with single stage conversion having low voltage stress on active switches, capacitors, and diodes. The operating principles, parameters design guideline of these converters are presented along with simulation results. The discussed topologies in this paper are aimed to increase the conversion system reliability and efficiency with decreased cost, volume, and weight. These power converter topologies are used for various applications such as photovoltaic (PV) systems, wind energy conversion, fuel cells, uninterruptible power systems, motor drives, energy storage systems, electric vehicle and power factor correction. Simulations are carried out in MATLAB/Simulink environment.

Corresponding Author:

V. Saravanan
Department of Electrical and Electronics Engineering
Arunai Engineering College, Anna University
Tiruvannamalai 606 603, Tamil Nadu, India
Email: vsaranaec@yahoo.co.in

1. INTRODUCTION

Photovoltaic (PV) applications, low voltage DC grid systems, fuel cell systems, grid connected inverters, electric vehicles, motor drives and electronic loads requires a desired DC link voltage either at the point of coupling or at the subsequent power converter arrangements, which should have constant or regulated DC voltage. However in reality, output DC voltages derived out from these DC sources such as PV systems are not uniform due to various reasons like source variability, intermittency and absence of appropriate power converter topologies. To avoid these issues, various DC power converter topologies are developed by various authors having the features of regulated voltage with adequate voltage gain are illustrated as mentioned in [1-7]. They had realized these necessities with the help of isolated/non-isolated, conventional boost/buck-boost, resonant converter topologies having high step up DC gains, when operated at certain duty ratio. However it produces a large current ripple in the inductor leading to higher conduction and switching loss. DC-DC converters having high step up voltage gain experiences variety of problems like voltage stress, power losses due to interfacing transformers. Switching losses in the diode and voltage unbalance on the output capacitors affect the performance of these converters with low efficiency in the form of reverse recovery/electromagnetic interference problems [8-17]. In this paper, switched capacitor ZSI and QZSI converter family based topologies are deliberated for the application of DC-DC conversion. The comparative key factors influencing the use of the proposed topologies are: continuous input current and voltage gain, connection of source and load at the common ground point, voltage stress across the capacitor and quantity of diode and switching devices. By employing a single active switch (MOSFET or IGBT), these converters can realize better DC-DC voltage conversion at duty cycle of value ranging from 0.1 to 0.9. Also the buck and boost features of this converters subjected to duty ratio.

2. BASIC SWITCHED CAPACITOR BOOST CONVERTER TOPOLOGIES

A third order boost DC-DC converter is presented in Figure 1, which contains of single switch S_W, diodes (D_1 and D_2), capacitors (C_1 and C_2), an inductor L and resistive load R_L. Following equations associated with boost converter are briefed in [18].

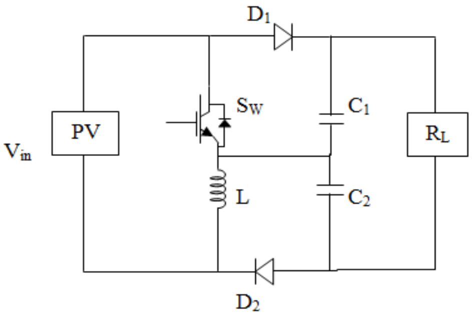

Figure 1. Third order boost DC-DC converter

The boost conversion factor, M is given by:

$$M = \frac{2-D}{1-D} \tag{1}$$

Voltage stress on active switch, V_s is given by:

$$Vs = \frac{Vin}{1-D} \tag{2}$$

Voltage stress across diodes, V_d is given by:

$$V_d = \frac{V_{in}}{1-D} \tag{3}$$

Figures 2 and 3 are examples of switched capacitor boost converter topologies. To obtain a better voltage gain, switched capacitors (C_1 and C_2) are connected in series to supply the load. When the switch S_W is turned on, input voltage source is connected to C_1 in series and load is connected to C_2 load. Following equations associated with switched capacitor DC-DC converter are briefed [19, 20]. The boost conversion factor, M is given by:

$$M = \frac{2}{1-D} \tag{4}$$

Voltage stress on active switch, V_s and voltage stress across diodes, V_d is given by:

$$Vs = Vd = \frac{Vout}{2} \tag{5}$$

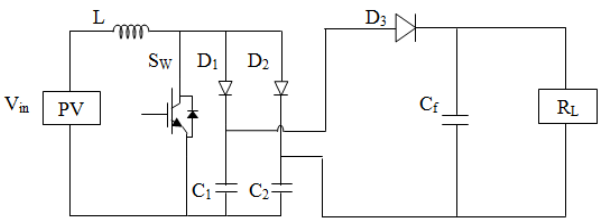

Figure 2. Switched capacitor DC-DC converter (topology 1) [16]

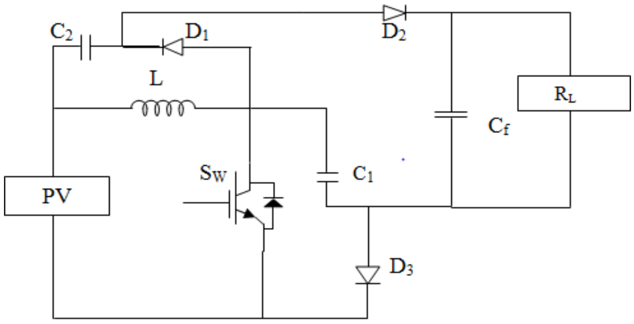

Figure 3. Switched capacitor DC-DC converter (topology 2)

3. Z-SOURCE DC-DC CONVERTER TOPOLOGIES

According to Figure 4, the Z-source converter is operating as a DC-DC boost operation, which consists of diode D_1, two identical inductors (L_1 and L_2) and (C_1 and C_2) are coupled to attain the Z-source operation. Switch (S_W) is active switch and L_f and C_f are second order low pass filters. The converter supplies power to the resistive load (R_L). By the symmetry of Z network, inductor $L_1$and L_2 ranges are selected equal to L; capacitor C_1 and C_2 ranges are selected equal to C, therefore $i_{L1}= i_{L2} = i_{L,}$ $V_{L1} = V_{L2} = V_L$ and $V_{C1} = V_{C2} = V_C$. The circuit has a higher input to output DC voltage boost conversion factor and isolates the source and load in case of a short circuit at the load side. MOSFET is switched at a switching frequency of $fs = 1/Ts$ and duty cycle of the switch D is given by $D = Ton/Ts,$ where Ton is pulse width and Ts is the switching period of PWM (pulse width modulation) signal. Following equations associated with Z-source DC-DC converter are briefed [21, 22].

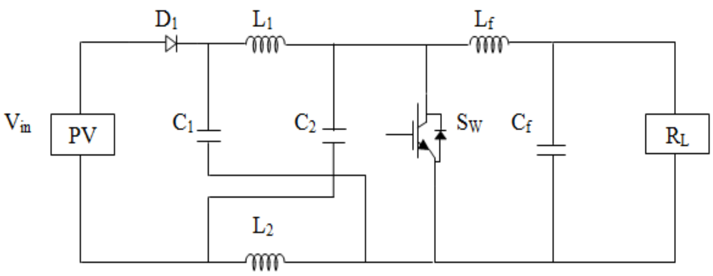

Figure 4. Z-source DC-DC converter (topology 1)

The boost conversion factor, M is given by:

$$M = \frac{1-D}{1-2D} \qquad \text{for } D < 0.5 \qquad (6)$$

Voltage stress on active switch, Vs is given by:

$$Vs = \frac{Vin}{1-2D} \qquad (7)$$

Voltage stress across diodes, Vd is given by:

$$Vd = \frac{Vin}{1-2D} \qquad (8)$$

Voltage stress across diodes, V_d is given by:

$$Vc = \frac{1-D}{1-2D}\,Vin \quad (9)$$

The modified version of Z source DC-DC converter as shown in Figure 5 consists of Z-source network (L_1, L_2, C_1, and C_2), a switch S_W, two diodes D_1 and D_2, a filter capacitor C_f and a load resistance R_L [23]. Both from Figures 5 and 6, the input source and load are located on the same side of the Z-source network, which share the same ground to produce high voltage gain with no additional components and low voltage stresses on the switch and diodes [24]. The other modified versions of Z-source DC-DC converter are shown in Figure 7 with additional diodes and capacitors. The Z-source network is consist of "D_1, L_1, L_2, C_1, C_2" and the switched capacitor network is consist of C_3, C_4, C_5, D_2, D_3, and D_4.

The boost conversion factor, M is given by:

$$M = \frac{2(1-D)}{1-2D} \qquad \text{for } D < 0.5 \quad (10)$$

Voltage stress on capacitors, Vc of C_1, C_2 can be expressed as:

$$Vc = \frac{1-D}{1-2D}\,Vin \quad (11)$$

Output voltage V_{out} is given by:

$$Vout = \frac{2(1-D)}{1-2D}\,Vin \quad (12)$$

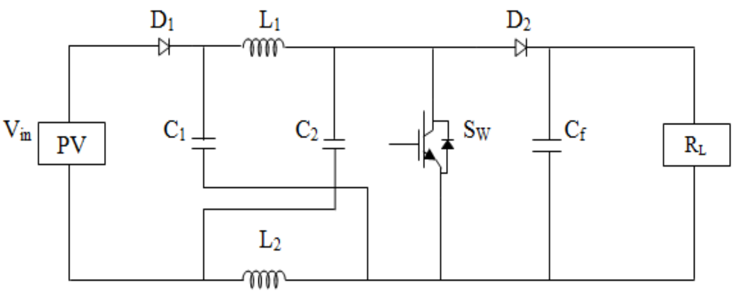

Figure 5. Z-source DC-DC converter (topology 2)

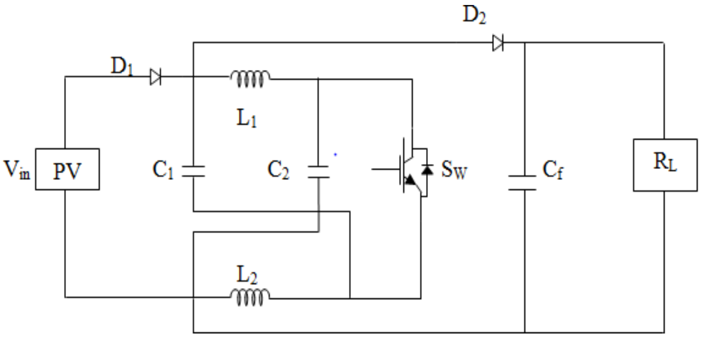

Figure 6. Z-source DC-DC converter (topology 3)

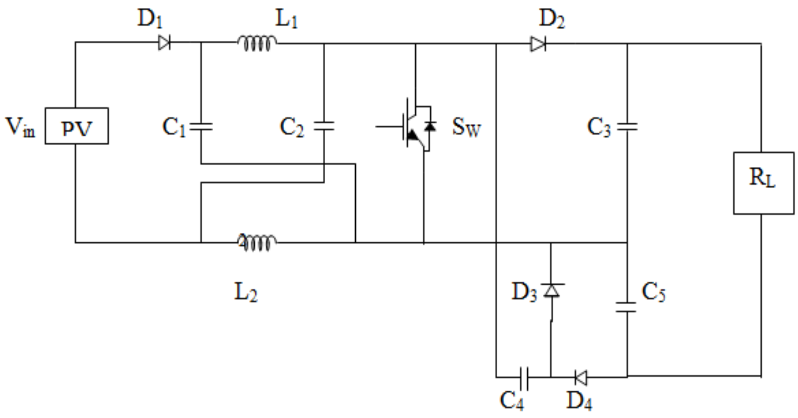

Figure 7. Z-source DC-DC converter (topology 4)

4. QUASI Z-SOURCE DC-DC CONVERTER TOPOLOGIES

The quasi Z-source converter is an exclusive Z-source network. It is connected between the input power source and switching circuit for the purpose of increase the DC output voltage of the converter by adjusting the shoot through (ST) duty ratio as illustrated in Figure 8 [25]. During the traditional operation state, only DC current goes through the inductors. During shoot through (ST) mode and non-shoot through mode, inductor current increases and decreases respectively. The other modified versions of quasi Z-source DC-DC converter topologies are exposed in Figures 9 and 10.

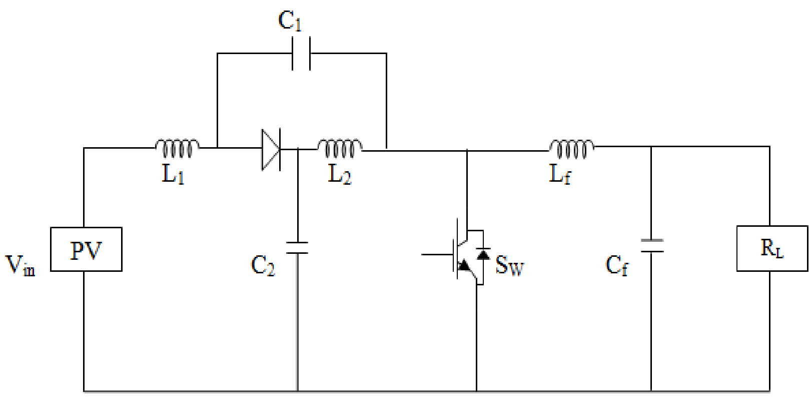

Figure 8. Quasi Z-source DC-DC converter (topology 1)

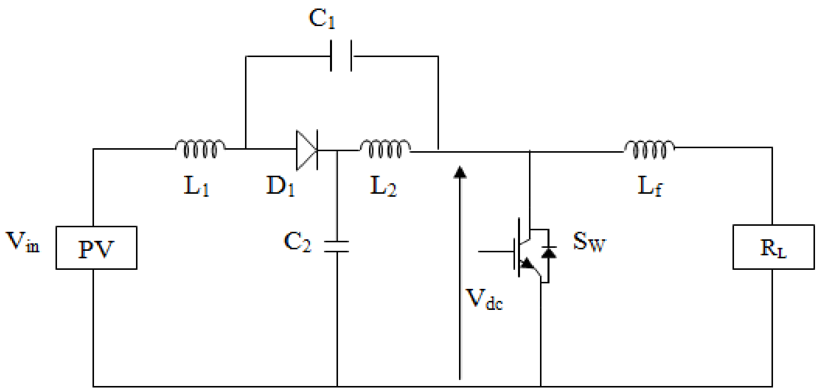

Figure 9. Quasi Z-source DC-DC converter (topology 2)

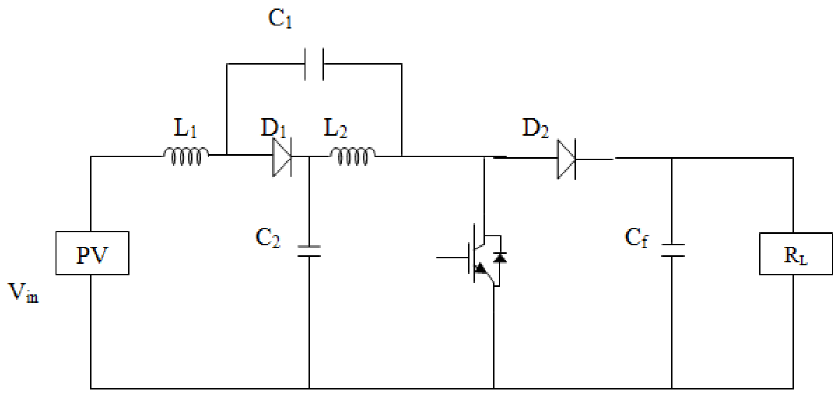

Figure 10. Quasi Z-source DC-DC converter (topology 3)

By the symmetry of Z network, inductor L1 and L2 ranges are selected equal to L; capacitor C1 and C2 ranges are selected equal to C. Then the value of i_{L1} and i_{L2} are equal to $i_{L,}$ V_{L1} and V_{L2} are equal to$V_{L,}$ V_{C1} and V_{C2} are equal to V_C. The system state equation is given by:

$$
\begin{aligned}
IL1 &= IL2 = \frac{(1-D)^2}{(1-2D)^2\ RL} Vin \\
VC1 &= \frac{D}{(1-2D)} Vin \\
VC2 &= \frac{1-D}{(1-2D)} Vin \\
IL &= \frac{(1-D)}{(1-2D)\ RL} Vin \\
Vdc &= \frac{1}{(1-2D)} Vin
\end{aligned}
\tag{13}
$$

Inductor current (I_L) is

$$IL = \frac{P}{Vin} \tag{14}$$

when the converter is operating at shoot through state mode, the maximum current ripple occurs due to the nature of the inductor. The range of current ripple (δ) is calculated according to (15):

$$\Delta IL = 2\ \delta\%\ IL \tag{15}$$

The value of the inductor is calculated according to (16):

$$L = \frac{VLDTS}{\Delta IL} \tag{16}$$

where D and Ts are the duty cycle at shoot through state and total switching time duration respectively.

In shoot through state operation mode, the ripple current of the converter is reduces because the inductor current (I_L) and capacitor current (IC) become equal. The voltage ripple of the converter is depends on VcδV%, the range of the capacitor is calculated according to (17). Quasi Z-source DC-DC converter topologies with switched capacitor network are shown in Figure 11 and Figure 12. The quasi Z-source network is included "L_1, $D_{1,}$ $L_{2,}$ C_1 and C_2" and the switched capacitor network is included C_3, D_4, C_4, D_5, C_5 and D_3 [26, 27]. Some of the very interesting Z-source DC-DC converter topologies of different configurations, better features with scaled down verifications are also presented in [28-30].

$$C = \frac{IL\ D\ TS}{VC\ \delta V\%} \quad (17)$$

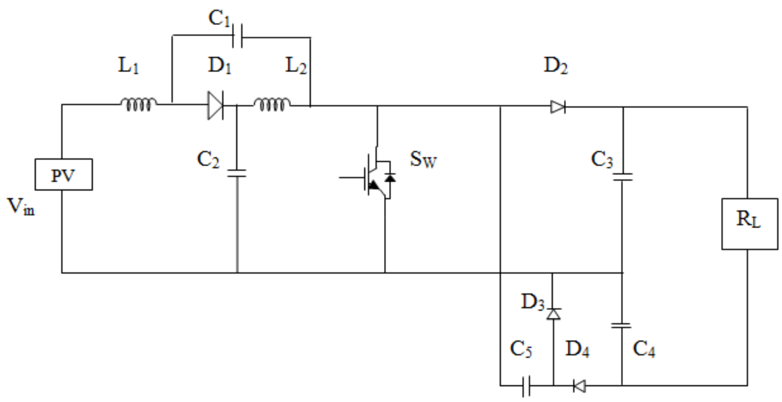

Figure 11. Quasi Z-source DC-DC converter (topology 4)

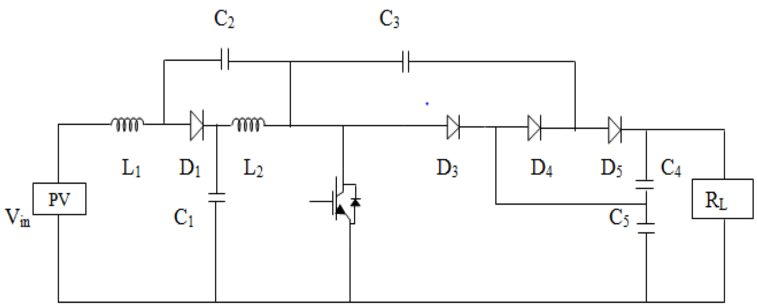

Figure.12. Quasi Z-source DC-DC converter (topology 5)

The boost conversion factor, M is given by:

$$M = \frac{2}{1-2D} \qquad \text{for D < 0.5} \quad (18)$$

Voltage stress on capacitors, Vc of C_1 to C_5 can be expressed as:

$$Vc1 = \frac{1-D}{2}\ Vout$$
$$Vc2 = \frac{D}{2}\ Vout \quad (19)$$
$$Vc3 = Vc4 = Vc5 = \frac{Vout}{2}$$

The inductor value of the Z-source network is calculated by using (20), ΔI_L is a maximum value of the current ripple.

$$L1 = L2 = \frac{D(1-D)Vin}{(1-2D)\ \Delta IL\ f} \quad (20)$$

The capacitor value of the Z-source network is calculated by using (21), ΔI_C is a maximum value of the voltage ripple.

$$C1 = \frac{2\,D\,Iout}{(1-2D)\,\Delta VC\,f}$$
$$C2 = \frac{2\,D^2\,Iout}{(1-2D)\,\Delta VC\,f}$$
$$C3 = \frac{2\,Iout}{\Delta VC\,f} \qquad (21)$$
$$C4 = \frac{4DIout}{(1-2D)^2\,\Delta VC\,f}$$
$$C5 = \frac{(1+\mathrm{D})\,Iout}{\Delta VC\,f}$$

5. RESULTS AND DISCUSSION

The analysis of these discussed converter topologies are based on the following assumptions. 1) Diode and switching devices are operating at ideal conditions, 2) The resistor, capacitor and inductor are assumed as frequency dependent, time invariant linear elements. 3) The value of the capacitor is assumed large with constant voltage in one switching time duration. 4) The converters operating in continuous conduction mode.

The chosen simulation values for all the discussed topologies are: V_{in} = 12 V, source side inductors L_1 and L_2 values are 330 μH and capacitors C_1 and C_2 values are 470 μF, filter values L_f and C_f values are 330 μH and 470 μF respectively, f_s= 40 kHz, duty cycle = 0.1 to 0.99 for switched capacitor DC-DC converter topologies and duty cycle = 0.1 to 0.6 for Z-source/quasi Z-source DC-DC converter topologies. Resistive load R_L of value 50Ω is chosen for all these converter topologies. Simulations are carried for these topologies for the corresponding duty ratio for the selected range in steps of 0.05 and the obtained output DC voltages are noted. The maximum output DC voltage for the corresponding duty ratio is presented in the following tables and the values for these ranges are shown in respective figures.

It can be observed that switched capacitor converter topologies exhibit very higher voltage gain for the duty ratio above 0.9 and Z-source/quasi Z-source topologies does the same at a duty ratio value ranging from 0.44 to 0.48. Table 1 gives the performance of switched capacitor DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 13 plots the output DC voltage of these converter topologies as a role of D.

Table 1. Performance of switched capacitor DC-DC converter topologies

Switched capacitor DC-DC converter topologies	Maximum output DC voltage(Volts)	Corresponding duty ratio
Third order boost DC-DC converter	135.4	0.95
Switched capacitor DC-DC converter (topology 1)	132.1	0.92
Switched capacitor DC-DC converter (topology 2)	213.2	0.93

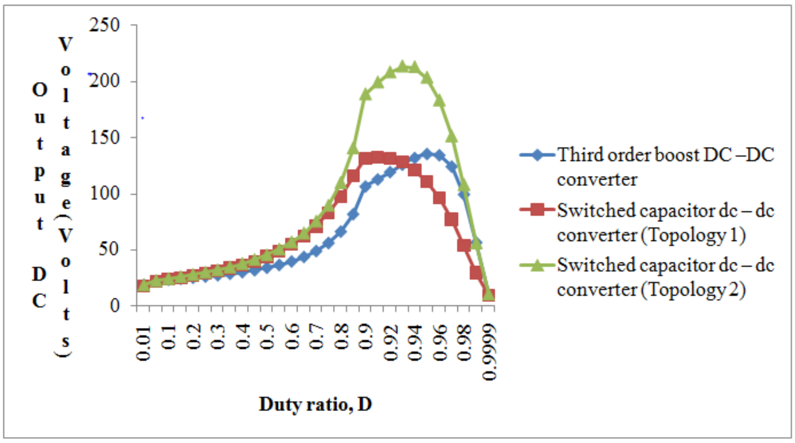

Figure 13. Output DC voltage of switched capacitor DC-DC converter topologies as a function of D

Table 2 gives the performance of Z-source DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 14 plots the output DC voltage of these Z-source DC-DC converter topologies as a role of D. Table 3 gives the performance of quasi Z-source DC-DC converter topologies, where the maximum output DC voltage obtained is tabulated with its corresponding duty ratio and Figure 15 plots the output DC voltage of these quasi Z-source DC-DC converter topologies as a function of D. It is observed that output DC voltage of switched capacitor DC-DC converter topologies are high at higher duty ratio, whereas Z-source/quasi Z-source DC-DC converter topologies exhibit better DC voltage boosting at a value of 0.4 which results in minimum stress to the switch.

Table 2. Performance of Z-source DC-DC converter topologies

Z source DC-DC converter topologies	Maximum output DC voltage (Volts)	Corresponding duty ratio
Topology 1	87.39	0.48
Topology 2	88.23	0.47
Topology 3	87.56	0.47
Topology 4	85.56	0.44

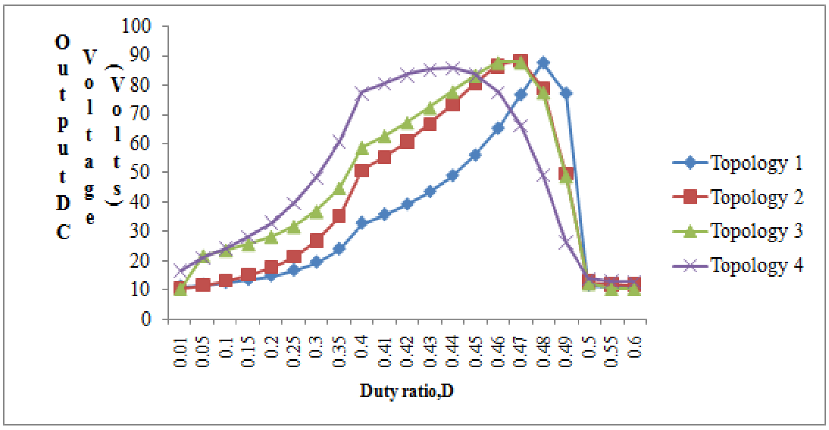

Figure 14. Output DC voltage of Z-source DC-DC converter topologies as a function of D

Table 3. Performance of quasi Z-source DC-DC converter topologies

Quasi Z source DC-DC converter topologies	Maximum output DC voltage (Volts)	Corresponding duty ratio
Topology 1	87.39	0.48
Topology 2	134.3	0.48
Topology 3	88.23	0.47
Topology 4	79.27	0.44
Topology 5	85.56	0.44

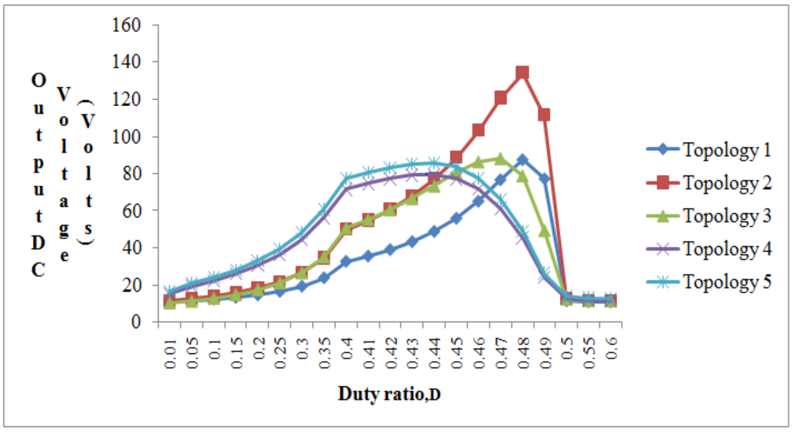

Figure 15. Output DC voltage of quasi Z-source DC-DC converter topologies as a function of D

6. CONCLUSION

A family of switched capacitor and Z-source/quasi Z-source DC-DC converter topologies for photovoltaic power applications has been worked in this paper. Steady state analysis of these topologies has been discussed with detailed simulation results to verify its effectiveness. Output DC voltage obtained for all the converter topologies is presented in a comprehensive manner to meet the requirement of various applications. The converters discussed in this paper have the advantages such as continuous input current, reduced capacitor voltage stress, low voltage stress across the output diode and power switches. Also, these converters are suitable for photovoltaic applications where a varying low DC input voltage is converted to a high stabilized DC output voltage.

ACKNOWLEDGEMENTS

This work supported by Indo-Sri Lanka Joint Research Program, Department of Science and Technology, Ministry of Science &Technology, Government of India (ICD -3425.60.798.14.00.31&35).

REFERENCES

[1] W. Li and X. He, "Review of Nonisolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications," in *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1239-1250, April 2011, doi: 10.1109/TIE.2010.2049715.

[2] B. Gu, J. Dominic, J. Lai, Z. Zhao and C. Liu, "High Boost Ratio Hybrid Transformer DC-DC Converter for Photovoltaic Module Applications," in *IEEE Transactions on Power Electronics*, vol. 28, no. 4, pp. 2048-2058, April 2013, doi: 10.1109/TPEL.2012.2198834.

[3] Y. Hsieh, J. Chen, T. Liang and L. Yang, "Novel High Step-Up DC-DC Converter for Distributed Generation System," in *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1473-1482, April 2013, doi: 10.1109/TIE.2011.2107721.

[4] K. Park and Z. Chen, "A Double Uneven Power Converter-Based DC-DC Converter for High-Power DC Grid Systems," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 12, pp. 7599-7608, Dec. 2015, doi: 10.1109/TIE.2015.2458301.

[5] W. Chen, X. Wu, L. Yao, W. Jiang and R. Hu, "A Step-up Resonant Converter for Grid-Connected Renewable Energy Sources," in *IEEE Transactions on Power Electronics*, vol. 30, no. 6, pp. 3017-3029, June 2015, doi: 10.1109/TPEL.2014.2336893.

[6] A. Chub, D. Vinnikov, E. Liivik and T. Jalakas, "Multiphase Quasi-Z-Source DC-DC Converters for Residential Distributed Generation Systems," in *IEEE Transactions on Industrial Electronics*, vol. 65, no. 10, pp. 8361-8371, Oct. 2018, doi: 10.1109/TIE.2018.2801860.

[7] G. R. Walker and P. C. Sernia, "Cascaded DC-DC Converter Connection of Photovoltaic Modules," in *IEEE Transactions on Power Electronics*, vol. 19, no. 4, pp. 1130-1139, July 2004, doi: 10.1109/TPEL.2004.830090.

[8] E. H. Ismail, M. A. Al-Saffar, A. J. Sabzali and A. A. Fardoun, "A Family of Single-Switch PWM Converters with High Step-Up Conversion Ratio," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 55, no. 4, pp. 1159-1171, May 2008, doi: 10.1109/TCSI.2008.916427.

[9] L. Yang, T. Liang and J. Chen, "Transformerless DC-DC Converters with High Step-Up Voltage Gain," in *IEEE Transactions on Industrial Electronics*, vol. 56, no. 8, pp. 3144-3152, Aug. 2009, doi: 10.1109/TIE.2009.2022512.

[10] A. Shahin, M. Hinaje, J. Martin, S. Pierfederici, S. Rael and B. Davat, "High Voltage Ratio DC-DC Converter for Fuel-Cell Applications," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 12, pp. 3944-3955, Dec. 2010, doi: 10.1109/TIE.2010.2045996.

[11] C. Pan and C. Lai, "A High-Efficiency High Step-Up Converter with Low Switch Voltage Stress for Fuel-Cell System Applications," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 6, pp. 1998-2006, June 2010, doi: 10.1109/TIE.2009.2024100.

[12] Y. Tang, D. Fu, T. Wang and Z. Xu, "Hybrid Switched-Inductor Converters for High Step-Up Conversion," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1480-1490, March 2015, doi: 10.1109/TIE.2014.2364797.

[13] B. Poorali, A. Torkan and E. Adib, "High Step-Up Z-Source DC-DC Converter with Coupled Inductors and Switched Capacitor Cell," in *IET Power Electronics*, vol. 8, no. 8, pp. 1394-1402, 8 2015, doi: 10.1049/iet-pel.2014.0200.

[14] K. Vijayalakshmi and C. R. Balamurugan, "Z-Source Multilevel Inverter based on Embedded Controller," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 6, no. 1, pp. 1-8, April 2017.

[15] Deepa Sankar and C. A. Babu, "Design and Analysis of a Novel Quasi Z Source based Asymmetric Multilevel Inverter for PV applications," *International Journal of Power Electronics and Drive System*, vol. 11, no. 3, pp. 1368-1378, 2020.

[16] S. Bala Kumar, Samuel Kefale, and Azath M., "Comparison of Z-Source EZ-Source and TZ-Source Inverter Systemsfor Wind Energy Conversion," *International Journal of Power Electronics and Drive System*, vol. 9, no. 4, pp. 1693-1701, Dec. 2018.

[17] M. Veerachary, "Third-order boost converter," in *IET Power Electronics*, vol. 11, no. 3, pp. 566-575, 2018, doi: 10.1049/iet-pel.2017.0186.

[18] X. Zhu, B. Zhang, Z. Li, H. Li and L. Ran, "Extended Switched-Boost DC-DC Converters Adopting Switched-Capacitor/Switched-Inductor Cells for High Step-up Conversion," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 5, no. 3, pp. 1020-1030, Sept. 2017, doi: 10.1109/JESTPE.2016.2641928.

[19] G. Wu, X. Ruan, and Z. Ye, "Nonisolated High Step-Up DC–DC Converters Adopting Switched-Capacitor Cell," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 1, pp. 383-393, Jan. 2015, doi: 10.1109/TIE.2014.2327000.

[20] G. Wu, X. Ruan and Z. Ye, "High Step-Up DC-DC Converter based on Switched Capacitor and Coupled Inductor," in *IEEE Transactions on Industrial Electronics*, vol. 65, no. 7, pp. 5572-5579, July 2018, doi: 10.1109/TIE.2017.2774773.

[21] V. P. Galigekere and M. K. Kazimierczuk, "Analysis of PWM Z-Source DC-DC Converter in CCM for Steady State," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 59, no. 4, pp. 854-863, April 2012, doi: 10.1109/TCSI.2011.2169742.

[22] M. K. Kazimierczuk, "Small-Signal Modeling of Open-Loop PWM Z-Source Converter by Circuit-Averaging Technique," in *IEEE Transactions on Power Electronics*, vol. 28, no. 3, pp. 1286-1296, 2012, doi: 10.1109/TPEL.2012.2207437.

[23] J. Zhang and J. Ge, "Analysis of Z-source DC-DC Converter in Discontinuous Current Mode," *2010 Asia-Pacific Power and Energy Engineering Conference*, Chengdu, 2010, pp. 1-4, doi: 10.1109/APPEEC.2010.5448927.

[24] H. Shen, B. Zhang, D. Qiu and L. Zhou, "A Common Grounded Z-Source DC–DC Converter With High Voltage Gain," in *IEEE Transactions on Industrial Electronics*, vol. 63, no. 5, pp. 2925-2935, May 2016, doi: 10.1109/TIE.2016.2516505.

[25] H. Liu, P. Liu and Y. Zhang, "Design and Digital Implementation of Voltage and Current Mode Control for The Quasi-Z-Source Converters," in *IET Power Electronics*, vol. 6, no. 5, pp. 990-998, May 2013, doi: 10.1049/iet-pel.2012.0366.

[26] Y. Zhang *et al*., "Wide Input-Voltage Range Boost Three-Level DC–DC Converter with Quasi-Z Source for Fuel Cell Vehicles," in *IEEE Transactions on Power Electronics*, vol. 32, no. 9, pp. 6728-6738, Sept. 2017, doi: 10.1109/TPEL.2016.2625327.

[27] Y. Zhang, C. Fu, M. Sumner and P. Wang, "A Wide Input-Voltage Range Quasi-Z-Source Boost DC-DC Converter With High-Voltage Gain for Fuel Cell Vehicles," in *IEEE Transactions on Industrial Electronics*, vol. 65, no. 6, pp. 5201-5212, June 2018, doi: 10.1109/TIE.2017.2745449.

[28] Y. Liu, H. Abu-Rub and B. Ge, "Front-End Isolated Quasi-Z-Source DC-DC Converter Modules in Series for High-Power Photovoltaic Systems-Part I: Configuration, Operation, and Evaluation," in *IEEE Transactions on Industrial Electronics*, vol. 64, no. 1, pp. 347-358, Jan. 2017, doi: 10.1109/TIE.2016.2598673.

[29] Y. Liu, H. Abu-Rub and B. Ge, "Front-End Isolated Quasi-Z-Source DC-DC Converter Modules in Series for High-Power Photovoltaic Systems-Part II: Control, Dynamic Model, and Downscaled Verification," in *IEEE Transactions on Industrial Electronics*, vol. 64, no. 1, pp. 359-368, Jan. 2017, doi: 10.1109/TIE.2016.2598675.

[30] J. Liu, J. Wu, J. Qiu and J. Zeng, "Switched Z-Source/Quasi-Z-Source DC-DC Converters with Reduced Passive Components for Photovoltaic Systems," in *IEEE Access*, vol. 7, pp. 40893-40903, 2019, doi: 10.1109/ACCESS.2019.2907300.

BIOGRAPHIES OF AUTHORS

V. Saravanan is carrying out R & D activities sponsored by various agencies of Government of India in the area of renewable energy systems and having teaching/industrial experience of about 16 years. He has published more than 70 research papers in National/International Journals/Conferences/Exhibitions.

M.Sabitha completed post graduation in power electronics and drives at Arunai Engineering College, Anna University, Chennai. Her area of interest includes power electronics and microgrid.

V. Bindu has a teaching experience of about 16 years. She had completed her post graduation in power electronics & drives with University Gold Medal from Anna University, Chennai in 2007. She has authored 10 papers in national/international journals. She consistently received best faculty Award for her service over these years. Her research area includes DC/DC converters and microgrid.

K. M. Venkatachalam currently pursuing Ph.D. degree in Electrical Engineering, Anna University, Chennai. He received his bachelor degree in electrical and electronics engineering from Anna University, Chennai, 2014. He received master degree in electrical drives and control from Pondicherry University, Puducherry, 2016. His area of research is renewable energy, inverters and micro-grid. He published 10 papers in conferences and journals.

M. Arumugam presently advisor in Arunai Engineering College, Tiruvannamalai, Tamilnadu, India. He served as first Director of National Institute of Technology - Trichirapalli in 2003. He has teaching experience of about 50 + years and guided a large number of UG and PG Projects and five Ph.D. He published large number of publications in reputed journals and conferences.