



UNIVERSITI PUTRA MALAYSIA

**MULTI-OBJECTIVE OPTIMIZATION OF STAND-ALONE HYBRID
RENEWABLE ENERGY SYSTEM BY GENETIC ALGORITHM**

MOHSEN FADAE NEJAD

FK 2013 66



**MULTI-OBJECTIVE OPTIMIZATION OF STAND-ALONE HYBRID
RENEWABLE ENERGY SYSTEM BY GENETIC ALGORITHM**

By

MOHSEN FADAE NEJAD

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfillment of the Requirements for the Degree of Master of Science**

November 2013

DEDICATION

To my wife, for her endless support and encouragement.

To my mother and my parents in law.

And...

To the memory of my father,

Hassan Fadaee Nejad (1953-2012),

for inspiring me to pursue my dreams.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

**MULTI-OBJECTIVE OPTIMIZATION OF STAND-ALONE HYBRID
RENEWABLE ENERGY SYSTEM BY GENETIC ALGORITHM**

By

MOHSEN FADAE NEJAD

November 2013

Chairman: Mohd Amran Mohd Radzi, PhD

Faculty: Engineering

Nowadays, a lot of countries have started reducing share of fossil fuels to be replaced by alternative energies. The role of renewable energy as a proper resource among alternative energies has been growing rapidly in the past few years. Human development, CO₂ emission reduction, availability of renewable sources and rising cost of fossil fuels are some of factors that make utilization of renewable energy systems become more important. In Malaysia, there have been some efforts on the utilization of renewable energies.

Although usage of renewable sources is the main reason for development, there are a few barriers against the utilization of renewable energy projects. Some of these

obstacles are cost, reliability and performance. Hybrid renewable energy system (HRES) that is a combination of more than two renewable energy sources in one system, has been developed as a possible solution for such problems. HRES as an improved RE system, has been able to make a cost-effective and more reliable unit with better performance as compared to a single renewable resource. Therefore, application of well-optimized HRES is a favorable renewable power solution for decision makers and governments like Malaysia.

In recent years, there have been many works on the optimization of stand-alone HRES, but a few of them have used optimization methods for multi objectives simultaneously. Optimization of more than one objects such as size, cost, control strategy, emissions and etc is a more complex issue. Multi-objective optimization of HRES by Evolutionary Algorithm have become attractive in recent years due to the effectiveness of such algorithms for complicated problems. Among these methods, Genetic Algorithm and Particle Swarm Optimization are known as two most effective methods for HRESs.

In this research, multi-objective optimization of stand-alone HRES in Malaysia by Genetic Algorithm is proposed. The optimization process of HRES is explained in three major steps in this thesis. First, a comprehensive literature review and data collection from NASA and Meteorological Department of Malaysia is provided. In the next step, feasibility study shows that solar and wind are suitable sources of renewable energy in Malaysia, but there is a low range of wind speed. Load estimation, tilt angle optimization and multi-objective optimization are on the last sections. HOGA, as a new

effective tool for multi-objective optimization by evolutionary algorithm is used in this research. HOGA (Hybrid Optimization by Genetic Algorithms) is developed by Dr. Lopez from Zaragoza university in Spain.

The results show that the PV-wind-battery combination is suitable for three study cases in Malaysia and the slope of 0° and 5° is the optimized angle of PV panels for these three study cases. Daily and monthly load for a rural community in Malaysia is estimated and sizing, cost and CO₂ emission optimization are provided in results. Cost analysis and best solutions for multi-objective optimization in these villages are explained. Finally, a comparative study between the results and previous research works is provided for validation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PENGOPTIMUMAN PELBAGAI OBJEKTIF SISTEM HIBRID TENAGA
DIPERBAHARUI SENDIRIAN MENGGUNAKAN ALGORITMA GENETIK**

Oleh

MOHSEN FADAE NEJAD

November 2013

Pengerusi: Mohd Amran Mohd Radzi, PhD

Fakulti: Kejuruteraan

Pada masa kini, sesetengah negara telah mengambil pendekatan dalam mengurangkan nisbah bahan api fosil dengan digantikan oleh tenaga alternatif. Peranan tenaga boleh diperbaharui sebagai sumber yang baik di kalangan tenaga alternatif telah berkembang pantas dalam beberapa tahun kebelakangan ini. Pembangunan manusia, pengurangan pelepasan CO², adanya sumber boleh diperbaharui dan peningkatan kos bahan api fosil adalah sebahagian faktor asas yang membuatkan penggunaan sistem tenaga boleh diperbaharui penting. Di Malaysia, terdapat beberapa usaha berkaitan pelaksanaan tenaga diperbaharui.

Walaupun keuntungan sumber boleh diperbaharui adalah sebab utama untuk pembangunan masa depan, akan tetapi terdapat beberapa halangan terhadap pelaksanaan projek tenaga boleh diperbaharui. Halangan ini termasuk kos, kebolehharaPan dan prestasinya. Sistem tenaga boleh diperbaharui hibrid merupakan gabungan lebih daripada dua sumber tenaga boleh diperbaharui dalam satu sistem, dibangunkan sebagai satu kemungkinan untuk menyelesaikan masalah tersebut. Sistem ini sebagai sistem tenaga boleh diperbaharui yang ditingkatkan, membolehkan penghasilan unit yang kos efektif dan lebih dipercayai dengan prestasi yang baik berbanding dengan sumber boleh diperbaharui tunggal. Oleh yang demikian, penggunaan sistem ini yang telah dioptimumkan merupakan satu penyelesaian setanding kuasa boleh diperbaharui bagi pembuat keputusan dan kerajaan seperti di Malaysia.

Dalam tahun kebelakangan ini, terdapat pelbagai kerja berkaitan pengoptimuman sistem tenaga boleh diperbaharui hibrid berdiri sendiri, tetapi hanya beberapa yang telah menggunakan kaedah pengoptimuman untuk objektif yang banyak secara serentak. Pengoptimuman pelbagai objek seperti saiz, kos, strategi kawalan, pelepasan dan lain-lain adalah isu yang lebih kompleks. Pengoptimuman pelbagai objektif bagi sistem tenaga boleh diperbaharui hibrid oleh algoritma evolusi secara meluas menjadi menarik sejak tahun kebelakangan ini disebabkan oleh keberkesanan algoritma tersebut untuk masalah yang rumit. Antara kaedah ini, algoritma genetik dan pengoptimuman sekumpulan zarah dikenali sebagai dua kaedah yang paling berkesan untuk sistem tenaga boleh diperbaharui hibrid.

Dalam kerja penyelidikan ini, pengoptimuman pelbagai objektif sistem tenaga boleh diperbaharui hibrid berdiri sendiri di Malaysia oleh algoritma genetik dicadangkan. Proses melaksanakan pengoptimuman untuk sistem ini diterangkan dalam tiga langkah utama dalam tesis ini. Pertama, kajian literatur yang menyeluruh dan pengumpulan data daripada NASA dan Jabatan Meteorologi Malaysia disediakan. Dalam langkah seterusnya, kajian kebolehlaksanaan menunjukkan bahawa suria dan angin adalah sumber tenaga diperbaharui yang bersesuaian di Malaysia, tetapi hanya kelajuan angin yang rendah boleh didapati. Anggaran beban, pengoptimuman sudut kecondongan dan pengoptimuman pelbagai objektif adalah bahagian yang akhir. HOGA, sebagai alat baru yang berkesan untuk pengoptimuman pelbagai objektif oleh algoritma evolusi digunakan dalam kajian ini. Semua data komponen seperti turbin angin dan ciri-ciri panel PV diterima daripada pengeluar yang terdapat di pasaran Malaysia.

Keputusan menunjukkan gabungan PV-angin-bateri sesuai untuk ketiga-tiga kajian kes di Malaysia dan kecondongan sekitar 0° dan 5° adalah sudut optimum bagi panel PV. Selain itu, dianggarkan beban bagi setiap rumah luar bandar diandaikan sebanyak 2.13 kW sehari dan dengan pengoptimuman pelbagai objektif seperti kos dan pelepasan, sistem ini dioptimumkan dengan betul. Akhirnya, satu kajian perbandingan antara keputusan yang setanding dan kerja-kerja penyelidikan sebelumnya disediakan untuk mengesahkan keputusan akhir yang diperolehi.

ACKNOWLEDGEMENTS

It would not have been possible to write this thesis without the help and support of some people. First and foremost, my greatest gratitude goes to my supervisor, Dr. Mohd Amran Mohd Radzi who has supported me throughout my thesis with his patience and knowledge. His advices have been abundantly helpful all the time of research. He has been one of the most punctual people that I ever met.

Moreover, I would like to thank the other members of supervisory committee, Prof.Mohd Zainal Abidin Ab Kadir and Associate Prof. Hashim Hizam for their precise comments and guidance.

I certify that a thesis Examination Committee has met on 15 November 2013 to conduct the final examination of Mohsen Fadaee Nejad on his thesis entitled "Multi-objective optimization of stand-alone hybrid renewable energy system by genetic algorithm" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Examination Committee were as follows:

Suhaidi Bin Shafie, Phd

Senior lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Gorakanage Arosha Chandima Gomes, Phd

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Noor Izzri Abdul Wahab, Phd

Senior lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Titik Khawa Abdul Rahman, Phd

Professor
Universiti Pertahanan Nasional Malaysia
Malaysia
(External Examiner)

NORITAH OMAR, PHD

Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 December 2013

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Mohd Amran Mohd Radzi, PhD

Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Zainal Abidin b. Ab. Kadir, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Hashim b. Hizam, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PHD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHSEN FADAE NEJAD

Date: 15 November 2013

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	x
DECLARATION	xii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
LIST OF ABBREVIATION	xxi
CHAPTER	
1 INTRODUCTION	1
1.1 Background	1
1.2 Statement of Problem and Motivation	6
1.3 Aim and Objectives	8
1.4 Scope of Research	8
1.5 Organization of the Thesis	11
2 LITRATURE REVIEW	
2.1 Introduction	13
2.2 Multi-Objective Optimization	15
2.3 Multi-Objective by Evolutionary Algorithm	18
2.3.1 Genetic Algorithm	19
2.3.2 Particle Swarm Optimization	22
2.3.3 Other Algorithms	22
2.4 Rural Electrification in Malaysia	26
2.5 Rural Electrification by Optimized HRESs	28
2.5.1 PV-Wind-battery HRRES	28
2.5.1.1 Applied Optimization Methods	28
2.5.1.2 Rural Electrification	31
2.5.2 PV-Wind-Diesel-Battery	32
2.5.2.1 Applied Optimization Methods	32
2.5.2.2 Rural Electrification	33
2.5.3 Other HRESs	34
2.5.3.1 Applied Optimization Methods	34

	2.5.3.2 Rural Electrification	35
	2.5 Summary	36
3	RESEARCH METHODOLOGY	
	3.1 Introduction	39
	3.2 Case Study	41
	3.3 Modeling	43
	3.3.1 Feasibility Study	43
	3.3.1.1 Solar Energy	43
	3.3.1.2 Wind Energy	48
	3.3.2 Load Estimation	50
	3.3.3 Tilt Angle	58
	3.3.4 Component Modeling	58
	3.3.4.1 PV System	59
	3.3.4.2 Wind Turbine	59
	3.3.4.3 Battery	
	3.3.4.4. Cost	61
	3.4 Data Collection	63
	3.4.1 Meteorological and Climate Data	63
	3.4.2 Components	64
	3.5 Optimization Tool	72
4	RESULTS AND DISCUSSION	
	4.1 Introduction	76
	4.2 Feasibility Study	76
	4.2.1 Solar Energy	76
	4.2.2 Wind Energy	84
	4.3 Load Estimation	96
	4.4 Tilt Angle Optimization	104
	4.5 Multi-objective Optimization	113
5	CONCLUSION	
	5.1 Conclusion	133
	5.2 Thesis Contributions	135
	5.3 Recommendations for Future Research	137
	REFERENCES/BIBLIOGRAPHY	141
	APPENDICES	150
	BIODATA OF STUDENT	153
	LIST OF PUBLICATIONS	154