



CONTROL OF WECS USING DOUBLY-FED INDUCTION GENERATOR

By

Eng. Mohamed Elsayed Abdallah

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
GIZA, EGYPT
2016

CONTROL OF WECS USING DOUBLY-FED INDUCTION GENERATOR

By

Eng. Mohamed Elsayed Abdallah

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

Under the Supervision of

Prof. Dr. Adel D. Shaltout

.....

Electrical Power and Machines Department
Faculty of Engineering, Cairo University

Prof. Dr. Abdel Latif Elshafei

.....

Electrical Power and Machines Department
Faculty of Engineering, Cairo University

Asst. Prof. Osama M. Arafa

.....

Power Electronics and Energy Conversion Department
Electronics Research Institute

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

CONTROL OF WECS USING DOUBLY-FED INDUCTION GENERATOR

By

Eng. Mohamed Elsayed Abdallah

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

Approved by the
Examining Committee:

Prof. Dr. Adel D. Shaltout

Faculty of Engineering, Cairo University

Thesis Main Advisor

.....

Prof. Dr. Mahmoud M. Abdel Hakiem

Faculty of Engineering, Cairo University

Internal Examiner

.....

Prof. Dr. Mohsen Taha El-hagery

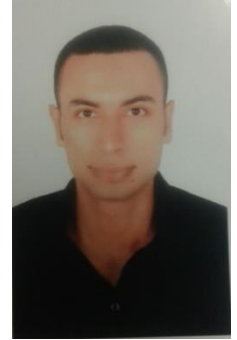
Power Electronics and Energy Conversion
Department, Electronics Research Institute

External Examiner

.....

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

Engineer: Mohamed Elsayed Abdallah Abdelmagied
Date of Birth: 03 / 01 / 1989
Nationality: Egyptian
E-mail : eng.msa12@eri.sci.eg
Phone. : +201151141130
Address : 33 Tahrir st., Dokki, Giza, Egypt.
Registration Date: 1/10 / 2013
Awarding Date: / / 2016
Degree: Master of Science
Department : Electrical Power and Machines Engineering



Supervisors : Prof. Dr. Adel Diyaa Eldin Shaltout
Prof. Dr. Abdel Latif Elshafei
Assoc. Prof. Dr. Osama M. Arafa (Electronics Research
Institute)

Examiners : Prof. Dr. Adel Diyaa Eldin Shaltout
Prof. Dr. Mahmoud Mohammed Abdel Hakiem
Prof. Dr. Mohsen Taha El-hagery (Electronics Research
Institute)

Title of Thesis: **CONTROL OF WECS USING DOUBLY-FED
INDUCTION GENERATOR**

Key Words: Double-fed induction generator, Wind energy conversion
systems, Wind turbine emulator, Maximum power point tracking.

Summary:

This thesis provides the complete design of DFIG-based WECS. This system is consisted of three parts the GSC, PMSM for wind emulation and the RSC which drive the DFIG. The performance of the system has been studied in the simulation and the experimental work using different types of controllers (PI-controller, MRAC and L1 adaptive controller).

The main advantage of DFIG system for WECS is that it offers separate real and reactive power controller, like a synchronous generator, even though the ability to run asynchronously. Another advantage is that the back-to-back power converter doesn't have to handle the system rated power, it just handles a fraction of the total generator power depending on the selected speed range. The typical speed range of this system is $\pm 30\%$ around the synchronous speed.

Acknowledgments

Most of all thanks to the God who gives me the strength while doing this work.

I would like to express my sincere gratitude and thanks to my supervisor Prof. Adel Shaltout for his supervision, continued advice, and helpful suggestions.

I would also like to express my sincere appreciation and thanks to my supervisor Prof. Abdel Latif Elshafi for his continuous help, support and advice.

My sincere thanks to my supervisor Assoc. Prof. Osama M. Arafa for his assistance specially in selecting thesis topic, kind encouragement, and experimental validation of the thesis.

I would like to express my gratitude to Assoc. Prof Dr. Ahmed Mansour, Dr. Ghada A. Abdel Azziz, Eng. Alaa Omar, Eng. Mohamed Samir, Prof. Hanafi H. Hanafi and Prof. Naser Abdel Rehim for their help and advices.

My sincere thanks to the Electronics Research Institute for the financial support of this research. Thanks to the Power Electronics and Energy Conversion Department for providing facilities.

My thanks to everyone stands beside me even with a word encouragement.

Eng. Mohamed Elsayed Abdallah

Dedication

TO

My parents, my brothers and my sister.

Table of contents

Acknowledgments.....	I
Dedication.....	II
Table of contents.....	III
List of Tables.....	VII
List of Figures	VIII
List of abbreviations.....	XV
List of Symbols.....	XVII
Abstract	XXI
Chapter 1. Wind energy concepts and control.....	1
1.1. Introduction.....	1
1.2. Wind turbine Classifications.....	4
1.2.1. Small and large wind turbines.....	4
1.2.2. On-land and offshore wind turbines	6
1.2.3. Wind turbine technologies	6
1.2.4. Horizontal and vertical axis wind turbines	7
1.2.5. Fixed- and variable-speed wind turbines	8
1.3. Wind Energy Conversion Systems Configurations	9
1.3.1. Fixed speed WECS without power converter	9
1.3.2. Variable speed WECS using full-capacity power converters	10
1.3.3. Variable speed WECS using wound rotor induction generator with variable rotor resistance	11
1.3.4. Variable speed WECS using doubly fed induction generator and partial capacity converter	11
1.3.5. Evaluation of the different WECS configurations	12
1.4. Literature review.....	14
1.4.1. Control schemes of a wind turbine and generator systems	14
1.4.2. Power Converter Topologies for Wind Turbine Generator System.....	18
1.4.3. Emulation of Wind Power Curve.....	18

1.5.	Thesis contribution.....	19
1.6.	Thesis organization	19
Chapter 2. Grid Side Converter Design and control		20
2.1.	Introduction.....	20
2.2.	System description	20
2.3.	VSC modeling in the synchronous reference frame	21
2.4.	General control scheme of GSC.....	23
2.5.	Grid filters.....	24
2.6.	Grid angle detection.....	27
2.6.1.	Fourier-Based Grid Angle Determination (FBGAD).....	28
2.7.	Control loops of GSC.....	30
2.7.1.	Currents control loops.....	30
2.7.2.	DC-link voltage control loop	31
2.8.	Controllers design	32
2.8.1.	Current-control loops design.....	33
2.8.2.	DC-link voltage controller	40
Chapter 3. Maximum Power Point tracking and DFIG control		43
3.1.	Introduction.....	43
3.2.	Maximum power point tracking in WECS	43
3.2.1.	Modeling of a Wind Turbine	44
3.2.2.	Maximum power point tracking techniques.....	46
3.2.3.	Blade pitch angle control	51
3.3.	Generator-side converter control	52
3.3.1.	Model of the DFIG in stator voltage frame.....	52
3.3.2.	General control scheme of rotor side converter	59
3.3.3.	Control-loop design.....	61
Chapter 4. System simulation and results		65
4.1.	Introduction.....	65
4.2.	Grid side converter.....	65
4.2.1.	Grid angle detection	65
4.2.2.	Simulation of GSC control.....	67
4.3.	Simulation of RSC control.....	77
4.3.1.	System operation at super-synchronous mode	78

4.3.2.	System operation at sub-synchronous mode	81
4.3.3.	Change from sub-synchronous to supper-synchronous mode	85
4.3.4.	Stochastic wind speed profile	86
4.3.5.	Conclusion	90
Chapter 5.	Experimental Setup	91
5.1	Introduction.....	91
5.2	General Hardware Overview	91
5.3	Wind Turbine Emulators	93
5.3.1	Wind Turbine Model	94
5.3.2	Emulation of wind turbine dynamics using PMSM.....	95
5.3.3	Experimental Results	98
5.3.4	Torque-Speed Characteristics at different wind speeds.....	99
5.3.5	Dynamic Tests	100
5.3.6	Conclusion	102
5.4	Grid side converter Control	103
5.4.1	Experimental results of the GSC.....	104
5.4.2	Conclusion	114
5.5	Rotor side converter control	115
5.5.1	Safe connection and disconnection of DFIG system	115
5.5.2	RSC performance using MRAC	120
5.5.3	Conclusion	129
Chapter 6.	Conclusions of the thesis and Future work	134
6.1.	Conclusions.....	134
6.2.	Future work.....	134
References.....		135
Appendices		144
Appendix A:	sensors.....	144
A)	Current sensor	144
B)	Voltage sensor.....	144
C)	Incremental position encoder.....	145
Appendix B:	inverters.....	147
Appendix C:	The dSPACE controllers	148
Appendix D:	Data of PMSM and DFIG	149