



MODELING, SIMULATION AND FAULT DIAGNOSIS IN A MICROGRID

By

Eng. Atef Mohamed Abd El Razek Mansour

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

MODELING, SIMULATION AND FAULT DIAGNOSIS IN A MICROGRID

By

Eng. Atef Mohamed Abd El Razek Mansour

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. Essam Aboul Zahab

Dr. Khaled Nagdy Faris

.....

.....

Electrical Power and Machines Department
Faculty of Engineering, Cairo University

Power Electronics and Energy Conversion
Department, Electronics Research Institute

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT**

2016

MODELING, SIMULATION AND FAULT DIAGNOSIS IN A MICROGRID

By

Eng. Atef Mohamed Abd El Razek Mansour

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. Essam Aboul Zahab

Electrical power and machines department
Faculty of Engineering-Cairo University

Thesis Main Advisor

.....

Prof. Dr. Hosam Kamal Youssef

Electrical power and machines department,
Faculty of Engineering-Cairo University

Internal Examiner

.....

Prof. Dr. Mohsen Taha El-hagry

Power electronics and energy conversion department,
Electronics Research Institute

External Examiner

.....

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2016

Engineer: Atef Mohamed Abd El Razek Mansour
Date of Birth : 19 / 6 / 1986
Nationality : Egyptian
E-mail : atef_mohamed52@yahoo.com
Phone. : 01152538330
Address : Tahway- Ashmoon- Menofia
Registration Date : 1/ 10 /2010
Awarding Date : / / 2016
Degree : Master of science
Department : Electrical power and machines engineering



Supervisors : Prof. Dr. Essam Mohamed Aboul zahab
Dr. Khaled Nagdy Faris

Examiners : Prof. Dr. Hosam Kamal Youssef
Prof. Dr. Mohsen Taha El-hagry
Prof. Dr. Essam Mohamed Aboul zahab

Title of Thesis : MODELING, SIMULATION AND FAULT DIAGNOSIS
IN A MICROGRID

Key Words: Photovoltaic and Microgrid, Fault diagnosis, Maximum Power
Point Tracking, Energy Management Controller.

Summary : A modeling of the PV is introduced to study its electrical characteristics under normal and at faulty conditions such as short circuit and partial shadow faults. Also a proposed intelligent fault detection and diagnosis technique based on fuzzy logic is introduced. A microgrid system composed of PV source, energy storage systems and DC load; is modeled by using Matlab/Simulink simulation tools. A proposed modified perturb and observe algorithm is introduced to track the maximum power point. The proposed method is compared with fuzzy logic maximum power point tracking. The simulation results show that the two algorithms are nearly the same. Also a proposed energy management controller for the adopted microgrid is introduced to control the power sharing among the power source, the energy storage systems and the load. This controller has the ability to select the suitable energy storage element to be charged or discharged according to the environmental conditions and the load power demand. The proposed controller stabilizes the output voltage at the reference voltage also decreases the voltage change during the transient periods. An experimental study on a lab scale is executed to verify some of the simulation results of the proposed maximum power point tracking algorithm.

Acknowledgement

No one but Allah, the most greatest, deserves all our thanks as he gave us the faith, the patience, and the power to complete this work successfully.

First of all, I would like to thank my advisor, Prof. Dr. Essam Aboul Zahab, for giving me continuous help, patience, understanding, willingness throughout the period of the research and the opportunity to research under his guidance and supervision.

I would like also to express my sincere gratitude to my advisor, Dr. Khaled Nagdy for his guidance, encouragement, remarkable patience and caring support during my finishing this thesis.

Also I am grateful to Pof. Dr. Mohsen Taha Elhagry for his valuable guidance and his insightful suggestions throughout this work.

Also I am really indebted for the Electronic Research Institute for providing all the resources required to carry out this thesis.

Also, I would like to thank all my friends in the department of power electronics and energy conversion for their always encouragement and support.

Last but not least I would like to thank all my family; my father, my mother, my brothers “Ahmed and Abdullah”, my wife , my daughter “Shahd”, and my son “Mohamed” for their support and encouragement and patience during my studying. I am indebted to all of them forever for all that they have done for me.

Table of contents

Acknowledgement	i
Table of contents	ii
List of Tables	vi
List of figures.....	vii
List of abbreviations	xi
List of symbols.....	xiii
Abstract	xvi
Chapter 1: Introduction	1
1.1 Preface	1
1.2 Thesis objectives	2
1.3 Thesis outline.....	2
Chapter 2: Faults diagnosis of photovoltaic Plants in a micro grid.....	4
2.1 Introduction	4
2.2 Modeling of the PV.	4
2.3 Factors that affects on the output characteristics of the PV module	10
2.4 Electrical configurations of photovoltaic modules in a micro grid	14
2.4.1 Series connection.....	14
2.4.2 Parallel connection of modules.....	16
2.5 Common Faults types of solar array.....	17
2.5.1 Partial shadow fault:	18
2.5.2 Short circuit fault:	18
2.6 Proposed fuzzy logic classifier	21
2.6.1 Input and output membership functions	22
2.6.2 Simulation results of the proposed fuzzy logic classifier	27
2.7 Solutions to decrease the faults effects on PV system	30
Chapter 3: Energy storage systems used in microgrid	32
3.1 Introduction	32

3.2 Mechanical energy storage systems:	33
3.2.1 Pumped hydro energy storage (PHES).....	34
3.2.2 Compressed air energy storage systems (CAESS).....	34
3.2.3 Flywheel	35
3.3 Chemical energy storage systems.....	36
3.3.1 Hydrogen energy storage.....	36
3.3.2 Flow batteries	37
3.3.3 Batteries	38
3.3.3.1 Sodium sulfur batteries (NaS)	38
3.3.3.2 Nickel cadmium battery	39
3.3.3.3 Nickel metal hydride battery (NiMH)	39
3.3.3.4 Lithium ion battery	40
3.3.3.5 Lead acid battery	40
3.4 The electrical energy storage systems	41
3.4.1 Superconducting magnetic energy storage (SMES).....	41
3.4.2 Supercapacitor (SC).....	42
3.5 The adopted energy storage systems modeling	43
3.5.1 Modeling of lead acid battery[40],[41].....	44
3.5.2 Modeling of the supercapacitor	47
Chapter 4: Proposed Energy Management controller for a Microgrid System and simulation Results	50
4.1 Introduction.....	50
4.2 System Configuration	54
4.2.1 PV module	56
4.2.2 Boost converter[48]	56
4.2.3 Battery with bidirectional converter	59
4.2.4 Supercapacitor (SC) with bidirectional converter	60
4.3 The Control strategy	60
4.3.1 The first control unit: Maximum power point tracking (MPPT) controller of the DC-DC boost converter	61
4.3.1.1 Modified P&O algorithm:	61

4.3.1.2. Fuzzy logic based maximum power point tracking algorithm	65
4.3.1.2.1. Fuzzification	65
4.3.1.2.2 Fuzzy rules.....	66
4.3.1.2.3 Defuzzification	68
4.3.2 The proposed Energy management controller.....	69
4.4 Simulation Results	71
4.4.1 Case A: Shadow occurs on the PV module and the load is constant at 5A.....	72
4.4.1.1 Config1: Using PV module without energy storage.....	72
4.4.1.2 Config2: PV with battery.....	76
4.4.1.3 Config3: PV with battery and SC.....	81
4.4.2 Case B: The insolation is constant and step change occurs in the load demand.	86
4.4.2.1 Config1: PV without energy storage.	86
4.4.2.2 Config2: PV with battery.....	90
4.4.2.3 Config3: PV with battery and SC.....	94
4.5 Conclusion	99
Chapter 5: System Setup and Experimental results	100
5.1 Overview	100
5.2 Experimental setup	100
5.3 System components	102
5.4 Experimental results and discussion.....	107
5.4.1 The first case.....	108
5.4.2 The second case	108
5.4.3 The third case.....	109
Chapter 6 : Conclusions of the thesis and future work.....	111
6.1 Conclusions	111
6.2 Future work	111
References.....	112
Appendices.....	118
Appendix “A” Fuzzy rules of (fault diagnosis fuzzy logic classifier)	118
Appendix “B” PV module specifications.....	126
Appendix “C” voltage sensor Specs.....	127

Appendix “D” Current sensor Specs.....	130
Appendix “E” DSPACE DS1102	133
Appendix “F” MOSFET Transistor IRFP460LC	135
Appendix “G” Electronic load	137
Appendix “H” battery specs.....	139
Published papers	141

List of Tables

Table 2. 1: Electrical characteristics of IS4000P 300 watt module at STC.....	7
Table 2. 2: simulation results at different values of short circuit	28
Table 2. 3: simulation results at different values of Partial shadow	29
Table 3. 1: comparison between battery types	41
Table 4: 1 Fuzzy Rules	67

List of figures

Figure 2. 1: Equivalent electrical circuit of PV cell.	5
Figure 2. 2: IS4000P 300W module.	7
Figure 2. 3: Simulated electrical characteristics of IS4000P 300W module.	8
Figure 2. 4: The subsystem which represent the mathematical equations of the PV module	9
Figure 2. 5: The second subsystem.	9
Figure 2. 6: MATLAB (SPS) based PV model of IS4000 PV module.	10
Figure 2. 7: I-V and P-V curves at constant temperature = 25°C, and varying insolation (G)	11
Figure 2. 8: I-V and P-V curves at constant $G=1000 \text{ W/m}^2$ and varying temperature.....	12
Figure 2. 9: I-V and P-V curves at constant $G=1000 \text{ W/m}^2$ and constant Temperature 25 °C and varying ideal factor.	13
Figure 2. 10: String of PV modules	14
Figure 2. 11: I-V and P-V curves of one PV module and two modules connected in series	15
Figure 2. 12: Group of PV modules	16
Figure 2. 13: I-V and P-V characteristic curves of one module and two PV modules connected in parallel.	17
Figure 2. 14: Two PV module connected in series with a shaded module and its corresponding I-V and P-V characteristic curves.....	19
Figure 2. 15: I-V and P-V characteristics of PV array at different percentages of short circuit at STC.....	20
Figure 2. 16: Fault diagnosis system on MATLAB	21
Figure 2. 17: Input membership functions	23
Figure 2. 18: Output membership functions.....	24
Figure 2. 19: I-V and P-V curve at partial shadow 20% on one module.....	25
Figure 2. 20: I-V and P-V curve at partial shadow 70% on one module.....	26
Figure 2. 21: P-V curve of two modules connecting in series and in parallel without shadow and with 50% shadow on a PV module.....	30
Figure 3. 1: Energy storage types	32
Figure 3. 2: Energy density and power density of different energy storage systems	33
Figure 3. 3: Pumped hydro energy storage.....	34
Figure 3. 4: Compressed air energy storage	35
Figure 3. 5: Flywheel structure.....	36
Figure 3. 6: Fuel cell structure.....	37
Figure 3. 7: Flow battery architecture	38
Figure 3. 8: Sodium sulfur battery structure	39

Figure 3. 9: Structure of SMES system	42
Figure 3. 10: Supercapacitor construction	43
Figure 3. 11: Model of battery	44
Figure 3. 12: Discharging curve of a battery	46
Figure 3. 13: Model of the SC	47
Figure 3. 14: Current discharge profiles (a) data sheet profiles, (b) simulated profiles.	49
Figure 4. 1: Block diagram of the proposed micro grid and its control strategy	51
Figure 4. 2 Proposed Microgrid system.....	52
Figure 4. 3: Power density versus energy density ranges for different energy storage system technologies [47]	53
Figure 4. 4: MATLAB Simulink model of the proposed system	55
Figure 4. 5 Topologies of boost converter (a) Boost converter circuit, (b) when SW is OFF, (c) when SW is ON.....	56
Figure 4. 6 Battery with buck boost bidirectional converter	59
Figure 4. 7 Super-capacitor with buck boost bidirectional converter.....	60
Figure 4. 8 Conventional perturb and observe (P&O) algorithm	62
Figure 4. 9: Conditions of (dP/dI) by varying the operating voltage to track MPP.	63
Figure 4. 10 Modified Perturb and observe flow chart.....	63
Figure 4. 11 Implementation of Modified Perturb and observe in MATLAB	64
Figure 4. 12 : The output duty cycle of modified P&O.....	64
Figure 4. 13 Inputs and output fuzzy sets of the fuzzy logic controller	66
Figure 4. 14: Rule editor of fuzzy logic controller block in MATLAB	67
Figure 4. 15: MATLAB Simulink structure of fuzzy MPPT algorithm.....	68
Figure 4. 16: The output duty cycle of fuzzy logic MPPT algorithm	69
Figure 4. 17: Proposed energy management controller block diagram	70
Figure 4. 18: the structure of the proposed energy management strategy in MATLAB.	71
Figure 4. 19: Case (A) config1 load power and PV power a) FLC MPPT, b) modified P&O MPPT.....	73
Figure 4. 20: Case (A) config1 load voltage a) FLC MPPT , b) modified P&O MPPT.	74
Figure 4. 21 : PV module characteristics (a) I-V curve, (b) P-V curve.....	75
Figure 4. 22: Case (A) config2 load power, PV power and battery power (a) FLC MPPT, (b) using modified P&O MPPT.	77
Figure 4. 23: Case (A) config2 load voltage. (a) using FLC MPPT, (b)using modified P&O MPPT.....	78
Figure 4. 24 Case (A) Config2 Duty cycle of the bidirectional converter of the battery (a) using Fuzzy MPPT, (b) using modified P&O	80
Figure 4. 25 : Case (A) Config2 State of charge of the battery pack	81
Figure 4. 26: Case (A) config3 load power, PV power, battery power and SC power (a) using FLC MPPT, (b) using modified P&O MPPT	82

Figure 4. 27: Case (A) config3 load voltage. (a) using FLC MPPT, (b) using modified P&O MPPT.	83
Figure 4. 28: Case (A) Config3 Duty cycle of the bidirectional converter of the battery (a) using Fuzzy MPPT, (b) using modified P&O	84
Figure 4. 29: Case (A) Config3 Duty cycle of the bidirectional converter of the SC (a) using Fuzzy MPPT, (b) using modified P&O	85
Figure 4. 30: Load current	86
Figure 4. 31. Case (B) config1 Load power and PV power (a) using FLC MPPT, (b) using modified P&O MPPT	87
Figure 4. 32. Case (B) config1 load voltage (a) using FLC MPPT, (b) using modified P&O MPPT.....	88
Figure 4. 33: characteristic curve of the PV module (a) P-V curve, (b) I-V curve	89
Figure 4. 34: Case (B) config2 load power, PV power, and battery power. (a) using FLC MPPT, (b) using modified P&O MPPT	91
Figure 4. 35: Case (B) config2 load voltage (a) using FLC MPPT, (b) using modified P&O MPPT	92
Figure 4. 36: Case (B) config2 duty cycle of the bidirectional converter of the battery (a) when using FLC MPPT (b) when using modified MPPT	93
Figure 4. 37: Case (B) config2 state of charge of the battery pack	94
Figure 4. 38 Case (B) config3 load power, PV power, battery power and SC power (a)using FLC MPPT (b) using modified P&O MPPT.....	95
Figure 4. 39. Case (B) config3 load voltage (a) using FLC MPPT , (b) using the modified P&O MPPT.	96
Figure 4. 40 Case (B) Config3 Dty cycle of the bidirectional converter of the battery pack (a) when using FLC MPPT (b) using the Modified P&O MPPT	97
Figure 4. 41: Case (B) Config3 the duty cycle of the bidirectional converter of the SC (a) when using FLC MPPT (b) using the Modified P&O MPPT	98
Figure 4. 42 state of charge of the Battery and the SC	99
 Figure 5. 1 Over view of the experimental setup	100
Figure 5. 2: block diagram of the system	101
Figure 5. 3: Voltage sensor.....	102
Figure 5. 4: Current sensor	103
Figure 5. 5: Optocoupler isolation circuit.....	103
Figure 5. 6: level shifter.....	104
Figure 5. 7: Driving signal of the MOSFET.....	104
Figure 5. 8: Boost converter	105
Figure 5. 9: DC Electronic load PLZ1004W	105
Figure 5. 10: Measured I-V Curve of the IS4000P PV module (a) at normal operation, (b) at partial shadow. Y axis is the PV current measured on channel (B) with deviation (2A)	

and x axis is the PV voltage measured in channel (D) with deviation (20 volt) and the PV power measured on channel (A).	107
Figure 5. 11: The maximum PV power measured on channel (1), the maximum PV current on channel (2), the battery current on channel (3) and the load current on channel (4)...	108
Figure 5. 12 : The maximum PV power measured on channel (1), the maximum PV current on channel (2), the battery current on channel (3) and the load current on channel (4)...	109
Figure 5. 13 The maximum PV power measured on channel (1), the maximum PV current on channel (2), the battery current on channel (3) and the load current on channel (4)...	110

List of abbreviations

CAESS	Compressed Air Energy Storage Systems
DC	Direct current
EMC	Energy Management Controller
ESS	Energy Storage Systems
IGBT	Insulated Gate Bipolar Transistor
L-ion	Lithium Ion
MPP	Maximum power Point
MPPT	Maximum Power Point Tracking
NaBr	Sodium Bromine
NaS	Sodium Sulfur
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
Pb-Acid	Lead Acid Battery
PHES	Pumped Hydro Energy Storage
P&O	Perturb and Observe
PV	Photovoltaic
PWM	Pulse Width Modulation
rpm	Revolution Per Minute
SC	Supercapacitor
SMES	Superconducting magnetic energy storage