DESIGN AND ANALYSIS OF SOLAR ENERGY FOR RURAL ELECTRIFICATION IN ECO-TOURISM DESTINATION OF LIOGU KU SILOU-SILOU, EPLISSI, SABAH

MARYON ELIZA MATIUS

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JUDUL : **REKABENTUK DAN ANALISIS TENAGA SOLAR UNTUK ELEKTRIFIKASI KAWASAN LUAR BANDAR DI DESTINASI EKO-PELANCONGAN LIOGU KU SILOU SILOU, EPLISSI, SABAH**

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Disahkan Oleh,

MARYON ELIZA MATIUS
MK1921047T

(Tandatangan Pustakawan)

Tarikh: 25 Februari 2023

(Dr. Wan Khairul Muzammil bin Abdul Rahim)
Penyelia Utama

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excepts, equations, summaries, and references, which have been duly acknowledged.

20 October 2022

Maryon Eliza Matius
MK1921047T

CERTIFICATION

NAME	:	**MARYON ELIZA MATIUS**
MATRIC NO.	:	**MK1921047T**
TITLE	:	**DESIGN AND ANALYSIS OF SOLAR ENERGY FOR RURAL ELECTRIFICATION IN ECO-TOURISM DESTINATION OF LIOGU KU SILOU-SILOU, EPLISSI, SABAH**
DEGREE	:	**MASTER OF ENGINEERING**
FIELD OF STUDY	:	**MECHANICAL ENGINEERING**
DATE OF VIVA	:	**20 OCTOBER 2022**

CERTIFIED BY;

Signature

1. MAIN SUPERVISOR
Dr. Wan Khairul Muzammil bin Abdul Rahim

____

2. CO-SUPERVISOR
Ir. Dr. Mohd. Azlan bin Ismail

____

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ABSTRACT

In search of a clean energy resource for a better environment and a 100% electrification rate, Malaysia has set a target to achieve 31% renewable energy contribution by 2025. However, in rural areas of Malaysia, especially Sabah and Sarawak, more than 50% of the population is below the poverty line as of 2017. To overcome these problems, this research intends to help in promoting renewable energy technology as a sustainable electricity generation mechanism, especially in rural areas where the national grid is not cost-effective due to challenging terrain in certain regions. The Eco-Tourism Destination of Liogu Ku Silou-Silou (EPLISSI), Kota Belud, Sabah, has been selected as the study site. This study aims to develop a small-scale off-grid solar PV system, analyze its performance, and find the most optimized design through simulation studies. Meanwhile, the method used to achieve the aims of this research includes the preliminary assessment, design development through the review of the past studies as well as computation and components' selection, components' fabrication and testing, and installation of the system and measuring devices. As for the simulation studies, the ESCoBox tool, Global Solar Atlas version 2.3 (GSA 2.3), and HOMER software were used. The ESCoBox and GSA 2.3 softwares were used in the preliminary study (i.e., before the photovoltaic (PV) system installation) to generate the load profiles, and to select the approximate size of the PV panel system, respectively. While the HOMER software optimises the system (post PV system installation) on the existing system. As a result, it is found that the EPLISSI's condition based on solar radiation and location are suitable for solar PV system installation. Before system installation, the GSA 2.3 web tool suggested that an energy output of 8.72 kWh/day can be generated from a 2.5 kWp solar PV system. This system can at least satisfy the ESCoBox's result of daily total average energy demand by EPLISSI of 4.6 kWh/day. As for the actual installation, the installed solar power capacity was 2.48 kWp (i.e., eight 310 W solar panels were used), together with 12 lead-acid batteries (i.e., 12 V, 100 Ah battery capacity). A 12-month worth of fieldwork data consisting of actual load demand, solar radiation, and wind speed were collected and used as inputs for the HOMER software. It was found that the existing installed system (i.e., termed as the first condition in the HOMER data analysis stage) in EPLISSI was not optimally designed, as a 14.3% capacity shortage exists. This PV system configuration also has a higher net present cost (NPC) and cost of electricity (COE) under the 15% maximum annual capacity shortage (MACS) limit. Using the actual electrical load demand and the on-site solar radiation data, the HOMER software suggested that an optimized system (second condition with 15% MACS) should consist of 5 kWp solar PV with 8 lead-acid batteries. This optimized system would be better in terms of the NPC (from RM 95836.15 to RM 91791.88, hence a reduction of 5.30%) and capacity shortage (from 14.3% to 13.5%, thus a reduction of 0.80%) compared to the existing system (first condition) in EPLISSI. Lastly, there exist 40% difference between the recommended PV capacity GSA 2.3, 2.5 kWp and HOMER, 1.5 kWp (in case of C2-SB). Smaller PV capacity is optimal for C2-SB system due to the incorporation of diesel generator (DG). This also result in lower NPC (from RM 95836.15 to RM 73918.00, hence a reduction of 22.87%) of the system.

ABSTRAK

REKABENTUK DAN ANALISIS TENAGA SOLAR UNTUK ELEKTRIKASI LUAR BANDAR DI DESTINASI EKO-PELANCONGAN LIOGU KU SILOU-SILOU, EPLISSI, SABAH

Malaysia telah menetapkan sasaran untuk mencapai 31% sumbangan sumber daripada jenis tenaga boleh diperbaharui menjelang 2025 untuk mencari sumber tenaga bersih bagi menjana elektrik. Namun, di Sabah dan Sarawak, lebih daripada 50% daripada penduduk berada di bawah paras kemiskinan setakat 2017. Bagi mengatasi masalah tersebut, penyelidikan ini berhasrat untuk membantu dalam mempromosikan teknologi tenaga boleh diperbaharui. Destinasi Eko-Pelancongan Liogu Ku Silou-Silou (EPLISSI), Kota Belud, Sabah telah dipilih sebagai tapak kajian. Manakala, objektif kajian ini adalah untuk membangunkan sistem solar fotovoltaik (PV) tanpa grid yang berskala kecil, menganalisis prestasinya serta mencari reka bentuk yang paling optimum melalui kajian simulasi. Sementara itu, kaedah yang digunakan untuk mencapai matlamat penyelidikan ini termasuk kejian penilaian awal, pembangunan reka bentuk melalui kajian literatur serta pengiraan dan pemilihan komponen, fabrikasi dan pengujian komponen, dan pemasangan sistem dan alat pengukur. Bagi kajian simulasi pula, ia dibantu oleh perisian ESCoBox, Global Solar Atlas versi 2.3 (GSA 2.3), dan HOMER. Kedua-dua perisian ESCoBox dan GSA 2.3 telah digunakan dalam kajian penilaian awal (sebelum pemasangan sistem solar PV) untuk membantu dalam penjanaan profil beban dan untuk memilih saiz saiz sistem panel PV. Manakala perisian HOMER digunakan untuk melakukan pengoptimuman sistem (pasca pemasangan sistem solar PV) pada sistem sedia ada. Hasilnya, didapati bahawa keadaan EPLISSI berdasarkan penilaian sinaran matahari dan lokasi adalah sesuai untuk pemasangan sistem solar PV. Hasil daripada perisian GSA 2.3, sistem solar PV berkapasiti 2.5 kWp boleh menjana sehingga 8.72 kWj/hari. Kapasiti sistem ini dapat memenuhi jumlah purata permintaan tenaga harian sebanyak EPLISSI sebanyak 4.6 kWj/hari. Saiz panel solar sebenar yang direka dan dipasang ialah 2.48 kWp (lapan panel solar berkapasiti 310 W digunakan) bersama 12 bateri asid plumbum (12 V, 100 Ah). Memandangkan data kerja lapangan selama 12 bulan yang telah dikumpul kemudiannya digunakan sebagai input untuk perisian HOMER, ia didapati bahawa sistem pemasangan sedia ada (keadaan pertama) di EPLISSI tidak direka bentuk secara optimum kerana terdapat kekurangan kapasiti sebanyak 14.3%. Konfigurasi sistem PV ini juga mempunyai kos semasa bersih (NPC) dan kos elektrik (COE) yang lebih tinggi di bawah 15% had kekurangan kapasiti tahunan maksimum (MACS). Dengan menggunakan beban elektrik sebenar dan data sinaran suria di tapak pemasangan, perisian HOMER mencadangkan bahawa sistem optimum (keadaan kedua dengan 15% MACS) terdiri daripada PV solar 5 kWp dengan 8 bateri asid plumbum. Sistem yang dioptimumkan ini adalah lebih baik dari segi NPC (dari RM 95836.15 kepada RM 91791.88, iaitu pengurangan sebanyak 5.30%) dan kekurangan kapasiti (daripada 14.3% kepada 13.5%, juga pengurangan sebanyak 0.80%). Akhir sekali, terdapat perbezaan 40% antara kapasiti PV yang disyorkan oleh GSA 2.3, 2.5 kWp dan HOMER, 1.5 kWp (dalam kes C2-SB). Kapasiti PV optimum yang lebih kecil terhasil bagi sistem C2-SB kerana penggabungan penjana diesel (DG). Ini juga menyebabkan NPC yang lebih rendah (daripada RM 95836.15 kepada RM 73918.00, oleh itu pengurangan sebanyak 22.87%).

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A	-	Area of a circle
R	-	Radius of a circle
$\mathbf{Q}_{solar}$	-	Solar power
I_{sc}	-	Solar constant
β_{opt}	-	Optimum tilt angle
δ	-	Declination Angle
N	-	Day number of year
L	-	Latitude
Long	-	Longitude
h	-	Hour angle
I_{tot}	-	Total solar irradiance
$\mathbf{I}_{\mathbf{D}}$	-	Direct irradiance
$\mathbf{I}_{\mathbf{DN}}$	-	Direct normal irradiance
$\mathbf{I}_{\mathbf{S}}$	-	Diffuse irradiance or sky radiation
$\mathbf{I}_{\mathbf{R}}$	-	Reflected irradiance
p/p_o	-	Atmospheric pressure relative to a standard atmosphere
z	-	Elevation
A	-	Apparent solar irradiation or apparent extra-terrestrial solar intensity
B	-	Atmospheric extinction coefficient
C	-	Ratio of diffuse radiation on a horizontal surface to direct normal irradiation
ρ	-	Foreground reflectivity
H	-	Insolation
E_{solar}	-	Total solar energy
$A_{\mathrm{collector}}$	-	Surface area of a collector
E_{elect}	-	Total electrical energy
η_{cell}	-	Solar cell efficiency
Ω	-	Ohm (internal resistance unit)
DIF	-	Ratio of the average daily diffuse radiation on a tilted surface to that on a horizontal surface
β_1	-	Solar altitude angle
β_2	-	Collector or module tilt angle
α_1	-	Solar azimuth angle
α_2	-	Azimuth angle of the normal to the collector surface
θ	-	Collector angle
α	-	Ground surface friction coefficient
V_1	-	Measured wind speed
V_2	-	Wind speed calculated at the reference height
h_1	-	Height
h_2	-	Reference height
$C_{ann,tot}$	-	Total annualised cost
C_{boiler}	-	Boiler marginal cost
H_{served}	-	Total thermal load served

E_{served}	-	Total electrical load served
f_{ren}	-	Renewable fraction
E_{nonren}	-	Non-renewable electrical production
H_{nonren}	-	Non-renewable thermal production

LIST OF ABBREVIATIONS

EPLISSI	-	Eco-Tourism Destination of Liogu Ku Silou-Silou
AST	-	Apparent solar time
LST	-	Local standard time
LSTM	-	Local standard time meridian
ET	-	Equation of time
BOS	-	Balance of System
SP	-	Solar Panel
BSS	-	Battery Storage System
SCC	-	Solar Charge Controller
INV	-	Inverter
HIC	-	Hybrid Inverter Charger
PV	-	Photovoltaic
SPV	-	Solar Photovoltaic
DG	-	Diesel Generator
WT	-	Wind Turbine
Batt	-	Battery
Conv	-	Converter
C1	-	Configuration 1
C2	-	Configuration 2
C3	-	Configuration 3
SA	-	Scenario A
SB	-	Scenario B
F	-	Fieldwork
H	-	Homer
COE	-	Cost of Electricity
NPC	-	Net Present Cost
MACS	-	Maximum Allowable Capacity Shortage
Mono-Si	-	Monocrystalline
Poly-Si	-	Polycrystalline
TFSC	-	Thin-Film Solar Cell
A-Si	-	Amorphous Silicon
CdTe	-	Cadmium Telluride
CVP	-	Concentrated PV
HCVP	-	High Concentrated PV
MC4	-	Multi-Contact, 4 millimetres
DNI	-	Direct Normal Irradiance
DHI	-	Diffuse Horizontal Irradiance
GHI	-	Global Horizontal Irradiance
DOD	-	Depth of Discharge
SOC	-	State of Charge
ROI	-	Return of Investment
IRR	-	Internal Rate of Return
CSR	-	Corporate Social Responsibility
RE	-	Renewable Energy
RMSD	-	Root-Mean-Square Deviation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In terms of a country's development, the electricity use rate could signify how well-developed the country is (Seshie et al., 2018; United States Energy Information Administration, 2017). However, it is not applied to the Organization for Economic Cooperation and Development (OECD) countries (i.e., the United States, Japan, and the United Kingdom), focusing on service economies rather than manufacturing economies (United States Energy Information Administration, 2017). According to International Energy Agency (2017), the global demand for electricity in 2018 rose by 4%. It has been at its fastest pace since 2010. For the power generation system to meet the rising electrical demand, the primary sources, such as coal and natural gas, represent nearly 60% of the global electricity supply (International Energy Agency, 2020).

However, researchers from all over the world are putting in continuous efforts to develop renewable energy (RE) technology. It is an effort to discover a worthy substitute for fossil fuels. They are the world's most significant culprit of triggering global warming and responsible for causing a high uncertainty of alarming climate (Shahzad, 2015). It can be implied that renewable technologies are here to stay and expand even more through various uses of RE technologies and judging from the current capability of this type of energy source, as stated by Gielen et al. (2019). A higher adoption rate will reduce the cost of owning these technologies (International Energy Agency, 2017). Soon, there is no doubt that RE technology will be the primary source of electricity, offering hope for a cleaner and better environment.