

## Optimal Grid-Connected PV System for a Campus Microgrid

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### ABSTRACT

This paper discusses on the implementation of a grid-connected PV system for university campus in Malaysia. The primary goal of this study is to develop a grid-connected microgrid comprises of Photovoltaic (PV) and a battery storage system to meet the campus load demand and minimize grid dependency. The microgrid modeled and simulated in Hybrid Optimization Model for Electrical Renewable (HOMER) software. Actual load profile and renewable resources were used as an input parameter for the hybrid system. The campus selected is Universiti Kuala Lumpur, British Malaysian Institute as it represents typical load profile for a small campus. Therefore, the results can be used to represent hybrid system development for other small campuses in Malaysia as well. Firstly, optimal sizing of renewable energy (RE) were simulated with respect to total Net Present Cost (NPC) and Cost of Energy (COE). Then, sensitivity analysis conducted to determine the system performance based on changes of load growth, and renewable resources. The results demonstrate optimal HRES combinations for the campus microgrid comprises of 50 kWp of PV generations with 50 kW inverter. However, inclusion of 576 kWh battery storage system will increase the NPC but has higher RE penetration.

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## 1. INTRODUCTION

Hybrid Renewable Energy System (HRES) is a combination of multiple renewable sources in a microgrid for electricity supply in an area [1]. It can operate either in standalone or grid-connected modes. Typically, standalone modes are used in remote or rural areas where grid connection is uneconomical [2]. In this mode, the renewable generation supported by traditional generations such as diesel and battery storage system. On the other hand, grid-connected modes normally used in buildings, factories and residential area. In this mode, the hybrid renewable sources will meet the load demand and sells the excess energy to the grid.

Technical and economic analysis is crucial for efficient utilization of a HRES in a microgrid. There are many software tools has been used to evaluate and analyse electrical, economical, and environmental performance of a HRES such as HOMER [3], H2RES [4], RETScreen [5] and EnergyPlan [6]. This study uses HOMER software for optimal hybrid systems design. Many researchers were found utilizing HOMER for hybrid system optimizations. For example, Laith M. Halabi et al uses HOMER to design a hybrid system in a remote village in Malaysia [7]. Their hybrid system design includes site survey alongside detailed technical-economic analysis for both on-grid and off-grid connections of a PV-Wind-diesel-battery system. Moreover, Khan et al uses HOMER to investigate the optimal hybrid system combinations in a tourism island located in the South China Sea [8], [9]. Actual load profiles and renewable sources of were

used in the study to evaluate different combination of renewable energy generations. Mohammad Mohammadi et al. presents a hybrid renewable system with PV and wind without conventional generation systems for a residential house in Tehran, Iran [10]. HOMER software was used to evaluate the system costs and greenhouse gasses emissions. Additionally, Samir M. Dawoud et al. modeled hybrid system comprises of PV and wind turbines for a remote area in Egypt [11]. Meanwhile, Asad Waqar et al. uses HOMER to minimize the CO<sub>2</sub> emission in a microgrid with Vehicle-to-grid (V2G) storage [12]. On the other hand, N.A. Jefry et al. integrates renewable energy generations in a Demand Response Program for buildings in Universiti Tun Hussein Onn, Malaysia campus [13]. HOMER was used to identify the technical and economics viability of the system.

Other advanced methods also been used by researchers to determine the optimal combinations of hybrid system in a microgrid. For instance, Yashwant Sawle et al. uses multi-objective function to determine the optimal design of a microgrid system [14]. Meanwhile, Abdelhamid Kaabeche et al. uses Firefly-inspired algorithm to determine optimal size HRES for an area in Algeria [15]. Many other advanced methods also used for optimal hybrid system sizing such as Genetic Algorithm [16], Particle Swarm Optimization [17], [18], Fuzzy [19] and Artificial Neural Network [20]. In this study, the HRES for a University campus were modeled in HOMER and results such as NPC, COE and CO<sub>2</sub> emission were assessed.

The rest of the paper are organized as follows: Section 2 describes the data collection for this study such as renewable sources and load profile. Section 3 presents the HRES modeled in HOMER that includes input parameters and specifications. Section 3 also demonstrates the results of HRES optimization and sensitivity analysis. Finally, Section 4 provides conclusion and summarizes the contribution of this study.

## 2. DATA COLLECTION

Universiti Kuala Lumpur, British Malaysian Institute located at 3°15'4" N latitude and 101°43'41" E longitude. The campus located in West Malaysia and has typical equatorial climate with hot and humid throughout the year. The data collected for this study comprises of solar irradiance, temperature and load profile.

### 2.1. Load Profile

Figure 1 shows the daily and monthly load profile of the campus. The peak demand occurs in the morning and late evening. This is due to the usage of electricity in offices, lecture halls and rooms in the morning. Meanwhile, in the evening, the rise of energy usage is mainly contributed by the student apartment. The energy usage highly contributed by PC and other equipments in student rooms.

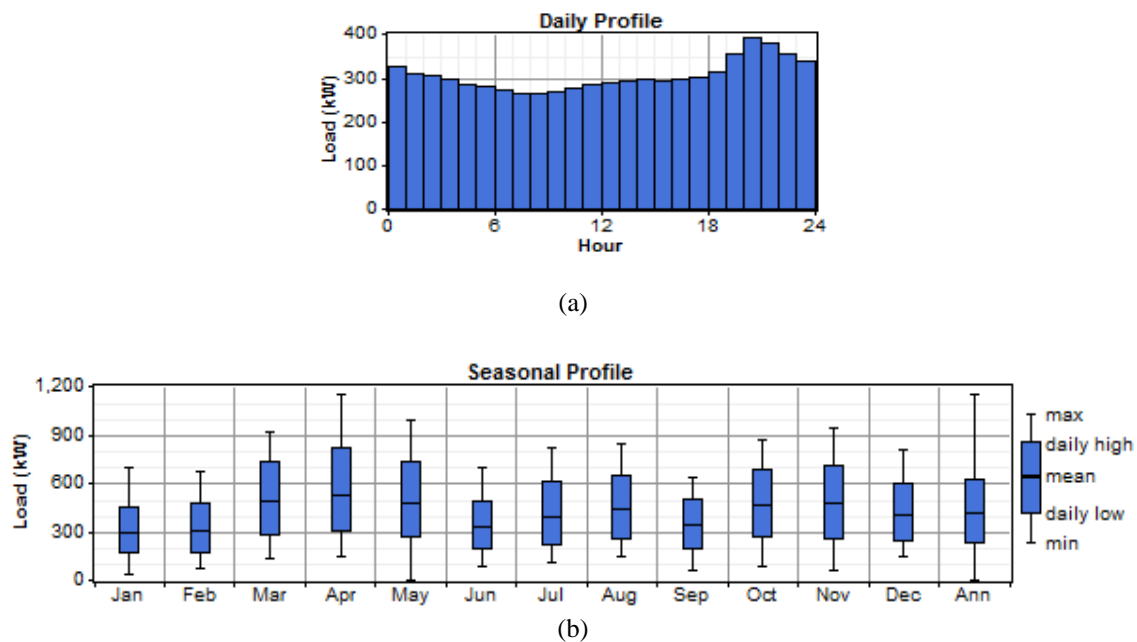


Figure 1. a) Daily solar radiation profile, b) Monthly solar radiation profile

**2.2. Solar Radiation**

The amount of solar radiation received in the location is crucial for installation of a PV system. The solar radiation data for three years used for this study (2015-2017), where the data was obtained from NASA POWER database. The solar radiation profile throughout the years were investigated to determine the feasibility of PV system installation. Figure 2 shows the solar daily and monthly solar radiation profile for the campus.

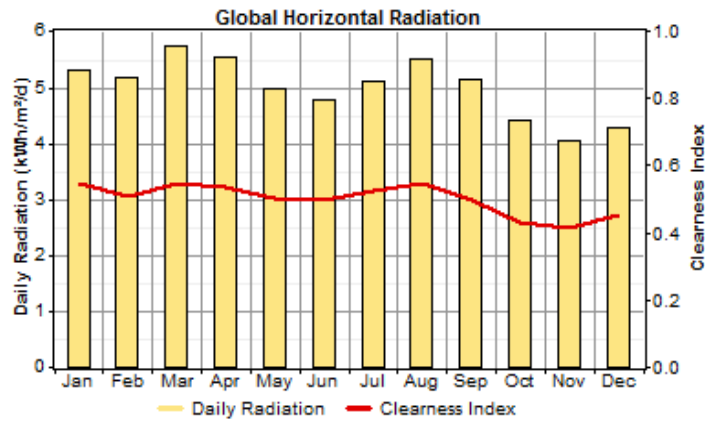


Figure 2. Daily Solar Radiation Profile

**2.3. Temperature**

The performance of PV system at site highly effected by the temperature variations. Therefore, temperature effect on PV panels also simulated to have PV system performance that closely matched the site conditions. Three year of temperature data (2015-2017) was used for this study.

**3. TECHNO-ECONOMIC ANALYSIS**

The input parameters used for this study includes the hourly solar radiation, temperature and load profile as discussed in Section 2. Moreover, the economic analysis includes parameters such as project lifetime of 25 years and annual interest rates. The current annual interest rates for Malaysia in May 2018 is 3.28%.

**3.1. HOMER Model and Components**

The grid connected hybrid system model comprises of four main components such as PV, inverter and battery storage system. The HOMER model is illustrated in Figure 3 and the components specifications are shown in Table 1. The economic analysis such as cost for this study is simulated in USD (US Dollar).

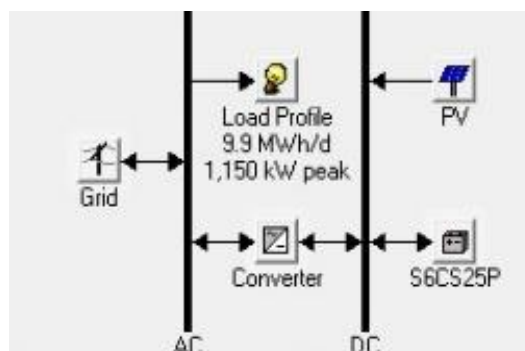


Figure 3. Hybrid system model in HOMER

### 3.1.1. PV Systems

The PV system size varied from 0 kW to 500 kW with 50 kW step size. The size variation of PV system is to ensure optimal size chosen in HOMER optimization analysis. The PV system costs comprises of both PV modules and Balance of Systems (BOS) that covers labour and mounting costs. This study also considers economics of scale to illustrate the impact of system size in respective to the cost.

### 3.1.2. Battery Storage System

The PV system size varied from 1kW to 500 kW with 50 kW step size. The size variation of PV system is to ensure optimal size chosen in HOMER optimization analysis.

### 3.1.3. Grid

The grid is the primary source of electricity for the campus complemented by PV system. The rate defined for this study is \$ 0.01/kWh price and \$ 0.05/kWh sellback. The same rate used for all weeks with 632 g/kWh of CO<sub>2</sub> emission factors.

Table 1. Technical and Economic Specifications for grid-connected hybrid system

No	Components	Specifications
1	PV System [21]	
	Size considered (kW)	0,50,100, 200, 250, 300,350, 400, 450, 500
	Capital cost (\$/W)	3.64
	Replacement cost (\$/W)	3.64
	Operation and maintenance cost (\$/year)	329
2	Inverter [21]	
	Size considered (kW)	0,100,150, 200, 250, 300,350, 400, 450, 500
	Capital cost (\$/W)	1.05
	Replacement cost (\$/W)	1.05
	Operation and maintenance cost (\$)	10,500
3	Batteries [9]	
	Model	Surrette 6CS25P (6V, 1156 Ah)
	Batteries per string	83
	Sizes considered	0,1,2,3,4,5
	Capital cost (\$/battery)	1,200
	Replacement cost (\$/battery)	1,200
	Operation and maintenance cost (\$/year)	10

## 3.2. Controller and Energy Management Systems

Both Load Following (LF) and Cycle Charging (CC) are considered by HOMER for optimal energy management in the microgrid. Best strategy will be chosen by HOMER based on minimal cost and high RE generations.

## 3.3. Optimization Results

The system optimal configurations sorted by HOMER based on the NPC. The optimal systems for the campus hybrid PV system is illustrated in Table 2. The results cover technical specifications such as sizes, capital cost, NPC, COE and renewable fraction (RF).

Table 2. Technical and Economic Specifications for grid-connected hybrid system

Rank	PV (kW)	Battery	Conv. (kW)	Grid (kW)	Dispatch Strategy	Initial capital (\$)	NPC (\$)	COE (\$/kWh)	RF
1	50	0	50	1000	CC	198,944	6,374,048	0.102	0.03
2	0	83	50	1000	CC	95,896	6,789,664	0.103	0.00
3	50	83	50	1000	CC	249,452	6,831,080	0.104	0.03

All system configurations listed utilizes cycle charging as an optimal dispatch strategy. The most optimal hybrid system configuration is 50 kW PV system with no battery storage followed by battery only system and hybrid PV-battery system. There is no total renewable energy solution for the campus due to generation limitation where RE sources unable to meet the demand. Moreover, the campus does not have the capacity for a large PV system installation, thus limiting to only 500 kW maximum capacity.

The most optimal system has initial capital of \$ 198,944 with \$ 6,374,048 NPC and 0.102 \$/kWh of COE. The RE generation only contributes 3 % from total generation. Battery only system with lower capital cost of \$ 95,896 shows promising results in term of reducing grid dependency. Although having lower capital cost, it has higher NPC and has no renewable energy contribution. The optimal PV system sizes followed by 50 kW PV system with battery storage. This system has capital cost of \$ 249,452 and \$ 6,831,080 NPC. This system has higher capital cost and NPC compared to other configurations due to integration of a battery storage system. However, this configuration shows promising results in high renewable energy contributions which is 3% from the total generations. The cost flow summary comparison of both PV only and PV system with battery storage is illustrated in Figure 4. The highest NPC contributed by the grid followed by PV for both hybrid configurations. The highest type of cost is the operating cost that contributes an average of \$6,430,340 and \$ 6,490,360 for grid-connected PV system and PV-battery system respectively. The initial capital needed for integration of 50 kW PV system is \$ 198,944 which includes \$ 153,556 for PV modules and \$ 45,389. The initial capital for installation of 720 kWh battery storage system is \$ 50,508.

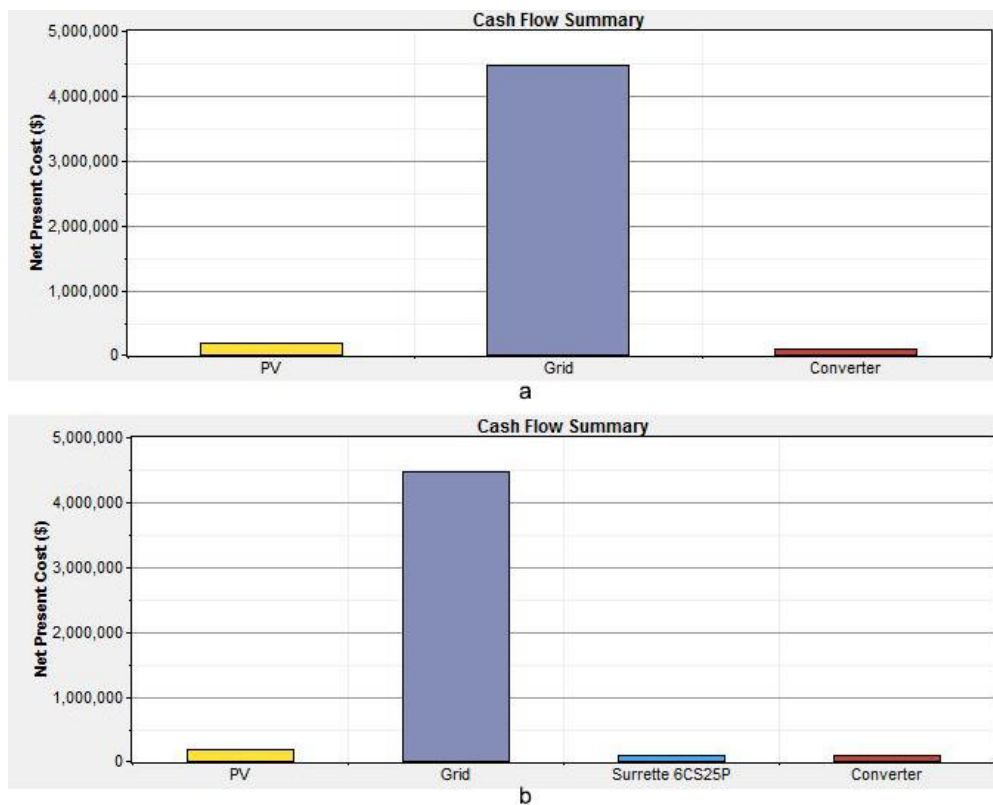


Figure 4. Cost summary comparison a) Grid-connected PV system, b) Grid-connected PV system PV system with battery storage

The estimated salvage for both systems is in year 25. The average operation cost for both systems is \$ 360,000/ year. Both systems has replacement cost for inverter charged at year 10 and year 20. However, for grid-connected PV-battery system has replacement cost for battery scheduled at year 12 and 24. Since PV system has total lifetime of 25 year, only capital cost was considered.

The electrical productions for PV only system and PV with battery storage are similar. However, the comparison of system with PV generations and battery only system is shown in Figure 5. The PV system contributes 75, 513 kWh/year of generations from a total generation of 3,610,057 kWh/year. All optimal configurations do not have any excess electricity or unmet electric load.

The grid energy purchased for PV only system is \$ 3,534,544. Meanwhile, the energy purchased for PV-battery system is \$ 3,534,239. Both systems does not have any energy sell to the grid. Table 3 illustrates the total emission for each pollutant. The results show slightly lower CO<sub>2</sub> emission for grid-connected PV-battery system compares to grid-connected PV system.

Table 3. Total emissions for pollutants

Pollutant	Emission (kg/year)	
	Grid-connected PV system	Grid-connected PV-battery system
Carbon dioxide	2,233,832	2,233,639
Carbon monoxide	0	0
Unburned hydrocarbons	0	0
Particulate matter	0	0
Sulfur dioxide	9,685	9,684
Nitrogen oxides	4,736	4,736

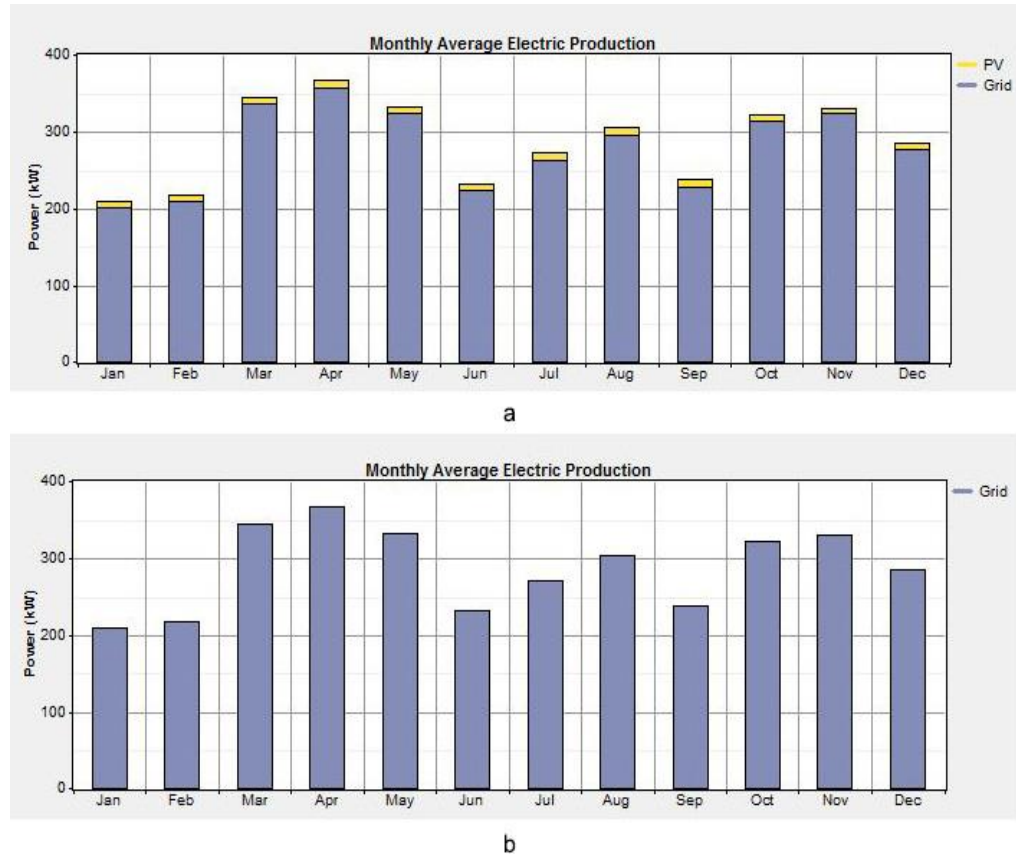


Figure 5. Monthly Electric Production a) PV integrated system b) Battery only system

### 3.4. Sensitivity Analysis

The sensitivity analysis was conducted to determine the output sensitivity towards variable changes. The sensitivity variables defined in this study is the annual average load profile. There were three values of annual average load defined in HOMER to simulate both increment and decrement of student occupation in the campus. The multiple average load values are 6,920 kWh/day, 9,886 kWh/day, 12,852 kWh/day and 14,829 kWh/day. The variation of loads simulates 30 % drops of student occupancies alongside 30 % and 60 % rise of student population from nominal load of 9,886 kWh/day. The variation of load profile versus total NPC and grid purchases is shown in Figure 6. The total NPC as well as grid purchases will increase as the load profile increases in the future. However, the PV system sizes does not vary where additional energy demand will be fulfilled by the grid only. Therefore, PV system size limited to 50 kW only for the campus microgrid.

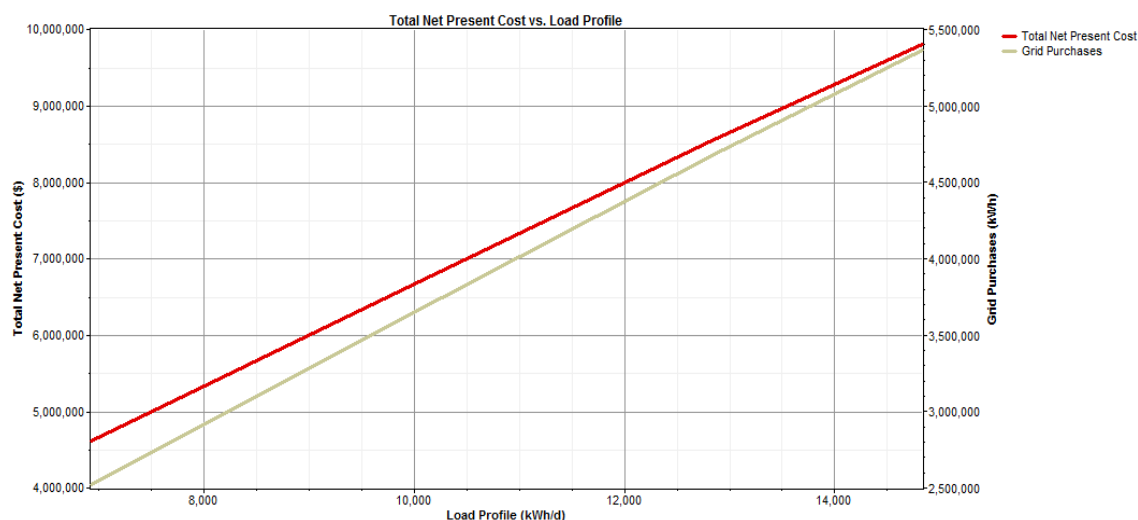


Figure 6. Sensitivity analysis total NPC against load profile variation.

#### 4. CONCLUSION

There are two optimal systems for the campus microgrid based on techno-economic analysis in HOMER. The most optimal system is grid-connected PV system followed by grid-connected PV system with battery storage. Both systems show promising results in mitigating grid dependency but have discrepancy in renewable energy contribution. Although, PV system with battery storage have higher initial capital, NPC and COE compared to PV only system, it does provide less CO<sub>2</sub> and higher RE penetration. Hence, both systems should be considered as the best option for PV system installation at this site.

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