CHAPTER 2

LITERATURE REVIEW

This chapter is a literature review which presents the different types of inverter topologies like VSI, CSI, ZSI and L-ZSI. The different types of control techniques in the literature are discussed in this chapter. The most common control techniques are reviewed.

2.1 INTRODUCTION

A Impedance Source Inverter (ZSI) is a Direct Current (DC) to Alternating Current (AC) power conversion concept that is very promising in the areas of power conditioning especially with alternative energy sources, Adjustable Speed Drives (ASD) and distributed generation. It has the unique ability to allow the DC link of the inverter to be shorted, which is not possible in traditional inverters. This will improve the reliability of the inverter circuit. The concept of boosting the input voltage is based on the ratio of “shoot-through” time to the total switching period.

The converted AC can be made available at any required voltage and frequency with the use of appropriate transformers, switching and control circuits. Traditional inverters are classified into two types, namely VSI and CSI. The VSI can be used for buck (step-down) operation in DC to AC power conversion or for boost (step-up) operation in AC to DC power rectification, without any additional DC to AC converter to buck/boost the DC-Link voltage. The CSI is suitable only for boost either in DC to AC power conversion or AC to DC power rectification. So far, in applications where a
wide range of voltage is desirable, an additional DC to DC converter is needed to meet the requirements.

2.2 Z-SOURCE INVERTER

Fang Peng et al. (2003) described that by controlling the shoot-through duty cycle, the Z-source could produce any desired output AC voltage, even greater than the line voltage. The Z-source inverter employs a unique LC network to couple the inverter main circuit to the diode front end and the new Z-source inverter system provides ride-through capability under voltage sags, reduces line harmonics, and extends output voltage range.

Subrata Mondal et al. (2003) observed that there is an over modulation strategy of space vector PWM of a three-level inverter with linear transfer characteristic that easily extends from the under modulation strategy. The over modulation strategy is very complex because of large number of inverter switching states, which are hybrid in nature, and it incorporates both under modulation and over modulation algorithms.

Tusitha Abeyasekera et al. (2003) described the distortion investigation of an inverter reference waveform generated using a Direct Look-Up algorithm. The sources of various distortion components are identified and the implications for application to variable speed drives and grid connected inverters are described. Harmonic and sub-harmonic distortion mechanisms are analysed, and compared with experimental results.

Fang Zheng Peng et al. (2005) explained the control methods for the Z-source inverter and their relationships of voltage boost versus modulation index. A maximum boost control is presented to produce the maximum voltage boost (or voltage gain) under a given modulation index.
The control method, relationships of voltage gain versus modulation index, and voltage stress versus voltage gain are analysed.

Chandana et al. (2005) described the control schemes for the Z-source inverter and modelling of the Z-source impedance network using perturbed mathematical analysis, and a Signal-flow graph with parasitic components is taken into consideration. The developed average control-to-output model reveals the presence of a right-hand-plane zero in the network transfer function, whose trajectories with variations in network parameters can be studied using classical root-locus analyses.

Poh Chiang Loh et al. (2005) made a detailed analysis of conventional pulse-width modulation strategies to switch a voltage-type Z-source inverter either continuously or discontinuously and single-phase H-Bridge Z-Source inverter modulation requirements.

Zhiguo Pan & Fang Z Pen (2006) suggested a control method to lower the harmonic components of the conventional voltage balancing control for the multilevel converters. A control method based on the line–line voltage redundancy of the three-phase inverter is proposed to lower the harmonic components of both the converter and inverter sides.

Miaosen Shen et al. (2006) recommended a constant boost-control method for the Z-source inverter, which can obtain maximum voltage gain at any given modulation index without producing any low-frequency ripple that is related to the output frequency and can minimize the voltage stress at the same time. Thus, the Z-network will be independent of the output frequency and determined only by the switching frequency.
Yi Huang et al. (2006) suggested a Z-source inverter system for a split-phase grid-connected photovoltaic system operation principle, control method, and characteristics.

Poh Chiang Loh et al. (2007) described a transient modelling and analysis of a voltage-type Z-source inverter that exhibits both steady-state voltage buck and boost capabilities using a unique LC-impedance network, coupled between the power source and converter circuit. The DC-side phenomenon is shown through small-signal and signal-flow-graph analyses to be having a right-half-plane zero in its control-to-output transfer function and the AC-side phenomenon is shown through space vector analysis to depend on the time intervals of inverter states used for reconstructing the desired inverter output voltage. Based on the AC vectorial analysis, a method for improving the inverter transient response is also presented.

Poh Chiang Loh et al. (2010) introduced a new family of embedded Z-source inverters that can produce the same gain as the Z-source inverters but with smoother and smaller current / voltage maintained across the dc input source and within the impedance network. An added filter will raise the system cost and, at times, can complicate the dynamic tuning and resonant consideration of the inverters. The same embedded concept can also be used for designing a full range of voltage- and current-type inverter.

Omar Ellabban et al. (2012) proposed direct dual-loop peak DC-link voltage control strategy, with outer voltage loop and inner current loop, of the Z-source inverter. The peak dc-link voltage is estimated by measuring both the input and capacitor voltages. With this proposed technique, a high-performance output voltage control can be achieved with an excellent transient performance including input voltage and load current variations with minimized non minimum phase characteristics caused by the
right half-plane zero in the control to peak DC-link voltage transfer function. Both controllers are designed based on a third-order small-signal model of the ZSI using the direct digital control method.

Poh Chiang Loh & Frede Blaabjerg in (2013) introduced Z-source inverters as a new class of inverters proposed with output voltage or current buck–boost ability. Despite their general attractiveness, there are some present limitations faced by the existing Z-source inverters, most of which are linked to their requirement for low modulation ratio at high input-to-output gain and the presence of an impedance network. The former means a high dc-link voltage, which can stress the semiconductor, switches unnecessarily. The latter leads to increase in cost and size, which in deed is undesirable. To lessen these concerns, an interesting approach is to use magnetically coupled transformers or inductors to raise the gain and modulation ratio simultaneously, while reducing the number of passive components needed.

Long Huang et al. (2013) proposes a new family of three-switch three-state single-phase Z-source inverters (TSTS-ZSIs) that can be classified into two groups, boost-based TSTS-ZSI and buck–boost-based TSTS-ZSI, according to the step-up circuit. All of the topologies have the merits of buck–boost capability and low voltage stress, and some of them have the feature of dual grounding. In addition, the step-up in dc side and inversion in ac side is completely decoupled in the proposed topologies. In terms of a linear voltage gain, the conventional linear control methods can be used, which makes the control system very simple. The operating principles of the two types of topologies are described, respectively, and the comprehensive comparison between them is provided.

Francis Boafo Effah et al. (2013) presented the control of a Z-source neutral point clamped inverter using the space vector modulation
technique. This gives a number of benefits, both in terms of implementation and harmonic performance. The adopted approach enables the operation of the Z-source arrangement to be optimized and implemented digitally without introducing any extra commutations.

Lei Pan (2014) described uses of a unique inductor and diode network for boosting its output voltage, provides a common ground for the DC source and inverter, and avoids the disadvantage caused by capacitor in the classical ZSI and SL-ZSI, especially in prohibiting the inrush current at startup as also the resonance of Z-source capacitors and inductors. The inverter can increase the boost factor through adjusting shoot-through duty ratio and increase the number of inductors. The working principle of the proposed ZSI and comparison with the classical ZSI and SL-ZSI are analyzed in detail.

2.3 DIFFERENT CONTROL SCHEMES

Poh Chiang Loh et al. (2007) described a three-level Z-source Neutral-Point-Clamped (NPC) inverter buck-boost power conversion solution with an improved output wave form quality. The designed Z-source inverter functions by selectively “shooting through” its power sources, coupled to the inverter using two unique Z-source impedance networks, to boost the inverter three-level output waveform.

Fang Zheng Peng et al. (2007) discussed a Z-source inverter control strategy used to control power from the fuel cell, power to the motor, and State Of Charge (SOC) of the battery for Fuel Cell Hybrid Electric Vehicles (FCHEV). By substituting one of the capacitors in the Z-source with a battery and controlling the shoot through duty ratio and modulation index independently, one is able to control the fuel cell power, output power, and SOC of the battery at the same time.
Miaosen Shen et al. (2007) made a comparison of conventional Pulse Width Modulation (PWM) inverter, DC–DC boosted PWM inverter, and source inverter for fuel cell applications. Total switching device power, passive components requirement, and constant power speed ratio of each of these inverters were calculated.

Quang-Vinh et al. (2007) described the algorithm to control linearly the capacitor voltage is suggested in order to improve the transient response for DC boost control of the ZSI. The peak value of the AC output voltage is used to control exactly the AC output voltage to its desired level. A modified space vector pulse width modulation scheme is applied to control the shoot-through time for boosting DC voltage.

Feng Gao et al. (2007) summarised the design of a dual Z-source inverter that can be used with either a single DC source or two isolated DC sources. Unlike traditional inverters, the integration of a properly designed Z-source network and semiconductor switches to the proposed dual inverter allows buck–boost power conversion to be performed over a wide modulation range. With three-level output waveforms generated, the dual inverter can be controlled using a carefully designed carrier-based pulse width-modulation.

Miaosen Shen & Fang Zheng Peng (2008) gave an account of analysis and control methods based on an assumption that the inductor current is relatively large, continuous, and has small ripple. This assumption becomes invalid when the load power factor is low or the inductance is small in order to minimize the inductor’s size and weight for some applications where volume and weight are crucial. Under these conditions, the inductor current has high ripple or even becomes discontinuous. Hence, these new operation modes and the associated circuit characteristics of Z-source inverter new operating modes are analysed.
Yu Tang et al. (2009) described an improved Z-source inverter topology which can reduce the Z-source capacitor voltage stress significantly to perform the same voltage boost, and has inherent limitation to inrush current at start up. The control strategy of the proposed Z-source inverter is exactly the same as the traditional one, so all the existing control strategy can be used directly. A soft-start strategy is also proposed to suppress the inrush surge and the resonance of Z-source capacitors and inductors.

Seyed Mohammad et al. (2010) discussed the Space Vector Modulation (SVM) of nine-switch inverter and nine-switch-z-source inverter. The proposed method increases the sum of modulation indices up to 15% in contrast with the conventional, scheme in which the sum of modulation indices is equal or less than one. The extra voltage available for a given input DC-voltage, translates to a higher torque a critical factor for defining the capacity of products in marketplace. Also, in order to further reduce the cost of power devices and also thermal heat effect, and to reduce the number of semiconductor switching, specific SVM switching pattern is presented.

Chandana Jayampathi et al. (2010) introduced a new family of extended-boost quasi Z-source inverter to overcome the problem associated in traditional Z-Source inverter. These new topologies can be operated with same modulation methods that were developed for original ZSI. Also, they have the same number of active switches as original ZSI preserving the single-stage nature of ZSI. Proposed topologies are analysed in the steady state.

Shuitao Yang et al. (2011) presented a comprehensive study on the new features of current-fed qZSIs, including the advantageous buck–boost function, improved reliability, reduced passive component ratings, and unique regeneration capability. The current-fed qZSIs are bidirectional with an
additional diode, unlike the voltage-fed ZSI that needs a switch to achieve bidirectional power flow. A modified space vector pulse-width-modulation method is proposed, and the available operating regions for motoring and regeneration operation are analysed.

Indrek Roasto et al. (2013) described Shoot-through control methods for qZSI-based DC/DC converters to increase the efficiency. A new modulation technique, pulse width modulation with shifted shoot-through, is compared with the conventional PWM shoot-through control method. The new method reduces switching frequency of bottom side transistors and inherently features partial soft switching.

Adda Ravindranath et al. (2013) compared a steady-state and small-signal analyses of Simple Boost Inverter (SBI), along with its pulse width modulation control strategies and presents a comparison of SBI and ZSI with the same input and output parameters. This topology also exhibits better electromagnetic interference noise immunity when compared to a traditional voltage-source inverter (VSI).

Qin Lei et al. (2014) described optimized PWM sequence in the modified SVPWM control to achieve the best efficiency at the full operation range. In order to select the best PWM sequence to obtain the best performance and efficiency, a complete analysis and calculation are presented for different sequences. For each criterion, the best sequences are selected to obtain better performance.

Yushan Liu et al. (2014) described the different switching control patterns, the available maximum shoot-through duty ratio, the maximum voltage stress across the switch versus voltage gain, and efficiency are compared in detail. A total average switch device power taking into account
the shoot-through current stress is proposed to evaluate the total stress of power switches.

Xu Peng Fang et al. (2014) gave an account of a single-phase ac power supply circuit that is based on modified voltage-fed quasi-Z-source inverter topology; it suits to the light or the heavy load and is fit for the resistive, inductive, or capacitive load. The topology, operating principle, voltage gain, control method, and its realization by DSP are described. The feasibility and rationality of the system is verified by the simulation and experimental results.

2.4 GRID CONNECTED INVERTER SCHEMES

Chandana Jayampathi et al. (2009) presented a controller design for a ZSI based Distributed Generation (DG) system to improve power quality of distribution systems. Power delivered from DG sources depends on factors like energy availability and load demand. The converters used in power conversion do not operate with their full capacity all the time. The unused or remaining capacity of the converters could be used to provide some ancillary functions like harmonic and unbalance mitigation of the power distribution system. As some of these DG sources have wide operating ranges, they need special power converters for grid interfacing. Being a single-stage buck–boost inverter, recently proposed Z-source inverter (ZSI) topology can be used in DG systems.

Dmitri Vinnikov & Indrek Roasto (2011) introduced a new step-up DC/DC converter topologies intended for distributed power generation systems. The topologies contain a voltage-fed quasi-Z-source inverter with continuous input current on the primary side, a single-phase isolation transformer, and a Voltage Doubler Rectifier (VDR). To increase the power
density of the converter, a three-phase auxiliary AC link and a three-phase VDR are proposed to be implemented.

Dong Cao et al. (2011) described non-isolated semi-Z-source inverters for a single-phase photovoltaic system with low cost and doubly grounded features. These semi-Z-source inverters employ the Z-source/quasi-Z-source network and only two active switches to achieve the same output voltage as the traditional voltage-fed full-bridge inverter does. The two active switches of the semi-Z-source inverter are controlled complementarily. Different from the traditional single-phase Z-source/quasi-Z-source inverter, shoot-through zero state is not applicable to the semi-Z-source inverter. The input DC source and the output AC voltage of the semi-Z-source inverter share the same ground, thus leading to less leakage ground current advantages over other non-doubly grounded inverters, such as voltage-fed full-bridge inverter.

Wei Qian et al. (2011) described the extension of the impedance-source (Z-source) inverters concept to the transformer-based Z-source (trans-Z source) inverters. The proposed four trans-Z-source inverters, consists of all the impedance networks, a transformer and one capacitor. Along with the main features of the X-Shape Z-source network, the new networks exhibit some unique advantages, such as the increased voltage gain and reduced voltage stress in the voltage-fed trans-ZSIs and the expanded motoring operation range in the current-fed trans-ZSIs, when the turns ratio of the transformer windings is over 1.

Haitham Abu-Rub et al. (2013) discussed an artificial-intelligence-based solution to interface and deliver maximum power from a Photo Voltaic (PV) power generating system in standalone operation. The interface between the PV DC source and the load is accomplished by a quasi-Z-source inverter.
(qZSIs). The maximum power delivery to the load is ensured by an Adaptive Neuro-Fuzzy Inference System (ANFIS) based on Maximum Power Point Tracking (MPPT). The proposed ANFIS-based MPPT offers an extremely fast dynamic response with high accuracy. The closed-loop control of the qZSIs regulates the shoot-through duty ratio and the modulation index to effectively control the injected power and maintain the stringent voltage, current, and frequency conditions.

Yuan Li et al. (2013) described the modelling and control issues of the qZSI used for distributed generation (DG), such as PV or fuel cell power conditioning. The dynamical characteristics of the qZSI network are first investigated by small-signal analysis. Based on the dynamic model, stand-alone operation and grid-connected operation with closed-loop control methods, which are the two necessary operation modes of DG in distributed power grids, are carried out. Due to the mutual limitation between the modulation index and shoot-through duty ratio of qZSI, constant capacitor voltage control method is proposed in a two-stage control manner. Minimum switching stress on devices can be achieved by choosing a proper capacitor voltage reference.

Baoming Ge et al. (2013) presented a new topology of the energy-stored qZSI to overcome this disadvantage a power limitation due to the wide range of discontinuous conduction mode during battery discharge. The operating characteristic of the proposed solution is analysed in detail and compared to that of the existing topology.

Jian Feng Liu et al. (2013) discussed a fixed frequency operating Sliding Mode (SM) current control method with fast response and improved stability. Different from the conventional SM control with variable switching frequency, the fixed-frequency SM controller is proposed to control the
modulation index and shoot-through duty ratio of the voltage-fed quasi-Z-source inverter (qZSI), which does not increase the passive components and filter design difficulty. A large-signal dynamic model of the system, which can be used for the system stability control in a wide operating range, has been established. By using linear approximation, the system small-signal model is also obtained to analyse the control system stability and transient response.

Feng Guo et al. (2013) gave an account of an operation analysis, controller design, and realization of a high-power, Bidirectional Quasi-Z-Source Inverter (BQ-ZSI) for electric vehicle applications. Based on the circuit analysis, a small signal model of the BQ-ZSI, which indicates that the circuit is prone to oscillate when there is disturbance on the dc input voltage, is derived. Therefore, a dedicated voltage controller with feed-forward compensation is designed to reject the disturbance and stabilize the DC-link voltage during a non-shoot through state.

Yushan Liu et al. (2013) described a control strategy for the quasi-Z-source inverter with a battery-based photovoltaic power conversion system. A battery-assisted qZSI can buck/boost PV panel voltage by introducing shoot-through states, and make full use of PV power by the energy-stored battery paralleled to the quasi-Z-source capacitor. A dynamic small-signal model of the battery-assisted qZSI is established to design a closed-loop controller for regulating shoot-through duty ratio and managing the battery’s energy storage. A modified space vector modulation technique for the qZSI is applied to achieve low harmonics, high voltage utilization, and high efficiency. A P-Q decoupled grid-tie power injection is fulfilled with the maximum power capture from PV panels and the unity power factor.
Yushan Liu et al. (2014) suggested an effective control method, including system-level control and pulse width modulation for quasi-Z-source cascade multilevel inverter (qZSI-CMI) based grid-tie photovoltaic power system. The system-level control achieves the grid-tie current injection, independent maximum power point tracking for separate PV panels, and dc-link voltage balance for all Quasi-Z-source H-Bridge inverter (qZSI-HBI) modules.

Dongsen Sun et al. (2014) presented an analytic model to accurately calculate the voltage and current ripples of each qZSI module. A qZSI impedance design method based on the built model is proposed to limit the ripples of DC-link voltage and inductor current.

Alexandre Battiston et al. (2014) described a control method that adapts the DC bus voltage of electric traction systems using permanent magnet synchronous machine fed by bidirectional Z-source inverter or other improved topologies. This control allows reducing both the overestimation of the dc bus voltage and losses in the inverter. The Sliding-Mode Control (SMC) method is used to control the Z-source converter, whereas flatness-based control is proposed to drive the actuator and generate the peak DC bus voltage reference. Flatness-based control is chosen because the actuator transients are well mastered. Extra shoot-through zero inverter states are inserted by means of implemented algorithm on a space-vector-modulation scheme.

2.5 SUMMARY

This chapter outlined a review of the literature on Z-source inverter. Operating modes of the Z-source inverter systems with its equivalent circuits were briefed from the literature. The operation of traditional three phase Z-source inverter was discussed and the significant drawbacks of the
traditional system were highlighted. The grid connected impedance source inverter grid was briefed from the literature analysis. The different control schemes for impedance source inverter were summarised from the literature. Z-source capacitor voltage to shoot-through duty ratio and Z-source capacitor voltage to modulation index were derived by state space averaging technique. The modification of impedance source is briefed here with L-Z source inverter.