Optimal Design of Grid-connected Photovoltaic (PV) Power Plants using Optimisation Algorithms

by

TEKAI EDDINE KHALIL ZIDANE
(1840912727)

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Electrical Engineering Technology
UNIVERSITI MALAYSIA PERLIS

2021

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's Full Name	:	TEKAI EDDINE KHALIL ZIDANE
Title	:	OPTIMAL DESIGN OF GRID-CONNECTED PHOTOVOLTAIC (PV) POWER PLANTS USING OPTIMISATION ALGORITHMS
Date of Birth	:	28 SEPTEMBER 1989
Academic Session	:	2020/2021

I hereby declare that this thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1997)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☑	**OPEN ACCESS**	I agree that my thesis to be published as online open access (Full Text)

I, the author, give permission to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during the period of _____ years, if so requested above)

Certified by:

SIGNATURE	**SIGNATURE OF SUPERVISOR**
166902406	DR. MOHD RAFI BIN ADZMAN
(NEW IC NO. /PASSPORT NO.)	**NAME OF SUPERVISOR**
Date: 26 April 2021	Date: 26 April 2021

NOTES: * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with the period and reasons for confidentiality or restriction

ACKNOWLEDGMENT

First and foremost, I am grateful to ALLAH, who helped and supported me to accomplish this PhD work. I would like to express my heartfelt thanks to my supervisor, Dr. Mohd Rafi Bin Adzman, for his academic and emotional support since day one. He assisted me at various stages of the thesis progress and guided me on the right track, especially where I had reached the 'crossroads'. During the most challenging times of writing this thesis, he provided me with moral support and gave me full freedom to pursue my research interest.

I would like to thank my co-supervisors, Dr. Mohammad Faridun Naim Tajuddin, Dr. Samila Mat Zali and Dr. Ali Durusu, for their constant support, availability and constructive suggestions, which were determinant for the accomplishment of the work presented in this thesis.

An exceptional thanks to my mother, to the memory of my father, who raised me with a love of science and supported me in all my pursuits. To my brothers and sister, thank you for all your support. Finally, I would like to thank my family for their everlasting love and unconditional support. I also want to sincerely express my gratitude and thanks to my friends, who have always been a major source of support when things started to get a little bit discouraging.

TABLE OF CONTENTS

		PAGE
DECLARATION OF THESIS		**i**
ACKNOWLEDGMENT		**ii**
TABLE OF CONTENTS		**iii**
LIST OF TABLES		**viii**
LIST OF FIGURES		**x**
LIST OF ABBREVIATIONS		**xiii**
LIST OF SYMBOLS		**xiv**
ABSTRAK		**xix**
ABSTRACT		**xx**
CHAPTER 1 : INTRODUCTION		**1**
1.1	Overview	1
1.2	Problem statement	4
1.3	Research objectives	6
1.4	Research questions	7
1.5	Research scope	7
1.6	Research contributions	8
1.7	Thesis outlines	10
CHAPTER 2 : LITERATURE REVIEW		**12**
2.1	Introduction	12
2.2	Main components of grid-connected PV power Plant	13
	2.2.1 PV modules	14

2.2.2 Inverters 20
2.2.3 Transformers 22
2.2.4 Wiring 25
2.2.5 Junction Boxes 26
2.3 Topologies for large-scale PV power plant 27
2.3.1 Central topology 28
2.3.2 Master-slave topology 29
2.3.3 String topology 30
2.3.4 Team Concept topology 31
2.3.5 AC-module topology 32
2.3.6 Multi-string topology 33
2.3.7 Comparison between PV plant topologies 34
2.4 PV plant optimal design 38
2.5 PV plant inverter size optimisation 47
2.6 PV module optimal tilt angle 51
2.7 International standards for PV plant components 54
2.8 Software tools for sizing a large scale PV power plant grid-connected 59
2.9 Chapter summary 62
CHAPTER 3 : METHODOLOGY 64
3.1 Formulation of the design problem 64
3.1.1 Objective function 65
3.1.2 Design variables 66
3.1.3 Constraints 67
3.2 System description and meteorological data 68
3.2.1 System description 69
3.2.2 Selected sites 70

3.2.3 Meteorological Data 70
3.3 PV power plant modeling 71
3.3.1 Irradiance model 72
3.3.2 PV module power 76
3.3.3 Area calculation model 78
3.3.4 Components arrangement 82
3.3.5 Cable calculation 86
3.3.6 Mounting structure 89
3.3.7 Shaded surface on PV modules 91
3.3.8 PV plant total energy 93
3.3.9 PV plant total cost 96
3.4 Case studies 98
3.4.1 Case 1: Optimal configuration of PV power plant using single optimisation: a comparative analysis considering CdTe and c-Si PV modules 98
3.4.1.1 PV modules and inverters 98
3.4.1.2 Whale Optimisation Algorithm 101
3.4.1.3 Salp Swarm Algorithm (SSA) 105
3.4.1.4 Grey Wolf Optimiser (GWO) 107
3.4.1.5 Implementation of the proposed algorithms for PV plant design problem 110
3.4.2 Case 2: Optimal design of PV power plant using hybrid optimisation 111
3.4.2.1 PV modules and inverters 112
3.4.2.2 Hourly and semi-hourly meteorological data 113
3.4.2.3 Sine Cosine Algorithm (SCA) 115
3.4.2.4 Hybrid grey wolf optimiser-sine cosine algorithm (HGWOSCA) 117

3.4.3 Case 3: Cost-effective topology for PV power plants using optimisation design: central structure versus string structure 120

3.4.3.1 PV modules and inverters 121

3.4.3.2 Particle swarm optimisation (PSO) 122

3.4.3.3 PV plant rated power 124

3.4.4 Case 4: Assessing the impact of key factors on the optimised design of PV power plants 125

3.4.4.1 Location 126

3.4.4.2 Meteorological data 127

3.4.4.3 Available land 129

3.4.4.4 PV modules and inverters 130

3.4.4.5 Objective function 132

3.4.4.6 Optimisation techniques 134

3.4.4.7 Step time of meteorological data 135

3.5 Chapter summary 136

CHAPTER 4 : RESULTS & DISCUSSION 137

4.1 Introduction 137

4.2 Results of case 1: Optimal configuration of PV power plant using single optimisation: a comparative analysis considering CdTe and c-Si PV modules 138

4.2.1 Scenario (1) 138

4.2.2 Scenario (2) 140

4.2.3 Comparison between scenario (1) and scenario (2) 142

4.3 Results of case 2: Optimal design of PV power plant using hybrid optimisation 144

4.3.1 Effect of PV module reduction coefficient 152

4.4 Results of case 3: Cost-effective topology for PV power plants using optimisation design: central structure versus string structure 154

4.4.1 Impact of inverter efficiency 156

4.5 Results of case 4: Assessing the impact of key factors on the optimised design of PV power plants 157

4.5.1 Location effect 158

4.5.2 Meteorological data effect 165

4.5.2.1 Solar irradiation 165

4.5.2.2 Ambient temperature 166

4.5.2.3 Wind speed 167

4.5.3 Available land effect 168

4.5.4 PV modules and inverters effect 169

4.5.5 Objective function effect 171

4.5.6 Optimisation techniques effect 172

4.6 Chapter conclusion 174

CHAPTER 5 : CONCLUSIONS AND FUTURE WORKS 179

5.1 Conclusions 179

5.2 Future Works 181

REFERENCES 182

LIST OF PUBLICATIONS 209