System Design and Cost Analysis Simulation of Small Scale Dual-Tariff Solar Photovoltaic (PV) System in UiTM Pulau Pinang Malaysia

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***Abstract*— The solar Photovoltaic (PV) systems have been gradually growing on demand in Malaysia. One of the main objectives in developing the solar PV plant is on the cost effective feed-in tariff (FIT). The aim of this paper is to design and analyse the cost-benefit of a small scale guard house in Universiti Teknologi MARA (UiTM) Pulau Pinang, Malaysia which applied the dual-tariff concept by using the HOMER software. A PV system generating electricity is constructed on a guard-house in UiTM Pulau Pinang, Malaysia that operates for 24 hours using a load of 9kWH/day. The supply system is modified to suit a dual-metering system in order to monitor actual electricity usage. Daytime will be defined between 7.00 am until 6.59 pm whilst the local energy supplier, Tenaga Nasional Berhad (TNB) supplied the energy for night time (7.00 pm to 6.59 am). A bank battery is used to provide backup power supply during day time if there is an unexpected weather change during that period. The estimated cost for dual-tariff PV system is predicted using HOMER. The cost of energy of total capital, replacement, operation, maintenance and salvages are found to be $31,600, $15,425, $15,851 and -$4,769 respectively. From the estimated cost summary, it is expected that the system will give a payback time in 25 years. With this cost analysis, it is useful to determine the energy saving; particularly suited to the dual-tariff electricity bills that offset the day loads using PV panels and low-tariff electricity during the night.**

***Index Terms*—solar PV, dual- tariff, HOMER.**

I. Introduction

In Malaysia, currently there are many incentives for renewable energy (REN) as promoted by Malaysian government in Malaysia 8th and 9th Plans [1]. One of the most popular renewable energy that currently been studied in Malaysia is solar Photovoltaic (PV) system. There are few states in Malaysia that has higher solar radiation which lead to high potential for solar PV studies. One of the states is Pulau Pinang which is situated in the northern region of Malaysia, geographically located at latitude (5.413 degrees) 5° 24' 46" North of the Equator and longitude (100.4077 degrees) 100° 24' 27" East of the Prime Meridian on the map of the world [2]. It has higher solar radiation ranging from 13.0 MJm^{-2} to 20.0MJm^{-2} or 3.0 $kWhm^2$ to 5.5 $kWhm^2$ monthly as shown in Table 1. From the graph in Fig 1, it shows that the solar radiation is higher in month of March, May and August.

Table 1: Solar Radiation in Pulau Pinang for Year 2008

Month	Solar Radiation (MJm-2)	Solar Irradiation (kWhm-2)
1	13.4671	3.740861
2	13.4671	3.740861
3	19.5735	5.437083
4	17.7793	4.938694
5	19.6945	5.470694
6	15.7460	4.373889
7	16.8487	4.680194
8	19.0516	5.292111
9	17.0567	4.737972
10	15.1768	4.215778
11	15.6213	4.33925
12	16.5442	4.595611

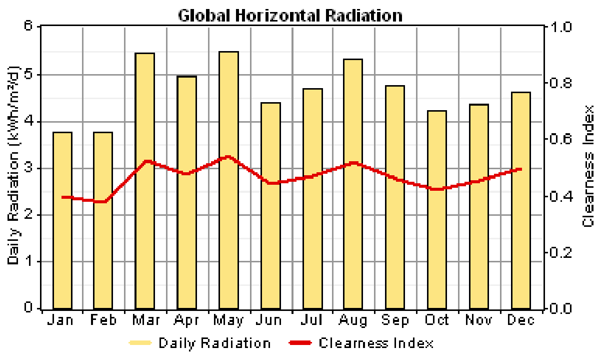

Fig 1: Annual solar radiation tabulation for Pulau Pinang

Tabulated data in Table 1 is very much critical in calculating the amount of solar energy or in specific terms Solar Irradiation, H that will be obtained throughout the whole year. Firstly, the solar radiation data need to be converted from MJm^{-2} to $kWhm^{-2}$. From here, the Peak Sun Hour (PSH) can be calculated where the number of equivalent hours when the solar irradiance is $1kWhm^{-2}$. For example, on Jan 2008, the solar radiation data is 13.4671 MJm^{-2}. The conversion factor is:

$$1 \text{ kWh} = 3.6 \text{ MJ}$$

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Thus,

$$13.4671\frac{MJ}{m^2}\times\frac{1\,kWh}{3.6\,MJ}=3.7408\,kWhm^{-2}$$

Therefore, to produce a 3.7408 kWh of energy per m^2, the radiation would have to continue at the rate of 1 kWm^{-2} for 3.74 hours. Thus, the number of PSH is 3.74. Note that the solar power intensity used is based on Global Solar Radiation at sea level, G_0 = 1 kWm^{-2} during designing stage for best practice even though it can be higher than 1 kWm^{-2}.

One of the main objectives in developing the solar PV plant is purely on the cost effective feed-in tariff. In an effort to offset the electricity consumption during day-use, amongst initiatives in large consumers includes;

a) Co-generation.
b) Dual-tariff systems.

In co-generation systems, localized generators are used to offset peak demand resulting in substantial economics on utility bills. However, co-generation gives some negative effect such as producing noise to the area around [3]. Whereas, in dual-tariff systems, the utility encourages electricity usage during night-time with low tariff rates between 7.00 pm – 6.00 am. It is a common practice in developed cold-weathered countries such as United Kingdom with the implementation of storage heaters, widely used in the communities. Thus, with the implementation of the dual-tariff concept, it will be able to reduce a large amount of electricity bills by supplying the on-peak demands from the solar PV plant.

The objective of this paper is to simulate the dual-tariff concept system design for solar
PV plant based on real structure in UiTM Pulau Pinang and analyzes the cost-benefit of the overall system which requires output supplies of 9kWh. This system is the first dual-tariff concept being developed in Malaysia where the solar PV will supply the load during the on-peak demand which defined between 7.00 am until 6.59 pm whilst the local energy supplier, Tenaga Nasional Berhad (TNB) supplied the energy for night time or off-peak which is from 7.00 pm until 6.59 am.

II. Methodology

A. The System Structure

The PV system is installed on a main guard-house in Universiti Teknologi MARA (UiTM) Pulau Pinang, Malaysia that operates for 24 hours using a load of 9kWh/day. The supply system is modified to suit a dual-metering to monitor actual usage. Daytime is defined between 7.00 am until 6.59 pm whilst the local energy supplier, Tenaga Nasional Berhad (TNB) supplied the energy for night time. The system is provided with battery storage backup to regulate deficiencies in unreliable solar energy. During the day time, the solar energy collected by the PV will be used to operate air-conditioning and lighting system, some stored energy during transitions and uses normal electricity during night time and some emergency lighting powered by the battery for overall optimization. Fig 2 below illustrates the dual-tariff solar PV system in UiTM Pulau Pinang. The change over circuit is used to connect the load to the [4] PV system during the day (7.00am – 6.59pm) and change connection to the grid in the night time (7.00pm – 6.59am).

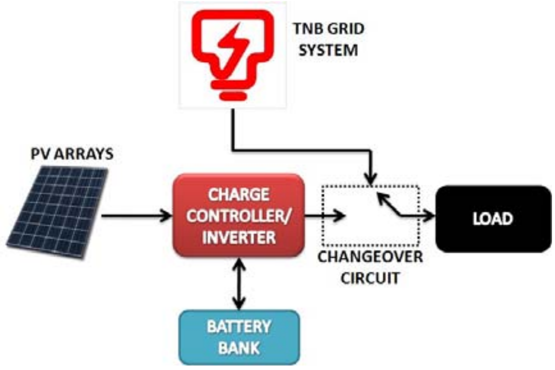

Fig 2: Dual-tariff system employing the use of PV Source and TNB grid.

B. Economical Study

The economical study is implemented in order to investigate the total cost for solar PV plant installation, the operation and maintenance cost and the payback time. By using HOMER software provided by National Renewable Energy laboratory (NREL), the simulation on the economical study is done [5]. The solar energy data and the estimated cost of each component in the solar PV plant are used as inputs to the software. The hourly load for guard house in UiTM Pulau Pinang is measured and used as an AC load to the software.

III. Result And Discussion

A. Energy Analysis

To simulate the energy yield and cost analysis of the solar PV plant, the hourly load from the guard house in UiTM Pulau Pinang is measured and computed. Table 2 tabulates the electrical appliances available in the guard house with their time of usage during day time only since the solar PV supply the energy for day time from 7 am till 6.59 pm. The computed annual average load for the guard house is depicted in Fig 3.

Table 2: List of Electrical Appliances in the Guard House and the Duration of Usage

Equipment	W	Qty	Duration (in hour) /day	kWh
Flourescent Lamp	18	2	2	0.072
Computer	100	1	12	1.2
Air condition	900	1	9	8.1
		Total kWh/day		9.372

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

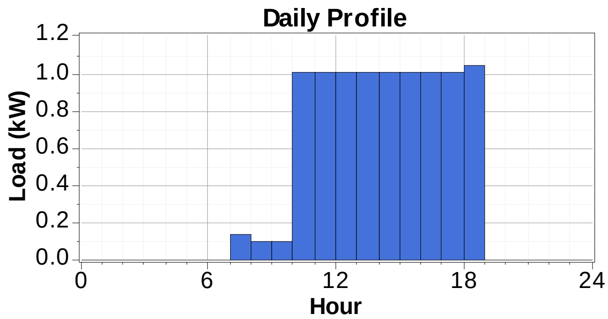

Fig 3: Daily Load for Solar PV Dual-Tariff System

The electrical appliance in Table 2 is selected based on the important usage by the guard. Computer is used throughout the day in order to assess and store all the information related to safety issue. The air-conditioning system is functioning for 9 hours during day time starting from 10 am to 7 pm whilst the lamp is used during morning time, from 7 am to 9 am. The daily load can be seen in Fig 3 which shows that air conditioning system carries the major kWh.

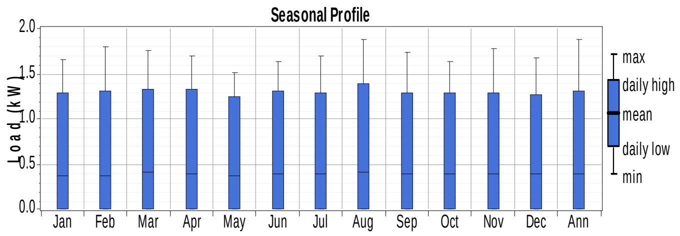

Fig 4: Annual Average Load for the Guard House

Fig 4 illustrates the average load that need to be catered for the guard house annually. By further analyzing from the load demand of the guard house using HOMER, the PV system architecture is proposed as mentioned in Table 3.

Table 3: Proposed System Architecture

PV Array	4 kW
Battery	32
Inverter	2 kW
Rectifier	2 kW

Based on proposed system architecture in Table 3, a 4kW PV array is combined together with a system voltage (SV) of 24V in order to accommodate the 9.372 kW load in the guard house. Battery used during this design process is a Trojan L16P type which is 6V and a capacity of 360 Ah.

Details on the battery:

String size	4
Strings in parallel	8
Batteries	32

Whilst the converter used is a 2 kW inverter system in order to convert from DC to AC supply.

B. *Economical Study*

In this study, the estimated cost for the solar PV dual-tariff system implementation is predicted using HOMER. The estimated cost included the capital cost, replacement cost, operation and maintenance cost and salvages cost for each component of the system as tabulated in Table 4.

Table 4: Detail Cost of the Solar PV Dual-Tariff System

Component	Capital ($)	Replace ($)	O&M ($)	Salvage ($)	Total ($)
PV	20,000	6,236	5,113	-3,495	27,854
Trojan L16P	9,600	8,354	8,181	-1,118	25,017
Converter	2,000	835	2,557	-155	5,236
System	31,600	15,425	15,851	-4,769	58,107

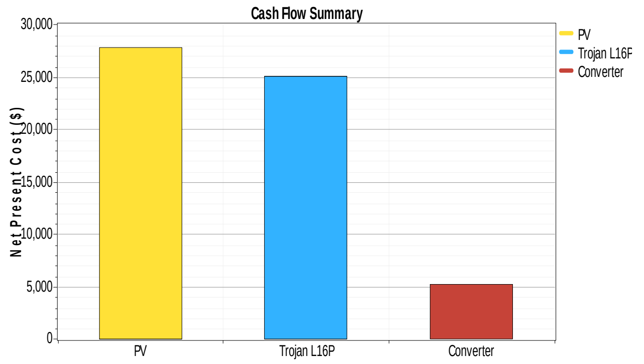

Fig 5: Cost Summary for each of component in the Solar PV Dual-Tariff System

It can be seen that the total capital cost, the replacement cost, the operation and maintenance cost and salvages cost are $31,600, $15,425, $15,851 and -$4,769 respectively. From the estimated cost summary, it is expected that the system will give a payback time in 25 years as depicted in Fig 6.

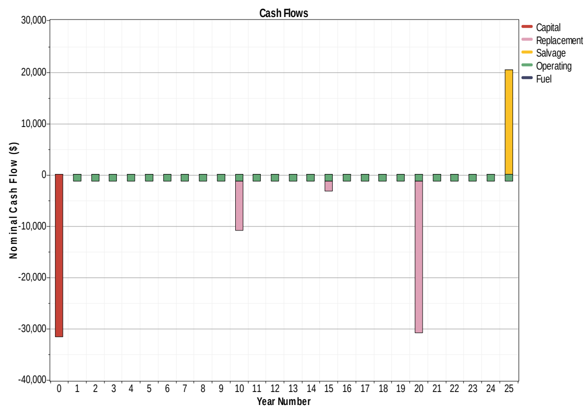

Fig 6: Cash Flows in 25 Years

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

IV. Conclusion

The system design and cost analysis of the dual-tariff solar PV system for guard house in UiTM Pulau Pinang have been simulated and forecasted using HOMER with an energy demand of 9kWH/day. From the results, it shows that the design of the dual-tariff system can be accomplished with the cost of energy of total capital, replacement, operation, maintenance and salvages are found to be $31,600, $15,425, $15,851 and -$4,769 respectively. It is expected that the system will give a payback time in 25 years. Thus, with the implementation of the dual-tariff concept, it could save the utilization of energy from the national grid and reduce the large amount of the electricity bills.

Acknowledgment

Financial support from Ministry of Science, Technology and Innovation (MOSTI) Malaysia EScience Grant No: 03-01-01-SF0186 is gratefully acknowledged for implementation of this project. Financial assistance of Universiti Teknologi MARA is also gratefully acknowledged.

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