Z-Source Inverter for Electric Vehicle Applications- A Review

Manish Bharat
Research Scholar ,VTU
Assistant Professor
[1]*School of Electrical and Electronics Engineering*
REVA University, Bengaluru, INDIA

Dr. ASR Murty
Research Supervisor ,VTU
Retd. Professor , RRCE
[1]*School of Electrical and Electronics Engineering*
Bengaluru, INDIA

[a] Corresponding author: manish.bharat@reva.edu.in

Abstract. - ***The transport industry is regarded as the futuristic and most powerful industry among all the industries. Since this industry is mostly driven by Electric Vehicle (EV)/Hybrid Electric Vehicles (HEV) powered by information and communication technologies (ICT) in future. These vehicles require advanced and efficient converters to drive. The paper presents the current Z-source converters applicability to drive EV/HEV to aid the transportation industry. The various topologies of Z-source converters have been discussed. The summary of the literature survey of the suitable Z-source topologies for EV/HEV application is also presented. The need for the new control technique along with new trans-Z source converter topology to drive EV/HEV is discussed. The paper also presents the authors proposal of dual power source trans-Z source converter for the EV/HEV applications.***

Index Terms**—**Z-source, Inverter, Topologies, Drive, Electric Vehicle, Hybrid Electric Vehicle. Trans-Z source**.**

Introduction

The environmental and ecological issues are directly related to the transportation vehicles running on fossil fuels. Therefore, Electric Vehicles/Hybrid Electric Vehicles (EVs/HEVs) are being introduced into the market due to their environmentally friendly operations. In these vehicles the power electronic converter plays an important role in driving the motor reliably and efficiently. The traditional inverters like voltage source inverters (VSI), current source inverters (CSI) were used to drive these vehicles with limitations. The limitations of the CSI drives are high harmonics in the output current, requiring additional filters at the input & output, results in high components count. Whereas, VSI drives are not suitable for high power applications, but suitable for highly dynamic applications. These topologies have two stage structure and do not have buck & boost capabilities. In order to overcome the above drawbacks of these traditional VSI & CSI inverters, an improved topology known as Z-source (Impedance Source) inverter topology was introduced by F.Z. Peng in 2003 [1]. The paper covers the review of Z-source inverter and its derivatives and proposes a technically viable inverter for electric drive applications.

The rest of the paper is arranged in to various sections: section 2 discusses the traditional Z-source inverters, section 3 delas with other topologies of Z-source inverters, section 4 presents the control techniques employed in the various inverters, section 5 deals with summary of the literature review, section 6 presents the authors proposal and section 7 presents the conclusion.

Z-SOURCE INVERTERS

The Z-source inverters (ZSIs) are the derivative of traditional VSI & CSI converters with an ability of buck-boost [2]-[3]. These converters are used as AC-DC, AC-AC, DC-DC and DC-AC converters in various applications [3]. The traditional Z-source inverter is depicted in figure 1.

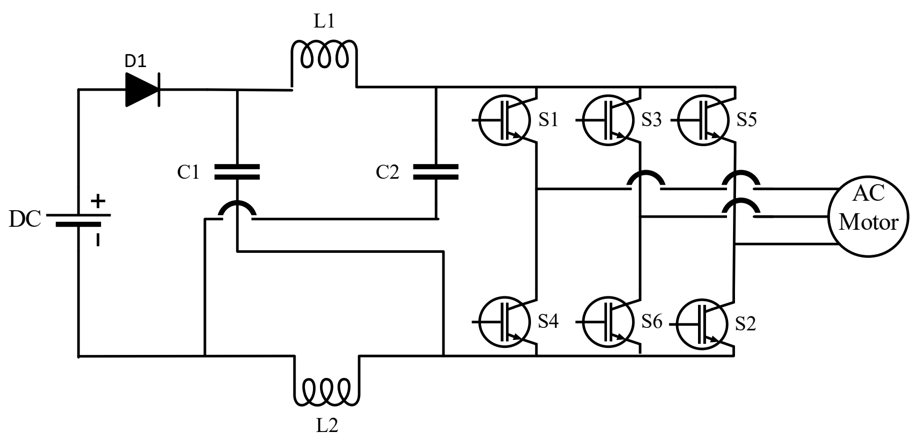

Fig.1: 3Ø Traditional Z-source inverter [3]

As seen from Fig.1 the Z-source inverter has a unique impedance network consisting of split inductance (L_1, L_2) and capacitance (C_1, C_2). The structure of this impedance network results in three operational states namely, initial/start-up state, active state and shoot-through state [3]. These three states of Z-source inverter are shown in figure 2(a), 2(b) and 2(c).

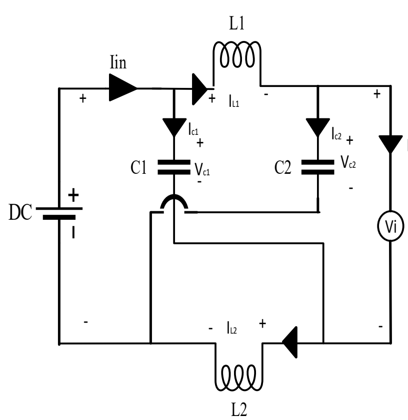

Fig.2 (a) Start-up state [3]

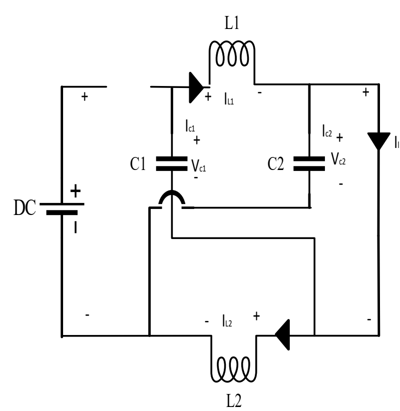

Fig.2 (b) Active state (Non-Shoot Through state) [3]

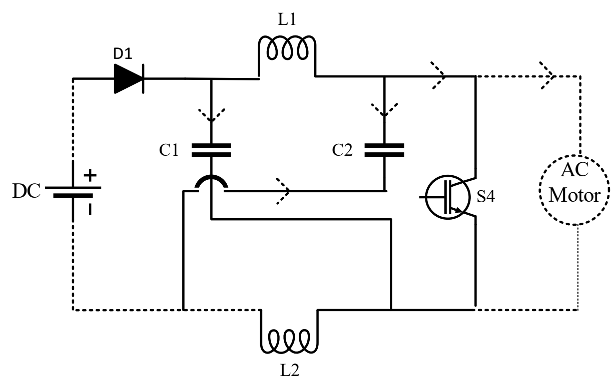

Fig.2 (c) Shoot-Through state.[3]

Since the Z-source inverter is symmetric, the parameters L_1=L_2 =L and C_1=C_2=C are equal. The converter operates in active and shoot-through state due to its symmetrical nature. The converter operates in active state (Non-Shoot Through Mode) for a period of T_1 of switching period T. The switching period is:

$$\mathrm{T} = \mathrm{T}_1 + \mathrm{T}_0 \tag{1}$$

Referring to figure 2 (b), it can be observed that, the inductors are discharging and capacitors are charging during active mode. By applying KVL around a loop consisting of V_{in}, L, C and DC link voltage V_{dc}, the voltage relations are given by:

$$V_{dc} = V_{in} + V_C - V_L \tag{2a}$$

$$V_L = -V_C \tag{2b}$$

$$\mathrm{V}_{dc} = \mathrm{V}_{\mathrm{in}} + 2\mathrm{V}_{\mathrm{C}} \tag{3}$$

Where V_{in} => Input dc voltage, V_{dc} => dc link voltage, V_L => voltage across inductor and V_C=>voltage across capacitor.

Next converter operates in shoot-through state for a period of T_0 of switching period T. During this state the dc link voltage is zero and voltage across inductor and capacitor are equal. Applying KVL around a loop consisting of V_{in}, L, C, the voltage relations are given by:

$$V_{in} - V_C - V_L = 0$$

$$V_L = V_{in} - V_C \tag{4}$$

$$V_{dc} = 0 \tag{5}$$

The voltage relations during active and shoot-through states are

$$\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} \mathrm{V_L(t)dt} = \frac{\mathrm{T_{st}V_C + T_1(V_{in} - V_C)}}{\mathrm{T}} = 0 \tag{6}$$

Solving (6) for voltage across capacitor,

$$\frac{V_C}{V_{in}} = \frac{T_1}{T_1 - T_{st}} = \frac{1 - D_{st}}{1 - 2\,D_{st}} \quad (7)$$

From (7),

$$D_{st} = \frac{V_C - V_{in}}{2V_C - V_{in}} \quad (8)$$

Where $D_{st} = \frac{T_{st}}{T}$ is the shoor-through duty cycle.From equations (3) and (7), the dc link voltage is given by:

$$V_{dc} = \frac{T}{T_1 - T_{st}} V_{in} \quad (9)$$

Equation (9) can also be expressed as:

$$V_{dc} = \frac{1}{1 - 2D_{st}} V_{in} = BV_{in} \quad (10)$$

Where B is the boost factor depends upon shoot through duty cycle D_{st}.

The Z-source converters are preferred in various industrial applications like, traction, energy conversion systems as they can operate in both buck and boost modes. The basic types of Z-source inverter topologies have been discussed in proceeding sections.

Quasi Z-Source Inverter [1]

The impedance network elements of the traditional Z-source inverter have been rearranged to achieve a reliable power conversion along with a high conversion efficiency. The resultant topology is known as Quasi Z-source inverter topology. The re-structured impedance network has resulted in 4-operating modes as shown in figures 2,3,4 and 5.

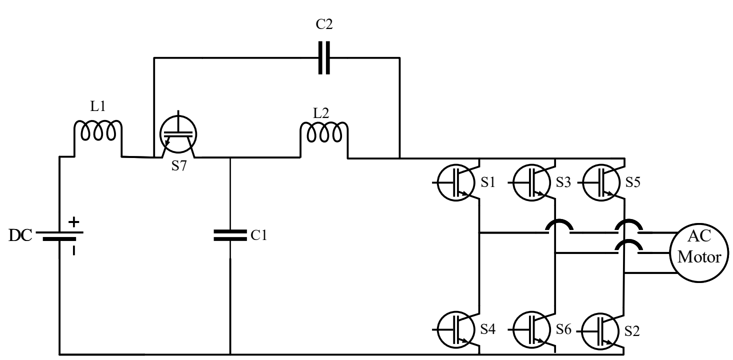

Fig.2: Voltage fed continuous current Z-source inverter [1]

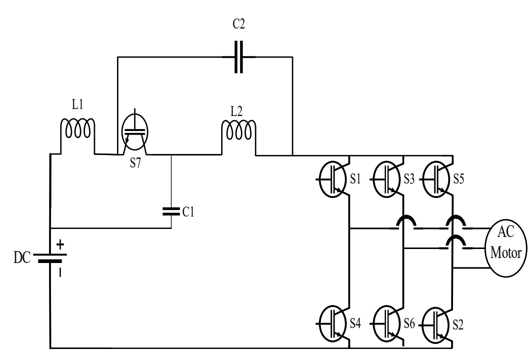

Fig.3: Voltage fed dis-continuous current Z-source inverter [1].

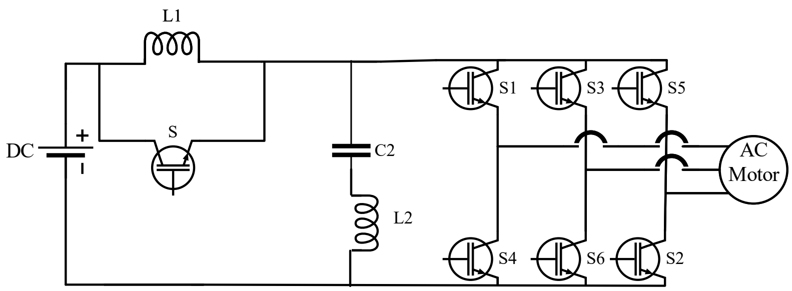

Fig.4: Current fed continuous current Z-source inverter [1]

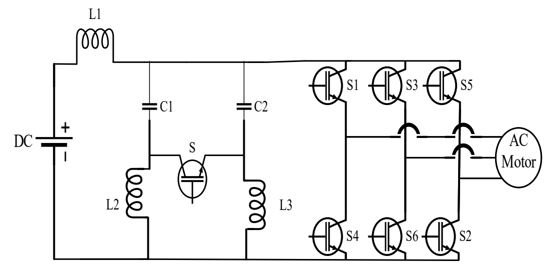

Fig.5: Current fed dis-continuous current Z-source inverter [1].

Embedded Z-Source Inverter [1] & [4]

The embedded impedance source inverter is realised to achieve a continuous input current with lower capacitor voltage rating. The embedded z-source inverter schematic is shown in figure 6.

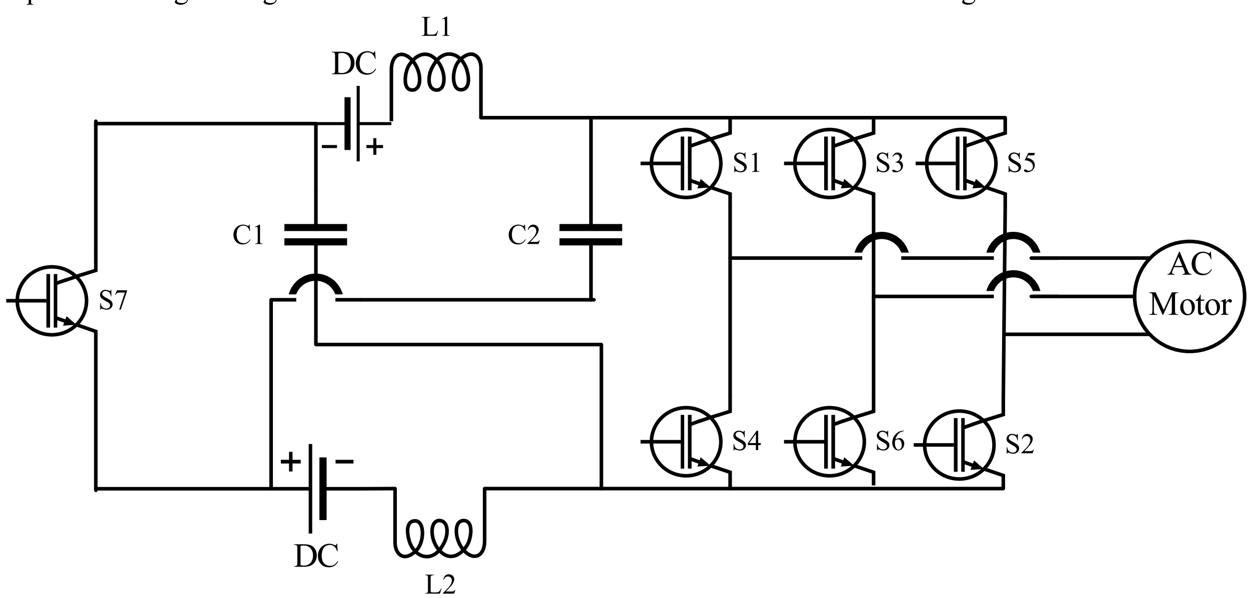

Fig.6: Embedded Z-source inverter [1]

The major advantage of this topology is that it reduces the voltage and current ripple. In this structure the dc sources are embedded with z-source elements.

Embedded Quasi Z-Source Inverter [1] & [5]

The basic features and operation of embedded quasi z-source inverter is exactly similar to embedded Z-source inverter [1] & [5]. The structure of this inverter is depicted in figure 7.

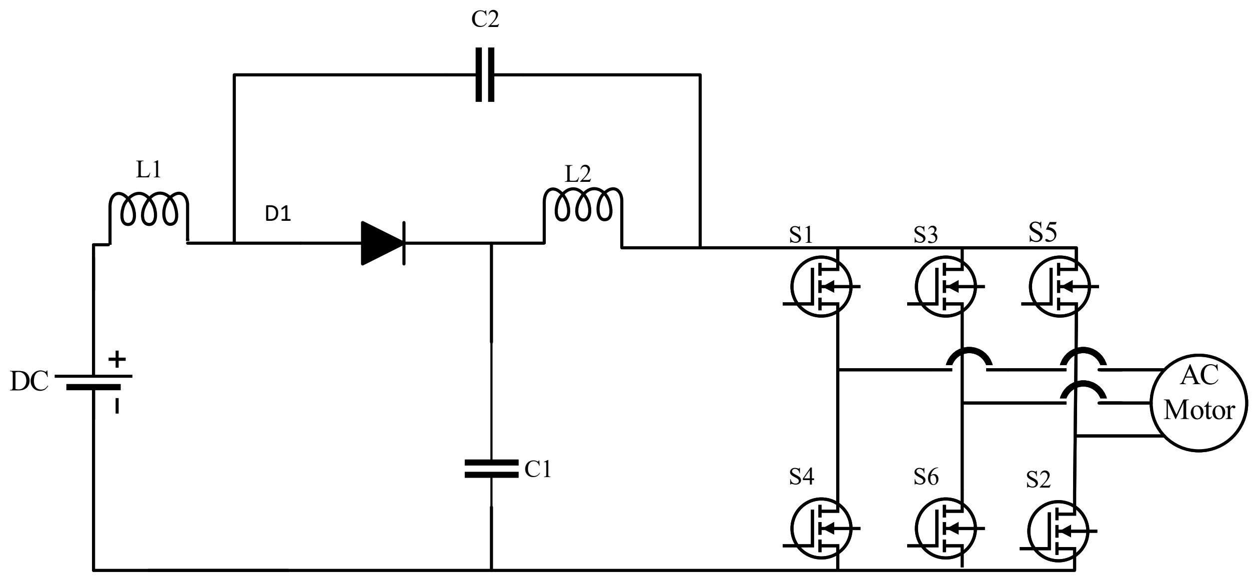

Fig.7: Embedded Quasi Z-Source Inverter [5]

This topology can operate with two sources without altering the voltage gain of traditional quasi z-source inverter [1].

Trans Z-Source Inverter [1] & [6]

The trans Z-source inverter is an improved version of traditional Z-source inverter with high voltage gain and less stress on the switches. The typical structure of the trans Z-source inverter is depicted in figure 8.

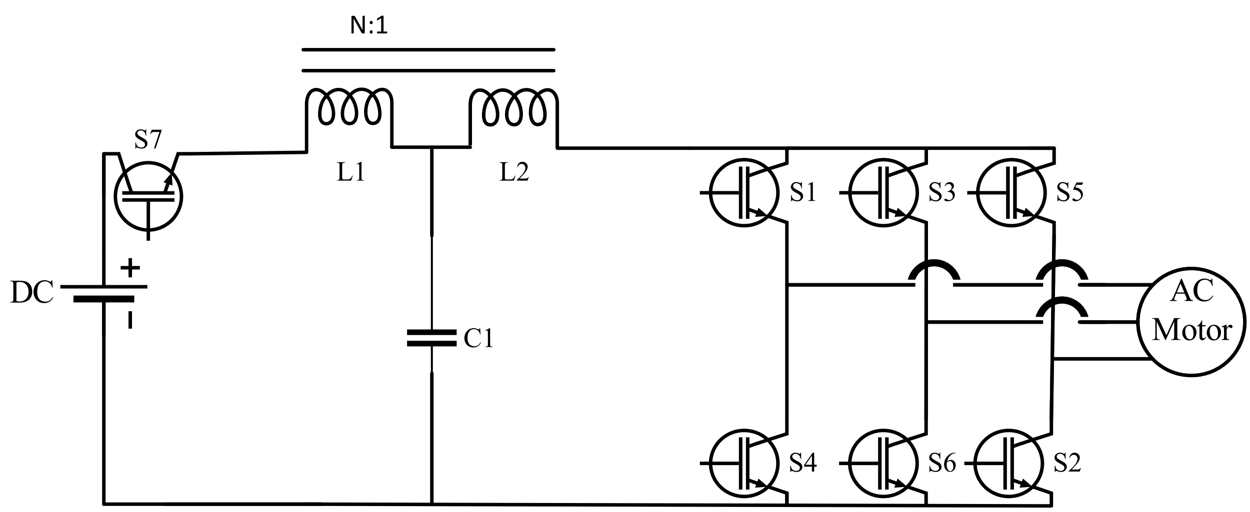

Fig.8: Trans Z-Source Inverter

Shoot through barriers have been eliminated in this inverter due to restructured impedance network. The cost of the circuit is high due to transformers and coupled inductors.

OTHER Z-SOURCE TOPOLOGIES

It is observed that various researchers have worked on z-source converters to improve their boost factor, current delivering capability by modifying the structure of the impedance, and dc input source location in the converter circuit. The Jing Yuan et al [7] have proposed an embedded enhanced-boost Z-source inverter. The converter design is such that the stress on the semiconductor switches has been reduced, the dc link voltage remains zero during shoot through state but the inductor currents increase. Since the dc sources are embedded in to the z-source network, the current becomes continuous. The circuit complexity is high due to the additional circuit elements in the modification of Z-network. This modified Z-source inverter is suitable for the applications which employs fuel cells as their energy source. The embedded switched capacitor Z-source inverter has been proposed in [8]. This converter performance is same as the converter proposed in [7]. The structure of the impedance network is different.

It is true that the performance of the converter can be improved by employing proper control mechanism of semiconductor switches. Malathi et al [9] have proposed a photovoltaic fed Z-source inverter with proportional integral (PI) and proportional, integral & derivative (PID) based control mechanism to improve the performance of the inverter. It is observed and claimed by the researchers that the performance of the inverter was better with PID rather than PI control mechanism. The gamma Z-source inverter is another variant of ZSI [10]. It has an impedance connected in a way that it resembles gamma letter and hence the name gamma Z-source (Γ-Z-source) inverter. The voltage gain of the inverter can be changed by varying the transformer ratio. This type of inverter is much suited for AC/DC microgrid.

The differential mode Γ-Z-source inverter is proposed in [11]. In this inverter the inductors are located in such a way that the ripple content in both voltage, currents of Z-network is less. The stress on the switches is also reduced but the total harmonic distortion (THD) is considerably high. Enhanced-Boost Z-Source Inverters with Switched Z-Impedance has been proposed by Fathi Kivi [12]. This inverter has two impedance networks to achieve high voltage gain with low shoot through state. The output wave form quality is high with high modulation index with short shoot through state.

The Z-Source Dual Active Bridge Bidirectional AC-DC Converter for Electric Vehicle Applications is proposed by Srijeeth et al [13]. The proposed inverter is mainly suitable for vehicle to home and grid to vehicle applications. ReddyPrasad Reddivari et al [14] have proposed a modified gamma z-source inverter for fuel cell -battery fed hybrid electric vehicle application. In this paper the proposed inverter performance was studied through simulation. The performance of the modified gamma z-source inverter is better than that of traditional gamma z-source inverter. The modified gamma z-source inverter study revealed that the battery size can be reduced in hybrid electric vehicles.

The traditional Z-source inverters have discontinuous input current, as a result the dc voltage becomes uncontrollable and hence the stability of the system. Thilak Senanayake et al [15] have introduced an improved impedance source consisting of input LC filter, a semiconductor switch in lieu of input diode and an impedance network. This structure helps the inverter to draw a continuous current from the dc source with less ripple as the LC filter present at the input of the inverter. The stress on the semiconductor devices also reduces. The presence of the input switch makes the inverter to function in both directions which is the necessary requirement of electric vehicles /hybrid electric vehicles. Also, dc link voltage can be controlled and there will be a continuous input current from the power source. Zeeshan Aleem et al [16] have proposed an improved gamma z-source inverter. An improvement is achieved by incorporating the diodes into the impedance network. The performance of the proposed inverter is same as that of its predecessors but for reduced leakage inductor currents.

The bidirectional quasi-Z-source inverter has been proposed in [17] for electric vehicle applications. The bidirectional operation of the inverter is achieved by connecting an active switch in antiparallel with the diode. An inner current control loop at the dc side, voltage control mechanism is used to achieve the better performance.

CONTROL STRATEGIES IN Z-SOURCE INVERTERS

The performance of any inverter completely depends upon efficient & reliable control strategy. It is understood that the Z-source inverters with modification can be employed in electric vehicle/hybrid electric vehicle drive applications. The review on the impedance network modification along with the control strategies employed in the Z-source inverters is carried out and the details are presented in the proceeding paragraphs.

M. Z.Zizoui et al [18] have proposed a 9 switch z-source power inverter driving double induction motors for electric vehicle application. The inverter uses a maximum constant boost control mechanism to operate the dual induction motors. Sertac Bayhan et al [19] have introduced a Z-Source (ZS) four-leg inverter fed with photovoltaic system along with a Model Predictive Control (MPC) strategy. The load employed in the experimental setup is unbalanced. In this inverter an LC filter is used in stead of boost converter and thus a single stage power converter is obtained. The control strategy and the structure of this modified z-source inverter can handle both balanced and unbalanced loads.

Siddhartha A.et al [20] presented a modified Z-source inverter connected to a grid integrated with charging mechanism for storage systems. The control mechanism used is pulse width modulation (PWM) technique. The input power source employed in this study was photovoltaic (PV) array. The performance of the presented inverter indicates that it can be employed commercially for standalone applications of power at malls, parking lots etc. It can also be utilized for charging EVs. In the next paper, the practical limitations of embedded Z-source dc-dc converters for PV applications have been studied and presented [21]. The modified Trans Z-source inverter is presented in [22] where in the input current is continuous and the high boost factor. The output voltage can be varied by varying transformer turns ratio and shoot through duty ratio. The control technique used in this converter is PWM.

Catherine Amala Priya. E et al [23] have presented a renewable energy source fed grid connected gamma z-source inverter with harmonics optimization technique. The converter employs both PWM and SVPWM as control mechanism. The performance study was conducted on Γ-Z-source inverter. The performance study reveals that the SVPWM controlled inverter has better performance due to reduced harmonics. A Single stage high boost Quasi-Z-Source inverter for off-grid photovoltaic application has been proposed in [24]. In this study a current fed control at AC side is used with second order filter. The result of the study was that there is a reduction output disturbance. In [25] & [26] the high voltage gain, reduced transformer and shoot through duty ratio z-source inverters are presented. An embedded z-source inverter with three dc sources of small magnitude is presented in [27]. The modified topology reduces the stress on the capacitors. The control techniques used to study the performance of the proposed modified embedded z-source inverter was PWM with a reduced ripple inductor current.

In [28] the performance analysis of Induction motor drives fed with traditional inverters such as VSI, CSI, Z-source has been presented. It is a simulation-based study and PWM technique was employed in the simulation study. In [29] a comparative study of Z-source inverter and dc-dc converter fed VSI has been presented. A simple boost control technique and sinusoidal PWM were employed in the study. The comparative analysis of various topologies of traditional z-source inverters have been studied and presented in [30]-[33]. The z-source inverter is more suitable for various traction applications as they have both buck -boost capability.

SUMMARY OF THE REVIEW STUDY

The review study conducted so far suggests that the advanced power electronic control systems and z-source inverters are the future trends in transportation industry. The simplicity and ease of modification in impedance network employed in the design of the inverter/converter are the major contributors to achieve high performance of the systems wherever these converters employed. The structure and the control mechanisms must be carefully selected to achieve the required performance of the converter. The traditional z-source inverters comparative topologies are tabulated in table 1.

Table-1: Z-Source Topologies Comparison

Impedance network	Boost Factor	Number of Capacitors	Number of Inductors	Voltage stress on the switches
Z-Source	$\frac{1}{1-2D}$ where $0 \le D \le 0.5$D	2	2	$\frac{1}{1-2D} V_{in}$
Q-Z-Source	$\frac{1}{1-2D}$ where $0 \le D \le 0.5$D	2	2	$\frac{1}{1-2D} V_{in}$
Embedded Z-Source	$\frac{1}{1-2D}$ where $0 \le D \le 0.5$D	2	2	$\frac{1}{1-2D} V_{in}$
Embedded Q-Z-Source	$\frac{1}{1-2D}$ where $0 \le D \le 0.5$D	2	2	$\frac{1}{1-2D}$ X $(V_1 + V_2)$
Trans-Z-Source	$\frac{1}{1-(1+n)D}$ where $0 \le D \le (1+n)^{-1}$D	1	Integrated 2 windings	$\frac{1}{1-(1+n)D}$ X V_{in}

Further, the review study involves the other modified z-source inverter topologies proposed by various researchers. These topologies were derived from traditional Z-Source inverter topology. The modifications were done by considering the structure of the impedance, switching device change/connectivity, in order to achieve high boost factor, voltage gain, low THD, continuous input current, reduced ripple in inductor currents and so on. These z-source variant topologies were proposed with various input power sources such as DC source, PV source etc. Table-2 shows the other Z-source inverter topologies suitable for EV/HEV applications.

Table-2 Other topologies of Z-Source Inverter for EV/HEV

Impedance network	Type of vehicle
Modified Γ-Z-source Inverter	HEV
Improved Z-Source Inverters / Trans-Z-source inverter	EV/HEV
Modified Γ-Z-source Inverter	EV
Bidirectional Q-Z-Source	EV
9 Switch Z-Source	EV

The review of the literature on the z-source converters, their variants suggests that the z-source converters can be a suitable system for various EV/HEV future transportation vehicles. The various technicalities involved in the design, development and implementation of these z-source topologies are very challenging. The study has revealed that:

i. There is no particular topology of ZSI which can be utilized for drive application with high efficacy, reliability and low cost.
ii. Most of the proposed models have complex hardware requirements and control, techniques.
iii. Knowledge on the techniques of control employed for the ZSI variants have to be studied and assessed.
iv. Knowledge on the various parameters which contributes to the overall cost of the systems must be gathered and minimized.
v. The requirements of passive elements for Trans-ZSI for drive applications with multiple power input sources have to be clearly defined and used in the construction of ZSI for drive application.
vi. The critical parameters associated with converters for the drive application must be clearly spelt and defined, which is a missed link.
vii. The topologies studied have not specified about the quality of the power delivered to the load.
viii. Is the quality of the power delivered by the converter to drive EV/HEV acceptable?
ix. The minimum possible input DC voltage, boost factor, ripple in the inductor current, passive components cost, size, details have to be clearly specified before suggesting any of the converter for drive applications.
x. The converter cost, power quality, battery life extension technologies, low power devices utilization are the major consideration.

PROPOSED AUTHORS SOLUTION

The fundamental topologies of Z-source inverters discussed in preceding sections were employed in various applications such as traction, energy conversion due to their high voltage gain and input current handling capacity. Since Z-source topologies can be easily modified to suit the applications and especially for electrical drive application. Based on the literature review study, it is noted that the future transportation vehicles can be driven with the modified z-source topology converters. The transportation vehicles which can be driven by these converters are electric vehicles and hybrid electric vehicles.

Further, Electric Vehicles/Hybrid Electric Vehicles (EVs/HEVs) are means of the future transportation vehicles. These transportation vehicles do not contribute to pollution as they operate on clean energy. These vehicles bring in string of benefits to the public and transportation industries.

These vehicles need highly efficient and reliable power converters to yield better performance. The power converters those are employed in electric drive applications are mostly pulse width modulation (PWM) based. These are voltage source (VS) and current source (CS) inverters. But these inverters are limited by a range as VSI performs as buck converter whereas CSI performs as boost inverter. In order to extend the range of operation, these inverters are combined with additional dc-dc converter to operate in both buck-boost mode. This increases the cost and complexity of the inverter as it becomes the double stage converter instead of single stage. Therefore, to extend the range of operation a magnetically coupled inverter known as Trans-Z Inverter has been developed for electric drive and other applications. It should be noted here that the trans-Z inverter is not specifically developed for EV/HEV applications.

The Trans-Z inverter is a type of inverters in which energy flows in two ways with the help of single diode, performs as buck-boost converter, has wide range, single stage in nature. Since, the EVs/HEVs vehicles need still improved and advanced converters, the researchers are concentrating on Trans-Z inverters. The Trans-Z source inverters have less capacitor counts in the circuitry and hence the cost reduction. The control mechanisms play a very important role in the performance of the inverter and end applications. Most commonly employed control mechanism in Trans-Z source inverter is predictive control and has variants. The predictive control variants are:

a. Trajectory based predictive control,
b. Hysteresis based predictive control, and
c. Model based predictive control

Model based predictive control is also known as finite control set and is more popular due to its design simplicity i.e. No modulator is required. These control techniques need to be reviewed carefully to bring in certain changes such that the performance of the converter is high along with reliability.

The proposed research is to throw a light on the control techniques, structure of the trans-Z source inverter such that the range can be increased. In addition, use of two inputs helps the Trans-Z source inverter to be independent of the fuel shortage if correct capacity fuel sources are not employed. The advanced power electronic devices with high operating characteristics makes the inverter design simple, increases efficiency, reliability and performance due to low count of components in design. The proposed research work is to focus on the development of new control technique for trans-Z source inverter with two input power sources that results in wide range of operation and hence the reliability.

References

1. Daouda Mande, João Pedro Trovão and Minh Cao Ta, "Comprehensive Review on Main Topologies of Impedance Source Inverter Used in Electric Vehicle Applications", World Electric Vehicle Journal 2020, 11, 37; doi:10.3390/wevj11020037.

2. LI Bo, LI Yue, YIN Huayi, and Hu Mengjie, "An Improved Strategy for Z Source Inverter"13th IEEE International Conference on Control & Automation (ICCA) July 3-6, 2017. Ohrid, Macedonia, 978-1-5386-2679-5/17/$31.00 ©2017 IEEE pp904-908 2017.

3. Kancharana Vinod Kumar, Reddiprasad Reddivari & Debashisha Jena (2019): A Comparative Study of Different Capacitor Voltage Control Design Strategies for Z-Source Inverter, IETE Journal of Research, DOI: 10.1080/03772063.2019.1650669.

4. Yam P. Siwakoti, Fang Zheng Peng, Frede Blaabjerg, Poh Chiang Loh, and Graham E. Town, "Impedance-Source Networks for Electric Power Conversion Part I: A Topological Review" IEEE Transactions on Power Electronics, Vol. 30, No. 2, February 2015 pp: 699-716.

5. Anh-Vu Ho, Ji-Suk Hyun, Tae-Won Chun, Hong-Hee Lee, "Embedded Quasi-Z-Source Inverters Based on Active Switched-Capacitor Structure", 978-1-5090-3474-1/16/$31.00 ©2016 IEEE pp:3384-3389.

6. Wei Qian, Fang Zheng Peng, and Honnyong Cha," Trans-Z-Source Inverters", IEEE Transactions on Power Electronics, vol. 26, no. 12, December 2011 pp:3453-3463

7. Jing Yuan, Yongheng Yang, Ping Liu, Yanfeng Shen, Zhipeng Qiu, Frede Blaabjerg, "An Embedded Enhanced-Boost Z-Source Inverter", 978-1-5386-6054-6/18/$31.00 © 2018 IEEE.

8. Jing Yuan, Yongheng Yang, Ping Liu, Yanfeng Shen, and Frede Blaabjerg, "An Embedded Switched-Capacitor Z-Source Inverter with Continuous Input Currents", 978-1-5386-8330-9/19/$31.00 ©2019 IEEE, page 2366-2371.

9. R.Malathi, M.Rathinakumar," Comparison of PV based Embedded Z-Source Inverter fed Three Phase Induction Motor with PI Controller and PID Controller based closed loop systems", 3rd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB17), 978-1-5090-5434-3©2017 IEEE.

10. Hossein Torkaman, Ebrahim Afjei , Ali Keyhani , Mobina Poursmaeil, "Control and management of hybrid AC/DC microgrid based on Γ-Z-source converter", doi: 10.1049/iet-gtd.2018.6365. IET Gener. Transm. Distrib., 2020, Vol. 14 Iss. 14, pp. 2847-2856 © The Institution of Engineering and Technology 2019.

11. Reddiprasad Reddivari, Debashisha Jena, "Differential mode gamma source inverter with reduced switching stresses", 2017 IEEE PES Asea Pacific Power and Energy Engineering Conference (APPEEC), 978-1-5386-1379-5/17/$31.00 ©2017 IEEE.

12. H. Fathi Kivi, and H. Madadi Kojabadi," Enhanced-Boost Z-Source Inverters with Switched Z-Impedance", DOI 10.1109/TIE.2015.2477346, IEEE Transactions on Industrial Electronics.
13. J. Srijeeth, Vignesh Chenni Thiagarajan, S.R. Mohanrajan, "Z-Source Dual Active Bridge Bidirectional AC-DC Converter for Electric Vehicle Applications", 978-1-5386-9316-2/18/$31.00 ©2018 IEEE.
14. ReddyPrasad Reddivari, Pruthviraj B G, Manish Bharat, and Arjun Kumar G B, "Müdified Gamma Süurce Inverter für Fuel Cell -Battery Hybrid Electric Vehicles", 978-1-4673-6658-8116/$3l.00 ©20 16 IEEE.
15. Thilak Senanayake, Ryuji Iijima, Takanori Isobe, Hiroshi Tadano, "Improved Impedance Source Inverter for Hybrid/Electric Vehicle Application with Continuous Conduction Operation", 978-1-4673-9550-2/16/$31.00 ©2016 IEEE, page no:3722-3726.
16. Zeeshan Aleem, Moin Hanif, "Improved ī-Z-source Inverter", 978-1-5090-0737-0/16/$31.00 ©2016 IEEE.
17. Sang-hyup Han, Heung-Geun Kim, Bon-Gwan Gu, Honnyong Cha, Tae-won Chun, Eu-Chul Nho, "Induction Motor Control System Using Bidirectional Quasi-Z Source Inverter", 9th International Conference on Power Electronics-ECCE Asia June 1 - 5, 2015 / 63 Convention Center, Seoul, Korea, page no:588-593.
18. M. Z.Zizoui, B.Tabbache , F.Belkhiri and M.E.H.Benbouzid, "Maximum Constant Boost Control of 9-Switch zSource Power Inverter-Based Electric Vehicles", The 5th International Conference on Electrical Engineering – Boumerdes (ICEE-B) October 29-31, 2017, Boumerdes, Algeria.
19. Sertac Bayhan, Mohamed Trabelsi, and Haitham Abu-Rub, "Model Predictive Control of Z-Source Four-Leg Inverter for Standalone Photovoltaic System with Unbalanced Load", 978-1-4673-9550-2/16/$31.00 ©2016 IEEE page:3663-3668.
20. Siddhartha A. Singh, Giampaolo Carl, Najath A. Azeez, and Sheldon S. Williamson, "Modelling, Design, Control, and Implementation of a Modified Z-source Integrated PV/Grid/EV DC Charger/Inverter", DOI 10.1109/TIE.2017.2784396, IEEE Transactions on Industrial Electronics.
21. ReddiPrasad Reddivari, Debashisha Jena, "Practical Limitations of Embedded Z-Source DC-DC Converters in PV Applications", 978-1-5386-2462-3/18/$31.00 ©2018 IEEE.
22. Swathyprakash and Rani S, "Modified Trans-Z-Source Inverter with Continuous Input Current and Improved Boost Factor", International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) – 2016, 978-1-4673-9939-5/16/$31.00 ©2016 IEEE.
23. Catherine Amala Priya. E and G. T. Sundar Rajan, "Renewable Energy Source based Γ- Z source inverter interlinked to grid with Harmonics optimization Techniques" 978-1-5386-1508-9/18/$31.00 ©2018 IEEE.
24. Arvind Yadav, Subhash Chandra, "Single stage high boost Quasi-Z-Source inverter for off-grid photovoltaic application", 2020 International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC) GLA University, Mathura, UP, India. Feb 28-29, 2020.
25. Soroush Esmaeili and Abdolreza Sheikholeslami, "Transformer Types of Extended Z-Source Inverter with High Voltage Gain and Reduced Transformer Turns Ratio", The 6th International Power Electronics Drive Systems and Technologies Conference (PEDSTC2015) 3-4 February 2015, Shahid Beheshti University, Tehran, Iran. 978-1-4799-7653-9/15/$31.00 ©2015 IEEE page no:183-188.
26. Soroush Esmaeili, Shekouh Karimi, Pouya Tarassodi and Alireza Siadatan, "Two-Stage Asymmetrical -Z-Source Inverter with High Voltage Gain and Reduced Shoot-Through Duty Ratio", 2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, 978-1-5090-2067-6/16/$31.00 ©2016 IEEE.
27. Milad Abbasi and Ebrahim Babaei, "A New Topology of Embedded Z-Source Inverter with Low Voltage Stress on Capacitors", 978-1-4673-9749-0/16/$31.00 ©2016 IEEE.
28. Md. Khurshedul Islam* , Md. Mustafa Zaved, Air Mohammad Siddiky, Khandakar Abdulla Al Mamun, "A Comparative Analysis among PWM Control Z-source Inverter with Conventional PWM Inverter for Induction Motor Drive", 978-1-5090-6122-8/16/$31.00 ©2016 IEEE.
29. Mrudul A. Mawlikar, Ms. Sreedevi S Nair, "A Comparative analysis of Z source inverter and DCDC converter fed VSI", 978-1-5090-2794-1/17/$31.00 ©2017 IEEE.

30. Reddiprasad Reddivari & Debashisha Jena (2018) "A critical analysis of Z-source converters considering the effects of internal resistances", International Journal of Electronics, 105:10, 1785-1803, DOI: 10.1080/00207217.2018.1482007

31. Reddiprasad Reddivari, Debashisha Jena," A Detailed Model of Z-Source Converter Considering Parasitic Parameters", 978-1-5386-2462-3/18/$31.00 ©2018 IEEE.