Design and simulation of a rooftop PV System in Taylor’s University Lakeside Campus

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Abstract. Solar photovoltaic (PV) system is proven to be a future-proof type of power generation for growing economies. There are almost zero pollutants released, low maintenance cost with high reliability as the lifespan of a solar PV stretches up to 30 years, a well-sought alternative form of sustainable energy. Moreover, the electricity consumption in Taylor’s University (TU), Malaysia is very high, a consequence, a huge fraction of the fund is used to settle an RM450,000 electricity bill on average annually. In this paper, the study focused on how to reduce electricity consumption in TU by proposing a design of a comprehensive solar PV system. PVSYST and Sketchup software are used to design and analyze the PV system. In the present study, a Grid-Connected Photovoltaic (GCPV) mounted on the available roof space of TU is investigated. Also, a detailed economic analysis that includes the payback period and annual savings achieved through the proposed PV installation is analyzed. Annual savings of RM 267,621.00 can be made upon utilizing the proposed idea. Besides that, TU would be able to recover the initial investment cost in approximately 8 years of payback period, proving that the implementation of a 433kWp of solar PV unit is a smart option to address the sustainable energy goals.

1. Introduction

Solar energy is the most promising and green energy source to fulfill the energy demands of growing economies [1]. Solar energy generation is broadly classified into solar PV and solar thermal energy conversion systems. Solar PV is the direct and more efficient energy conversion of solar energy in the market today [2-4]. A solar PV system provides significant environmental benefits and advantages; greenhouse gas reduction and reutilizing empty spaces being two major advantages. Moreover, there is almost zero harmful emission being released and self-sustainable as the lifespan of a solar PV system stretches up to 30 years. As such, solar PV systems like the grid-connected, off-grid, large-scale solar (LSS), and building integrated (BIPV) are considered the most sustainable and accessible types of systems to provide renewable energy [5-7]. Researches have been carried out throughout the world to enhance the efficiency of PV and energy storage technology by enhancing the mechanical, structural, and heat-dissipating properties of PV cells and making this technology more reliable and accessible to the public [8-15]. Malaysia predominantly dependent on conventional power generation; relying mostly on coal, natural gas, and large hydropower. Also, Malaysia is not keen on using nuclear power as it creates challenges in waste disposal and maintenance of nuclear power plants [16, 17]. However, the country shows very strong potential in utilizing solar power to meet energy demands. It is a country that receives rather consistent solar radiation, ranging from 400-600 MJ/m² every month [18], potentially generating solar power up to 6500 MW in a year [19].
Akash et al. designed and simulated a 110 kWp standalone rooftop solar PV system to deliver an uninterrupted energy supply for hostel building and found that the hostel building can be made self-sufficient by the project. Xiangyang et al. optimized a grid-connected solar PV system by replacing a rooftop solar thermal system. The investigation is optimized based on maximizing the utilization of energy and minimizing the electricity sold to the grid. The study showed that the cost of a solar PV system can be recovered in 13 years under the government renewable energy incentive program of Illinois. Anil et al. designed and analyzed a 50 kW rooftop solar PV power plant for financial feasibility with government subsidy. The study found that the power plant produced electricity more than 5200 kWh/month, which reduced GHG emission by 4070 kg/month [20]. Sharma et al. simulated the PV system design using PVsyst software with different load conditions of an academic institute. The comprehensive study involved the feasibility check of the complete system by carbon dioxide emission count for the PV installation[21]. Usah et al. conducted a techno-economic comparative study of PV plants situated at different locations with different climatic conditions and peak sunshine hours (PSH). The results showed that the location with the highest number of PSH is the more economical site for PV installation, facilitating policy framework for optimization of installation site for large scale PV energy production[22]. Arun et al. designed a PV plant on the rooftop in an educational institute in India using PVsyst software, where there was already an existing PV plant. Using the software, the authors could enhance the efficiency of the plant by eliminating the shading loss using PVsyst. There was an 8.7% increase in the performance ratio of the plant due to a reduction in shading losses [23]. Mouhcen et al. explored and evaluated one of the largest PV plants in Algeria for 36 months using PVsyst. Various factors like yield factor, performance ratio, and capacity utilization factors were evaluated and compared with actual plant data. The authors found that the PV plant data coincide with the simulated PVsyst data [24]. Abdullah et al. designed and proposed a mono facial solar PV plant on the rooftop of University residence using PVsyst, PVSOL, and System advisor model (SAM). The results contributed 18.4% renewable energy in the annual energy demand of the university residence [25]. Mais et al. designed a 148.8 kWp solar PV plant in Jordan. PVsyst software is utilized to simulate the system performance and found that the simulated value coincided with the theoretically obtained values. Furthermore, the simulation on the feasibility study and cost analysis is also conducted, the result showed a shorter payback period and lower Levelized Cost of Electricity (LCOE) [26]. Wijeratne et al. investigated 23 different PV management and design software and 4 mobile applications. 15 key aspects of PV plant design and management were analyzed using these software and found 14 challenges in those software while designing a PV plant. Hence the finding showed that none of the software provides a complete solution for the PV plant installation enabling the decision-makers, researchers, and professionals to choose accurate design strategies while designing a solar PV project [27].

Despite the great potential solar energy holds, solar PV system deployment reported is less than 5% globally and thus, the growth in implementing solar PV must be accelerated to meet the cleaner air and greener sustainable energy goals[28]. For instance, with 4 kW solar arrays deployed in homes for 25 years, approximately 199,697 lbs of CO2 can be reduced. Only 13 solar panels are used to produce such promising results. One could imagine how beneficial PV technologies would be if it is implemented nationwide, all the more reason why Taylor’s University (TU) should have a solar PV system installed on campus ground; not only for power generation, it can serve as a tool to advocate people about clean energy[19].

To date, TU has exhausted a huge amount of resources on electricity, at approximately 1,100,000 kWh over a semester; a value obtained from conducting simple interviews with TU personnel. A study in Hong Kong has also shown that the occupancy rate of a building has an indistinct impact on energy consumption [29]. It is, therefore, safe to assume that the higher the occupancy rate, the higher the electricity consumption. Also, many researchers have stated that when a building is large and nearer to be spherical, the energy needs are decreased significantly because of the small surface area to volume ratio [30]. Hence, this study is aimed to propose a sustainable option to be implemented in an institution of higher learning in TU, Malaysia. A PV system design and how it benefits the institution in a long run, expressed in monetary value is discussed in the present investigation.
2. Methodology

2.1. Site Information
The solar site investigated in the present study is Taylor’s University lakeside campus (TULC), Malaysia located in the West of Malaysia with a coordinate of 3.0750°N, 101.5911°E [9]. Figure 1 shows a schematic diagram of the rooftop area of Block A, B, C, D, and E on TU. However, in this study the analysis is focused on the usable space in Block C, D, and E and found that the dimensions of the three rooftops are similar; summing up to a total of 2646m² of surface area. Therefore, a grid-connected PV system is the preferred system configuration. Also, the dimensions of each block are computed to the nearest estimation. There is no need for a battery as a backup because the institution can resume supply if the solar power generation is ever interrupted. In other words, TU can use a fraction of all of their energy needs with the solar power generated and use power from the grid during the night, cloudy conditions, and rainy days. Besides being able to feed the surplus energy back to the grid, this type of configuration is straightforward and has very low operating and maintenance (O&M) costs [31, 32].

![Figure 1. Satellite view of TULC (image is taken from Google Earth)](image)

As for solar radiation, most solar PV system installers import metrological data from either NASA or Meteornorm [31]. Greentech Malaysia, the government’s acknowledged body uses solar radiation data from these two sources for energy-related issues within the national framework [33]. To put it in simpler terms, NASA and Meteonorm are the global accredited climatological databases, both are often used in solar PV or renewable energy-related designs. Both the organizations have weather stations across the globe, however, the Meteonorm database is a better option as it an on-ground weather station located near TU; in Petaling Jaya, Malaysia. Figure 2, Figure 3, Figure 4, and Figure 5 shows the sunshine duration, daily global radiation, diffuse and global radiation, and monthly ambient temperature data for the TU site, which is obtained by interpolating Meteonorm data from Kuala Lumpur airport weather station.

Besides that, with the aid of Sketchup, the proposed system is designed. The buildings are drawn and measured based on the satellite image as shown in Figure 1. The tool allows us to visualize the overall design of the building and PV system. In the system design, there are a total of 1139 PV panels, grouped into 17 pieces per string connected to a combiner box before the energy generated is passed on to the
inverter and lastly to be fed to the load. Figure 6 illustrates two different views of the proposed investigation.

**Figure 2.** Sunshine duration for Taylor's University lakeside campus

**Figure 3.** Daily global radiation data for Taylor's University
2.2. PV Module and Inverter selection

Essentially, a grid-connected PV (GCPV) solar system comprises solar modules and inverters for power generation, which is also called a utility-interactive system because it is permanently connected to the power grid. Expensive storage batteries are unnecessary can be omitted from the design [32]. Therefore, it is crucial to understand the characteristics of these two components before determining the most suitable solar panels and inverters. Generally, the solar cells are strung in a series connection, the module to be put together in parallel to form a PV module. Almost 80% of the solar modules are made up of crystalline silicon-based (c-Si) cells and are proved to have the ability to promote photoelectric conversion [34, 35].

To date, most PV modules are classified into three main types: monocrystalline (mono c-Si), polycrystalline (poly c-Si), and thin film. Figure 7 shows the different types of PV modules. They vary not only in terms of colors, but also their module efficiency and operating power. Typically, a mono c-Si module is the most efficient one, with an efficiency of approximately 20% under standard test conditions (STC) [35]. This is closely followed by poly c-Si and lastly thin film. Poly c-Si is one of the most commonly used PV technologies because it has a lower price point when compared to mono c-Si.
However, the efficiency is low, usually ranges between 14% to 16%, resulting in lower space efficiency [36]. It will take at least 1.5 times more poly c-Si panels to match the same output power of a system that encompasses mono c-Si panels. On the other hand, the thin-film is mostly found in electronic devices such as calculators or watches. They are cheaper compared to other two technologies but, it suffers from eminent power output degradation, as high as 35% when exposed to sunlight and thus will not be considered in this study [35].

![Figure 7. Different types of PV modules used in a PV system](image)

On the other hand, an inverter functions as a device, which converts direct current (DC) absorbed by the PV arrays into alternating current (AC) and then is fed directly to the electricity load. A grid-tie inverter that can be normally found in a GCPV system operates in parallel with the local utility grid. The efficiency or the power rating must match the PV array, at least at about 90%, otherwise, significant inverter losses will be produced during operation and thus, impact the solar power generation [37]. Essentially, the type and structure to be chosen depending on the optimization between the cost and efficiency of the power output of the components [7]. Also, the PV system capacity must first be determined before acquiring both the panels and inverters, because they must match the array to maximize the energy yield.

### 2.3. System description

The primary concept of a solar PV system is to maximize the energy output by utilizing the spaces with many PV modules at a lower cost. In this paper, the solar photovoltaic system will be designed using PVSYST and Sketchup design software, based on the key design factors that will affect the efficacy of the proposed system. The parameters are as follow:

- Detailed layout study to determine the potential location for system deployment
- Suitable solar modules and inverters to be used in the system
- Average solar irradiance received at the solar site
- Optimum tilt angle and pitch of the solar modules
- Estimated solar system capacity and energy output

Then, a simple yet efficient economic study on the proposed design will be conducted to understand the advantages of system deployment. The initial capital cost and payback period expressed in years to break even on the investment made are estimated.

When it comes to how efficient a PV system operates, the performance ratio (PR) determines the quality of the plant. It is independent of the solar site and is often referred to as a quality factor. PR is a ratio of the actual (P\text{plant, total}) energy output and the estimated energy outputs (P\text{plant, nom}) of the design. Studies have proven that a high-performing solar PV design usually operates at PR values ranging between 75% and 85% [38, 39]. So, it is best to determine this parameter which can then be used for results comparison purposes. The calculation can be performed using Equation (1)[38]:
\[ PR(\%) = \frac{P_{plant,total}}{P_{plant,nom}} \times 100 \quad (1) \]

Then, the nominal PV plant output in kWh can be calculated using Equation (2)[40]. Essentially, the nominal power or maximum electricity of a PV plant is expressed in Watt Peak. This value is then used as a reference for determining the type of PV modules and inverters in the design.

\[ P_{plant,nom} = total \ no. \ of \ PV \ module \times P_{out,panel} \quad (2) \]

In this study, JKM380M-72-V and Context CL-60E are chosen as the PV modules and grid-tie inverters respectively. The solar module has a generating capacity of 380W with a dimension of 1979 × 1002 × 30mm whereas the inverters have a maximum power of 66kW and a CEC efficiency of 98.5%. The specifications of the PV panel are shown in Table 1.

| Table 1. Specification of PV panel |
|-----------------------------------|
| **Module Type** | JKM380M-72-V |                  |
|                   | Irradiance 1000W/m2 | Irradiance 800W/m2 |
| Maximum Power (Pmax) | 380Wp | 286Wp |
| Maximum Power Voltage (Vmp) | 40.5 V | 38.6V |
| Maximum Power Current (Imp) | 9.39A | 7.42A |
| Open-circuit Voltage (Voc) | 48.9V | 47.5V |
| Short-circuit Current (Isc) | 9.75A | 7.88A |
| Module Efficiency STC (%) | 19.6% |                  |

2.4. Optimum angle and pitch

To increase the collected yield of the PV array, the solar panels should be tilted at an optimum angle, and it best to be oriented perpendicular to the sun [19]. If not, the array would not produce as much power as it could because of shadow effects. To achieve maximum power output, one solution is a tracking system [41]. A tracking system is however costly and not always applicable [42]. Thus, in this study, the tilt angle is to be changed manually according to seasons in Malaysia. Malaysia, which is located near the equator, typically experiences 2 seasons: the dry season in April to September, and the rest of the year is the wet season. The optimum tilt angles during the wet season in Kuala Lumpur are said to be 19° and 0° for the dry season. Since TU is located near Kuala Lumpur, the optimum angle recommended in Kuala Lumpur can be applied at TULC too [43]. As for the azimuth angle, solar PV installations in the northern hemisphere is 90° or more for south-facing panels [5, 28]. Also, it is best to space out the solar panel rows, denoted as x in Figure 8 to maximize the collected yield [44].
3. **Result and discussion**

Theoretically, the solar PV system capacity is estimated as 510.72 kWp in the present study, and the PV array is made up of 1344 solar modules. However, there is a slight difference between the actual and theoretical values. Based on the simulated results, the nominal power of the system is 433 kWp which will then be fitted on the usable space in Block C, D, and E. Also, from Figure 9, the simulated PR is 81.4%. The difference in these values is most likely because losses were not considered. The most significant loss is the PV array loss, as high as 17.1% and followed by 1.5% system losses. Moreover, the trend is shown in the histogram (Figure 9) is rather consistent. This shows that the design is optimized and would most likely function at the simulated efficiency. The proposed PV design could potentially generate up to 555 MWh of energy in a year. The degradation rate of the PV system is not taken into consideration in the current study. Thus, proving that 8.33% of revenue exhausted on electricity bills is saved every month. Fig. 10 shows the monthly useful energy produced by the PV array installed on the TU rooftop. Due to the hot and humid equatorial climatic condition of Malaysia as shown in Fig. 4, all the months except March is having a useful energy gain of 81%, while in March there is a very small decrease of 1% in useful energy production, this is due to the high ambient temperature, global radiation in that month. As the ambient temperature increases the efficiency of the PV cell drops and adds up to the PV array losses.
Figure 9. Normalized production and Loss factors of the proposed PV design
3.1. Economic Analysis

Economical study is conducted mainly to identify the initial capital cost and payback period for the PV installation. The cost of each component and service must be determined beforehand as shown in Table 2 [45, 46]. The cost needed for cabling and wiring, although significant, is excluded in this study.

Figure 10. Useful energy produced

Useful energy produced

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Figure 10. Useful energy produced
Table 2. Cost of the components in a GCPV system

| Components/Items          | Cost                |
|---------------------------|---------------------|
| PV Module                 | RM 2.56/W [28]      |
| Inverter                  | RM 0.62/W [28]      |
| Mounting Structure        | RM 1.18/W [28]      |
| Balance of System (BOS)   | 10% of PV cost [30] |
| O&M cost                  | 2% of PV cost [30]  |

Then, the initial capital cost and its cost breakdown of the proposed PV design are calculated and tabulated in Table 3 shown as follows.

Table 3. Result of Design Study and Topology Optimization

| Components/Items           | Cost (RM)          |
|---------------------------|--------------------|
| PV Module                 | 1,108,019.20       |
| Inverter                  | 245,520.00         |
| Mounting Structure        | 510,940.00         |
| Balance of System (BOS)   | 110,801.92         |
| O&M cost/year             | 22,160.38          |
| Total initial cost (excluding O&M) | RM 1,975,281.12 |

PV modules are one of the components which account for almost 56.10% of the initial capital cost compared to the cost needed to acquire the 6 inverters. In this case, the cost of balance of systems (BOS) i.e. fixing the mounting system including labors is half of the PV array cost, estimated to cost approximately RM 510,940.00. Essentially, fortnightly cleaning of the PV modules to reduce dust or dirt falls under the category of O&M. It is crucial to maintain the operating condition of the plant. With that, the expected annual savings gained from the PV installation is RM267,621.00 and thus, shows that the estimated payback period is 7.4 years. This signifies that TU would be able to recover the investment.
made by the eighth year of installation and make a clean profit from then on, assuming that the average lifespan of a solar PV system is 30 years.

4. Conclusion
This paper highlights the design and the economic study of the solar PV system, to achieve a high-performance yet cost-efficient design. However, there are a few design parameters that must be determined to proceed with design simulation and drawing. The parameters include solar irradiance, tilt angle, type of PV modules, and inverters. Both design optimization processes are completed with the aid of PV design packages; PVSYST and Sketchup respectively. The software is used to show the expected yearly energy output as well as the losses in the proposed design whereas the 3D computer-aided design serves as a visual representation of the proposed project.

The economic study is then completed to determine whether the design is operating effectively and is usually measured in monetary terms. Moreover, it shows the cost breakdown of the design. As a result of that, a PV design with the ability to produce up to 555 MWh energy which roughly takes up RM 1,975,281.12 to be erected. However, it is proven that TU will manage to save up to RM 267,621.00 annually and by the year 2030, the institution would have breakeven the investment made. All in all, the analysis is undertaken within this work is to serve as a foundation for PV system design and other considerations will need to be taken into account in the future if the institution wishes to get a solar plant installed. As such, the simulation model needs to be confirmed with experimental data which can be obtained from the actual on-site analysis. It is also recommended to consider the institution’s electrical wiring or cabling system in the future as it might influence the power output.

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