



## MODELING AND FEASIBILITY STUDY OF A DISH-MICRO GAS TURBINE SYSTEM IN DIFFERENT REGIONS OF MALAYSIA



**SYARIFFAH BINTI OTHMAN**

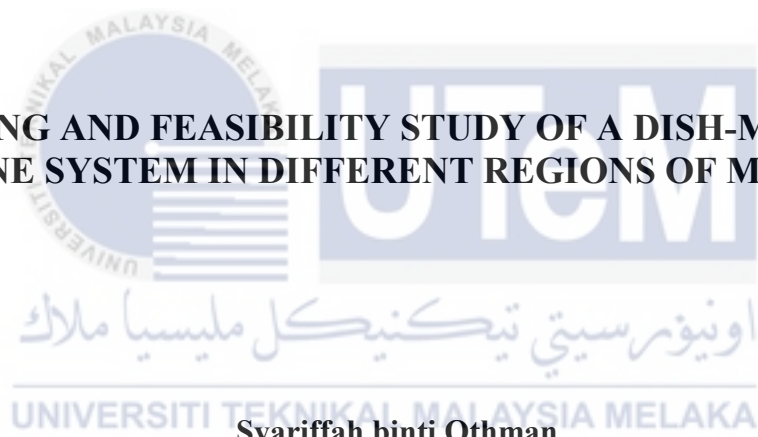
**DOCTOR OF PHILOSOPHY**

**2022**



**Faculty of Electrical Engineering**

**MODELING AND FEASIBILITY STUDY OF A DISH-MICRO GAS  
TURBINE SYSTEM IN DIFFERENT REGIONS OF MALAYSIA**



**Syariffah binti Othman**

**Doctor of Philosophy**

**2022**

**MODELING AND FEASIBILITY STUDY OF A DISH-MICRO GAS TURBINE  
SYSTEM IN DIFFERENT REGIONS OF MALAYSIA**

**SYARIFFAH BINTI OTHMAN**

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



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2022**

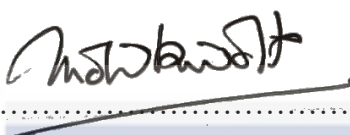
## DECLARATION

I declare that this thesis entitled “Modeling And Feasibility Study Of A Dish-Micro Gas Turbine System In Different Regions Of Malaysia” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

   
Signature : .....  
Name : Syariffah binti Othman  
Date : 31 January 2022  
  
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature :   
Supervisor Name : Emeritus Professor Datuk Dr. Mohd Ruddin  
Bin Ab Ghani FASc  
Date : 31 January 2022

اونيورسيتي تيكنيكل مليسيا ملاك  
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## DEDICATION

To my beloved late father, mother, children, family and friends.

For their endless love, support and encouragement.



## ABSTRACT

Concentrated solar power (CSP) systems are a renewable energy source that can help decouple the energy mix from fossil fuel combustion and its associated environmental effects. Due to high costs, complexity, and poor dependability, existing small-scale CSP solutions (Dish-Stirling) have not entered the market. These projects intended to address the drawbacks of small-scale CSP by combining a solar dish with the compact and relatively inexpensive micro gas turbine (MGT) technology. The study's objective is to investigate the performance and viability of a 30kW dish-MGT in Malaysia. In this study, a hybrid system of solar micro gas turbine with a combustion chamber was investigated. A dish-MGT system with three main components: a concentrator, a receiver, and a micro gas turbine was the subject of this study. Matlab Simulink is used to simulate the background of the dish-MGT system and its components model. Meanwhile, the performance of the three major components was tested under three different solar irradiation conditions: low, medium, and high. Thus, five sites or locations have been chosen for this study by considering the highest Direct Solar Irradiance (DNI) and based on regions. In the northern part of Peninsular Malaysia, George Town has the highest DNI. Besides that, Subang, in the middle part of Peninsular Malaysia, Kuantan, on the east coast of Peninsular Malaysia, Senai, in the southern part of Peninsular Malaysia, and Kuching, in East Malaysia. To investigate the impact of climatic conditions on system performance and electricity generation, a thermodynamic model was built. The highest daily solar irradiation cycle outlet power for 81 m<sup>2</sup> dish collector aperture area was 30 kW, with a solar-to-electric efficiency of 36%. Dish-MGT has a higher total yearly energy, Levelized Cost Of Energy (LCOE), and capacity factor of 87 kWh, MYR 1.01/kWh, and 33%, respectively, than a traditional dish system such as dish-Stirling. The developed model of the dish-MGT system shows that the system is technically feasible but not economically feasible and not environmentally sustainable. In conclusion, the study's findings showed that Malaysia's dish-MGT system is capable of serving local demand reliably. However, in order to improve the LCOE and reduce CO<sub>2</sub> emissions, more work is required. The findings of this study can assist policymakers and regulators in better understanding the potential for CSP development in this country and other equatorial countries.

## **PEMODELAN DAN KAJIAN KEBOLEHLAKSANAAN SISTEM PIRING-MIKRO GAS TURBIN DI PELBAGAI WILAYAH DI MALAYSIA**

### **ABSTRAK**

*Concentrator Solar Power (CSP) merupakan sumber tenaga boleh diperbaharui yang boleh membantu memisahkan campuran tenaga daripada pembakaran bahan api dan kesan alam sekitar yang berkaitan. Disebabkan oleh kos yang tinggi, kebolehpercayaan yang lemah, penyelesaian CSP berskala kecil sedia ada (Dish-Stirling) belum lagi berada di pasaran. Kajian ini bertujuan untuk menangani kelemahan CSP berskala kecil dengan menggabungkan solar piring dengan teknologi mikro gas turbin (MGT) yang padat dan agak murah. Objektif kajian adalah untuk menyiasat prestasi dan daya maju 30kW dish-MGT di Malaysia. Di dalam kajian ini, sistem hibrid turbin gas mikro solar dengan ruang pembakaran diselidik. Sistem MGT dengan tiga komponen utama: penumpu, penerima dan turbin gas mikro merupakan subjek kajian ini. Matlab Simulink digunakan untuk mensimulasikan setiap komponen utama di dalam model sistem piring MGT. Selain dari itu, prestasi tiga komponen utama diuji dalam tiga kadar pancaran solar yang berbeza: rendah, sederhana dan tinggi. Oleh yang demikian, lima lokasi telah dipilih untuk kajian ini dengan mempertimbangkan nilai Direct Solar Irradiance (DNI) yang tertinggi berdasarkan wilayah masing-masing. Di bahagian utara Semenanjung Malaysia, George Town mempunyai nilai DNI yang tertinggi. Selain itu, wilayah Subang di bahagian tengah Semenanjung Malaysia, Kuantan di pantai timur Semenanjung Malaysia, Senai di bahagian selatan Semenanjung Malaysia dan Kuching di Malaysia Timur. Model termodinamik telah dibina di dalam kajian ini bagi menyiasat kesan keadaan iklim terhadap prestasi sistem dan penjanaan tenaga elektrik. Kuasa keluaran kitaran sinaran matahari tertinggi untuk kawasan bukaan pengumpul seluas 81 m<sup>2</sup> adalah 30kW, dengan kecekapan solar ke elektrik sebanyak 36%. Piring-MGT mempunyai jumlah tenaga tahunan yang lebih tinggi iaitu 87kWj, Levelized Cost of Energy (LCOE) dan faktor kapasiti masing-masing sebanyak MYR 1.01/kWj, dan 33%, berbanding sistem piring tradisional iaitu piring – Stirling. Model piring MGT yang dibangunkan ini menunjukkan bahawa sistem ini boleh dilaksanakan secara teknikal, namun ia tidak ekonomikal dan tidak mampan. Kesimpulannya, hasil kajian menunjukkan sistem piring-MGT Malaysia mampu memenuhi permintaan tempatan dengan berkesan. Walau bagaimanapun, untuk memperbaiki LCOE dan mengurangkan pelepasan CO<sub>2</sub>, pengubahsuaian yang lebih baik diperlukan. Oleh itu, penemuan kajian ini dapat membantu memberikan maklumat yang berguna kepada penggubal dasar dan pihak yang mengawal selia dalam memahami potensi pembangunan CSP di negara ini dan juga negara-negara khatulistiwa yang lain.*



## ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for *Hadiah Latihan Persekutuan* Scholarship. My utmost appreciation goes to my main supervisor, Emeritus Professor Datuk Dr. Mohd Ruddin Bin Ab Ghani for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Also, to my co-supervisor, Assoc. Prof. Dr. Gan Chin Kim, who constantly supported my journey. Last but not least, from the bottom of my heart a gratitude to my beloved mother and for her encouragements and who have been the pillar of strength in all my endeavors. My eternal love also to all my children, Shamsul Hairul Akmal, Sofea Hanissa and Shamsul Haziq Aisy, for their patience and understanding. I would also like to thank my beloved parents for their endless support, love and prayers. Finally, thank you to all the individuals who had provided me the assistance, support and inspiration to embark on my study.

## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF SYMBOLS</b>	<b>xiii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xv</b>
<b>LIST OF APPENDICES</b>	<b>xvii</b>
<b>LIST OF PUBLICATIONS</b>	<b>xix</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Motivation For The Research	4
1.3 Problem Statement	6
1.4 Research Objective	8
1.5 Scope of Research	8
1.6 Contribution of Research	9
1.7 Thesis online	10
<b>2. LITERATURE REVIEW</b>	<b>12</b>
2.1 Introduction	12
2.2 Concentrated Solar Power	13
2.2.1 CSP Technologies	13
2.2.1.1 Parabolic Trough Concentrator	14
2.2.1.2 Power Tower	15
2.2.1.3 Linear Fresnel Reflector	16
2.2.1.4 Parabolic Dish	17
2.2.2 Concentrated Photovoltaic	19
2.2.3 Comparison CSP Technology	20
2.2.4 CSP Technologies For Malaysia's Environment	22
2.2.5 Hybridization Concentrated Solar Power	23
2.2.5.1 Hybridization With Natural Gas	25
2.2.5.2 Summary of CSP Natural Gas Hybrids System	29
2.3 Micro Gas Turbine's Vs Stirling Engine	31
2.4 Microturbine System	31
2.4.1 Description of The system	34
2.4.2 Micro Gas Turbine Component	36
2.4.2.1 Compressor	36
2.4.2.2 Recuperators	37
2.4.2.3 Receiver	38
2.4.2.4 Combuster	39

2.4.3	Micro Gas Turbine Advantages	39
2.5	Hybrid Dish-MGT System	40
2.5.1	Development of Hybrid Solar Micro Gas Turbine	41
2.5.2	Micro Gas Turbine In Power Generation	42
2.5.2.1	30kW MGT	44
2.5.3	Solar Energy	45
2.5.3.1	Solar Radiation Concentrators	46
2.5.3.2	Solar Receiver	48
2.5.4	Solar Powered Gas Turbine Systems	48
2.5.5	Micro Gas Turbine Solar Dish Layouts	50
2.5.6	Overview of Performance Micro Gas Turbine Model	52
2.5.7	Economic Model For Solar Power System	53
2.6	Meteorological Data	55
2.7	Software For dish-MGT Simulation	56
2.7.1	Matlab Simulink	56
2.7.2	Meteonorm	57
2.8	Review Micro Gas Turbine Research	58
2.9	Malaysian Studies On CSP Technology	60
2.10	Chapter Summary	60
<b>3.</b>	<b>METHODOLOGY</b>	<b>66</b>
3.1	Introduction	66
3.2	Research Design	67
3.3	Research Methodology	70
3.3.1	Dish Collector Design	71
3.3.2	Receiver Design	71
3.3.3	Micro Gas Turbine Design	72
3.3.4	Verification Of The Model	73
3.4	Data Description And Validation	73
3.4.1	Data Employed For The Model	73
3.4.2	Economic Data Employed	75
3.5	Site Selection	76
3.6	Direct Normal Irradiance Data	79
3.6.1	Yearly DNI Data	80
3.6.2	Monthly DNI Data	80
3.6.3	Daily Solar Irradiance Data	84
3.7	Development of 30kW Dish-MGT	89
3.7.1	Parameter of Parabolic Dish	89
3.7.2	Solar Receiver For High-Temperature	90
3.7.3	Microturbine Modelling	91
3.7.4	Hybrid Operation	97
3.7.5	Parasitic Losses	99
3.8	Chapter Summary	99
<b>4.</b>	<b>RESULTS AND DISCUSSION</b>	<b>101</b>
4.1	Introduction	101
4.2	Background Data	101
4.3	Simulation of Dish-MGT System	102
4.4	Performance Indicator Analysis	105

4.4.1	Thermodynamic Performance Indicator	106
4.4.1.1	Heat Input To The System	106
4.4.1.2	Solar Power Receiver	109
4.4.1.3	Dish-MGT Power Output	110
4.4.1.4	Net Generator Power	112
4.4.1.5	Annually Energy	113
4.4.1.6	Optical Efficiency	114
4.4.1.7	Solar To Electric Efficiency	115
4.4.2	Economic Performance Indicator	117
4.4.2.1	Levelized Cost of Electricity	117
4.4.2.2	Capacity Factor	119
4.4.3	Environmental Performance Indicator	120
4.4.3.1	Carbon Dioxide Emissions	121
4.4.3.2	Fuel Consumption	123
4.5	Performance of The Dish-MGT System In Malaysia Environment	126
4.6	Performance Comparison Between The Dish-MGT And The Dish-Stirling	127
4.7	Validation Economic Analysis of The Dish-MGT And Dish-Stirling	129
4.8	Chapter Summary	131
<b>5.</b>	<b>CONSLUSION AND RECOMMENDATIONS</b>	<b>134</b>
5.1	Conclusion	134
5.2	Achievement of Research Objectives	135
5.3	Significance of Research Outputs	136
5.4	Recommendations	138
	<b>REFERENCES</b>	<b>139</b>
	<b>APPENDICES</b>	<b>166</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Summary Of CSP's Various Research	3
2.1	Overview CSP Technology	21
2.2	Summary of CSP Natural Gas Hybrid System	30
2.3	Development Stages of Microturbine	33
2.4	Engine Performance Data In ISO Conditions	36
2.5	Specifications of The Micro Gas Turbines	44
2.6	Reviewed Studies Hybridization Dish-Microturbines	62
2.7	Investigation of Different Techniques Based On CSP Technology In The Malaysia Environment	64
3.1	Boundry Condition For The Dish Collector Design	71
3.2	Design Parameters Of MGT Generator System	72
3.3	Parameters Are Employed For The Hybrid Calculation of 30kW Output Power	74
3.4	The Latitude And Longitude Data For Five Locations In Malaysia	78
3.5	Annual DNI Data For Five Malaysian Sites	80
3.6	Concentrator Parameter	90
3.7	Receiver Parameter	91
3.8	Parasitic Losses For Different System Outputs	99
4.1	The High, Medium, And Low Daily Solar Irradiance Data For	103

	George Town, Penang	
4.2	Optical Efficiency For The Dish-MGT System	115
4.3	LCOE For Five Locations In Malaysia	118
4.4	Capacity Factor For Five Locations In Malaysia	120
4.5	Carbon Dioxide Emission For Five Locations in Malaysia	122
4.6	Performance Of The Component In 30kW Dish-MGT System At Highest Daily Solar Irradiance In George Town	127
4.7	Performance Comparison Between Dish-MGT And Dish-Stirling System	128
4.8	Comparison of The Annual Energy Produced By The Dish-MGT System And Dish-Stirling System	129
4.9	Results of The Economic Performance Between The Dish-MGT System And Dish-Stirling System	130



## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Annual Additions of Renewable Power Capacity By Technology, 2013-2019	4
1.2	Concentrating Solar Thermal Power Global Capacity, By Country And Region, 2009-2019	6
2.1	Parabolic Trough System	15
2.2	Power Tower System	16
2.3	Linear Fresnel Reflector System	16
2.4	Parabolic Dish System	17
2.5	Concentrated Photovoltaic System	20
2.6	A Recuperated Solar Gas Turbine	28
2.7	CAD Model of A Single Shaft Turbo-Compressor	37
2.8	Performance Comparison Between Tubular And Volumetric Receivers	38
2.9	Ideal (1-2s-3-4s) And Actual (1-2a-3-4a) Bryton Cycle	43
2.10	Beam And Diffuse Solar Radiations	45
2.11	Pattern of Variations In DNI At George Town, Penang	46
2.12	Concentration Ratio	47
2.13	Solar-Only (left) And Solar-Hybrid (right) System Configurations	49
2.14	Standard Performance of A Hybrid System In An Ideal (left) And Cloudy (right) day	50

2.15	Layout of A Standard Solar Hybrid Dish-MGT System	51
3.1(a)	Research Design Overview	69
3.1(b)	Research Design Block Diagram	69
3.2	Research Methodology	70
3.3	Location Of Meteorological Data Monitors And Solar Radiations Monitors	77
3.4	Direct Normal Irradiation For Malaysia	79
3.5	Monthly DNI Data For George Town, Penang	81
3.6	Monthly DNI Data For Kuantan, Pahang	81
3.7	Monthly DNI Data For Senai, Johor	82
3.8	Monthly DNI Data For Subang, Selangor	82
3.9	Monthly DNI Data For Kuching, Sarawak	83
3.10	Daily DNI Data For George Town	84
3.11	Numbers of Days Daily DNI Data For George Town In A Year	84
3.12	Daily DNI Data For Kuantan	85
3.13	Numbers of Days Daily DNI Data For Kuantan In A Year	85
3.14	Daily DNI Data For Senai	86
3.15	Numbers of Days Daily DNI Data For Senai In A Year	86
3.16	Daily DNI Data For Subang	87
3.17	Numbers of Days Daily DNI Data For Subang In A Year	87
3.18	Daily DNI Data For Kuching	88
3.19	Numbers of Days Daily DNI Data For Kuching In A Year	88
3.20	Components of Microturbine	92
3.21	Control Functions of Microturbine	93
3.22	Speed Controller For The Microturbine	94



3.23	Block Diagram of The Fuel System	94
3.24	Compressor-Turbine Package of A Microturbine	95
3.25	Block Diagram of The Temperature Controller	96
3.26	Simulink Model of The Microturbine	96
3.27	Open Solar Microturbine Cycle	98
4.1	Irradiance For Five Locations In A Year For Malaysia Environment	102
4.2	The High, Medium, And Low Irradiance For George Town, Penang	103
4.3	Solar Irradiance For Five Locations In Malaysia	104
4.4	System Performance For The Variation In DNI	105
4.5	Simulation Results For Heat Input To The System Under High Level of Irradiance In George Town, Penang	107
4.6	Simulation Results For Heat Input To The System Under Medium Level of Irradiance In George Town, Penang	108
4.7	Simulation Results For Heat Input To The System Under Low Level of Irradiance In George Town, Penang	108
4.8	Simulation Results For Solar Power Receiver To The System Under High, Medium And Low Levels of Irradiance In George Town, Penang	110
4.9	Monthly Output Power For Dish-MGT in George Town, Penang Malaysia	111
4.10	Monthly Net Power For Dish-MGT in George Town, Penang	112
4.11	Annual Energy For Five Locations In Malaysia	114
4.12	Schematic of The CSP System Component (Parabolic Dish And The Receiver)	114
4.13	Solar To Electric Efficiency For Five Locations In Malaysia	116

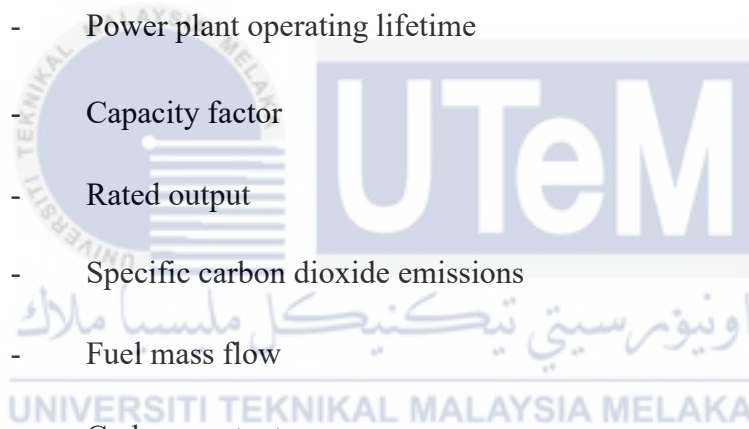
4.14	Correlation between fuel consumption and solar irradiance in George Town, Malaysia	123
4.15	Fuel Consumption And CO <sub>2</sub> Emissions For Five Locations In Malaysia	124
4.16	Fuel Consumption And Annual Energy For Five Locations In Malaysia	125
4.17	Monthly Fuel Consumption and Solar Irradiance in George Town, Malaysia	126



## LIST OF SYMBOLS

$A_a$	-	Aperture area of the parabolic dish
$A_r$	-	Area of the solar receiver window
$\eta$	-	efficiency
$\eta_{conc}$	-	Concentrator's optical efficiency
$CR_g$	-	Geometrical concentration ratio
$CR_{opt}$	-	Optical concentration ratio
$r_p$	-	Pressure ratio
$\rho_h$	-	Heat input
$\rho_l$	-	Heat release
$q_{in}$	-	Heat input to the system
$I_{DNI}$	-	Solar irradiance
$A_{dish}$	-	Concentrator's aperture area.
$q_H$	-	Solar power intercepted by the receiver
$\rho$	-	Reflectivity of the concentrator
$\emptyset$	-	Intercept factor
$P_{ele}$	-	Power output
$\eta_{ele}$	-	Electrical efficiency
$P_t$	-	Turbine power

$P_{cm}$	-	Compressor power
$P_{net}$	-	Net power
$P_{parasitics}$	-	Parasitic power
$\eta_{opt}$	-	Optical efficiency
$\eta_{overall}$	-	Overall efficiency
$C_{fuel}$	-	Annual fuel cost
$E_{net}$	-	Net annual electricity
$\alpha$	-	Annuity factor
$i$	-	Interest rate
$\eta_{op}$	-	Power plant operating lifetime
$C_f$	-	Capacity factor
$P_{nom}$	-	Rated output
$f_{co_2}$	-	Specific carbon dioxide emissions
$m_f$	-	Fuel mass flow
$\mu_f$	-	Carbon content
$\varepsilon_{HS}$	-	Solar heat exchange efficiency
$\varepsilon_t$	-	Turbine isentropic efficiency
$\varepsilon_c$	-	Compressor isentropic efficiency



## LIST OF ABBREVIATIONS

BESS	-	Battery Energy Storage Systems
CH <sub>4</sub>	-	Methane
CO	-	Carbon Monoxide
CO <sub>2</sub>	-	Carbon Dioxide
CPV	-	Concentrated Photovoltaic
CSP	-	Concentrated Solar Power
DNI	-	Direct Normal Irradiance
HC	-	Hydrocarbons
HRSG	-	Heat recovery Steam Generator
HSRC	-	Hybrid Solar Receiver Combustors
HTF	-	Heat Transfer Fluid
ISOC	-	Integrated Solar Combined Cycle
LCOE	-	Levelized Costs of Electricity
LVG	-	Negligible Value Gate
MGT	-	Micro Gas Turbine
NO <sub>x</sub>	-	Nitrogen Oxides
O&M	-	Operation And Maintenance
OMSoP	-	Optimized Microturbine Solar Power
PD	-	Parabolic Dish

PV	-	Photovoltaics
RE	-	Renewable Energy
RSiC	-	Recrystallized Silicon Carbide
SAM	-	Solar Advisor Model
SiC	-	Silicon Carbide
STIG	-	Steam Injection Gas Turbines
TCES	-	Thermochemical Energy Storage
TES	-	Thermal Energy Storage
TIT	-	Turbine Inlet Temperature
TRANSYS	-	Transient Systems Simulation Program With A Modular Structure
UAV	-	Unmanned Air Vehicles



## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	Matlab Simulink With Concentrator, Receiver And Micro Gas Turbine Subsystem	153
A2	Microgas Turbine Model	154
B1	The High, Medium, And Low Daily Solar Irradiance Data For Kuantan	155
B2	The High, Medium, And Low Daily Solar Irradiance Data For Senai	156
B3	The High, Medium, And Low Daily Solar Irradiance Data For Subang	157
B4	The High, Medium, And Low Daily Solar Irradiance Data For Kuching	158
C1	Monthly Output Power For Dish-MGT In Kuantan	159
C2	Monthly Output Power For Dish-MGT In Senai	159
C3	Monthly Output Power For Dish-MGT In Subang	160
C4	Monthly Output Power For Dish-MGT In Kuching	160
C5	Monthly Fuel Consumption And Solar Irradiance In Kuantan	161
C6	Monthly Fuel Consumption And Solar Irradiance In Senai	161
C7	Monthly Fuel Consumption And Solar Irradiance In Subang	162
C8	Monthly Fuel Consumption And Solar Irradiance In Kuching	162
C9	Correlation Between Fuel Consumption And Solar Irradiance In Kuantan	163
C10	Correlation Between Fuel Consumption And Solar Irradiance In Senai	163

C11	Correlation Between Fuel Consumption And Solar Irradiance In Subang	164
C12	Correlation Between Fuel Consumption And Solar Irradiance In Kuching	164

