FEASIBILITY STUDY OF A GRID TIED PV SYSTEM FOR UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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ABSTRACT

Universiti Teknikal Malaysia Melaka (UTeM) has to consider renewable energy as part of electricity generation to save cost of electricity. Photovoltaic (PV) system hereof is appropriate because it is reliable for sunny location like Melaka. Therefore, the purpose of this research is to carry out feasibility study of providing electricity from PV system for UTeM. The proposed system comprises of grid tied PV and battery storage. The techno-economic analysis of the proposed system was performed using Hybrid Optimization of Multiple Energy Resources (HOMER) software. The optimal size and the cost-effective configurations of the system were identified. From the simulation result, the optimal grid tied PV system has the minimum net present cost (NPC) and economic benefits over base system (utility grid) with 16.6% internal rate of return (IRR) and 5.7 years payback period. The results obtained can be used as references for the stakeholders and policy makers in developing grid tied PV system for university campuses.

Keywords: grid tied PV system; HOMER; techno-economic analysis; net present cost; payback period.

1. INTRODUCTION

Globally, demand for energy is increasing because of the population and economic growth [1, 2]. The high energy demand cannot be fulfilled by conventional energy sources because they are limited in nature. The consumption of conventional energy sources like fossil fuels also lead to Greenhouse Gas (GHG) emissions, which contribute to global warming [3, 4]. Hence, an urgent need for renewable energy does exist [4, 5]. In 2018, 169 countries had adopted some form of energy targets [6]. Denmark, Norway, Sweden, Austria, New Zealand, Latvia and Germany are among the countries that have high share of renewables on power systems [3].

On the other hand, Malaysia is one of the countries that has low share of renewables on power systems [3]. In 2018, Malaysia reported a 2% of renewable energy contribution to its power system [7]. Malaysia government has set a target of 20% share for renewables in country's electricity mix by 2025 [8, 9]. In late 2018, Malaysia government has also introduced Net Energy Metering (NEM) program, where solar energy will be first used and the surplus energy will be supplied to the main grid on a one-to-one offset basis [10, 11]. The potential customers to adopt NEM scheme are from commercial and industrial sectors because the country has over 4.12 million buildings in Peninsular Malaysia that is suitable for solar rooftop [7].

PV technology is a valuable type of renewable energy source because it is carbon negative, silent and reliable for sunny locations [12]. The trend prices for PV module and inverter have decreased significantly in the past two years [12, 13]. Now, PV technology leads in the power sector where around 100 GW (55% of renewable capacity) of PV was installed globally [6]. PV system can be segregated according to its function, operation and connection. Standalone and grid tied are two types of PV system. The latter supplies surplus power to the main grid when it has reached the load demand. Selling the surplus power produced by consumer to the main grid can reduce cost of electricity and the payback period [14]. Grid tied PV system is divided into two namely with battery storage or without. The first is beneficial to backup electrical power from the main grid during an outage or an emergency. The latter is simple and very practical because it has few components. The main objective of installing a grid tied PV system is to reduce the electricity bill and to gain profit from solar investment.

Techno-economic analysis of grid tied PV system is very crucial to reduce costs and increase efficiency. Some study has been conducted to evaluate technical, economical and environmental aspects of grid tied PV system in higher education institution. Ref. [15] performed techno-economic assessment of grid tied PV system for the University of Jordan. A presentation of different technical solutions of this system were considered including fixed and tracking solar PV modules. The system was modelled and simulated using TRNSYS software. Besides, the authors used two engineering models for project construction; the Build Operate Transfer (BOT) model and the Engineering Procurement Construction (EPC) engineering model. The study concluded that the fixed PV system with EPC model is the most attractive choice with 15030 kWp system size, 32% IRR and 3 years payback period. Ref. [16] evaluated grid tied PV system at a university campus in Indonesia. The system was modelled and simulated using HOMER software. The authors highlighted the NPC value for developing 150 kWp GCPV system without battery storage is higher than using electricity from the power utility grid because electricity cost to the higher education institution is subsidized by the government. Ref. [17] investigated the installation of a large scale PV system at a university in USA. SAM Software was used to analyze the energy performance model while MREA Software is used for financial analysis to calculate system cost, payback period, return on investment and cash flow. A comparison of financial results under a five-year and a ten-year SREC contract in a direct ownership model was also presented. The study concluded that the installation of 1 MWp PV system at top three sites on campus with direct and third-party ownership model are technically and economically feasible options for electricity cost savings. Ref. [18] analyzed the environmental and economical aspects of 1MWp grid tied PV system at Universiti Malaysia Pahang. PVGIS and PV Watts were used to perform technical analysis of the proposed PV system. The study summarized that with 1 MWp PV system the university can produce about 1390 MWh of electricity per year with a reduction of 818.71 tCO_2 of GHG emission per year. However, there is no study conducted to develop a PV system for UTeM.

Therefore, this paper presents a grid tied PV system development for UTeM with techno-economic assessment. The paper laid out as follows: Section 2 explains the input parameters of HOMER simulation tool. Section 3 describes the economic feasibility analysis parameters. Section 4 explains briefly the system design specification. Section 5 presents and discusses the simulation and optimization results. Finally, Section 6 presents the conclusions.

2. INPUT PARAMETERS DESCRIPTION

In this study, the grid tied PV system is simulated and optimized using HOMER software. This software requires several input parameters likes primary load inputs, solar global horizontal irradiance (GHI) data and initial costs per unit of each component. Primary load inputs and solar GHI will be elaborated in this section, while initial costs of each component are presented in Section 4.

2.1 Load Profile of UTeM Main Campus

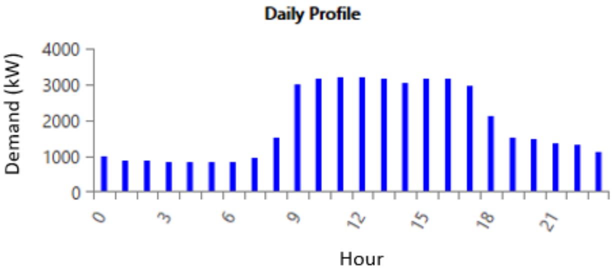
In this study, UTeM is chosen for evaluation. UTeM is the first public technical university in Malaysia. UTeM was established in 2001 with the aim to generate and disseminate engineering, entrepreneurial knowledge and science. The university, which operates from two campuses namely the Main Campus and the Technology Campus, has 8 faculties and 2 learning centers. Currently, the university employs 878 faculty staff and has over 12,000 students. UTeM Main Campus is in Durian Tunggal, Melaka (2°18.7' N latitude and 102°19.2' E longitude). The campus map is illustrated in Figure-1.

Generally, in academic building, the electrical energy will be allocated to certain parts including heating, ventilation and air conditioning (HVAC) systems, lighting, PCs and projectors [19]. UTeM consumes the electrical energy for air conditioning, lighting, lifts and electrical appliances such as PCs, printers and projectors.

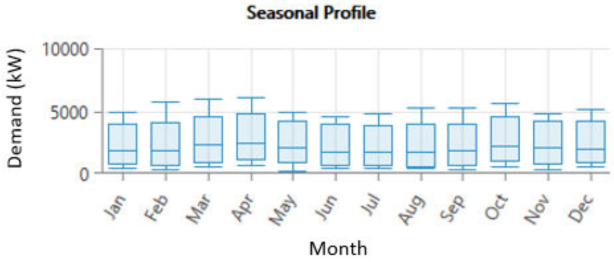
The study is focused on the Main Campus area. The load profile, which shows the power consumption for the Main Campus area is based on the electricity bills in 2018.

Figure-1. Main Campus map.

The daily load profile for Main Campus is presented in Figure-2(a) and monthly load profile is shown in Figure-2(b). The highest electricity use in this campus is 3,216.34 kW daily from 9 am to 5:30 pm. This is due to the teaching and learning activity of the campus routine in offices, lecture rooms and laboratories. In the evening, the electricity consumption is slightly reducing because it is only used in student hostels. The average electricity use is 48,194.11 kWh/day where 3,731.56 kW is peak load and 0.54 is load factor.



(a)



(b)

Figure-2. Load profile for UTeM Main Campus (a) Daily load profile (b) Monthly load profile.

2.2 Solar Global Horizontal Irradiance Data

In this study, the one year of solar global horizontal irradiance (GHI) data obtained from Meteonorm is used. [20]. The monthly solar GHI data for Melaka in 2018 is illustrated in Figure-3. The range of irradiance is from 4.065 kWh/m2/day to 5.194 kWh/m2/day and the annual average of solar irradiance is 4.55 kWh/m2/day.

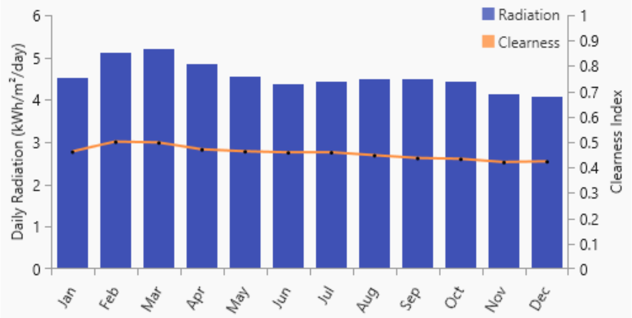


Figure-3. Monthly solar GHI data and clearness index for Melaka, Malaysia.

2.3 HOMER Software

HOMER is a software used to design and optimize the hybrid distributed generation systems, which consist of a combination of solar PV, storage, wind, combined heat and power plant (CHP) and backup generators. This software was developed at the National Renewable Energy Laboratory (NREL), and now licensed to HOMER Energy [21]. In HOMER, simulation can be carried out by modelling the performance of various hybrid systems and determining their sizing and life cycle cost. Optimization task can also be performed via HOMER by simulating various system configurations and identifying the optimal system configuration with the minimum NPC. Besides, HOMER can be used to analyse sensitivity by performing multiple optimizations for each value of the input variable to calculate the changes in the model.

2.4 Nominal Discount Rate

In HOMER Grid simulation, there are two required economic input parameters: nominal discount rate and project lifetime. The real discount rate, also known as interest rate, is defined as a conversion between one-time costs and annualized costs. Following equation shows the relationship between the real discount rate and the nominal discount rate [21]:

$$i = \frac{i'-f}{1+f} \tag{1}$$

where i' is the nominal discount rate, f is the expected inflation rate and i is the real discount rate. In this study, the nominal discount rate is set to be 6%.

In HOMER Grid simulation, the project lifetime is defined as the duration over which the costs of the system take place. Project lifetime is used in HOMER to calculate annualized costs from net present costs. In this study, the project lifetime is set to 25 years.

3. ECONOMIC PARAMETERS

Economic parameters are presented in this section to assess a grid tied PV system. Before trying to install the system, it is important to calculate the total NPC and COE. These parameters are required to evaluate whether it is a good investment or not and to predict the time for the project to make a profit. A table of economic metrics showed economic measures such as simple payback period, IRR, return on investment (ROI), is presented in HOMER to compare the difference between two systems (wining system architecture and base case architecture). The winning system is a system with minimum NPC while the base case system is a system with minimum initial capital cost.

3.1 Total Net Present Cost

The difference between present value of all the costs and the present value of all the revenue is called the total net present cost (NPC) [21]. The costs include capital costs, operation and maintenance (O&M) costs, replacement costs, fuel costs, emission penalties, and the costs of buying electricity from the main grid. In HOMER, the NPC is calculated by adding the total discounted cash flows in each year of the project lifetime. NPC is an important economic output parameter in HOMER because in optimization results, all the system configurations are ranked according to it. The equation for NPC is as follows [21]:

$$C_{NPC} = \frac{C_{total,ann}}{CRF(i,R_{proj})} \tag{2}$$

$$CRF_{(i,n)} = \frac{i(1+i)^N}{i(1+i)^N-1} \tag{3}$$

where $C_{total,ann}$ is total annualized cost (RM/year), CRF is capital recovery factor, i is real discount rate and R_{proj} is project lifetime (years), N is number of years.

3.2 Levelized Cost Of Energy

The average cost per kWh of electrical energy generated by the system is called cost of energy (COE) [21]. In HOMER, COE is calculated using following equation:

$$COE = \frac{C_{total,ann}}{E_{primary,AC}+E_{primary,DC}+E_{grid,sales}} \tag{4}$$

where $E_{primary,AC}$ is AC primary load served (kWh/year), $E_{primary,DC}$ is DC primary load served and $E_{grid,sales}$ is total grid sales (kWh/year). The total annualized cost $C_{total,ann}$ is sum of the annualized costs of each system component. In HOMER, this parameter is used to calculate COE and NPC.

3.3 Simple Payback

In HOMER, simple payback is defined as the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive [21]. The simple payback shows the time required by the system to recover the total investment costs.

3.4 Initial Rate of Return

In HOMER, the discount rate at which the base case and current system have the same net present cost is called internal rate of return (IRR). HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero [21].

3.5 Return on Investment

The return on investment (ROI) measures the amount of return on a particular investment relative to the initial investment. In HOMER the ROI is calculated using following equation:

$$ROI = \frac{\sum_{i=0}^{R_{proj}} C_{i,ref} - C_i}{R_{proj}(C_{cap} - C_{cap,ref})} \tag{5}$$

where $C_{i,ref}$ is nominal annual cash flow for base (reference) system, C_i is nominal annual cash flow for current system, C_{cap} is capital cost of the current system and $C_{cap,ref}$ is capital cost of the base (reference) system. The ROI is expressed as a percentage or a ratio.

4. MODELLING OF GRID TIED PV SYSTEM

The grid tied PV system modelled in HOMER as illustrated in Figure-4 comprises of PV panel, converter, battery and campus building as load. The descriptions of selected components of the system is summarized in Table-1. The explanations of each component are given in this section.

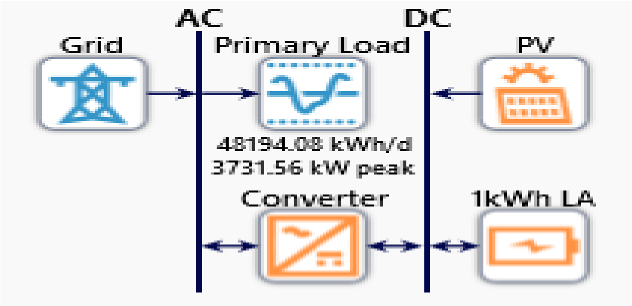


Figure-4. Model of grid tied PV system in HOMER.

4.1 Solar Panel

In this study, generic solar panel is chosen. The 14,000 kW PV system is used to fulfil the requirement of the load profile. The PV panel generates and supplies electricity to the campus building. The surplus electricity from the PV panel is then supplied to the main grid. The PV panel has 25 years' lifetime. The initial capital/replacement and O&M cost of PV panel are RM 20,930 and RM 130/year respectively for 5 kW panel.

4.2 Converter

Rectifier and inverter are used in this system because it involves 2 types of energy conversion namely AC-DC and DC-AC power. The inverter has 95% efficiency and 15 years' lifetime. The inverter needs to be replaced once in 25 years' period of lifetime. Contrarily, the rectifier has 100% relative capacity to inverter and 95% efficiency. The initial capital cost of the converter/replacement cost is RM 1200. There is no O&M cost for converters.

4.3 Battery

The deep cycle battery is recommended to be used with PV system [22]. Thus, a generic 1kWh lead acid battery model is selected in this study. This battery has 10 years' lifetime. The initial capital/replacement and O&M cost of battery are RM 2100 and RM 70/year respectively.

Table-1. Techno-economic specifications of the components in grid tied PV system.

Ref.	Components	Specifications
[23]	PV panel Size (kW) Capital cost (RM) Replacement cost (RM) O&M cost (RM/year) Lifetime (years)	5/10/1000/2000 20930/39000/2769000/4511000 20930/39000/2769000/4511000 130/234/1950/3900 25
[24]	Converter Size (kW) Efficiency (%) Capital cost (RM) Replacement cost (RM) Lifetime (years)	1 95 1200 1200 15
[25]	Battery Model Batteries per string Nominal voltage (V) Capital cost (RM/pc) Replacement cost (RM/pc) Operation and maintenance cost (RM/year) Lifetime (years)	Generic 1kWh Lead Acid 1 12 2100 2100 70 10

5. RESULTS AND DISCUSSIONS

The optimization results of the proposed grid tied PV system are illustrated in Table-2. The results show the techno-economic details of each system architecture including system sizing, NPC, COE, initial capital cost, operating cost, renewable fraction (RF) and CO2 emission. Based on the results, the optimal configuration of the proposed grid tied PV system consists of power from grid, 14,000 kW PV and 9,225 kW converter which gives NPC, COE and operating cost of RM 56.6M, 0.179 RM/kWh and 1.58M RM/year respectively. The optimal system is considered environmentally friendly because its renewable fraction could reach 70%. The system also produces the lowest emission compared to the other configurations with CO_2 emission of 5,425 tonnes/year. Figure-5 depicts the average electricity generated by PV panel and grid per month. 18,593,180 kWh/year of electricity is produced by PV panel and 7,524,038 kWh/year is supplied by the main grid. In this regard, the electricity consumption by AC primary load is 17,590,839 kWh/year and the electricity that sales to the grid is 7,206,838 kWh/year.

Table-3 shows the economic comparisons between the winning system architecture, which is grid-tied PV system without battery, and the base case system (grid). The IRR for the optimal system is 16.6% and the payback period is 5.7 years.

Table-2. Optimization results.

Architecture				Cost				System	
PV (kW)	**Battery (unit)**	**Grid (unit)**	**Converter (kW)**	**NPC (RM)**	**COE (RM/kWh)**	**Initial Capital (RM)**	**Operating Cost (RM/year)**	**RF (%)**	**CO_2 (kg/year)**
14,000		1	9,225	56,633,560	0.179	36,485,045	1,576,152	69.7	5,424,832
13,940	15	1	8,823	56,941,060	0.181	35,929,942	1,756,303	69.4	5,432,166
		1		97,535,030	0.434	0	7,629,846	0	12,682,995
	209	1	14.6	98,479,890	0.438	456,394	7,668,056	0	12,685,005

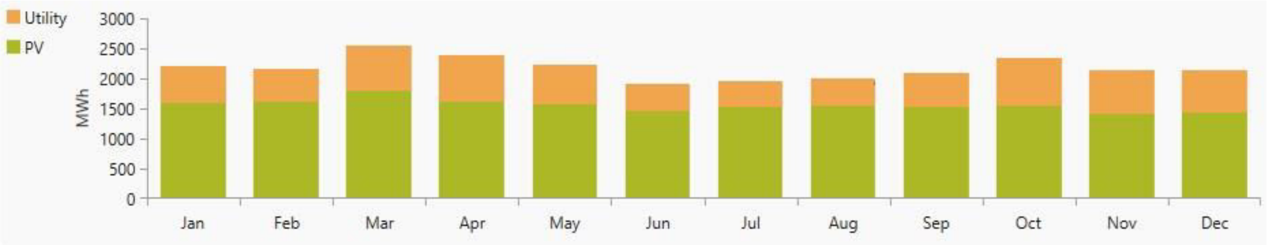


Figure-5. Monthly average electrical production by PV panel and grid.

Table-3. Economic comparisons between the winning system (optimal system) and base system (utility grid).

Metric	Value
Internal rate of return, IRR (%)	16.6
Return on investment (%)	12.6
Simple payback (year)	5.7

6. CONCLUSIONS

The study performed techno-economic analysis of a grid tied PV system at Main Campus of Universiti Teknikal Malaysia Melaka (UTeM), with a size of 14,000 kWp. The proposed system was modelled using HOMER. The system has a payback period of 5.7 years and IRR of 16.6%. From the results obtained, it can be concluded that the implementation of grid tied PV system at Main Campus of Universiti Teknikal Malaysia Melaka is feasible.

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