



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRICAL POWER AND MACHINES DEPARTMENT

A High-gain Power Converter for interfacing PV Systems

M.Sc. Thesis

Prepared by:

Eng. Mostafa Ibrahim Mohamed Aziz

Submitted in partial fulfilment of the requirements for the M.Sc. degree in Electrical Engineering

Supervised by:

Prof Dr. Ahmed Abd El-Sattar Abd El Fattah

Dean

Faculty of Engineering

Future University in Egypt

Prof Dr. Mostafa Ibrahim Mohamed Marei

Electrical Power and Machine Dept.

Faculty of Engineering

Ain Shams University

Cairo, 2018

EXAMINERS COMMITTEE

For the Thesis:

Thesis title: A High-gain Power Converter for interfacing PV Systems

by:

Eng. Mostafa Ibrahim Mohamed Aziz.

A thesis submitted to the Faculty of Engineering –Ain Shams University in partial fulfillments of the requirements for the M.Sc. degree in Electrical Power and Machines Engineering

Name, title and affiliation

Signature

Prof. Dr. Said Wahsh

Prof. of Power electronics
Electronics Research Institute

Prof. Dr. Naggat Hassan Saad

Electric Power and Machine Department
Faculty of Engineering- Ain Shams University

Prof. Dr. Ahmed Abd-El-Sattar Abd-El-Fattah

Electric Power and Machine Department
Faculty of Engineering- Ain Shams University

Prof. Dr. Mostafa Ibrahim Mohamed Marei

Electric Power and Machine Department
Faculty of Engineering- Ain Shams University

SUPERVISORS COMMITTEE

Name: Mostafa Ibrahim Mohamed Aziz

Thesis title: A High-gain Power Converter for interfacing PV Systems

Degree: Submitted in partial fulfillment of the requirements for the M.Sc.
degree in electrical engineering.

Name, title and affiliation

Signature

Prof. Dr. Ahmed Abd-El-Sattar Abd-El-Fattah

Electric Power and Machine Department
Faculty of Engineering- Ain Shams University

Prof. Dr. Mostafa Ibrahim Mohamed Marei

Electric Power and Machine Department
Faculty of Engineering- Ain Shams University

STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the requirements for M.Sc. degree in Electrical Engineering. The included work in this thesis has been carried out by the author at the department of electrical power and machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

Name: Mostafa Ibrahim Mohamed Aziz

Signature:

Date: ... / ... / 2018

RESEARCHER DATA

Name : Mostafa Ibrahim Mohamed Aziz

Place of birth : Cairo - Egypt

Last academic degree : Bachelor of Electrical Engineering

Field of specialization : Electrical Power and Machines

University issued the degree : June - 2011

Date of issued degree : 28/07/2011

Job : Senior Engineer - E&I Department - Gulf
of Suez petroleum company

ABSTRACT

This thesis presents two systems for interfacing PV array to DC and AC grids. Two cascaded boost converters are proposed for PV interfacing with DC grid. The first converter is conventional boost converter (CBC) which has smooth voltage control and work at lower duty cycle for maintaining high efficiency. The CBC is responsible for performing maximum power point tracing (MPPT) on PV array. The perturb and observe (P&O) technique is used for controlling duty cycle of the CBC to track the maximum power point. The second converter is multilevel modular capacitor clamped DC/DC converter (MMCCC). This converter has high conversion ratio and high efficiency and it is responsible for step up of PV array voltage to the grid level. The structure of the MMCCC is reduced to allow only power flow in one direction from PV system to the DC grid. The reduced structure has lower number of switches and diodes which reduce converter cost. Moreover, a soft-starter which consists of resistor and bypass switch, is connected to the low voltage side of the MMCCC to allow for the initial charging of the capacitors to their operational voltage levels. This method eliminates the need for independent control technique during startup and limits inrush current of capacitor charging to the switches rated current, which decreases the converter cost. For PV array interface with AC Grid, also two cascaded converters are proposed. The first converter is unidirectional MMCCC including soft starter for capacitor charging and the second converter is three phase current controlled voltage source inverter VSI. The MMCCC steps up the PV array voltage to the DC link voltage required for VSI. The VSI performs MPPT on the PV array and control current injected to the AC grid. Hysteresis current control (HCC) is used for controlling the switches of the inverter. The P&O technique is used to allow for extracting maximum power from PV array. Simulation is performed using EMTDC/PSCAD platform to validate the effectiveness of the proposed topologies.

ACKNOWLEDGMENT

All praise is due to Allah, Most Merciful, and the Lord of the Worlds, who taught man what he knew not. I would like to thank God Almighty for bestowing upon me the chance, strength and ability to complete this work.

My words can't express my gratitude to my advisors: Prof. Ahmed Abd el Sattar Abd el Fattah, Prof. Mostafa Ibrahim Marei, whom introduced me to the world of power electronics and guided me through my research and career to the best. I wouldn't be able to finish this work without their support, guidance, encouragement and confidence in me. Both of them treated me not just as their student but also as their son.

My sincere gratitude goes to my mother, father and my family. This work would not have been possible without their continuous encouragement, patience, support and assistance.

Mostafa Ibrahim

Cairo, Egypt

2018

TABLE OF CONTENTS

ABSTRACT	VI
ACKNOWLEDGEMENT.....	VII
TABLE OF CONTENT	VIII
LIST OF FIGURES	XI
LIST OF TABLES.....	XV
LIST OF ABBREVIATION.....	XVI
LIST OF SYMBOLS	XVII
Chapter one: INTRODUCTION.....	1
1.1. Overview.....	2
1.2. Aim of this research.....	3
1.3. Thesis outlines.....	4
Chapter two: LITRATURE SURVEY	5
2.1. Background.....	6
2.1.1. Centralized inverter topology.....	6
2.1.2. String topology.....	8
2.1.3. Multistring topology.....	8
2.1.4. AC module topology.....	9
2.1.5. DC module topology.....	10
2.2. High-step-up DC/DC converters.....	13
2.2.1. Isolated DC/DC converters.....	13
2.2.2. Non-isolated DC/DC converter.....	14
2.2.2.1. Conventional boost converter.....	14
2.2.2.1.1. CBC applications and limitations.....	14
2.2.2.1.2. Three level conventional boost converter.....	15
2.2.2.1.3. Interleaved conventional boost converter.....	16
2.2.2.1.4. Cascaded conventional boost conventional converter.....	16
2.2.2.2. Boost converters with high conversion ratio.....	18

2.2.2.2.1.	Converters based on coupled inductor.....	18
2.2.2.2.2.	Converter based on switched capacitors.....	19
2.2.2.2.3.	Converter based on switched capacitors and inductors.....	19
2.2.2.2.4.	Converter based on switched capacitors and coupled inductors...	20
2.3.	General solution for high gain boost converter.....	21
2.4.	Switched capacitor DC/DC converters.....	23
2.4.1.	Flying capacitor multilevel DC/DC converter (FCMDC).....	23
2.4.1.1.	Pros of this topology	24
2.4.1.2.	Cons of this topology	25
2.4.2.	Series and parallel converter.....	25
2.4.2.1.	Pros of this topology.....	25
2.4.2.2.	Cons of this topology.....	25
2.4.3.	Switched capacitor bidirectional DC/DC converter.....	26
2.4.3.1.	Pros of this topology.....	26
2.4.3.2.	Cons of this topology.....	27
2.4.4.	Ladder DC/DC converter.....	27
2.4.4.1.	Pros of this topology.....	27
2.4.4.2.	Cons of this topology.....	28
2.4.5.	Magnetic-less multilevel dual voltage DC/DC converter.....	29
2.4.5.1.	Pros of this topology.....	30
2.4.5.2.	Cons of this topology.....	30
2.4.6.	Switched-capacitor DC/DC converter with low input current ripple.....	30
2.4.6.1.	Pros of this topology.....	30
2.4.6.2.	Cons of this topology.....	31
2.4.7.	Fibonacci switched capacitor DC/DC converter.....	31
2.4.7.1.	Pros of this topology.....	32
2.4.7.2.	Cons of this topology.....	33
2.4.8.	Charge pump switched capacitor DC/DC converter.....	33
2.4.8.1.	Pros of this topology.....	35
2.4.8.2.	Cons of this topology.....	35
2.4.9.	Switch-mode step up DC/DC converter.....	35

2.4.9.1. Pros of this topology.....	36
2.4.9.2. Cons of this topology.....	36
2.4.10. Multilevel modular capacitor clamped DC/DC converter circuit (MMCCC).....	37
2.4.10.1. Converter steady state operation.....	38
2.4.10.2. Pros of this topology.....	39
2.4.10.3. Cons of this topology.....	40
2.4.11. Capacitor-based step-up DC/DC converter with continuous input current.....	40
2.4.11.1. Pros of this topology.....	41
2.4.11.2. Cons of this topology.....	41
2.5. Discussion.....	41
Chapter three: THE PROPOSED PV-GRID INTEGRATION SYSTEMS.....	43
3.1. The PV system characteristics.....	44
3.2. Perturb and observe MPPT technique.....	46
3.3. Proposed switched capacitor DC/DC converter.....	47
3.3.1. The MMCCC start up procedure.....	48
3.3.2. The proposed start up method.....	49
3.3.3. The proposed unidirectional MMCCC steady state operation.....	51
3.4. Proposed PV - DC grid integration system.....	53
3.5. Proposed PV - AC grid integration system.....	54
Chapter four: SIMULATION RESULTS.....	56
4.1. Unidirectional 5-level MMCCC with soft starter simulation results.....	57
4.2. PV - DC grid integration system.....	62
4.3. PV - AC grid integration system.....	66
Chapter five: CONCLUSION AND RECOMMENDATIONS.....	71
5.1. Conclusion.....	72
5.2. Recommendations for future work.....	72

LIST OF FIGURES

Figure 2.1 (a) Integration of PV system using power converters and HF transformer.	7
Figure 2.1 (b) Integration of PV system using DC/DC, DC/AC converters and LF transformer ...	7
Figure 2.1 (c) Integration of PC system using only DC/AC converter and LF transformer	7
Figure 2.2 String topology of PV- Grid integration system.	8
Figure 2.3 Multistring topology of PV grid integration system.	9
Figure 2.4 AC module topology for PV grid integration system	10
Figure 2.5 DC module topology for PV grid integration system	11
Figure 2.6 CBC circuit	14
Figure 2.7 Three level conventional boost converter.	15
Figure 2.8 ZVT three level conventional boost converter.....	15
Figure 2.9 Conventional interleaved boost converter.....	16
Figure 2.10 Cascaded Conventional boost converter	17
Figure 2.11 Integrated cascaded conventional boost converter.....	17
Figure 2.12 Coupled inductor boost converter	18
Figure 2.13 SC-N stage DC/DC converter	19
Figure 2.14 Converter based on switched capacitor and inductors	20
Figure 2.15 Converter based on switched capacitor and coupled inductors.	21
Figure 2.16 Proposed conceptual system for PV - DC grid integration.....	22
Figure 2.17 Proposed conceptual system for PV - AC grid integration.....	23
Figure. 2.18 Flying capacitor multilevel DC/DC converter	24
Figure 2.19 The FCMLDC switching pattern	25
Figure 2.20 Series and parallel switched capacitor DC/DC converter	26
Figure 2.21 Switched capacitor bidirectional DC/DC converter.....	27

Figure 2.22 Ladder topology DC/DC converter.....	28
Figure 2.23 Ladder topology basic switching cell.....	28
Figure 2.24 Magnet less Multilevel DC/DC converter circuit and converter switching cell.	29
Figure 2.25 Switched capacitor DC/DC converter with low input current ripple.....	31
Figure 2.26 Switched capacitor DC/DC converter with low input current ripple switch pattern .	31
Figure 2.27 Fibonacci switched capacitor DC/DC converter.....	32
Figure 2.28 (a) First state of Fibonacci converter operation	32
Figure 2.28 (b). Second state of Fibonacci converter operation.....	33
Figure 2.29 Charge pump DC/DC converter circuit.....	33
Figure. 2.30 Switch mode step up DC/DC converter circuit.....	35
Figure. 2.31 Switch mode DC/DC converter switches timing diagram	36
Figure 2.32 Multilevel modular capacitor clamped DC/DC converter circuit.	37
Figure 2.33 MMCCC single module structure	37
Figure 2.34 (a) MMCCC circuit in first operating state	38
Figure 2.34 (b) MMCCC circuit in second operating state	39
Figure 2.35 MMCCC switches gating signal	39
Figure 2.36 Capacitor-based step-up DC/DC converter circuit	40
Figure 3.1 PV model equivalent circuit.....	44
Figure 3.2 (a), (b) I_{PV} - V_{PV} curve under different irradiance and temperature.....	45
Figure 3.3 (a), (b) P_{PV} - V_{PV} curve under different irradiance and temperature.....	45
Figure 3.4 P&O Algorithm	46
Figure 3.5 (a), (b), (c) and (d) Show converter start up stages.....	49
Figure 3.6 Unidirectional MMCCC including softstarter.	50
Figure 3.7 (a) State 1 of unidirectional MMCCC operation.....	51

Figure 3.7 (b) state 2 of Unidirectional MMCCC operation	51
Figure 3.8 General block diagram for PV - DC grid integration system.....	53
Figure 3.9 General Block diagram for PV - AC grid integration system.....	54
Figure 3.10 Voltage source inverter (VSI) circuit.....	55
Figure 4.1 The unidirectional 5 -level MMCCC.	57
Figure 4.2 MMCCC capacitor charging voltage when soft starter is included	58
Figure 4.3 MMCCC switches current when soft starter is included.	58
Figure 4.4 MMCCC switches current when soft starter is not included	59
Figure 4.5 MMCCC switches voltage stress during start up and steady state operation.	60
Figure 4.6 MMCCC diodes voltage stress during start up and steady state operation.....	61
Figure 4.7 PV module to DC grid integration system under study	62
Figure 4.8 (a), (b) PV module P-V and V-I characteristics.....	63
Figure 4.9 PV output current during different irradiance level.	63
Figure 4.10 Output Power from PV module and power injected to DC grid.....	64
Figure 4.11 Conventional boost converter input and output voltage	64
Figure 4.12 Conventional boost converter duty ratio.	64
Figure 4.13 MMCCC input and output current	65
Figure 4.14 The proposed PV string to AC grid integration system.....	66
Figure 4.15 (a), (b) PV string P-V and V-I characteristics.....	67
Figure 4.16 PV string output current under different irradiance level.....	67
Figure 4.17 MMCCC input and output voltage.....	68
Figure 4.18 MMCCC input and output current.....	68
Figure 4.19 VSI reference current, inverter output current, phase voltage of the grid.....	69
Figure 4.20 VSI current under different irradiance level.....	69

Figure 4.21 Active and reactive power injected to grid.....	70
---	----

LIST OF TABLES

Table 2-1: Magnetic-less multilevel dual voltage DC/DC converter switching pattern.....	29
Table 2-2: Different conversion ratios of charge pump topology in different configuration	34
Table 3-1 : Table 3.1 Current paths of MMCCC in the state 1 and state 2.....	52