A Survey on Various Topologies of Z-Source Inverters

Himanshu[1], Dr. Rintu Khanna[2], Dr.Neelu Jain[3]

[1]*Research scholar, PEC university of Technology,chandigarh*
[2,3]*Associate Professor, PEC university of Technology,chandigarh*

Abstract

This paper discusses the latest development in the field of Z-source inverters. Z-source inverters are a new breed of inverters specially designed to be used in photovoltaic applications. It is basically designed to overcome the limitations of traditional voltage source inverter (VSI) and Current source inverter (CSI). Various topologies designed so far are discussed on the basis of size, cost, no. of passive elements, THD of output voltage etc.

Keywords—*ZSI,THD,boost factor,SBI,VSI,CSI.*

I. INTRODUCTION

According to the latest survey in the field of total electrical power generation, India is producing 288 GW of power which is very huge but the worst part is the total contribution of renewable sources of energy to grid connected power which is only about 28%. From this data it is clearly visible that renewable sources of energy are not quite popular when it comes to electrical power generation. The most obvious reason for under utilization of renewable sources of energy seems to be their efficiency which is quite low and sometimes also their reliability.

In the present scenario solar power is very effective source of energy as it has tremendous potential to generate electricity but the power generated by photovoltaic is in DC form, so to connect solar power to grid power it has to be converted into AC. Inversion operation is performed by convention inverters, which is two stage process because boost operation is also required in order to connect the photovoltaic power to the grid.

Z-source inverters are new breed of inverter in which voltage boost operation can be simultaneously performed along with inversion operation, which greatly reduces the losses occurring due to two stages while using conventional inverter method. These losses include the losses occurring due to transformer or due to DC-DC boost converter. ZSI although reduces the overall cost by reducing the stages but it has several disadvantages, first is its size due to presence of passive elements i.e. capacitors and inductors and due to this its cost also increases.

In recent years there is a lot of research been done to improve the topological design of z-source inverter but only a few designs have removed the disadvantages such as cost, size and performance of ZSI. In this paper some latest topological designs are discussed which are modified to give optimum performance by either reducing the size, total harmonic distortion or other factors like no. of passive elements. These parameters are very important parameters in determining the overall performance of the inverter.

Z-source inverter is different from conventional Z –source inverter in a way that the former uses passive elements apart from DC source and power electronic switches.

II. CONVENTIONAL Z-SOURCE INVERTER

In 2002, F.Z. Peng came up with the idea of Z-source inverter in which the LC- impedance network is included so as to transform the conventional voltage source inverter into Z-source inverter.

Z-source inverter has overcome the limitations of conventional Voltage Source Inverter and Current Source Inverter and therefore very useful in photovoltaic applications.
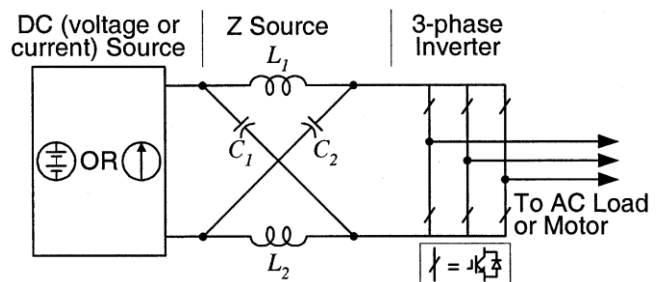

Fig.1. Z-Source Inverter

In this Z-source inverter, impedance network is included so as to obtain both inversion and boost operation simultaneously. The operation of Z-source inverter is different from conventional voltage source inverter in a way that it uses shoot through states apart from six active states of conventional VSI.

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be observed in the traditional voltage-source and current-source

converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and provides a novel power conversion concept.

The Z-source rectifier/inverter system can produce an output voltage greater than the ac input voltage by controlling the boost factor, The Z-source inverter can boost–buck voltage,
minimize component count, increase efficiency, and reduce cost.

III. IMPROVED Z-SOURCE INVERTER

To overcome the limitations of conventional Z-source inverter improved Z-source inverter is introduced recently. As during start-up the conventional Z-source inverter has huge in-rush current, so to overcome this limitation improved Z-source inverter is designed. The applications of improved Z-source inverter are found in starting of induction motors which requires soft starting.
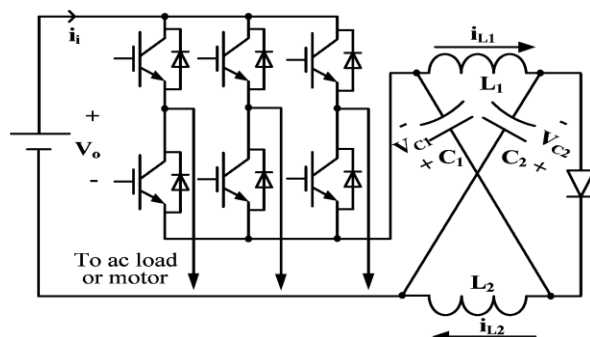

Fig.2. Improved Z-Source Inverter

The improved Z-source inverter is shown in Fig. 2. The elements used are exactly the same as the previous one. The difference is that the positions of the inverter bridge and diode are exchanged and their connection directions are inversed. The voltage polarity of Z-source capacitors in the proposed topology remains the same as the input voltage polarity; therefore, to get the same voltage boost, the capacitor voltage stress can be reduced to a significant extent. In addition, as can be seen from Fig. 2, the topology has inherent inrush-current limitation ability compared to the previous one, because there is no current path at start-up.

IV. SWITCHED INDUCTOR Z-SOURCE INVERTER

This topology is totally different from any other existing Z-source inverters from the viewpoint of circuit structures and operation principles.
In this topology, the main emphasis is given to boost factor rather than cost and size of the inverter although the addition of six more diodes and two more inductors lead to huge size of the inverter but

boost factor in this case is greatly increased therefore this topology is very useful in case of photovoltaic application where the boost factor plays an important role.

There are some of the factors due to which this inverter is assumed to be more beneficial than the others. The main characteristics of this inverter are: basic X-shaped structure is retained, the boost factor is increased from $1/(1-2D)$ to $(1+D)/(1-3D)$ just by addition of six diodes and two inductors.

More often it is observed that there is conflict between modulation index, M and duty ratio, D.by introduction of switched inductor Z-source inverter this problem at least got the initial solution.
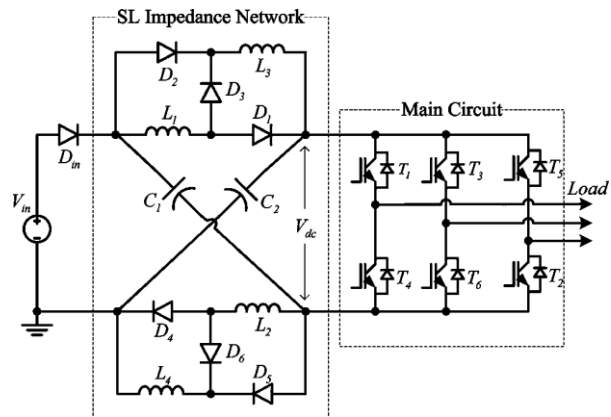

Fig.3. Switched Inductor Z-Source Inverter

The switched inductor inverter could be widely used in the distributed generation. Furthermore, the concepts of SL Z-source impedance network can be applied to all areas of dc–ac, ac–dc, ac–ac, and dc–dc power conversion, which will be beneficial for the engineering applications using impedance-type power inverters.

V. EMBEDDED EZ-SOURCE INVERTER

During voltage-boost operation, voltage waveform can be filtered by placing a second-order LC filter before diode. But including an additional filter might raise the overall cost of the system slightly and might introduce unnecessary dynamic and resonant complications to the system if not designed properly.
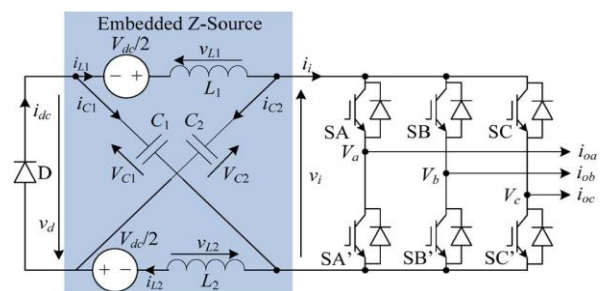

Fig.4. Embedded EZ-Source Inverter

Therefore, instead of using an external LC filter, an alternative family of embedded Z-source (referred to as EZ-source in short, where E- is included to represent —embedded) inverters, which adopts the concept of embedding the input dc sources within the LC impedance network.

Despite these modifications, the voltage or current gain of the inverters is kept unchanged, as can be proven mathematically. The EZ-source inverters are therefore competitive alternatives that can be used for cases where implicit source filtering is critical. Comparing with conventional Z-source inverter it shows the advantages of drawing smoother current from source with no external filter required.

VI. EXTENDED BOOST Z-SOURCE INVERTER

The extended boost Z-source inverter topology is not a single topology but it is a family of topologies. All these topologies can be modulated using the modulation methods proposed for the original ZSI.

The other main advantage of these proposed new topologies is their expandability. This was not possible with the original ZSI, i.e., if one needs to increase the boosting range, another stage can be cascaded at the front end without increasing the number of active switches.
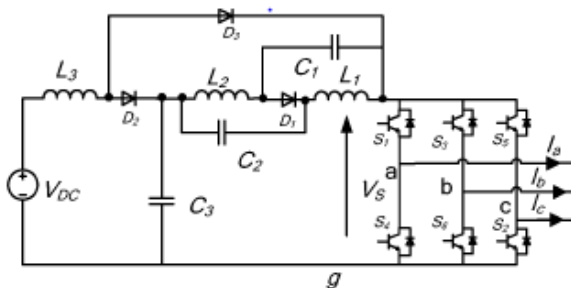

Fig.5. Extended Boost Z-Source Inverter

However we can classify Extended Boost Z-source inverter in two categories which diode assisted topologies and capacitor assisted topologies. The main advantage of both these categories is that the voltage gain can be increased just by adding some passive elements or diodes and not increasing the no. of switches. All the topologies show higher boost and lower voltage stress across the capacitors compared to those of traditional ZSI. Lower voltage stress on capacitors play an important role as it determines the size and rating of the capacitors used in the inverter.

VII. LZ-SOURCE INVERTER

Different to the original ZSI, the proposed inverter has no capacitor, and is composed of two inductors. The LZ topology provides inrush current suppression, unlike the traditional topologies, because no current flows to the main circuit at start-

up. This topology also provides a common ground for the source and inverter.

The L-Z source inverter employs a unique inductor and diode network to couple the low dc voltage energy source to the main circuit of the inverter, and avoids the disadvantage causing by capacitor in the classical ZSI and SL-ZSI, especially in prohibiting the inrush current at start-up and the resonance of Z-source capacitors and inductors.

Same modulation techniques i.e. simple boost control, maximum boost control and constant boost control etc. as for conventional Z-source inverter are valid to L-Z source inverter.
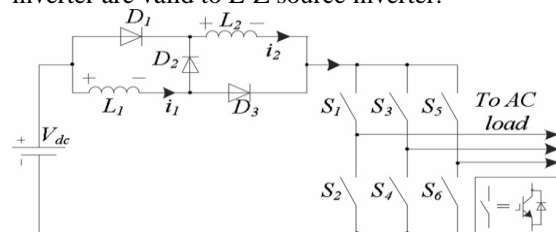

Fig.6. LZ-Source Inverter

The inverter can increase the voltage gain through adjusting shoot-through duty ratio and increasing the number of inductor.

The LZ-source inverter is the only inverter so far which is able to eliminate the capacitor completely. But it shows very high DC link voltage when it comes to serve an inductive load.

VIII. SWITCHED BOOST INVERTER

A. Ravindranath *et al.* proposed this topology which exhibits properties similar to that of ZSI with lower number of passive components
In the present scenario a lot of research has been done in Z-source inverter topologies but most of the topologies are of 3-phase inverter type. But switched boost inverter is single phase inverter topology so its application are primarily for standalone photovoltaic applications and also it shows very good performance when it comes to low power applications.

Still it got some disadvantages such as additional switch which increases switching losses and another disadvantage is modulation techniques available for the smooth operation of SBI, new pulse modulation technique is developed by the author for its operation.
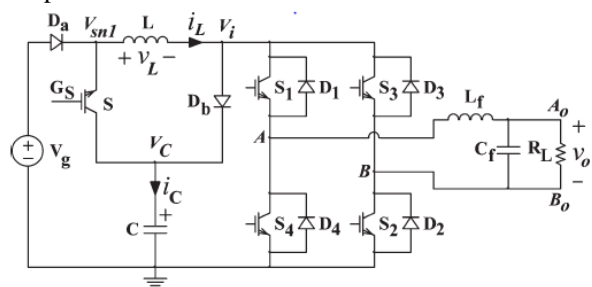

Fig.7. Switched Boost Inverter

but due to the increase in the number of semiconductor devices, the SBI requires a better protection circuit compared to ZSI The average dc link voltage of SBI is only $(1 - D)$ times that of ZSI. Therefore, SBI has to operate at a higher M compared to ZSI to obtain the same ac output voltage.

The switched boost inverter shows the same ac output voltage with lower number of passive elements as compared to conventional Z-source inverter which uses two capacitors and two inductors to boost the voltage but in this inverter only single capacitor is used which is the main reason for more cost, size and weight of the inverter

But for proper output voltage the SBI has to be operated on high modulation index. SBI is mainly suitable for low power applications. One of the major disadvantage of SBI is that the conventional modulation techniques used in case of ZSI are not valid for this inverter.

REFERENCES

[1] J. Rodriguez, J.S. Lai, and F. Z. Peng, ―Multilevel inverters: A survey of topologies, controls, and applications,‖ IEEE Trans. Ind. Electron., vol.49, no. 4, pp. 724–738, Aug. 2002.

[2] F. Z. Peng, ―Z-source inverter, IEEE Trans. Ind. Appl., vol. 39, no. 2,pp. 504–510, Mar./Apr. 2003.

[3] M. Shen, J. Wang, A. Joseph, F.Z. Peng, L.M. Tolbert, and D.J., Adams, ―Constant boost control of the Z-source inverter to minimize current ripple and voltage stress, IEEE Trans. Ind. Appl., vol. 42, no. 3, pp.770-778, May/June 2006.

[4] Miao Zhu, Kun Yu, Fang Lin Luo, "Switched Inductor Z-source Inverter", IEEE Trans. Power Electron., Vol. 25, No. 8, pp. 2150- 2158, August 2010.

[5] L. Pan, ―L-Z source inverter, IEEE Trans. Power Electron., vol. 29, no. 12, pp. 6534–6543, Dec. 2014.

[6] F. Z. Peng, M. Shen, and Z. Qian, ―Maximum boost control of the Z-source inverter, IEEE Trans. Power Electron., vol. 20, no. 4, pp. 833–838, Jul./Aug. 2005.

[7] A. Ravindranath, S. Mishra, and A. Joshi, ―Analysis and PWM Control of Switched Boost Inverter, Accepted for publication in IEEE Trans. Ind. Electron., 2013.

[8] R. Adda, S. Mishra, and A. Joshi, ―A PWM control strategy for switched boost inverter, in Proc. 3rd IEEE Energy Convers. Congr. Expo., Phoenix, AZ, 2011, pp. 4208–4211.

[9] Y. P. Siwakoti, P. C. Loh, F. Blaabjerg, and G. E. Town, ―Y source impedance network, IEEE Trans. Power Electron., vol. 29, no. 7, pp 3250–3254,July 2014.

[10] P. C. Loh, D. M. Vilathgamuwa, Y. S. Lai, C. G. Tin, and Y. Li, ―Pulse-width modulation of Z-source inverters, IEEE Trans. Power Electron., vol. 20, no. 6, pp. 1346–1355, Nov. 2005.

[11] P. C. Loh, D. G. Holmes, Y. Fukuta, and T. A. Lipo, ―Reduced common mode modulation strategies for cascaded multilevel inverters, IEEE Trans. Ind. Appl., vol. 39, no. 5, pp. 1386–1395, Sep./Oct. 2003.

[12] Nguyen, M.K., Lim, Y.C., Choi, J.H.: ‗Two switched-inductor quasi-Z-source inverters‘, IET Power Electron., 2011, 5, (7), pp. 1017–1025

[13] C. J. Gajanayake, D. M. Vilathgamuwa, and P. C. Loh, ―Small-signal and signal-flow-graph modeling of switched Z-source impedance network, IEEE Power Electron Letter, vol. 3, no. 3, pp. 111–116, Sep. 2005

[14] F. B. Effah, P.Wheeler, J. Clare, and A.Watson, ―Space-vector-modulated three-level inverters with a single Z-source network, IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2806–2815, Jun. 2013.

[15] M. Shen, A. Joseph, J. Wang, and F. Z. Peng, ―Comparison of traditional inverters and Z-source inverter for fuel cell vehicles, IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1453–1463, Jul. 2007.

[16] Y. Li, S. Jiang, J. Cintron-Rivera, and F. Peng, ―Modeling and control of quasi-Z-source inverter for distributed generation applications, IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1532–1541, Apr. 2013.

[17] S. Rajakaruna and L. Jayawickrama, ―Steady-state analysis and designing impedance network of Z-source inverters, IEEE Trans. Ind. Electron., vol. 57, no. 7, pp. 2483–2491, Jul. 2010.

[18] Calzo, G., Lidozzi, L.A., Solero, L., Crescimbini, F.: ‗Three-phase Z-source power supply design‗, IET Power Electron., 2012, 5, (8), pp. 1270–1281

[19] Babaei, E., Hossein Hosseini, S.: ‗New cascaded multilevel inverter topology with minimum number of switches‗, Elsevier Energy Convers. Manage., 2009, 50, pp. 2761–2767

[20] Nguyen, M.K., Lim, Y.C., Choi, J.H.: ‗Two switched-inductor quasi-Z-source inverters‗, IET Power Electron., 2011, 5, (7), pp. 1017–1025 [29] J. Holtz, ―Pulse width modulation—a survey, IEEE Trans. Ind. Electron ,vol. 39, no. 6, pp. 410–420, Dec. 1992.

[21] B.Y. Husodo, M. Anwari, and S.M. Ayob, ―Analysis and Simulations of Z-source Inverter Control Methods, IEEE Transactions on Industry Applications, vol. 42, pp. 770 – 778, May-Jun 2006

[22] Thangaprakash S. and Krishnan A., ―Modified space vector modulated Z-source inverter with effective DC boost and lowest switching stress, The Journal of Engineering Research, Vol. 7, No. 1, pp. 70-77, 2010

[23] B. Mirafzal, M. Saghaleini and A.K. Kaviani, ―An SVPWM-Based Switching Pattern for Stand-Alone and Grid-Connected Three-Phase Single-Stage Boost Inverters, Power Electronics, IEEE Transactions on,vol. 26, pp.1102-1111, 2011

[24] Y. Tang, S. J. Xie, C. H. Zhang, Z. G. Xu. ‗Improved Z-source inverter with reduced Z-source capacitor voltage stress and soft-start capability‗ IEEE Transactions on Power Electronics, vol. 24, no. 2, pp. 409–415, 2009

[25] A. Ravindranath, S. Mishra, and A. Joshi, ―A PWM control strategy for switched boost inverter, in Proc. 3rd IEEE Energy Conversion Congress and Exposition (ECCE), Phoenix, 2011, pp. 4208–4211.

[26] P. C. Loh, F. Gao, and F. Blaabjerg, ―Topological and modulation design of three-level Z-source inverters, IEEE Trans. Power Electron., vol. 23,no. 5, pp. 2268–2277, Sep. 2008.

[27] P. C. Loh, C. J. Gajanayake, D. M. Vilathgamuwa, and F. Blaabjerg, ―Evaluation of resonant damping techniques for Z-source current-type inverter, IEEE Trans. Power Electron., vol. 23, no. 4, pp. 2035–2043, Jul. 2008.

[28] N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics: Converters, Application and Design. New York: Wiley, 2003.

[29] T. Yu, X. Shaojun, Z. Chaohua, and X. Zegang, ―Improved Z-source inverter with reduced Z-source capacitor voltage stress and soft-start capability, IEEE Trans. Power Electron., vol. 24, no. 2, pp. 409–415,Feb. 2009.

[30] G. N. Veda Prakash and M. K. Kazimierczuk, ―Small-signal modeling of open-loop PWM Z-source converter by circuit-averaging technique, IEEE Trans. Power Electron., vol. 28, no. 3, pp. 1286–1296, Mar. 2013.

[31] F. B. Effah, P.Wheeler, J. Clare, and A.Watson, ―Space-vector-modulated three-level inverters with a single Z-source network, IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2806–2815, Jun. 2013.

[32] F. Guo, L. Fu, C.-H. Lin, C. Li,W. Choi, and J.Wang, ―Development of an 85-kW bidirectional quasi-Z-source inverter with DC-link feed-forward compensation for

electric vehicle applications, IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5477–5488, Dec. 2013

[33] K. Park, K.-B. Lee, and F. Blaabjerg, ―Improving output performance of a Z-source sparse matrix converter under unbalanced input-voltage conditions, IEEE Trans. Power Electron., vol. 27, no. 4, pp. 2043–2054, Apr. 2012.

[34] X. Liu, P. C. Loh, P. Wang, and X. Han, ―Improved modulation schemes for indirect Z-source matrix converter with sinusoidal input and output waveforms, IEEE Trans. Power Electron., vol. 27, no. 9, pp. 4039–4050, Sep. 2012.

[35] O. Ellabban, J. Van Mierlo, and P. Lataire, ―A DSP-based dual-loop peak DC-link voltage control strategy of the Z-source inverter, IEEE Trans. Power Electron., vol. 27, no. 9, pp. 4088–4097, Sep. 2012.

[36] Y. Zhou, L. Liu, and H. Li, ―A high-performance photovoltaic module integrated converter (MIC) based on cascaded quasi-Z-source inverters (q-ZSI) using eGaN FETs, IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2727–2738, Jun. 2013

[37] P. C. Loh, F. Gao, P.-C. Tan, and F. Blaabjerg, ―Three-level ac–dc–ac Z-source converter using reduced passive component count, IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1671–1681, Jul. 2009.

[38] D. Li, P. C. Loh, M. Zhu, F. Gao, and F. Blaabjerg, ―Generalized multi-cell switched-inductor and switched-capacitor Z-source inverters, IEEE Trans. Power Electron., vol. 28, no. 2, pp. 837–848, Feb. 2013.

[39] M.-K. Nguyen, Y.-C. Lim, and G.-B. Cho, ―Switched-inductor quasi-Z-source inverter,‖ IEEE Trans. Power Electron., vol. 26, no. 1, pp. 3183–3191, Nov. 2011.

[40] P.C. Loh, D. Li, and F. Blaabjerg, ―Γ-Z-source inverters,‖ IEEE Trans. Power Electron., vol. 28, no. 11, pp. 4880–4884, Nov. 2013.

[41] D. Li, P. C. Loh, M. Zhu, F. Gao, and F. Blaabjerg, ―Cascaded multi-cell trans-Z-source inverters,‖ IEEE Trans. Power Electron., vol. 28, no. 2,pp. 826–836, Feb. 2013.

[42] M.-K. Nguyen, Y.-C. Lim, and Y.-J. Kim, ―A modified single-phase quasi- Z-source AC–AC converter, IEEE Trans. Power Electron., vol. 27, no. 1, pp. 201–210, Jan. 2012.

[43] K. A. Corzine and R. W. Ashton, ―A new Z-source DC circuit breaker, IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2796–2804, Jun. 2012.

[44] M.-K. Nguyen, Y.-G. Jung, Y.-C. Lim, and Y.-M. Kim, ―A single-phase Z-source buck–boost matrix converter, IEEE Trans. Power Electron.,vol. 25, no. 2, pp. 453–462, Feb. 2010.

[45] K. Viswanathan, R. Oruganti, and D. Srinivasan, ―Dual-mode control of tri-state boost converter for improved performance, IEEE Trans. Power Electron., vol. 20, no. 4, pp. 790–797, Jul. 2005.

[46] S. Yang, X. Ding, F. Zhang, F. Z. Peng, and Z. Qian, ―Unified control technique for Z-source inverter, in Proc. IEEE Power Electron. Spec. Conf., 2008, pp. 3236–3242.

[47] F. Gao, P. C. Loh, F. Blaabjerg, and D. M. Vilathgamuwa, ―Dual Z-source inverter with three-level reduced common-mode switching, IEEE Trans. Ind. Appl., vol. 43, no. 6, pp. 1597–1608, Nov./Dec. 2007.

[48] F. Z. Peng, A. Joseph, J.Wang, M. Shen, L. Chen, Z. Pan, E. Ortiz-Rivera, and Y. Huang, ―Z-source inverter for motor drives, IEEE Trans. Power Electron., vol. 20, no. 4, pp. 857–863, Jul. 2005.

[49] F. Z. Peng, M. Shen, and K. Holland, ―Application of Z-source inverter for traction drive of fuel cell battery hybrid electric vehicles, IEEE Trans. Power Electron., vol. 22, no. 3, pp. 1054–1061, May 2007.

[50] Y. Huang, M. Shen, F. Z. Peng, and J. Wang, ―Z-source inverter for residential photovoltaic systems, IEEE Trans. Power Electron., vol. 21,no. 6, pp. 1776–1782, Nov. 2006.

[51] Y. Li, J. Anderson, F. Z. Peng, and D. Liu, ―Quasi-Z-source inverter for photovoltaic power generation systems, in Proc. IEEE 24th Annual. Appl.Power Electron. Conf. Expo., Feb., 2009, pp. 918–924.

[52] U. Supatti and F. Z. Peng, ―Z-source inverter based wind power generation system, in Proc. IEEE Int. Conf. Sustainable Energy Technologies, Nov., 2008, pp. 634–638.

[53] U. Supatti and F. Z. Peng, ―Z-source inverter with grid connected for wind power system,‖ in Proc. IEEE Energy Convers. Congr. Expo., Sep., 2009, pp. 398–403.

[54] J.-H. Park, H.-G. Kim, E.-C. Nho, T.-W. Chun, and J. Choi, ―Grid connected PV system using a quasi-Z-source inverter, in Proc. IEEE 24th Annual Appl. Power Electron. Conf. Expo., Feb., 2009, pp. 925–929.

[55] F. Z. Peng, ―Z-source networks for power conversion, in Proc. IEEE 23rd Annu. Appl. Power Electron. Conf. Expo., 2008, pp. 1258–1265.

[56] R. Antal, N. Muntean, and I. Boldea, ―Modified Z-source single-phase inverter for single-phase PM synchronous motor drives, in Proc. 11th Int. Conf. Optim. Electr. Electron. Equipment, 2008, pp. 245–250. [65] I. Boldea, R. Antal, and N. Muntean, ―Modified Z-source single-phase inverter with two switches, in Proc. IEEE Int. Symp. Ind. Electron.,Jun./Jul., 2008, pp.257–263.

[57] E. S. Sreeraj, K. Chatterjee, and S. Bandyopadhyay, "One-Cycle- Controlled Single-Stage Single-Phase Voltage-Sensorless Grid- Connected PV System," IEEE Transactions on Industrial Electronics,, vol. 60, pp. 1216-1224, 2013.

[58] B. N. Alajmi, K. H. Ahmed, G. P. Adam, and B. W. Williams,"Single-Phase Single-Stage Transformer less Grid-Connected PV System," IEEE Transactions on Power Electronics,, vol. 28, pp. 2664-2676, 2013.

[59] T. Kerekes, R. Teodorescu, M. Liserre, C. Klumpner, and M. Sumner, ―Evaluation of three-phase transformer less photovoltaic inverter topologies, IEEE Transactions on Power Electronics, vol.24, no. 9,pp.2202-2211, Sept. 2009.

[60] X. Lu, K. Sun, Y. Ma, L. Huang, S. Igarashi, ―High efficiency Hybrid cascade inverter for photovoltaic generation,‖ TENCON 2009, pp.1-6.