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EVALUATION OF PHOTOVOLTAIC SYSTEM INSTALLATION FOR A MOSQUE IN UNIVERSITI TEKNOLOGI MALAYSIA

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ABSTRAK

Kajian ini bertujuan untuk mengkaji keberkesanan kos bagi pemasangan system PV di sebuah masjid di Malaysia. Masjid Sultan Ismail di Universiti Teknologi Malaysia telah dipilih sebagai sebuah kajian kes. Sistem grid-tied PV akan digunakan untuk menjana elektrik dan dipasang di atas bumbung masjid tersebut. Rangka bagi sistem grid-tied PV terdiri daripada enam langkah, i.e. (1) Anggaran awal saiz sistem, (2) Penentuan awal jumlah modul yang diperlukan, (3) Pemeriksaan jumlah voltan bagi modul yang digunakan, (4) Pemilihan *inverter*, (5) Pemeriksaan had voltan dan konfigurasi modul, dan (6) konfigurasi *array*. Pengiraan dilakukan untuk mendapatkan maklumat-maklumat penting seperti jumlah sinaran matahari, luas permukaan bumbung masjid, dan lain-lain. Teknik ini boleh mengurangkan bil elektrik dan menjimatkan tenaga sehingga 47% dengan kriteria masa bayar balik selama 13 tahun.

ABSTRACT

The purpose of this research is to evaluate the cost effectiveness of installing a PV system to a mosque in Malaysia. Sultan Ismail Mosque in Universiti Teknologi Malaysia (UTM) was selected as a case study. Grid-tied PV system is planned to be used to generate electricity and will be installed on the roof of the mosque. The framework for grid-tied PV system consists of six steps, i.e. (1) Initial estimation of system size, (2) Deciding on the initial number of modules needed, (3) Checking the module voltage, (4) Inverter selection, (5) Checking voltage limits and module configuration, and (6) Array configurations. There are some calculations in order to estimate essential data such as amount of global solar radiation, area of the mosque roof, and few others. This technique is able to reduce electricity bill and save energy up to 47% with a payback period of 13 years.

Keywords: *Mosque, Malaysia, solar system, grid-tied PV, energy minimization, payback period*

1.0 INTRODUCTION

Antony *et. al*. [1] defines photovoltaic (PV) as the active solar technology which produces electricity from solar radiation using solar cells encapsulated in panels called PV modules. Eicker [2] stated that photovoltaic means a direct conversion of short-wave solar irradiance into electricity. Solar energy is a new technology but nevertheless has been used by many countries nowadays in generating electricity, producing heat and warming water. Solar energy is free, renewable, clean and available in abundance all around the world.

The strategic location of Malaysia in hot humid tropics facing high degree of diffuse radiation each year makes Malaysia a suitable place to install solar system. PV system has been applied in Malaysia but only in several houses (e.g. private bungalow house at Setia Eco-Park, Selangor and greenhouse at Universiti Putra Malaysia (UPM) Research Park) and offices (e.g. Green Tech Malaysia (GTM) Green Office Building at Kuala Lumpur).

Al-Shamiry *et. al.* [3] presented a study on the installation and testing of a complete photovoltaic hybrid system for a tropical greenhouse cooling in Universiti Putra Malaysia (UPM) Research Park. The hybrid photovoltaic system consists of two photovoltaic sub-systems connected to each other with the national electricity grid used as a backup unit. It includes 48 photovoltaic solar panels with 18.75 watt each, one inverter, one charge controller and a battery bank (with 12 batteries). The PV supplied 92.86% of the system energy requirement which is very satisfactory and worthwhile.

In 2008, Ahmad *et. al.* [4] prepared a showcase project that installs 7.36 kWp building integrated photovoltaic (BIPV) system at Monash University, Sunway Campus Malaysia. This BIPV project received almost 100% financial support (showcase project) from GTM under the Malaysia Building Integrated Photovoltaic (MBIPV) Project. A total of 115 units, each with 64 Wp (plus 1 dummy module) amorphous silicon solar modules, were used to cover an area of about 110 m^2. The price for this 7.36 kWp system is RM194,931.

Yaakub [5] then has introduced an economic study of photovoltaic application at FKE building in UTM. The system design consists of 1200 units of polycrystalline module with 24 units of inverter. The total capital cost for this system is RM2,355,000 and the total installation cost per capacity is RM25 per watt peak.

This paper evaluates the system design and suitability of PV system in terms of economics to be applied at a mosque in Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

2.0 METHOD

2.1 Data Extraction and Collection

The first step in establishing the minimum energy network is by conducting a site survey. For lighting system, data on the energy profile for the mosque were collected. Beside that, the annual monthly global solar radiation for Johor were also collected from Green Technology Malaysia (GTM) to ensure that the mosque can receive higher amount of radiation so that the solar system can be applied to the mosque. Grid-tied PV system will be used and hence its suitability for UTM mosque roof needs to be assessed. The data needed are the orientation, angle of inclination, surface area, and any possible sources of shading of the roof.

2.2 Site Survey

Site survey is an essential part of system design. There must be no shading on the roof. If shading occurs on the roof, proper shading analysis needs to be carried out. In this study, a sketch of the building layout with dimensions was produced and the orientation of the building was noted. The information collected was highly detailed in order to prepare a cost estimation for the energy system that is going to be applied. For angle of inclination the types of the roof, either a sloping roof or flat roof, was first determined. This is because different types of roof will provide different angles of inclination.

2.3 Modules Selection

The modules were then chosen according to the modules efficiency and cell material, which is either monocrystalline, polycrystalline, amorphous, CdTe or CIS, or thin film technology as shown in **Table 1**. Monocrystalline silicon cell was chosen in installing the solar system on the roof of Sultan Ismail Mosque due to its high quality and comprehensiveness with international product certification. From the point of view of the product quality, the main requirements are:

- Modules enable electricity sound performance of the installation,
- Modules have long working lives, are suitable for the environment in which they will be installed and suffer minimal degradation over time in terms of performance,
- Modules meet required technical specifications.

Table 1: Commercially available cells in the world [1]

Type of cell	**Construction**	**Surface area needed for 1 kWp**	**Module Efficiency**	**Current stage of development**
Monocrystalline silicon	Uniform crystalline structure – single crystal	7 – 9 m^2	13 – 17 %	Industrial production
Polycrystalline silicon	Multi-crystalline structure – different crystals visible	8 – 9 m^2	11 – 14 %	Industrial production
Amorphous silicon	Atoms irregularly arranged. Thin film technology	16 – 20 m^2	5 – 8 %	Industrial production
Thin film copper-indium-diselenide	Thin film, various deposition methods	11 – 13 m^2	10 – 12 %	Industrial production
Cadmium-telluride & others	Thin film technology	-	9 – 10 %	Ready to go into production

2.4 Designing Grid-tied PV Solar System

The system design process consists of 6 steps and was implemented as follows:

Step 1: Initial estimation of system size
This step requires calculating the PV array peak power so that the initial maximum power that will be produced by the system can be estimated.

Step 2: Deciding on the initial number of modules needed
In estimating the initial number of modules, the values of PV array power and module peak power is needed (see Equation 1). It is also important to check if the modules will fit on the roof and can be arranged in two forms which are landscape and portrait layout.

$$\textit{Number of modules} = \frac{PV\ array\ peak\ power}{Modules\ peak\ power} \qquad (1)$$

Step 3: Checking the module voltage
It is required to check the modules voltage because every module has its own technical specifications. It is essential to do the observation during sizing to avoid any problem. All of the standard data sheet should be given in Standard Test Condition (STC) corresponding to 1000 W/m^2 of solar radiation at a module operating temperature of 25°C and air mass of 1.5. Based on the data sheet, the module voltage at the desired temperature can be estimated. The formulas are given in Equations 2 to 4 where V_{OC} is the open circuit voltage, V_{MPP} is the maximum peak power voltage, T_C (V_{OC}) is the voltage temperature coefficient, T_1 is the minimum location temperature and T_2 is the maximum location temperature.

$$V_{OC}\ (\text{at } T_1°C) = V_{OC}\ (\text{at } 25°C) + (T_1+25)[\ T_C\ (V_{OC})] \qquad (2)$$
$$V_{MPP}\ (\text{at } T_1°C) = V_{MPP}\ (\text{at } 25°C) + (T_1+25)[\ T_C\ (V_{OC})] \qquad (3)$$
$$V_{MPP}\ (\text{at } T_2°C) = V_{MPP}\ (\text{at } 25°C) - (T_2-25)[\ T_C\ (V_{OC})] \qquad (4)$$

Step 4: Inverter selection
Inverter will convert the DC electricity produced by the PV array into electricity at a voltage and frequency suitable to be fed onto the grid. The number and power rating of inverters are determined by the overall power of the PV system and the chosen system concept. Suitable inverter can be chosen by using the inverter power rating and the appropriate inverter from the standard data sheet.

Step 5: Checking voltage limits and module configuration
The aim of this step is to decide on the number of modules in a string. The string voltage needs to be within both the upper and lower limit of the inverter V_{MPP} range. Besides that, the open circuit voltage of the string also needs to be checked to ensure that it is below the maximum inverter input voltage. The modules are usually series-connected in strings, one for each inverter DC input terminal. The input DC voltage range of the inverter will determine the number of modules to be connected together in each string. This can be calculated using Equation 5 and 6.

$$\textit{Maximum number of modules} = \frac{V_{PV\ UPPER}}{V_{MPP}(at\ T1°C)} \qquad (5)$$

$$\textit{Minimum number of modules} = \frac{V_{PV\ LOWER}}{V_{MPP}(at\ T2°C)} \quad (6)$$

(6) *Step 6: Array configuration.*

It is necessary to check if the total number of modules originally decided upon can be divided into strings of equal numbers by using Equation 7.

$$\frac{\text{Planned number of modules}}{\text{Number of modules per string}} = \text{Number of strings} \quad (7)$$

The design and sizing process involve going through the available options and coming up with the optimal solution. After going through the previous steps, it is possible that the total number of modules, the array peak power, the type of modules or the inverter might have to be modified again. This may need to be done several times and may involve doing some of the calculations again.

2.5 Cost Estimation and Quotation

In installing a PV system, the cost estimation needs to be considered because the most expensive item in any PV system will be the PV modules. Other costs include the inverter and the PV combiner box. Besides PV modules and inverters, complete PV systems also involve wire, cables, switches, fuses, connectors and other miscellaneous parts. A factor of 25% was used to estimate the additional system costs. There will also be a time consideration in installing a PV system and this will also lead to cost estimation. There are also the costs of site visits, transport, planning and administrative costs. Payback period also needs to be considered in PV installation system, as shown in Equation 8.

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Net cash flow each year}} \quad (8)$$

3.0 RESULTS AND DISCUSSION

3.1 Solar Radiation on Skudai, Johor

Universiti Teknologi Malaysia is located in Skudai, Johor at a latitude of 1.55927N and a longitude of 103.63763E. Based on this latitude and longitude, UTM receives solar radiation throughout the day and this signifies that the installation of solar system in Sultan Ismail Mosque is highly feasible. From **Figure 1**, the annual average of the radiation incident or global horizontal radiation on a horizontal surface is 4.55 $kWh/m^2/day$ which is equal to 136.5 kWh/m^2 monthly.

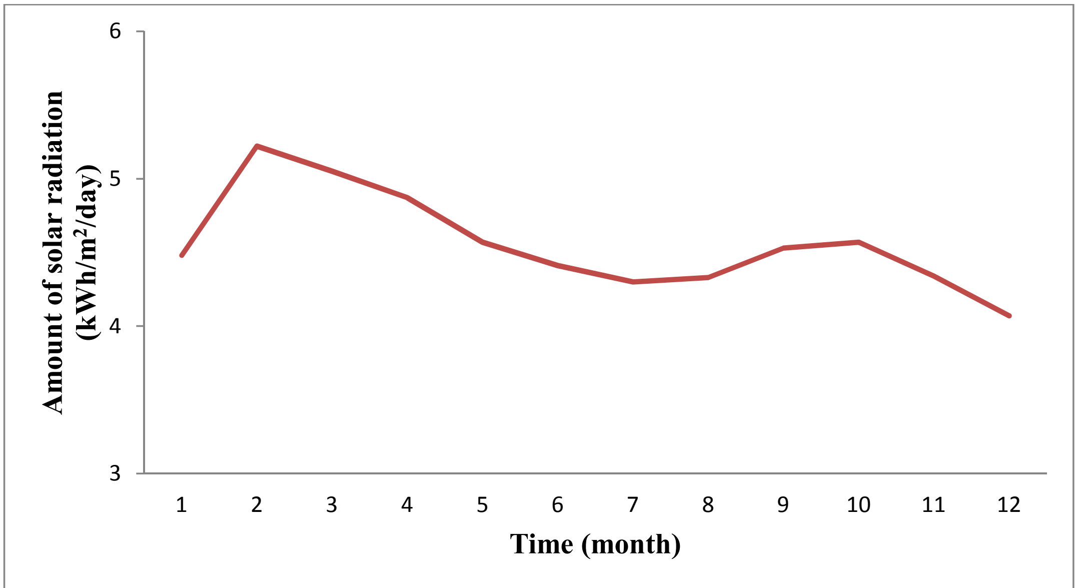

Figure 1. Monthly radiation incident average on a horizontal surface for 2008 (kWh/m^2/day) [6]

3.2 Energy Profile of Sultan Ismail Mosque

Figure 2 shows the amount of energy used in Sultan Ismail Mosque for the past 4 years. It can be seen that the annual average of the energy used has a range with a minimum of 17,657 kWh and a maximum of 22,664 kWh monthly.

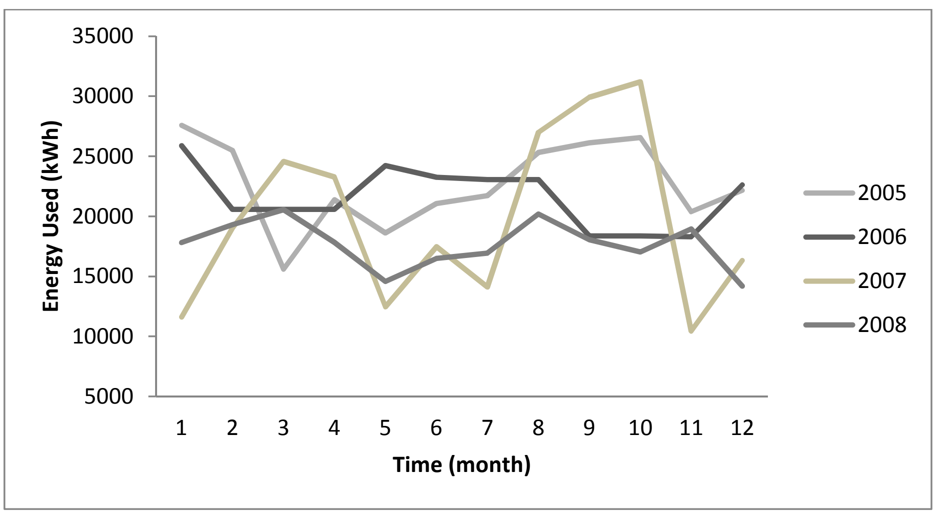

Figure 2 Energy profile for Sultan Ismail Mosque, kWh for 4 years

3.3 Shading and Available Area on the Roof

Shading of the modules should altogether be avoided because this will drastically reduce the output. From observations and predictions on the mosque roof, recurring shadings caused by parts of the building have been determined as shown in **Figure 3,** labeled from 1 to 7. Hence, only the sites labeled as A, B and C are left for the PV installation.

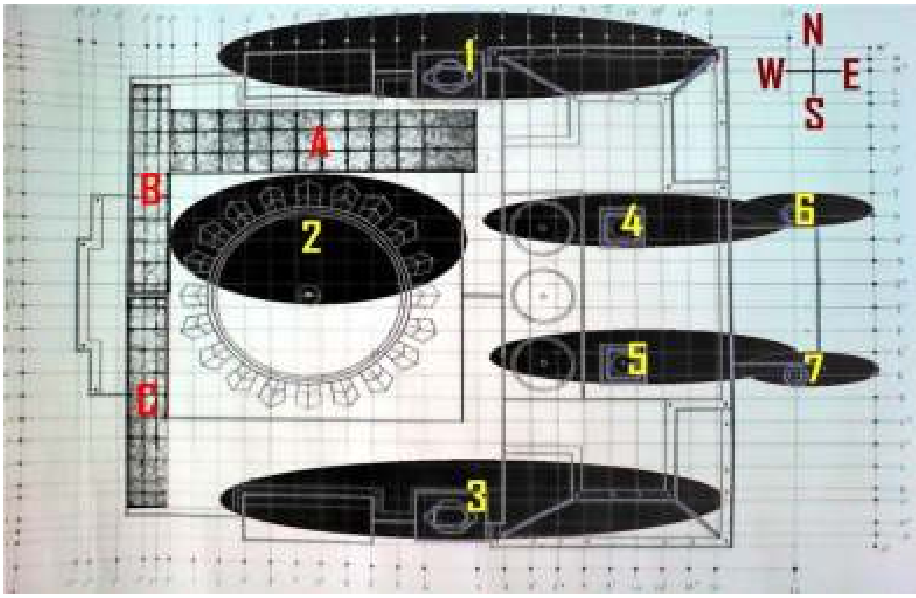

Figure 3. Shading and suitable area for PV installation

From the analysis presented in **Section 3.1**, Sultan Ismail Mosque receives 136.5 kWh/m^2 of global horizontal radiation monthly and uses a maximum electricity of 22,664 kWh/month. Based on the efficiency of monocrystalline modules, the minimum amount of energy that will be converted into electricity is 13 % of the solar radiation amount. Hence, the solar PV can prospectively generate 10,683 kWh/month

3.4 Grid-tied PV System Design

After several trial-and-errors, the following configuration emerges and is deemed the best configuration for the PV system installation in Sultan Ismail Mosque in UTM.

- PV array peak power - 35.92 kWp (area A)
  - 15.48 kWp (area B, C)
- Number of modules - 160 x 180 Wp modules (area A)
  - 84 x 180 Wp modules (area B, C)
- Configuration - 2 strings of 8 modules (area A)
  - 3 strings of 7 modules (area B, C)
- Multi-string inverter with a DC nominal power rating, $P_{DC\ NOMINAL}$ of 3.5 kW and maximum PV array power rating, $P_{PV\ MAX}$ of 3.8 kW.

3.5 Cost Estimation and Payback Period

Table 2 estimates the total PV system installation cost that is going to be installed on the roof of Sultan Ismail Mosque. Most of the cost corresponds to the price of the modules because it is the most expensive element in a PV system installation. And finally the total estimated cost for this PV system is RM426,331.76.

Table 2: Total installation cost estimation

Item	Quantity	Price/Unit (RM)	Subtotal Cost (RM)
Modules	328	543.69	178,330.32
Inverters	18	8,138.55	146,493.88
Balance of system costs (cables, wire, fuses, switches etc)	25%(modules + inverter)		81,206.05
Planning, permits etc	5% (subtotal)		20,301.51
Total installation PV system cost			**426,331.76**

By installing a PV system, it is estimated that UTM will save 10,683 kWh monthly. Based on the new electricity tariff mentioned by Tenaga Nasional Berhad (TNB) for large usage such as universities and factories, the rate is 26.2 cent per kWh. From this value, the payback period was estimated and resulted in a 13-year payback time by using Equation 8 in **Section 2.5**.

Previously, UTM needs to purchase 22664 kWh of energy monthly but PV installation will save 47.14 % of their expenditure and only pay for 11,981 kWh of energy from TNB.

4.0 COMPARISON STUDY

Table 3 shows the results of a comparison between the grid-tied PV systems that have been selected and a previous study in Malaysia. Note that the grid-tied PV system is using monocrystalline module which gives a much smaller installation cost compared to the PV system using polycrystalline module.

Table 3: Comparison between selected technology with a previous study

Building	Type of Module Used	No of Module	Total Installation Cost
Faculty of Elctrical Engineering Building	Polycrystalline	1200	RM2,355,000
Sultan Ismail Mosque	Monocrystalline	328	RM427,000

5.0 CONCLUSION

This paper has successfully evaluated the potential and benefit of installing a new grid-tied PV solar system to Sultan Ismail Mosque and towards Universiti Teknologi Malaysia (UTM). The findings show that the system can reduce UTM's electricity bill by RM33,000 annually (47% reduction). The capital investment is approximately RM427,000 giving a payback period of 13 years. UTM might want to consider this option since the life-time of a PV system is more than 30 years. With the feed-in tariff system to be launched by Malaysian government in 2012, the economics of a PV system is predicted to be more attractive.

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