Design and analysis of potential grid connected floating photovoltaic system in UTHM

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A project report submitted in partial
fulfillment of the requirement for the award of the Degree of Master of
Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBURARY 2020

ACKNOWLEGEMENTS

In the name of Allah (SWT), the most gracious, and the most merciful. All praises be to Allah (SWT) for blessing me and giving me the strength to complete this project.

I would like to express my heartfelt thanks to my Supervisor (Dr. MOHD NOOR BIN ABDULLAH) for his immense and timely help given during this project.

My greatest thanks to my family, especially both my parents whose has given much of love, courage, sacrifice and support. Thanks also to my brothers and sisters and all my friends and colleagues who give me ideas and supported me in order to complete this report. Thank you all for your kindness and generosity may Allah (SWT) bless you all rewarding paradise In Sha Allah.

ABSTRACT

Every month Universiti Tun Hussein Onn (UTHM) management pays around RM 1 million for electricity bills. The aim of this project is to explore the feasibility of implementing a grid connected Floating Photovoltaic (FPV) system at the campus of UTHM. There are multiple unutilized water bodies (ponds/lakes) within the campus premises covering a total area of more than 50,000 m^2. A 4000 m^2 located at the lake near faculty of technical and vocational education (FPTV) is considered of the total available area for the feasibility study. A total of 1372.6 kW can be generated by deploying 335W mono crystalline PV modules with 21% efficiency on a floating mechanism (floaters) on the selected area. The FPV system is then simulated using MATLAB Simulink to observe the performance parameters of the FPV system such as total harmonic distortion (THD), current and voltage waveforms. Hybrid Optimization Model for Electric Renewable (HOMER) software has been used to obtain results such as the net present cost (NPC), cost of operation (COE), CO_2 emissions impact and the payback period of the grid connected FPV system. The FPV system provides the lowest cost of energy (LCOE) RM0.418 kWh and a total net present cost (NPC) of RM 52.3 million. This system can decrease CO_2 emissions by about 1241 t/yr.

ABSTRAK

Pengurusan Universiti Tun Hussein Onn (UTHM) setiap bulan membayar kira-kira RM1 juta untuk bil elektrik. Matlamat projek ini adalah untuk meneroka kebolehlaksanaan pelaksanaan sistem *Floating Photovoltaic (FPV)* yang menghubungkan grid di kampus UTHM. Terdapat pelbagai badan air yang tidak digunakan di dalam premis kampus yang meliputi kawasan seluas lebih daripada 50,000 m^2. Sebuah tasik 4000 m^2 terletak di tasik berhampiran Fakulti Pendidikan Teknikal dan Vokasional (FPTV) dianggap sebagai kawasan yang tersedia untuk kajian. Sebanyak 1372.6 kW boleh dihasilkan dengan menggunakan modul PV kristal mono 335W dengan kecekapan 21% pada mekanisme terapung di kawasan yang dipilih. Sistem FPV kemudiannya disimulasikan menggunakan MATLAB Simulink untuk melihat. Prestasi sistem FPV seperti jumlah penyelewengan harmonik (THD), arus gelombang dan voltan. Diguanakan *Hybrid Optimization Model for Electric Renewable* (HOMER) untuk mendapatkan hasil seperti kos sekarang bersih (NPC), kos tenaga (COE), kesan pelepasan CO2 dan tempoh bayaran balik sistem grid FPV yang berkaitan. Sistem FPV menyediakan kos tenaga terendah (LCOE) RM0.418 kWh dan jumlah kos sekarang bersih (NPC) sebanyak RM 52.3 juta. Sistem ini dapat mengurangkan pelepasan CO_2 dengan kira-kira 1241 t/yr.

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LIST OF SYMBOLS AND ABBREVIATIONS

η	-	Efficiency
A	-	Surface area
m^2	-	Meter square
S	-	Shading coefficient
CPV	-	Concentrated Photovoltaic
CSP	-	Concentrated Solar Power
FPV	-	Floating Photovoltaic
FiT	-	Feed-in-Tariff
FPTV	-	Faculty of technical and vocational education
GHG	-	Green House Gases
GHI	-	Global Horizontal Irradiance
HDPE	-	High Density Poly-Ethylene
IRR	-	Internal Rate of Return
IPP	-	Independence Power Producer
LSS	-	Large Scale Solar
LCC	-	Life Cycle Cost
LUCE	-	Levelized Unit Cost of Electricity
LOCE		Lowest Cost of Energy
MPPT	-	Maximum Power Point Tracking
NA	-	Number of Arrays
NEM	-	Net Energy Metering
NM	-	Number of modules
NI	-	Number of Inverters
NPC	-	Net Present Cost

OCGT	-	Combined Cycle Gas Turbine
PV	-	Photovoltaic
P&O	-	Perturb and Observe
RES	-	Renewable Energy Sources
RET	-	Renewable Energy Technology
RE	-	Renewable Energy
ROI	-	Return Of Investment
SEDA	-	Sustainable Energy Development Authority
SHS	-	Solar Home System
SV	-	String Voltage

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CHAPTER 1

INTRODUCTION

1.1 Overview of the project

Solar energy is a resource with both scalability and technology maturity to meet constantly rising global demand for power generation [1]. Amongst solar power technologies, photovoltaic (PV) technology has experienced rapid growth and is expected to continue its key role in creating sustainable energy future [2]. With about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010 [3]. Despite the ever dropping price of PV panels and continuously increasing efficiency the challenge of providing reliable and cost effective services remains one of the major global challenges facing the world in this century. The efforts in using renewable energies (RE) have often revolved on using the same technology. For example, Solar Home Systems (SHS), solar PV systems and micro hydro power have been intensively used , but such options are still unable to overcome some of the physical restraints of traditional PV. Reliance on a single technology generally results in a lower efficiency thereby increasing the overall cost.

A floating PV (FPV) system can increase the efficiency by cooling off the surface of the PV panel, enhance the reliability of supply and help overcome the lack of space issue. FPV installations open up new opportunities for scaling up solar generating capacity, especially in countries with high population density and competing uses for available land. They have certain advantages over land based systems, including utilization of existing electricity transmission infrastructure at hydropower sites, close proximity to demand centres (in the case of water supply reservoirs), and improved energy yield thanks to the cooling effects of water and the decreased presence of dust. Additionally, the water is also conserved due to reduction in evaporation of water from the lake or reservoir. The plant can be installed on a pond, lake, reservoir, or on any other water body. The exact magnitude of these performance advantages has yet to be confirmed by larger installations, across multiple geographies, and over time, but in many cases they may outweigh any increase in capital cost. The first commercial installation was a 175 kW system built at the Far Niente Winery in California in 2008 [4]. The system was floated atop a water reservoir to avoid occupying land better used for growing grapes. Medium to large floating installations (larger than 1 MW) began to emerge in 2013. Recently, plants with capacity of tens and even hundreds of megawatts have been installed in China (the leading FPV installer in the world in terms of capacity installed) [5][6].

1.2 Problem Statement

In face of the ever growing energy crises and the eminent depletion of fossil fuels. RE solutions are heavily being integrated across different platforms. In Malaysia, the Energy, Science, Technology, Environment and Climate Change Ministry has set a target of 20% of the country's electricity to be generated from renewable sources by 2030, an increase from 2% currently [7]. The problem of the continuing growth in demand for "clean" energy in many developed countries is met through connections of renewable energy sources (RES). The urgency of implementing RES, particularly PV solar plants, caused significant environmental benefits of these systems over the "traditional" energy [8]. FPV is a reasonable solution for some of the problems that traditional PV has been facing and is really suitable for the geographic nature of Malaysia. The fundamental power quality issues such as voltage distortion, harmonics and voltage sag will still be there, but it’s a promising alternative for the traditional PV in terms of space utilization and efficiency improvements.

The proposed design will be implemented in Univesiti Tun Hussein Onn Malaysia (UTHM) campus. UTHM is located at the southern state of Johor in peninsular Malaysia and has a high potential for PV generation. Due to the large number of electrical loads in campus, UTHM management spends approximately 1 million RM monthly on electricity bills. Moreover, increase in load demand and tariff prices is another factor that causes the increment of electricity bills in UTHM campus

[9]. There is a lot of unutilized water bodies (lakes) within the campus premises. This project studies the prospects of installing a FPV on these lakes and will it help reduce the overbill of UTHM. Moreover, the nature of (FPV) system requires less operation and maintenance (O&M) cost, reduce carbon dioxide (CO_2) emissions and a longer system lifespan.

A significant number of universities globally are planning relevant investments, in order to improve their sustainability in shortened medium term. To further enhance this approach, support policies have been introduced in several countries, while in some cases PV energy generation for self consumption can be profitable without subsidies [10] [11].

1.3 Objective

Objectives of this project:

i. To observe the performance of FPV system using MATLAB/Simulink.
ii. To simulate the proposed grid connected FPV system using HOMER.

1.4 Scope of the Project

The scope of the project is as follows:

i. The solar radiation data is obtained from several sources such as journals, and reports and used to observe the irradiance profile at UTHM area [12].
ii. Annual load data for the year 2018 is used for the design.
iii. The lake near faculty of technical and vocational education (FPTV) in UTHM campus is selected for the installation of the FPV system.
iv. Power, voltage, current and THD of the system are obtained using MATLAB Simulink.
v. Economic analysis of the FPV system in UTHM will be obtained using HOMER software.

1.5 Report outline

This report consists of 5 chapters namely, Introduction, literature review, methodology, results and analysis and conclusion.

Chapter 2 the literature review related to the topic, such as the basics of PVs, RE generation in Malaysia, review on FPV technology and net metering concept. Also previous and contemporary researches will be discussed in this chapter.

In Chapter3 an overview with a flow chart illustrates the methodology followed in this project. The project location, lakes selection and measurements, installation methods of the FPV, PV system inverter, PV system design calculations, Data collection, parameters setting and development of a MATLAB/Simulink model and simulation in HOMER and.

Results obtained by MATLAB/Simulink and HOMER are discussed in chapter 4. A comparison between the campus power profile before and after the connection of FPV will be discussed and the energy, economic and environmental results obtained by HOMER such as the net present cost, cost of energy, the operation cost, payback period and the carbon dioxide emissions.

Chapter 5 is a summary of the work done in this project. Prospects of future work and improvements are discussed in this chapter as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The concept of injecting PV power into the utility grid has earned widespread acceptance in these days of renewable energy generation & distribution. Grid-connected inverters have evolved significantly with high diversity. Efficiency, size, weight, reliability etc. have all improved significantly with the development of modern and innovative inverter configurations and these factors have influenced the cost of producing inverters [13].

An overview of the renewable energy generation in Malaysia, literature review of PV, and focuses on FPV technology. Net metering programs in Malaysia will also be reviewed in this chapter.

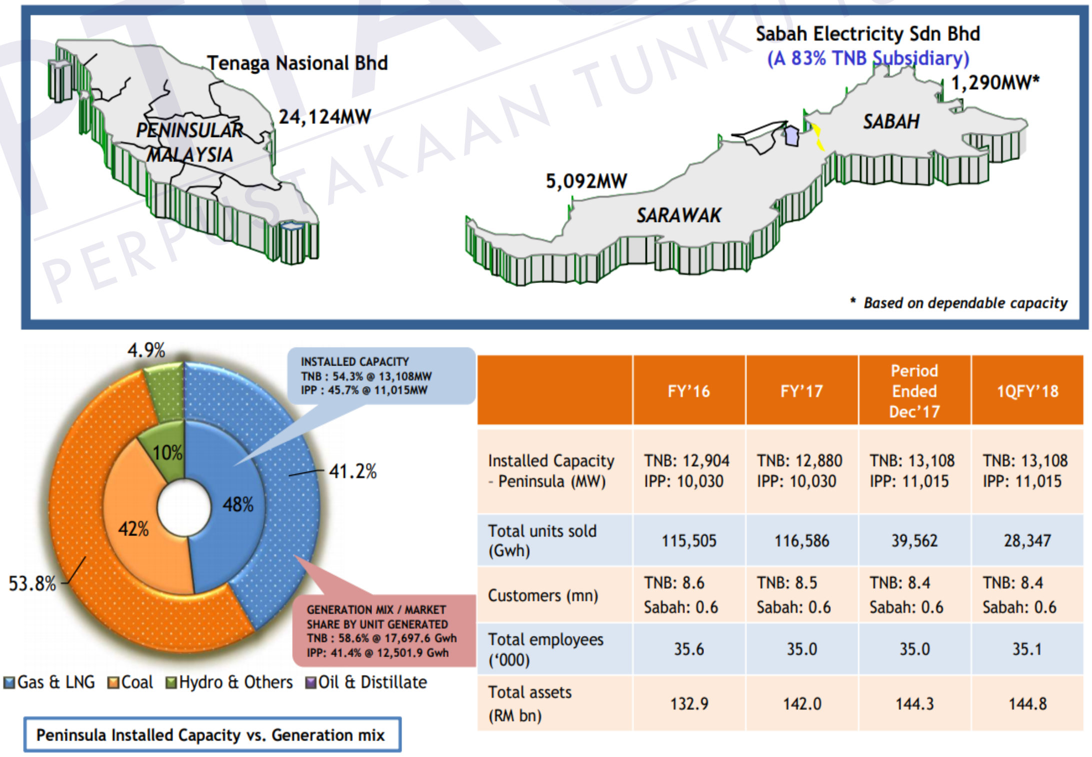
2.2 Electricity generation in Malaysia

Electricity generation started in Malaysia in 1984 at Selangor and it was based on coal, wood and charcoal. As the economy grew more plants were constructed in small capacities.

In the 3 decades to follow fossil fuels drove the economic boom that Malaysia has went through. Nowadays, huge and diverse plants were adopted under the under the country's Fuel Diversification Policy. Other policies and incentives promoted the gradual diversification of the electricity generation scheme in the country. In 2017 alone, for example, coal provided up to 53.8% of the energy generation while gas contributed 41.2% as shown in Figure 2.1 [14]. The Malaysian public utility company also known as Tenaga Nasional Berhad (TNB) and the private utility company also known as Independent Power Producer (IPP) main entities responsible for supplying electricity in Malaysia. On the way to integrate more renewable energy sources and diversify the energy production a statutory branch of the ministry of energy was created. One of the key roles of the Sustainable Energy Development Authority (SEDA) is to administer and manage the implementation of the Feed in Tariff (FiT) mechanism, including a Renewable Energy fund mandated under the Renewable Energy Act of 2011[15]. The Renewable Energy fund was created to support the FiT scheme.

As of 2016, Peninsular Malaysia alone is dealing with an electricity demand of up to 82% from Malaysia’s population of 31 million, with an average increment at a 1.8% rate annually. Electricity generating capacity, on the other hand, is adequate with comfortable margin to meet demand [16].

Malaysian energy generation is mainly based on Hydro power plants and thermal power plants, with a minor penetration of biomass, biogas, renewable and small hydro. In Figure 2.1 [17].



	FY’16	FY’17	Period Ended Dec’17	1QFY’18
Installed Capacity - Peninsula (MW)	TNB: 12,904 IPP: 10,030	TNB: 12,880 IPP: 10,030	TNB: 13,108 IPP: 11,015	TNB: 13,108 IPP: 11,015
Total units sold (Gwh)	115,505	116,586	39,562	28,347
Customers (mn)	TNB: 8.6 Sabah: 0.6	TNB: 8.5 Sabah: 0.6	TNB: 8.4 Sabah: 0.6	TNB: 8.4 Sabah: 0.6
Total employees (‘000)	35.6	35.0	35.0	35.1
Total assets (RM bn)	132.9	142.0	144.3	144.8

Figure 2.1: Peninsular Malaysia and Sabah’s installed capacity generation mix [17]

2.3 Renewable energy in Malaysia

Dependency on fossil fuels is expected to continue until renewables plus storage technologies can be commercially integrated into the system, with the Energy Commission continually monitoring its development and progress. The use of renewables is also encouraged through programmes such as Feed in Tariff (FiT), Large Scale Solar (LSS) and Net Energy Metering (NEM). Currently, more than 20% of the total installed capacity in Malaysia is from renewables which is inclusive of off-grid installation and cogeneration. Approved LSS programmes generating up to 1,000MW and NEM generating up to 500MW will, indeed, increase renewables share in future [16]. Currently, Peninsula has a total licenced capacity of 392MW, mostly fuelled by solar PV 235MW), followed by biomass (89MW), mini hydro (34MW) and biogas (34MW). The chart below shows the increment of the licenced capacity for RE from 2015 to 2016 [18].

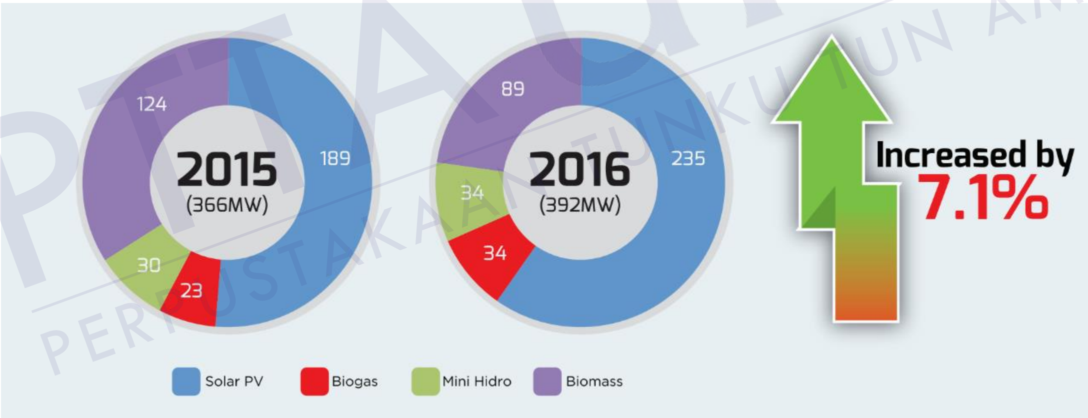


Figure 2.2: Renewable energy capacity mix in Malaysia 2015 & 2016 [19]

Figure 2.3: Peninsular Malaysia RE active projects [19]

Table 2.1 shows the installed capacity of renewable energy for each state in peninsular Malaysia [18]. The largest amount of installed capacity from renewable energy is from Solar PV. This is due to the Feed In Tarif (FiT) programs introduced by the government and to the fact that Malaysia has high solar potential. The state with least installed RE capacity is K.Lumpur with a capacity of only 2.74 MW from Solar PV. Selangor is the mostly diverse in terms of sources of renewable energy installed with a capacity of 152.07 MW. According to the 5 five fuel strategy policy, the renewable energy sources are forecasted to generate 20% from the total electrical demand by 2030 as compared to the current 2% [20].

Table 2.1: Installed capacity of renewable energy power plants for each state in peninsular Malaysia [18]

State	Installed Capacity (MW)
Perlis	15.93
Kedah	11.52
Kelantan	7.2
Pulau Pinang	14.67
Perak	16.55
Selangor	66.46
Pahang	24.57
K.Lumpur	2.74
Negeri Sembilan	40.74
Melaka	16.75
Johor	14.79
Terengganu	10.31

Solar has a special consideration in terms of importance and funding. Due to the strategic location and the government aim to reduce CO_2 emissions. Malaysia is located between 1 degree and 7 degree in North latitude and 100º degree and 120º degree in East longitude, which is second largest solar radiation region in eastern Asia [21]. As a result, there is a large potential for PV energy to be absorbed by the PV cells in Malaysia. The average daily solar radiation in Malaysia is within the range of (4.12 kWh/m^2 –5.56 kWh/m^2). The highest solar radiation was estimated to be (6.8 kWh/m2/day) in August and November, whereas the lowest was found to be (0.61 Wh/m^2/day) in December [22].

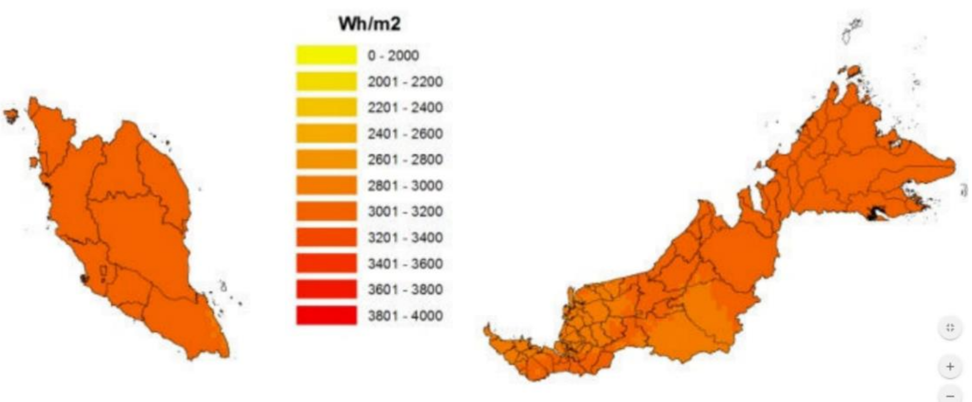


Figure 2.4: Solar irradiance across Malaysia [12]

The Jawatankuasa Perancangan dan Pelaksanaan Pembekalan Elektrik dan Tariff (JPPPET) on 18th August 2015, has agreed on LSS programme for a duration of four years starting 2017 until 2020. The capacity allocated for the LSS programme is 1,000MW by 2020 with annual capacity capped at 200MW for four years of implementation starting 2017 [18].

Table 2.2: Installed capacity based on renewable energy type

Renewable energy type	Installed Capacity
Solar PV	242.28
Biomass	70.93
Mini Hydro	49.64
Biogas	47.04
Total Installed capacity	409.89

Figure 2.5: Large scale solar (LSS) current projects [19]

2.4 PV technology

PV technology has been viewed as a promising solution for the ever growing energy crises since the past few decades. The fact that prices kWh produced per cell are dropping. Furthermore the technological advancement in regards to other components of the system, more efficient inverters and less expensive batteries.

The principle of photovoltaic When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity. An inverter can convert the power to alternating current (AC).

2.4.1 Types of PV cells

Based on the technology and techniques used to manufacture the PV cell, the most commonly used commercial cells are of one of the following type, Mono-crystalline, Poly-crystalline and Thin film. Each has its own applications depending on the efficiency and the space available. Table 2.3 illustrates the different types of PV cells and their respective efficiency levels.

- Monocrystalline Silicon PV: To produce monocrystalline silicon a crystal of silicon is grown from highly pure molten silicon. This single crystal cylindrical ingot is cut into thin slices between 0.2 and 0.3mm thick- this is the basis of a solar PV cell. The edges are cut off to give a hexagonal shape so more can be fitted onto the module. These PV cells have efficiencies of 13-16% and are the most efficient type of the three types of silicon PV cell. However, they require more time and energy to produce than polycrystalline silicon PV cells, and are therefore slightly more expensive [23].

- Polycrystalline Silicon PV: Polycrystalline silicon is also produced from a molten and highly pure molten silicon, but using a casting process. The silicon is heated to a high temperature and cooled under controlled conditions as a mauled. It sets

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