MODELING AND DESIGN OF A PV BASED QZSI FOR GRID-TIED APPLICATIONS

By
Ahmad Omar Omar AsSakka

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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Title of Thesis:

Modeling and Design of a PV based QZSI for Grid Tied applications

Key Words:

Grid-Tied Applications, Photovoltaic (PV), Quasi-Z-Source Inverter (QZSI).

Summary:

The Quazi Z-Source Inverter (QZSI) is utilized instead the traditional ZSI in PV applications; because its advantages over the traditional ZSI. This QZSI is controlled using two-stage control scheme which is inspired from the two-stage control Module Integrated Converters (MICs). The two-stage control structure is based on a derived SSM of the QZSI impedance network. A Modified Direct Incremental Conductance Maximum Power Point Tracking (MDIC-MPPT) algorithm is used to overcome the problems associated with the existing techniques. The obtained results based on SSM analysis are compared to those obtained using different Particle Swarm Optimization (PSO) techniques.

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Dedication

This thesis work is dedicated to my father Omar AsSakka, may Allah have mercy on him. A great gratitude to my mothers, Samiah Mohammad and Enaam Mahmod for their soul of encourage and support along my life. I would like also to dedicate this work with special thanks to my wife Sarrah Esmaeel for her encourage and patience besides me. An admittance of love and respect to my daughter Fatemah AzZahraa, my son Omar, and my sisters: Hend, NorolHoda, and Zainab.

I also dedicate this work with honors to all my uncles, aunts, and cousins for their interest and guidance.

Table of Contents

ACKNOWLEDGMENT	i
Dedication	ii
Table of Contents	iii
List of Symbols & Abbreviations	v
List of Figures	vi
Abstract	ix
Chapter One : Introduction and General Overview	1
1.1 Preface	1
1.2 Intermediate Power Processing Inverters	1
1.3 Scope of the Thesis	2
1.4 Outlines of the Thesis	3
Chapter Two : Brief and Mathematical Model of Impedance Source Inverters	4
2.1 Introduction	4
2.2 Literature Review on Types of Module Integrated Converters	4
2.2.1 Single Stage Module Integrated Inverters	6
2.2.2 Traditional Impedance Source Inverter	7
2.3 Circuit Analysis of Quazi Z-Source Inverter	13
2.4 Brief about Particle Swarm Optimization Techniques	16
2.4.1 Particle Swarm Optimization Procedure	17
2.4.2 Adaptive Weighted Particle Swarm Optimization	17
2.4.3 Adaptive Accelerated Coefficients Particle Swarm Optimization	19
2.4.4 Modified Adaptive Accelerated Coefficients Particle Swarm Optimization	20
2.5 Summary of the Chapter	21
Chapter Three : Control of the PV Based QZSI Using Stationary Frame Current Controller	22
3.1 Introduction	22
3.2 Dynamic Modeling of Quazi Z-Source Impedance Network	25
3.2.1 Small-Signal Model of Quazi Z-Source Impedance Network	25
3.2.2 Dynamic Characteristics of Quazi Z-Source Impedance Network	30

3.3 Capacitor voltage Control of the Quazi Z-Source Inverter 32
3.4 Two-Stage Control Structure of the Quazi Z-Source Inverter 34
3.4.1 DC Side Control 34
3.4.2 AC Side Control 36
a) Outer Capacitor Voltage Control 38
b) Interior Current Control Loop 38
3.5 Summary of the Chapter 39
Chapter Four : Design Steps of QZSI Network and Simulation Results 40
4.1 Introduction 40
4.2 Design Steps of Quasi Z-Source Impedance Network 40
4.2.1 Inductors Selection 41
4.2.2 Capacitors Selection 41
4.3 *LC* Filter Design 41
4.4 Simulation Results Using MATLAB 42
4.4.1 Simulation Results Considering Unstable Weather Conditions 43
4.4.2 Simulation Results for Sudden Failure in the Parallel Strings 51
4.4.3 Comparison with 100 kW MATLAB Model 60
4.4.4 Comparison with 15 kW MATLAB Model 64
4.5 Summary of the Chapter 67
Chapter Five : Conclusions of The Thesis and Future Work 68
5.1 Conclusions 68
5.2 Future Work 70
References 71
Appendix A 75

List of Symbols & Abbreviations

AACPSO	Adaptive Accelerated Coefficients PSO
AWPSO	Adaptive Weight PSO
CC	Centralized Converter
CSI	Current Source Inverter
DIC-MPPT	Direct Incremental Conductance MPPT
EMI	Electromagnetic Interference
HFT-MIC	High Frequency Transformer Module Integrated Converter
$\mathbf{I_{PV}}$	PV Module Output Current
LFT-MIC	Line Frequency Transformer Module Integrated Converter
MAACPSO	Modified AACPSO
MBC	Maximum Boost Control
MCBC	Maximum Constant Boost Control
MIC	Module Integrated Converter
MPPT	Maximum Power Point Tracking
NST	Non Shoot-Through state
PDCL	Pseudo DC Link
$\mathbf{P_{PV}}$	PV Module Output Power
PSO	Particle Swarm Optimization
PV	Photovoltaic
QZSI	Quasi Z- Source Inverter
RHP	Right Half Plane
SBC/CBC	Simple (or Constant) Boost Control
SPWM	Sinusoidal Pulse Width Modulation
SSM	Small Signal Modeling
ST	Shoot-Through state
$\mathbf{V_{PV}}$	PV Module Output Voltage
VSI	Voltage Source Inverter
ZSI	Z-Source Inverter (Impedance-Source Inverter)

List of Figures

Figure (1.1): Annual world PV Cell/Module Production. 1
Figure (2.1): Line Frequency Transformer MIC. 4
Figure (2.2): High Frequency Transformer MIC. 5
Figure (2.3): Transformer-less Two-Stage MIC. 6
Figure (2.4): Transformer-less Single stage MIC. 7
Figure (2.5): Types of MICs. 7
Figure (2.6): Impedance Source Inverter (ZSI). 8
Figure (2.7): Simple Boost Control (SBC) PWM. 10
Figure (2.8): Maximum Boost Control (MBC) PWM. 10
Figure (2.9): MBC-PWM with 3^{rd} harmonic Injection. 11
Figure (2.10): MCBC- PWM. 12
Figure (2.11): Voltage fed – QZSI. 13
Figure (2.12): The equivalent circuit of the QZSI network. 14
Figure (2.13): Schematic Representation of the Motion of a Particle in PSO. 17
Figure (3.1): QZSI with Battery Assisted on C_1. 22
Figure (3.2): QZSI with Battery Assisted on C_2. 23
Figure (3.3): Bidirectional QZSI for Motor Applications. 23
Figure (3.4): QZSI with Switched Inductor Instead L_2. 24
Figure (3.5): Trans QZSI with Continuous Input Current. 25
Figure (3.6): The equivalent circuit of the QZSI network. 26
Figure (3.7): SSM of QZSI Impedance Network. 29
Figure (3.8): Pole-Zero Trajectories of $G_{\hat{d}_o}^{\hat{v}_c}(s)$ Due to Sweep of L. 31
Figure (3.9): Pole-Zero Trajectories of $G_{\hat{d}_o}^{\hat{v}_c}(s)$ Due to Sweep of D_o. 31
Figure (3.10): Pole-Zero Trajectories of $G_{\hat{d}_o}^{\hat{v}_c}(s)$ Due to Sweep of C. 32
Figure (3.11): System Configuration of the Proposed QZSI for Grid Connected Applications. 33
Figure (3.12): Two-Stage Control Structure for Grid-Tied Applications QZSI. 34
Figure (3.13): DC Side Control Stage of QZSI. 35
Figure (3.14): Flow Chart of The IC-MPPT. 36
Figure (3.15): Flow Chart of The MDIC-MPPT. 36
Figure (3.16): Change in Irradiance. 37
Figure (3.17): Change in Temperature. 37
Figure (3.18): Comparison between MPPT Techniques. 37
Figure (3.19): Block Diagram for Current Regulator of QZSI for Grid-Tied Applications. 38

Figure (4.1):	Change in Irradiance.	43
Figure (4.2):	Change in Temperature.	43
Figure (4.3):	The Input Voltage, Current, and Power due to Unstable Weather Conditions for both SSM and PSO.	44
Figure (4.4):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using SSM.	45
Figure (4.5):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using PSO/AWPSO.	45
Figure (4.6):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using AACPSO.	46
Figure (4.7):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using MAACPSO.	46
Figure (4.8):	The Output 3-phase Voltages and Currents Using SSM.	47
Figure (4.9):	The Output 3-phase Voltages and Currents Using PSO/AWPSO.	47
Figure (4.10):	The Output 3-phase Voltages and Currents Using AACPSO.	48
Figure (4.11):	The Output 3-phase Voltages and Currents Using MAACPSO.	48
Figure (4.12):	The Output Voltage and Current of Phase a Using SSM.	49
Figure (4.13):	The Output Voltage and Current of Phase a Using PSO/AWPSO.	49
Figure (4.14):	The Output Voltage and Current of Phase a Using AACPSO.	50
Figure (4.15):	The Output Voltage and Current of Phase a Using MAACPSO.	51
Figure (4.16):	The Input Voltage, Current, and Power due to the change in parallel strings for SSM and PSO.	52
Figure (4.17):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using SSM.	53
Figure (4.18):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using PSO/AWPSO.	53
Figure (4.19):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using AACPSO.	54
Figure (4.20):	The Reference and Measured Voltage of Capacitor C_1 and The Variation of DC Link Voltage using MAACPSO.	54
Figure (4.21):	The Output 3-phase Voltages and Currents Using SSM.	55
Figure (4.22):	The Output 3-phase Voltages and Currents Using PSO/AWPSO.	56
Figure (4.23):	The Output 3-phase Voltages and Currents Using AACPSO.	56
Figure (4.24):	The Output 3-phase Voltages and Currents Using MAACPSO.	57
Figure (4.25):	The Output Voltage and Current of Phase a Using SSM.	58
Figure (4.26):	The Output Voltage and Current of Phase a Using PSO/AWPSO.	58
Figure (4.27):	The Output Voltage and Current of Phase a Using AACPSO.	59
Figure (4.28):	The Output Voltage and Current of Phase a Using MAACPSO.	59
Figure (4.29):	The Average Input Voltage, Current, Power Due to Unstable Weather Conditions Using 100 kW MATLAB Model.	62
Figure (4.30):	The Average Input Voltage, Current, Power Due to Unstable Weather Conditions	62

	Using 100 kW SSM Model.	
Figure (4.31):	The Output Voltage and Current of Phase a Using 100 kW MATLAB Model.	63
Figure (4.32):	The Output Voltage and Current of Phase a Using 100 kW SSM Model.	63
Figure (4.33):	The Average Input Voltage, Current, Power Due to Unstable Weather Conditions Using 15 kW MATLAB Model.	65
Figure (4.34):	The Average Input Voltage, Current, Power Due to Unstable Weather Conditions Using 15 kW SSM Model.	65
Figure (4.35):	The Output Voltage and Current of Phase a Using 15 kW MATLAB Model.	66
Figure (4.36):	The Output Voltage and Current of Phase a Using 15 kW SSM Model.	66

Abstract

Impedance-source inverters (ZSIs) have many advantages over traditional Voltage Source Inverters (VSIs) and Current Source Inverters (CSIs); as they can be used as VSIs or CSIs according to applications they are utilized in. They also can be used as (Buck/Boost) inverters depending on PWM technique they are derived with; regardless the power circuit used. That leads in high efficient, robust, cheap and reliable operating conditions. However, they have some limitations on their applications because of their discontinuous current-fed property which make it unsuitable for Photovoltaic (PV) based applications. In This Thesis, An alternating Quasi Z-Source Inverter (QZSI) which is equivalent to ZSI; is introduced. In addition, it has some advantages over traditional ZSI such as its continuous current-fed property, it covers a wide voltage gain, and it has a common DC bus between source and inverter leading to less Electromagnetic Interference (EMI) problems which makes it convenient for Maximum Power Point Tracking (MPPT) techniques used in PV applications. This QZSI is controlled using a two- stage control technique which is inspired from two-stage MICs control. The first stage is the DC side control stage which involves a Modified Direct Incremental Conductance MPPT (MDIC-MPPT) algorithm based on Maximum Constant Boost Control (MCBC) method to achieve maximum power harvesting for the PV Grid-Tied applications. The second stage is the AC side control stage which is responsible for AC power control by means of C_1 capacitor voltage control. This stage consists of two cascaded controller loops. The first controller loop is the outer voltage controller loop which generates the AC reference current to stabilize the voltage level on C_1 capacitor at a certain level. The second controller loop is the interior current controller loop which tracks the sinusoidal reference current generated by the voltage controller. This current controller obtained parameter is simple without any need to complicated or artificial intelligence based controllers. Furthermore, it is designed in stationary frame without any need to mathematical transformation. The simulation results are compared to results obtained using Particle Swarm Optimization (PSO) techniques to verify the used analysis. The proposed modeling is compared to simulated system using d-q transformation based control, as given in MATLAB. The obtained results are promising in all PV applications.

Chapter One: Introduction and General Review

1.1 Preface:

In the recent decades, there is a global growth in electrical energy consumption which results in a gross lack of fossil fuels. A big interest is developed towards clean, independent, reliable and renewable sources that can help in solving the global energy problems, here comes the solar energy. PV sources have no supply limitations and are predicted to be the biggest contributors to electricity generation among all renewable energy candidates by 2040 as reviewed in [1]. The annual world PV cell/module production between 1988 and 2005 is displayed in Figure (1.1) and that in 2005 presented a growth of 45% over 2004 as given in [2]. In 2010, PV was leading renewable energy technology in terms of capacity growth in Europe, with 13.3 GW installed, as a comparison to 9.3 GW for wind energy as presented in [3].

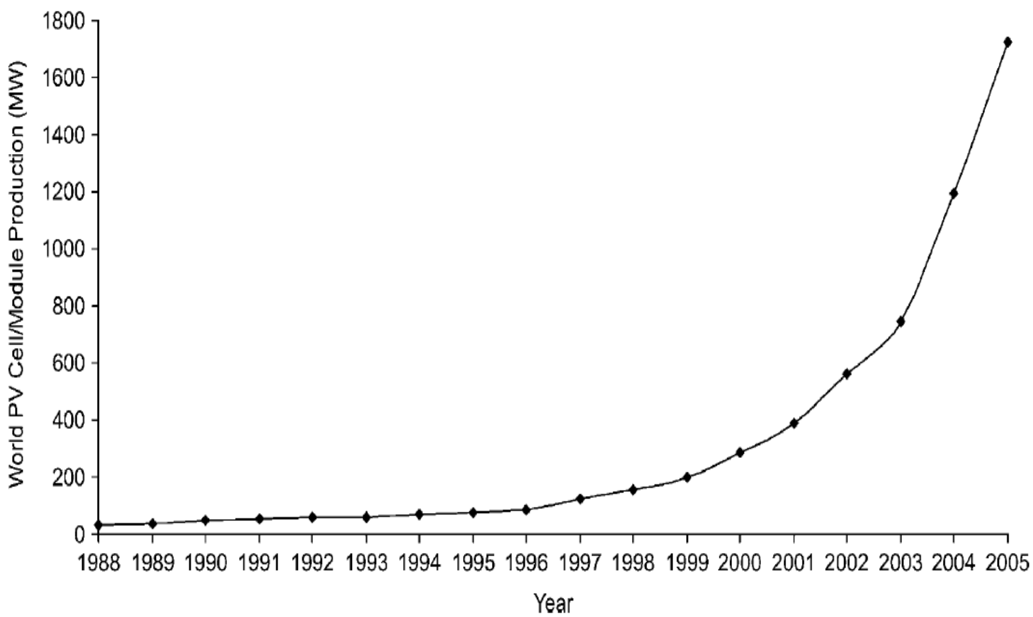

Figure (1.1): Annual World PV Cell/Module Production (1988–2005).

1.2 Intermediate Power Processing Inverters

From power shape point of view, the necessity of intermediate power processing stage is reasonably appeared (i.e. Power Inverter) to convert from the PV plant DC output to the global systems AC output. Traditionally, Centralized Converters (CCs) were the commonly used for PV plant tie with AC utility grids leaving behind some problems such as expensiveness, impracticality, decrease in efficiency, heaviness in weight and immensity on volumetric size [4]. In addition to shading and panel mismatching problems associated with that on PV field side. Hence, a new technology has appeared that revolves around minimizing the size and power rating into small units aiming to solve the mentioned problems and introduces more flexibility in using such converters. This technology yields Module Integrated Converters (MICs), Table (1.1) compares between CCs and MICs as presented in [4-5].

TABLE (1.1): Comparison between CCs and MICs

Centralized Converters (CCs)	Module Integrated Converters (MICs)
Special design and application	More practical
Cheaper and cost effective	Higher cost
Heavy in weight	Lighter in weight
Enormous volumetric size	Smaller on volumetric size
Can’t be setup for stand-alone applications	Available for stand-alone setup
Lower power density	Higher power density [4]

1.3 Scope of the Thesis

As will be explained in the next chapter, the most appropriate Module Integrated Converter (MIC) type for PV applications is the Single Stage type. Among the Single Stage configurations, Z-Source Inverters (ZSIs) come to overcome the problems associated with the traditional Voltage Source Inverters (VSIs) and Current Source Inverters (CSIs); as the S.C and O.C on one phase leg of these two types respectively became no longer a threat for the reliability of the inverter. The Electro-Magnetic Interference (EMI) problems are no more taken into account due to the extra Shoot-Through (ST) state. In addition, the Impedance Source Inverters inherits the advantages of both of VSIs and CSIs from their functions point of view. ZSI can be used as a VSI which holds the bucking property or as a CSI which holds the boosting property. This is owed to its unique feature involved in ST state which manages ZSI to boost the DC link voltage to the desired level suits the application it is utilized in.

Unfortunately, the discontinuous input current property of the traditional ZSI represents an obstacle to maximum power harvesting PV applications. The position of the diode which breaks off the current path of the input current during the ST zero state, so the power extracted from the used PV module cannot be maximized. New Quazi Z-Source Inverter (QZSI) configurations are developed in 2008 to overcome the weakness points of the traditional ZSIs. One of these configurations has a continuous current property which is excellent for PV applications especially MPPT applications. The input current path will no longer be cut off during ST zero state.

As will be explained after in [16], the most appropriate Pulse Width Modulation (PWM) method to control QZSI is the Maximum Constant Boost Control (MCBC) method. MCBC is an optimization between the SBC and MBC methods to decrease the voltage stress across the used electronic switches and the low frequency current ripples on the impedance network at the inverter inductors.

The point of research is to utilize the PV based QZSI instead of the traditional ZSI in grid tied applications using a Two-Stage Control technique which is simple and easy to be implemented. This technique depends on two stages, the DC side control stage and the AC side control stage. In the DC side control stage, a Modified Direct Incremental Conductance-Maximum Power Point Tracking (MDIC-MPPT) algorithm is used based on MCBC method. MCBC is an efficient PWM