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Design and Simulation of a Quasi Z-Source Inverter for Photovoltaic Energy Conversion

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Abstract- Renewable energy sources such as solar power are highly dependent on environmental conditions, which often leads to fluctuations in output voltage and current. These variations create challenges for conventional inverter systems like Voltage Source Inverters (VSI), Current Source Inverters (CSI), and even traditional Z-Source Inverters (ZSI), affecting their efficiency and reliability. To address these issues, this paper focuses on the design and simulation of a Quasi Z-Source Inverter (QZSI) for photovoltaic (PV) energy conversion. The QZSI is an improved version of the ZSI, achieved by modifying the impedance network. This topology offers several advantages, including the ability to perform both buck and boost operations in a single stage, reduced component stress, and a continuous input current, which is particularly beneficial for PV systems. Additionally, the QZSI allows the use of shoot- through states without damaging the inverter, enabling effective voltage boosting under varying input conditions. In this work, the operating principle, voltage boost capability, and control strategy of the QZSI are studied. A simulation model is developed using MATLAB/Simulink to evaluate system performance under different operating scenarios. The results demonstrate that the QZSI provides improved voltage stability and overall efficiency, making it a suitable choice for renewable energy applications.

Keywords – Quasi Z-Source Inverter (QZSI), Renewable Energy, Photovoltaic (PV) Systems, Buck–Boost Conversion, Shoot-Through Operation, MATLAB/Simulink, Voltage Stability, Impedance Network, DC–AC Conversion.

I. INTRODUCTION

A microgrid is an electrical system composed of interconnected loads and distributed energy resources, such as photovoltaic arrays, energy storage devices, and controllable loads or prosumers, operating together to supply reliable electricity within a defined local area. Instead of relying on distant central power stations powered by fossil fuels or nuclear energy, microgrids enhance supply reliability and flexibility while reducing transmission losses and environmental impact. The transition towards renewable energy technologies, particularly solar power, has enabled modern distributed generation systems to efficiently and sustainably meet local electricity demand.

Extracting maximum energy from renewable sources requires advanced Maximum Power Point Tracking (MPPT) algorithms to maintain optimal operating points despite changing conditions. Common MPPT techniques, such as Perturb & Observe, Incremental Conductance, and modern intelligent methods, often encounter difficulties when trying to locate the global power maximum during unpredictable shading or dynamic solar irradiance. This project uses a Modified Power Ratio Variable Step (MPRVS) approach based on the P&O algorithm, which operates without proportional-integral regulation to minimize power fluctuations near the maximum power point and stabilize battery charging.

To further improve microgrid efficiency, the project integrates a Quasi Z-Source inverter, known for its flexible buck-boost operation and robust voltage gain, in conjunction with a single-ended primary inductance converter (SEPIC) that serves as the DC-DC interface for high-quality power tracking and impedance adaptation. While prior studies have considered various inverter topologies and traditional MPPT controls, this work focuses on modelling, simulating, and experimentally validating a standalone PV microgrid using advanced MPPT and power electronics. The developed solution demonstrates enhanced reliability and efficient energy extraction, with both simulation and hardware models planned for thorough performance validation.

II. LITERATURE SURVEY

Brief review of Literature survey:

The literature survey highlights recent advances and limitations in quasi-Z-source inverter (QZSI) technology for PV systems. Some studies focus on battery-assisted or grid-connected designs, with issues such as reliance on grid support, resonance and stability problems, or simulation-only validation.

Table-2.1 Literature Survey

S.no	Reference Paper	Author/Source/Year	Limitations
1	Photovoltaic System with a Battery- Assisted Quasi-Z-Source Inverter: Improved Control System Design Based on Novel Small-Signal Model	Ivan Grgic, et al. / MDPI / 2022	Limitation for standalone applications where grid support is not available.
2	Quasi-Z-Source Inverter-Based Photovoltaic Power System Modeling for Grid Stability Studies	Lulis Monjo, et al. / MDPI / 2021	Stability problems are not well known can cause system resonances and reduce system damping.
3	Implementation of Quasi-Z source inverter for renewable energy applications	M. Raja Nayaka, et al. / ELSEVIER / 2021	Simulation-only, no hardware validation, basic MPPT, limited scope, efficiency.
4	Design and Development of Grid- connected Quasi-Z-Source PV Inverter	Zulhani Rasin, et al. / Research Gate / 2018	This project lacks SEPIC converter, advanced MPRVS MPPT, standalone microgrid focus, and comprehensive dynamic hardware validation
5	Control of Quasi Z-Source Converter in a Microgrid Using Modified Power Ratio P&O MPPT	Ch. Sreenu, et al. / Reasearch Gate / 2023	The recommended freestanding microgrid technology can only be used in rural areas.
6	A Comparison of Quasi-Z-Source Inverter and Traditional Two-Stage Inverter for Photovoltaic Application	Ayman Ayad, Stefan Hanafiah, Ralph Kennel	Higher voltage stress on switches for qZSI; performance comparison focused mainly on THD, efficiency, voltage stress not covering all possible dynamic scenarios

III. PROBLEM STATEMENT

Standalone photovoltaic (PV) systems are widely used in rural and remote areas, but their performance is affected by fluctuations in solar irradiation, leading to unstable voltage and reduced efficiency. Conventional inverters such as VSI and CSI are not suitable for such conditions due to limited voltage control, higher cost, and poor dynamic response. Even traditional Z-source inverters face issues like discontinuous input current and higher stress on components. Additionally, the use of separate DC–DC converters and basic control methods increases system complexity and reduces overall performance. Therefore, there is a need for a reliable and efficient power conversion system that can handle wide input variations while maintaining stable output. This work addresses these challenges by designing and simulating a Quasi Z-Source Inverter (QZSI), which provides improved buck–boost capability, continuous input current, and better performance for photovoltaic applications.

IV. OBJECTIVES

The project focuses on designing a Quasi Z-Source Inverter (QZSI) for photovoltaic applications, making use of its ability to achieve both buck and boost operations within a single- stage conversion.

1. A simulation model of the proposed QZSI is developed in MATLAB/Simulink to study its performance under different operating conditions.
2. The work involves understanding the operating modes of the QZSI, especially the shoot-through and non-shoot-through states, and how they contribute to voltage boosting.
3. The inverter performance is examined by observing output voltage, current waveforms, and voltage gain at different modulation index values.
4. The system is further analysed to check how effectively it maintains performance when the input voltage varies, as typically seen in solar energy systems.

V. SCOPE OF THE PROJECT

This project focuses on the design and simulation of a Quasi Z-Source Inverter (QZSI) for photovoltaic applications using

MATLAB/Simulink. The main aim is to study how the inverter behaves under changing input conditions, which are common in solar energy systems. Special attention is given to understanding the different operating modes of the QZSI, particularly the shoot-through and non-shoot-through states, and how they help in achieving voltage boosting.
The work includes analysing important performance parameters such as output voltage, current waveforms, and voltage gain for different modulation conditions. It also explores how the QZSI can perform both buck and boost operations in a single stage, making it more suitable for standalone renewable energy systems.

In addition, A basic comparison with conventional inverter limitations is considered to highlight the benefits of the proposed approach. The scope is limited to simulation studies and provides a base for future hardware implementation and further improvements in control techniques.

VI. DESIGN OF THE PROPOSED SYSTEM

In this work, a Quasi Z-Source Inverter (QZSI) is designed and simulated to study its behaviour under different operating conditions. The main focus is on how the inverter can handle voltage variations and still maintain a stable output using its unique operating principle.The system consists of a DC source connected to the QZSI impedance network formed by inductors and capacitors. This network enables both voltage boosting and filtering, allowing the inverter to operate safely even when shoot-through conditions are applied. Unlike traditional inverters, this structure prevents short-circuit issues during such states.

The inverter bridge is controlled using a time-based switching logic developed in MATLAB. In normal operation, the switches are driven in a complementary manner to generate an AC output. Along with this, short-duration shoot-through pulses are introduced within each switching cycle. These pulses are controlled using a predefined duty ratio and high-frequency switching signal.

During the shoot-through interval, all switches in the inverter are turned ON simultaneously for a very small duration. This helps in increasing the DC-link voltage without affecting the safety of the circuit. The duration of this interval directly influences the voltage boost obtained at the output.The complete system is implemented in MATLAB/Simulink, where the switching logic is used to generate gate pulses for the inverter. By varying parameters such as duty ratio and switching frequency, the performance of the system is analyzed in terms of output voltage, waveform characteristics, and voltage gain.

Overall, the design focuses on demonstrating how controlled shoot-through states and proper switching can improve the performance of a QZSI, making it suitable for applications where input conditions are not constant.

System Architecture

The proposed system focuses on the design and simulation of a Quasi Z-Source Inverter (QZSI) for standalone operation. The structure mainly consists of a DC source, an impedance network, an inverter bridge, and a load. The aim is to study how the inverter performs under different operating conditions and how it handles variations in input voltage.

In this work, a DC source is used in place of a photovoltaic supply to simplify the analysis and focus on the operation of the QZSI. This input is connected to the impedance network, which is formed using inductors and capacitors. This network is responsible for energy transfer and allows the inverter to perform both step-up and step-down operations. It also enables safe operation during shoot-through conditions, which is a key feature of this topology.

The inverter bridge converts the DC input into AC output for the load. The switching signals are generated using a time-based control logic implemented in MATLAB. During normal operation, the switches work in a complementary manner, while short shoot-through intervals are inserted within each switching cycle to achieve voltage boosting. The duration of these intervals is controlled using a duty ratio.

The complete system is modelled and simulated in MATLAB/Simulink to analyse its behaviour. The output is studied in terms of voltage, current, and waveform characteristics under different modulation conditions.

Main Components of the System

1. **DC Source (PV Representation):**
A constant DC input is used instead of a solar source to represent the photovoltaic output and simplify system analysis.
2. **QZSI Impedance Network:**
Made up of inductors and capacitors, this network enables energy storage, voltage control, and safe shoot-through operation.
3. **Inverter Bridge:**
Converts DC power into AC output for the load.
4. **Switching Control Logic:**
A time-based control method used to generate gate pulses, including both normal switching and shoot-through intervals.
5. **Load:**
Represents the application where the converted AC power is utilized.

Quasi Z-Source Inverter Model

Figure presents the equivalent power circuit of Quasi Z-source inverter which comprises of LA, LB, CA, CB components with impedance circuit. The considered Z-Source Quasi inverter has no filter requirement, better buck/boost characteristics, able to regulate the phase angle output, less size, continuous conducting mode working, less harmonic content, high efficiency and with better power performance over the conventional inverter as major advantages. The Quasi Z-source inverter operates in two modes of operation. In the non-shoot mode, the equivalent circuit has 6 active states with 2 zero states. The TS is the total switched inverter with TA and TB as the shoot through the state and the non-shoot through state, respectively. The duty ratio Dduty of SEPIC converter is mathematically written as:

$$D_{duty} = \frac{T_A}{T_S}$$

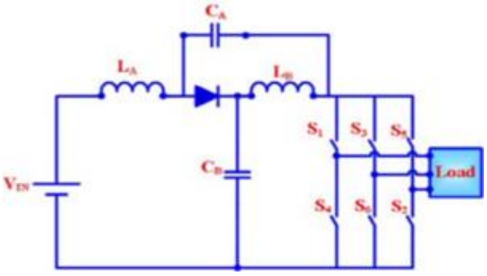

Fig.3.2: Equivalent power circuit of Quasi Z-source inverter

Mode I: The equivalent model of Quasi Z-source inverter is depicted in Figure 3.3 and mathematical equations governing non-shoot through the state is expressed as:

$$V_{L_A} = V_{IN} - V_{C_A}$$

$$V_{L_B} = -V_{C_B}$$

$$V_{DIODE} = 0$$

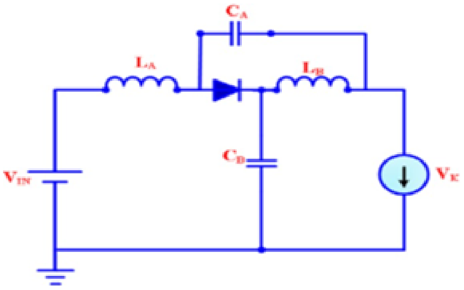

Fig.3.3: The Equivalent model of Quasi Z-source inverter in non-shoot through state

Mode II: Figure 3.4 illustrates the equivalent model of Quasi Z-source inverter in shoot through the state mode with the mathematical expression as:

$$V_{L_A} = V_{IN} + V_{C_A}$$

$$V_{L_B} = V_{C_B}$$

$$V_{DIODE} = V_{C_A} + V_{C_B}$$

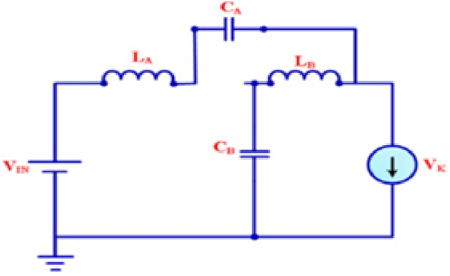

Fig.3.4: The Equivalent model of Quasi Z-source inverter in shoot through state

Under the steady condition, the average inductor voltage becomes zero.

$$V_{L_A} = \left[\frac{(V_{IN} + V_{C_B})T_A + (V_{IN} - V_{C_A})T_B}{T_S}\right] = 0$$

$$V_{L_B} = \left[\frac{V_{C_A}T_A + (-V_{C_B})T_B}{T_S}\right] = 0$$

On solving the above equations, capacitor voltage (VCA&VCB) is calculated mathematically as:

$$V_{C_A} = \left(\frac{T_B}{T_B - T_A}\right) \times V_{IN}$$

$$V_{C_B} = \left(\frac{T_A}{T_B - T_A}\right) \times V_{IN}$$

Maximum voltage across DC-link $= V_{C_A} + V_{C_B}$ from Equations VCA & VCB

Maximum DC-link voltage $= \left|\frac{1}{1 - 2\frac{T_A}{T_S}}\right| V_{IN} = K \times V_{IN}$

VII. RESULTS AND METHODOLOGY

The working of the proposed system is based on the operation of a Quasi Z-Source Inverter (QZSI) using a DC input source. In this project, a constant DC supply is used in place of a photovoltaic source to clearly study the behaviour of the inverter without external variations. The DC input is first applied to the impedance network of the QZSI, which consists of inductors and capacitors. This network plays a key role in energy transfer and allows the system to operate in both step-up and step-down modes. One of the important features of this inverter is the shoot-through condition, where switches in the same leg are turned ON simultaneously for a short duration. Unlike conventional inverters, this does not cause a short circuit because the impedance network limits the current and supports safe operation.

During normal operation, the inverter switches work in a complementary manner to produce an AC output. Along with this, shoot-through intervals are introduced within each switching cycle using a time-based control logic. These intervals help in boosting the DC-link voltage, and the level of boosting depends on the duration of the shoot-through period, which is controlled by the duty ratio.

The inverter bridge converts the processed DC voltage into AC supply for the load. The entire system is implemented in MATLAB/Simulink, where the switching logic generates the required gate pulses. By varying parameters such as duty ratio and switching frequency, the performance of the inverter is analysed.

Proposed Methodology

1. The Quasi Z-Source Inverter (QZSI) is designed by selecting appropriate values for the inductors and capacitors in the impedance network.
2. The complete system is modelled in MATLAB/Simulink, including the DC source, impedance network, inverter bridge, and load.
3. A time-based switching control logic is developed in MATLAB to generate gate pulses for the inverter switches. This includes both normal switching and shoot- through intervals.
4. The shoot-through duty ratio is defined and incorporated into the switching logic to achieve voltage boosting.
5. Simulation is carried out under different operating conditions by varying parameters such as duty ratio and switching frequency.
6. The output performance is analysed by observing voltage, current waveforms, and voltage gain of the inverter.
7. The results are studied to understand the behaviour of the QZSI and to verify its ability to provide stable and efficient power conversion.

Block Diagram

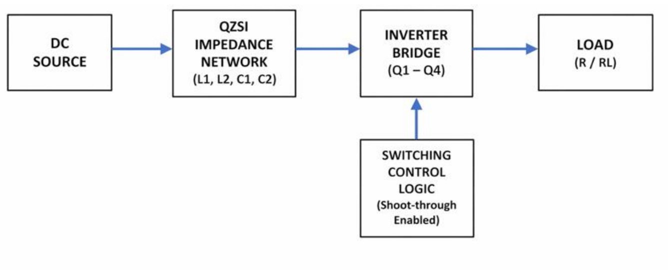

Fig.7.1: Block Diagram

Software Implementation

The software implementation of this project is carried out using MATLAB/Simulink, which is used to model and analyse the Quasi Z-Source Inverter (QZSI) system. The focus is on understanding the behaviour of the inverter under different operating conditions and evaluating its performance through simulation. The system is built by modelling the DC source, QZSI impedance network, inverter bridge, and load within the Simulink environment. A time-based switching control logic is developed using MATLAB to generate gate pulses for the inverter switches. This logic includes both normal switching operation and shoot-through intervals required for voltage boosting. Simulations are performed by varying key parameters such as switching frequency and shoot- through duty ratio. The output of the system is observed in terms of voltage and current waveforms to analyse the inverter performance. The effect of shoot-through on voltage gain and overall operation is also studied.

Simulink Models

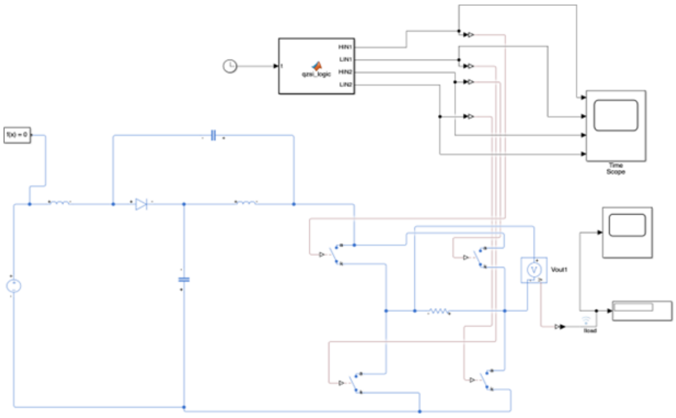

Fig.7.2: Quasi Z-Source Inverter Simulink Model

Fig. 7.2 showcases the quasi Z-source inverter Simulink model, emphasizing improved voltage boost and operational reliability, particularly valuable for renewable energy integration.

Results

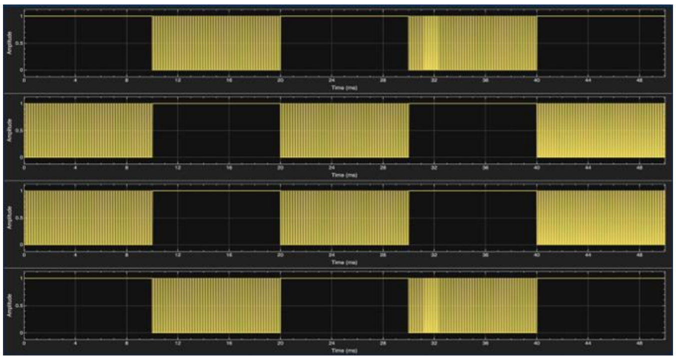

Fig.7.3 Quasi Z-Source Inverter Switching signals

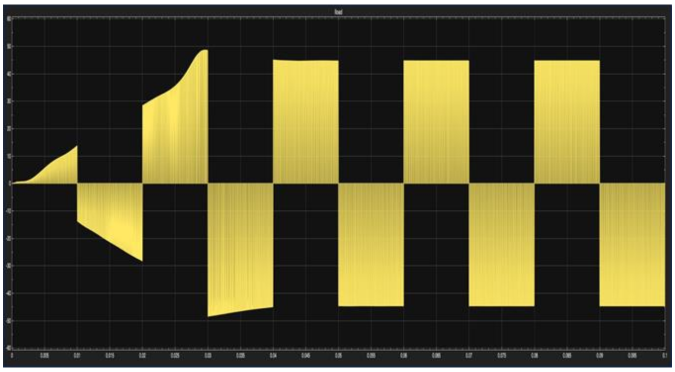

Fig.7.4 Quasi Z-Source Inverter output

The Fig.7.3 shows the switching pulses generated for the Quasi Z-Source Inverter using the implemented time-based control logic. It can be observed that the pulses follow a complementary pattern during normal operation, ensuring proper inverter switching. In addition to this, short-duration intervals are present where all switches are turned ON simultaneously, representing the shoot-through state. These shoot-through pulses are inserted periodically within each switching cycle and are controlled by the defined duty ratio. This switching strategy enables safe operation and supports voltage boosting in the QZSI.

The Fig.7.4 shows the output voltage waveform obtained from the Quasi Z-Source Inverter. The waveform appears as a stepped AC signal, produced due to the switching action of the inverter. It can be observed that the voltage alternates between positive and negative levels, indicating proper DC to AC conversion. The effect of shoot-through operation can also be seen in the increased voltage levels compared to a conventional inverter. Overall, the waveform demonstrates stable operation of the inverter under the given switching conditions.

VIII. CONCLUSION AND FUTURE SCOPE

The final chapter discusses the project's progress, findings, and future development possibilities. It addresses practical considerations such as assembling components, voltage/current calculations, component budgeting, and technical questions typically asked during project evaluations. As a future work, the project can be extended by using the multilevel inverter with the application of advanced intelligent MPPT algorithms viz. Jaya DE, hybrid ANFIS-ABC methods. The chapter concludes by summarizing the achievements so far and outlining the continuation plan for hardware building and testing in subsequent project phases

Future Scope

The future scope of our project encompasses several promising directions for expansion and enhancement. These improvements can significantly increase system functionality, usability, and integration with modern smart grid technologies.

Key areas of future scope include:

- Implementation of advanced multilevel inverter topologies such as Cascaded H-Bridge (CHB), Neutral-Point Clamped (NPC), or Modular Multilevel Inverters (MLI) that provide higher voltage gain, reduced switching losses, improved power quality, and lower Total Harmonic Distortion (THD).
- Application of intelligent and hybrid optimization-based MPPT algorithms including Jaya optimization, Differential Evolution (DE), and hybrid Adaptive Neuro-Fuzzy Inference System with Artificial Bee Colony (ANFIS-ABC) to enhance maximum power extraction under partial shading and rapidly changing environmental conditions.
- Development of sophisticated battery management systems (BMS) with accurate state- of-charge (SOC) estimation and health monitoring for extending battery life and improving reliability.
- Adoption of advanced control strategies such as model predictive control (MPC) and adaptive control for optimal energy management, power flow regulation, and improved system stability.
- Integration of communication and IoT-based real-time monitoring frameworks for smart grid applications enabling remote diagnostics, fault detection, and efficient operation.

IX. CONCLUSION

The project titled "Design and Development of Quasi-Z-Source Inverter for Standalone PV Microgrid" has been successfully initiated with the development of both the simulation models and preliminary hardware setup. The SEPIC converter, Quasi Z-Source Inverter (QZSI), and photovoltaic (PV) array have been modeled and analyzed using MATLAB/Simulink to evaluate their performance under varying irradiance and load conditions. The simulation results confirm that the proposed topology offers improved buck–boost capability, shoot-through immunity, and enhanced voltage regulation compared to conventional inverter systems.

At this stage, the Modified Power Ratio Variable Step (MPRVS) based MPPT algorithm is under integration to further optimize power extraction from the PV source. Hardware development has commenced, and component testing is in progress to validate the simulated results. Once completed, the experimental setup will provide a comprehensive evaluation of system efficiency, harmonic performance, and dynamic response under real-time conditions.

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