



Cairo University

# **STUDIES ON SOLAR GRID-INTERCONNECTED QUASI Z-SOURCE INVERTER**

**By**

**Ahmed Salah Nabih Ahmed**

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the  
Requirements for the Degree of  
**MASTER OF SCIENCE**  
In  
**ELECTRICAL POWER AND MACHINES ENGINEERING**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY**  
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Under the Supervision of

**Prof. Osama A. Mahgoub**

**Faculty of Engineering**  
**Cairo University, Egypt**

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Approved by the Examining Committee

**Prof. Osama Ahmed Mahgoub (Thesis Main Advisor)**

Faculty of Engineering - Cairo University

-----

**Prof. Hosam Kamal Mohamed Youssef (Internal Examiner)**

Faculty of Engineering - Cairo University

-----

**Prof. Yousry Abdel-Gawad Atia (External Examiner)**

Electronics Research Institute

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## List of Symbols

$\Delta I_L$	Peak to peak inductor current ripple
$\Delta V_C$	Peak to peak capacitor voltage ripple
$B$	Boost factor of the inverter
$BC-VSI$	Boost converter cascaded with voltage source inverter
$C$	Capacitance of the impedance network
$D$	Steady state Shoot Through - ST duty ratio
$d$	Controlled (transient) ST duty ratio
$f_0$	Power frequency
$f_c$	Corner frequency of the Filter
$f_s$	Switching frequency of the PWM carrier
$G$	Theoretical voltage gain of the QZSI
$i_D$	Instantaneous diode current
$i_{dq}$	Vector of grid current in $dq$ axes
$I_g$	Line RMS current
$I_i$	Instantaneous inverter bridge current
$I_L$	Average inductor current
$I_{PV}$	Operating current of PV string
$L$	Inductance of the impedance network
$M$	Modulation index
$MBC$	Maximum Boost Control
$MCBC$	Maximum Constant Boost Control
$NST$	Non-shoot through
$P_s$	Injected active power to grid
$PV$	Photovoltaic
$Q_s$	Injected reactive power to grid
$QZSI$	Quasi Z-source inverter
$SBC$	Simple Boost Control
$ST$	Shoot through
$SVM$	Space-vector modulation
$T_0$	Shoot through time

$T_I$	Non-shoot through time
$THD$	Total Harmonic Distortion
$T_s$	PWM switching time
$V_c$	Average capacitor voltage
$V_{C1}$	Average voltage across the capacitor $C_1$
$V_{C2}$	Average voltage across the capacitor $C_2$
$V_{DC}$	Peak value of the DC-link voltage
$V_{in}$	Input voltage
$v_L$	Instantaneous voltage across the inductor
$v_{max}$	Peak value of the fundamental component of the phase voltage
$V_n$	Lower shoot through reference
$V_p$	Upper shoot through reference
$V_{PV}$	Operating voltage on PV string terminals
$V_s$	Phase voltage at PCC
$VSI$	Voltage source inverter
$V_t$	AC phase voltage at converter terminals
$WTHDn$	Weighted Total Harmonic Distortion of the $n^{th}$ order
$ZSI$	Z-source inverter
$ZSVM2$	Modified SVM (with two modified reference signals)
$ZSVM4$	Modified SVM (with four modified reference signals)
$ZSVM6$	Modified SVM (with six modified reference signals)

## Abstract

Renewable energy sources present a trendy solution for energy shortage problem. However, these sources features variable and inconsistent power delivery over the course of the day. Power converters is, therefore, installed to stabilize the power delivery and regulate the output voltage to the utility level. Quasi Z-Source Inverter (QZSI) represents a single-stage buck-boost DC-AC converter, alternative to the traditional DC-DC converter cascaded with voltage-sourced inverter VSI topology, and is suitable for renewable energy integration systems.

In this thesis, a detailed analysis and design of QZSI is presented for grid-interconnected applications. The design procedure of the output low-pass filter is addressed; taking into account the variation in harmonic performance between the traditional PWM techniques for voltage source inverters and the modified PWM techniques for ZSIs. Moreover, an analytical study of harmonic performance of six different modulation techniques for ZSIs is presented. The harmonic spectrum of each modulation technique is estimated using double Fourier series approach. The analytical approach is adopted to exclude the common errors caused by practical conditions from simulation or experimental setups, and to present a fair comparison between the different modulation techniques. A collective evaluation of the modulation techniques using weighted total harmonic distortion is presented; taking into account the impact of the applied voltage gain on the harmonic performance.

This thesis, furthermore, proposes a control system design for QZSI in PV grid-tied applications. The control system is designed based on the dynamic characteristics of the converter and comprises three cascaded controllers. The first is output current controller designed in the synchronous rotating frame. The second is DC-link voltage controller. Sampling and measurement of the DC-link voltage signal is discussed using modified space-vector modulation. The last is maximum power point tracking (MPPT) in which a new strategy is proposed to provide wide operating range of DC-link voltage and shoot-through duty ratio, minimize the voltage stress on the inverter bridge, and prevent overlap between shoot-through duty ratio and modulation index. Simulation results are presented to validate the controllers design.