

**STUDY ON INTEGRATED SOLAR PV AND AIR CONDITIONING
SOLUTIONS FOR LOW-CARBON COOLING INFRASTRUCTURE
GROWTH IN INDONESIA**

By

Karel Christofferro
12018001

BACHELOR'S DEGREE
in

CHEMICAL ENGINEERING
SUSTAINABLE ENERGY AND ENVIRONMENT CONCENTRATION
FACULTY OF LIFE SCIENCES & TECHNOLOGY



SWISS GERMAN UNIVERSITY
The Prominence Tower
Jalan Jalur Sutera Barat No. 15, Alam Sutera
Tangerang, Banten 15143 - Indonesia

Revision after the Thesis Defense on July 1, 2024

STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.



Karel Christofferro

Student

13 July 2024

Date

Approved by:



Dr.-Ing. Evita H. Legowo

Thesis Advisor

13 July 2024

Date



Dena Hendriana, B.Sc., S.M., Sc.D.

Thesis Co-Advisor

13 July 2024

Date

Dr. Hery Sutanto, S.Si., M.Si.

Dean

Date

Karel Christofferro

ABSTRACT

STUDY ON INTEGRATED SOLAR PV AND AIR CONDITIONING SOLUTIONS FOR LOW-CARBON COOLING INFRASTRUCTURE GROWTH IN INDONESIA

By

Karel Christoferro, Students
Dr.-Ing. Evita H. Legowo, Advisor
Dena Hendriana, B.Sc., S.M., Sc.D., Co-Advisor

SWISS GERMAN UNIVERSITY

Solar PV-powered air conditioning system is the key for providing sustainable cooling infrastructure for many places in Indonesia such as factories, warehouses, rural areas, and exhibition places. The portable air conditioner combined with integrated PV system without battery system was being studied on this work. The main goal is to see if the system capable or not providing sustainable cooling solution, the actual power output of this built system, and also the effect of temperature and humidity to the PV power output. The work involves PV system design from the AC load requirement, the PV modules, and its configuration which match the chosen inverter while also supported with other mounting, safety, and cabling system. The system testing was done in several methods to study the characteristics between the AC load, DC power supply, and the inverter, while also observing temperature and humidity. It is found that the 570 W of actual rated power of the air conditioner was unable to be fulfilled since the system could only produce maximum 164.5 W with continuous power of 120 W, differ to its approximated power output. Moreover, temperature and humidity did not give significant effect on the PV power output.

Keywords: PV system, PV modules, inverter, air conditioner, temperature, humidity, DC, AC, cooling system

© Copyright 2024
by Karel Christofferro
All rights reserved

DEDICATION

I dedicate this works to fulfill the acceleration of energy transition in Indonesia.

ACKNOWLEDGEMENTS

Firstly, I am very grateful to Jesus Christ the almighty God, for His blessing and guidance for me through the entire process over thesis period. I am most grateful that I was able to execute this topic, expanding my expertise in another sector of renewable energy. It was a very new experience that tested my knowledges and practical skills.

I would like to express my appreciation and thank a lot of people. To my current and my future families, for their endless support and great empathy even when I was busy and far from them. To my father for all his financial support and also followed with carrier and life lessons. To my mother for all her wisdom and endless care. To my little brother for his long-distance support.

I would like to give several people for their assistance on my thesis work in SGU. To Dr.-Ing. Evita H. Legowo who was very helpful on guiding, calming, and raising the potential of her beloved student. Ma'am Evita was particularly helpful in writing this thesis book while giving core values on how to execute the thesis work. To Mr. Dena Hendriana, B.Sc., S.M., Sc.D. as my co-advisor who was very helpful on giving technical advices for this work while also giving many perspectives how to accomplish the result and analysis. To Mr. Rizal Pauzan Ramdhani and Mr. Gerald Justin Goenawan, who welcomed me for any both assistance and consultation.

I would also like to thank and give my appreciation to my beloved girlfriend, Natasha Valerie. From the beginning of our study in Swiss German University, we have been through all the study progress together, even though we have only just been together for less than a year. A huge gratitude for having confidence in my abilities to not only complete a degree but to complete it with excellence.

In the end, I have found my choice to study Sustainable Energy and Environment was one of the best decisions which I always eager to learn, understand and work on it with my best of abilities.

TABLE OF CONTENTS

	Page
STATEMENT BY THE AUTHOR.....	2
ABSTRACT.....	3
DEDICATION.....	5
ACKNOWLEDGEMENTS.....	6
TABLE OF CONTENTS.....	7
LIST OF FIGURES	10
LIST OF TABLES.....	12
Chapter 1 - INTRODUCTION	13
1.1 Background.....	13
1.2 Research Problems	14
1.3 Objectives	15
1.4 Significance of Study	15
1.5 Research Questions	16
1.6 Hypothesis	16
Chapter 2 - LITERATURE REVIEW	17
2.1 Indonesia's Climate Condition	17
2.1.1. Temperature Profile	17
2.1.2. Solar Energy Potential in Indonesia	19
2.2 Cooling Requirement.....	20
2.2.1. Warehouses and Factories	21
2.2.2. Rural Areas	21
2.2.3. Exhibition Places	21
2.3 Solar Energy	22
2.3.1. Principle of Solar Energy	22
2.3.2. Solar Resource Map.....	23
2.3.3. Solar Irradiance vs Irradiation	24
2.3.4. Types of Solar Irradiance	25
2.3.5. Peak Sun Hour	25
2.4 PV Power Plant.....	26
2.4.1. Principle of PV Power Plant.....	26
2.4.2. On-grid Solar System	27
2.4.3. Off-grid Solar System.....	28
2.4.4. Hybrid Solar System.....	28
2.5 Components of PV Power Plant	29

2.5.1.	Solar Cells and Solar Modules	29
2.5.2.	Inverter	33
2.5.3.	Battery	34
2.5.4.	MPPT.....	35
2.5.5.	DC Boost Converter	36
2.5.6.	Mounting structures.....	37
2.5.7.	Safety components.....	38
2.5.8.	Combiner boxes.....	38
2.5.9.	Cabling, grounding equipment, conduit	38
2.5.10.	Electricity meters.....	39
2.6	Designing PV System.....	39
2.6.1.	Site Information and System Description.....	40
2.6.2.	Total Load Consideration	40
2.6.3.	Inverter Sizing	41
2.6.4.	Determining System Voltage and Battery Size	41
2.6.5.	Sizing PV Arrays	42
2.6.6.	PV Module Configuration	43
2.6.7.	Mounting Structure.....	45
2.6.8.	Safety Components.....	46
2.6.9.	Cabling, grounding equipment, conduit	46
2.6.10.	Meters and monitoring devices	46
2.7	Air Conditioner.....	47
2.7.1.	Vapor Compression (VC) cycle	47
2.7.2.	Absorption refrigeration cycle.....	48
2.7.3.	Thermoelectric (TE) cycle.....	49
2.7.4.	Portable air conditioning system	50
2.7.5.	Load requirement according the AC's type.....	51
2.8	Factors Affecting Electricity Output of PV Plant.....	53
2.8.1.	Solar Irradiance.....	53
2.8.2.	Angle and Orientation	54
2.8.3.	Temperature.....	55
2.8.4.	Humidity	55
2.9	IV measurement for solar cells characteristics	56
2.9.1.	Open-circuit Voltage	57
2.9.2.	Short-circuit Current.....	57
2.9.3.	Maximum power point	57
2.9.4.	Fill factor	57
2.10	Sensors, loggers, and monitoring devices.....	59
2.11	State of the Art.....	60
2.11.1.	(Patil et al., 2017) did his research which titled “Fabrication of Solar Air Cooler for Remote Area.”.....	60
2.11.2.	Axaopoulos and Theodoridis did their research which titled “Design and Experimental Performance of a PV Ice-maker” (Axaopoulos & Theodoridis, 2009).....	61

2.11.3. Pimentel and Branco did their research which titled “Modelling distributed photovoltaic system with and without battery storage: A case study in Belem, northern Brazil” (Pimentel da Silva & Branco, 2018).....	62
Chapter 3 – RESEARCH METHODS.....	64
3.1. Venue and Time	64
3.2. Materials and Equipment	64
3.2.1. Materials	64
3.2.2. Equipment	71
3.3. Design of Experiment	74
3.4. Experimental Procedure	76
3.4.1. Design of the solar PV-powered air conditioning system	76
3.4.2. Installation of the system:	78
3.4.3. Data collection	80
3.4.4. System testing	81
3.4.5. Data analysis and Thesis Writing	82
3.5. Analytical Method	82
3.5.1. System’s capability to directly power air conditioner	82
3.5.2. System performance evaluation.....	83
3.5.3. Factor that affecting the PV power output	83
Chapter 4 – RESULTS AND DISCUSSIONS	85
4.1. Initial Assessment of PV System and Monitoring Devices	85
4.1.1. PV modules	86
4.1.2. Inverter	86
4.1.3. Air conditioner.....	86
4.1.4. Cables and wiring system	86
4.1.5. Sensors and controllers	87
4.2. The Capability of PV System on Powering Air Conditioner.....	87
4.3. System Performance Evaluation	99
4.4. Factors Affecting PV Power Output	104
4.4.1. Solar irradiance	104
4.4.2. Temperature.....	104
4.4.3. Humidity	105
4.4.4. Overall temperature and humidity analysis.....	106
Chapter 5 – CONCLUSIONS AND RECCOMENDATIONS	109
5.1. Conclusions.....	109
5.2. Recommendations.....	110
GLOSSARY	111
REFERENCES	112
CURRICULUM VITAE.....	118

LIST OF FIGURES

Figures	Page
Figure 2.1: Daily average high and low air temperature at 2 meters above the ground (Spark, n.d.).....	17
Figure 2.2: World solar resource map (Solargis, 2020).....	23
Figure 2.3: Indonesia's solar resource map (Solargis, 2020)	24
Figure 2.4: Peak sun hour illustration	26
Figure 2.5: Types of solar systems (Xindun, 2022).....	27
Figure 2.6: Illustration of charge transport on basic structure of solar cell (ACS, n.d.)	29
Figure 2.7: Solar modules configuration (Naseer-Kasim, n.d.).....	31
Figure 2.8: Solar panel's angle and orientation (Quizlet, n.d.).....	32
Figure 2.9: PV inverter topologies (Dogga & Pathak, 2019).....	33
Figure 2.10: Cable size and amp rating table, (a) DC cable on 12 V DC (Planet, 2023), (b) AC cable on 220 V AC (Technology, 2020).....	39
Figure 2.11: Battery sizing (Alfahed, 2019)	42
Figure 2.12: Schematic of VC cooling cycle	48
Figure 2.13: Schematic of VC heating cycle	48
Figure 2.14: Absorption system with heat exchanger.....	49
Figure 2.15: Schematic of the thermoelectric air-conditioner	50
Figure 2.16: Current-Voltage Characteristics of an Ideal Solar Cell	56
Figure 2.17: Description of Fill Factor	58
Figure 2.18: Characteristics curves of a PV module (a) I-V curve and (b) P-V curve	59
Figure 3.1: LONGI 550Wp Mono PERC Halfcut	66
Figure 3.2: Specification on LONGI LR5-72HPH-550M	66
Figure 3.3: Power Inverter 2000 W DC48 V to AC220 V	67
Figure 3.4: Inverter's specification from manual book, 2000 W maximum power, 1000 W continuous power, 48 V DC to 220 V AC	68
Figure 3.5: AC Portable Midea 1/2pk.....	68
Figure 3.6: Solar mounting system	69
Figure 3.7: Safety components	70
Figure 3.8: Cabling system	70
Figure 3.9: GY-BME280 Barometric Pressure Sensor Humidity Temperature Sensor 12C.....	71
Figure 3.10: Temperature and humidity hygrometer	72
Figure 3.11: PZEM-017 0-300 V RS485 Modbus DC meter	72
Figure 3.12: PZEM-004T Power Meter 100A 3.0 version Single Phase Watt Meter	73
Figure 3.13:Arduino Mega 2560 R3 ATmega 2560 with ATmega 16u2	73
Figure 3.14: Design of experiment (first part)	74
Figure 3.15: Design of experiment (second part)	75
Figure 3.16: Panel box	79
Figure 4.1: Measurement setup of PLN powering AC	88
Figure 4.2: PLN powering AC.....	88

Figure 4.3: PLN powering AC on the first minute	89
Figure 4.4: Measurement setup of Solar PV powering AC, (a) Air conditioner turned on in cool mode with full fan 17°, (b) Data recording using Node-red dashboard on laptop, (c) Sun appearance at the start of measurement.....	89
Figure 4.5: Solar PV powering AC	90
Figure 4.6: Measuring setup of load testing using laptop and air cooler, (a) Air cooler turned on in maximum fan, (b) Data recording using Node-red dashboard on laptop, (c) Sun appearance at the start of measurement.....	91
Figure 4.7: Power of various load comparison	91
Figure 4.8: Voltage of various load comparison.....	92
Figure 4.9: Current of various load comparison	92
Figure 4.10: DC voltage of various load comparison	93
Figure 4.11: DC current of various load comparison.....	93
Figure 4.12: DC power of various load comparison.....	94
Figure 4.13: Load testing using lamps	95
Figure 4.14: Sun appearance at the start of lamp testing	95
Figure 4.15: Load testing combination result	95
Figure 4.16: Power surge under one minute	97
Figure 4.17: Voltage surge under one minute.....	97
Figure 4.18: Current surge under one minute	97
Figure 4.19: Temperature (°C) vs Power (W) of 4 days measurement.....	104
Figure 4.20: Humidity (%) vs Power for 4 Days Measurement	106

LIST OF TABLES

Table	Page
Table 2.1: Average of high temperature at 2 meters above the ground of several cities in Indonesia (Spark, n.d.)	18
Table 2.2: Average low temperature at 2 meters above the ground of several cities in Indonesia (Spark, n.d.)	18
Table 2.3: Comparison of daily averages, minimum and maximum of Indonesia and several regions in it. (Solcast, 2019)	20
Table 3.1: Materials used for the PV system	65
Table 3.2: Equipment used for measurement.....	71