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Battery System Sizing for 6.9 MW_p Grid-Connected Photovoltaic System in UTHM

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Abstract: Renewable energies, such as photovoltaic system (PV) has recently gained popularity in the electrical industry. However, the fluctuating energy demand appears to have resulted in expensive electricity bills. Peak shaving is the most effective method for managing power bills for on-demand users and is used to eliminate short-term demand peaks that result in bigger demand peaks. Therefore, by using battery energy storage systems (BESS) for grid storage can reduce the wastage of electrical energy produced and improve efficiencies. The purpose of this project is to simulate a GCPV system located in Universiti Tun Hussein Onn Malaysia, Parit Raja and proposed a suitable battery storage system by using PVsyst software. Comparative studies of the two different strategies such as self-consumption (Selco) with and without battery energy storage have been carried out. Finally, the finding shows that solar power with battery storage is the best way to achieve the best performance. The battery itself does not cause pollution and does not affect business operations. They make solar energy beneficial to more customers, which in turn creates further savings.

Keywords: GCPV, Battery Energy Storage, Self-Consumption (Selco)

1. Introduction

Solar PV systems are being built at a faster rate than before. By the year 2050, global electricity consumption is expected to reach 73,000 TWh with an annual growth rate of 3.1% and will continue to increase at a drastic rate [1]. Currently, solar PV is at the forefront of the renewables transition due to the better performance, cheaper PV panel production costs, and simplicity of installation compared to other renewables [2]. To achieve the Sustainable Development Goals (SDGs), a battery will be added to the GCPV system to store excess energy and thus, avoiding energy wastage. Batteries are an increasingly used storage technology due to their location flexibility, scalability, and maintenance-free operation. In combination with energy management (EM) strategies, battery self-consumption photovoltaic solar power generation, BESS also benefits the energy system by helping to balance electricity demand and supply on the demand side in sophisticated ways [3]. BESS can offer a variety of cost-saving services and is now becoming an increasingly profitable investment [4]. Furthermore,

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battery ageing is a recognized important characteristic and depends on operation incentives, climate conditions, and other contextual factors [5].

In particular, the potential for power saving, longevity, and reduction of CO_2 emissions are emphasized. However, utility bills for large consumers of electricity in business, education, and industry can form a significant part of monthly electricity bills [6]. According to the National Renewable Energy Laboratory (NREL), capacity charges often account for 30% to 70% of customers' electricity bills [7]. During the Covid19 pandemic, energy demand seemed to have had some nasty ups and downs, resulting in high electricity bills.

From the problem posed before, the most effective way to manage utility bills for on-demand customers is called peak shaving. Peak shaving actively manages cumulative demand to eliminate short-term demand peaks that lead to higher peaks. This process reduces and smoothed peak loads and reduces the overall cost of service charges. Solar power with battery storage is the best way to achieve the best performance [8].

The objective of this study is to simulate the performance of a GCPV system built on the rooftop of Universiti Tun Hussein Onn, Malaysia with and without battery energy storage. The study includes monthly and annual evaluations based on various performance indices such as the capacity factor (CF), performance ratio (PR), system efficiency, array yield, final yield (YF) and system losses. Besides that, on this examination, we can decide appropriate power storage (BES) for the system under the self-consumption scheme. Finally, a model based on the important parameters impacting the performance of the GCPV system was constructed, statistically analyzed, and tested. This targeted approach has the potential to change the perspective for evaluating the performance of solar PV installations.

Therefore, in this study, a solar PV system was designed to analyse the target yield, PR, and environmental performance of a 6.9 MWp GCPV system at Universiti Tun Hussein Onn, Malaysia using real climate conditions. The performance analysis of the installed GCPV system was carried out using real-time meteorological data for 2021 and in accordance with the MS IEC 61724:2010 developed by SEDA. Aside from that, suitable battery sizing for the whole system will be evaluated. A model based on the important parameters impacting the performance of the GCPV system was constructed, statistically analysed, and tested. This targeted approach has the potential to change the perspective for evaluating the performance of solar PV installations.

2. Materials and Methods

The International Energy Agency methodological approach and execution for GCPV system simulation were followed (IEA). The study's principal implementation is in the form of performance evaluation and battery energy storage design using PVsyst software. In this project's research, all materials will be defined depending on their utility.

2.1 PVsyst software

PVsyst software was utilized in achieving the objectives. PVsyst software is a technology for discovering, simulating, and interpreting both off-grid and grid-connected PV systems. This software is ideal for designing solar applications. PVsyst on the other hand generates both data by implementing theoretical model calculations. Depending on the availability of the system database, the user can easily set the system input such as PV panels, inverters, or even batteries in accordance with the system manufacturers.

2.2 GCPV system sizing using PVsyst

When selecting a PV system, size is a key factor to consider. Figure 1 shows the method used to determine the batter size for the GCPV system. To obtain the appropriate battery size, the user must select the manufacturer of the solar panel, the type of battery, and the charge controller. The system design will be undersized or large if the input parameter is not identified. It appears that it will have a negative impact on future solar cell use and result in economic waste.

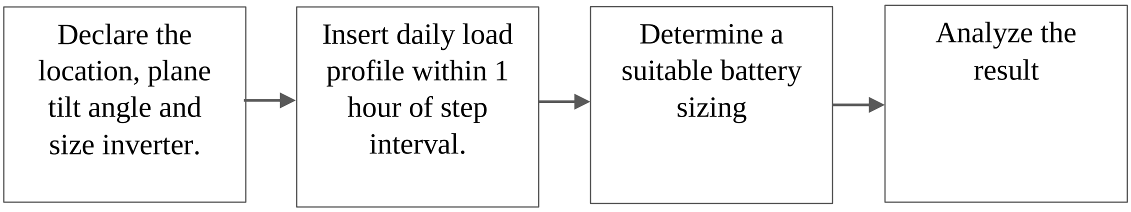

Figure 1: Procedures for battery sizing

2.2.1 Geographical coordinates for the site location

A 6.9 MWp GCPV system was installed on the rooftop of Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja with a latitude of 1.86°N and a longitude of 103.08°E. There are 25 locations allocated to 6.9MWp. Performance analysis will be conducted for the whole system size. This study was conducted based on actual meteorological data as well as geographical location. Both data were imported from Metronome, which is widely available on the internet and provides the data for any location in the world. Therefore, meteorological data such as electricity production, global solar irradiance, and ambient temperature were imported and utilized in both case studies of GCPV systems with and without batteries.

2.2.2 Tilt angle for PV module

Figure 2 shows tilt and azimuth angles are important parameters in determining the performance of a PV system. The GCPV system orientation and tilt angle were set to 5° and the azimuth angle is 0. To clarify, in both case studies for GCPV systems with and without battery, the type of solar panel and the tilt angle were identical.

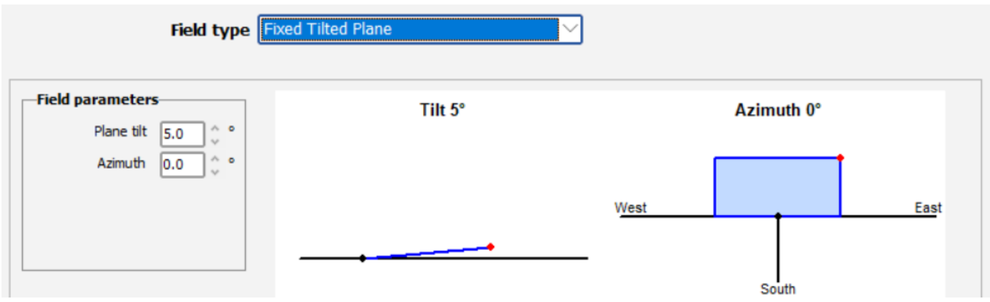

Figure 2: Fixed tilt solar panel

2.3 Energy load demand

Load estimation is done by listing all loads and calculating the average daily consumption for the system. Therefore, before estimating the required energy produced by loads, it is necessary to consider the operating time for load consumption. A formula for calculating the energy required per day [9].

$$E_{loadi} = N \times P \times h \quad \text{Eq.1}$$

where E_{loadi} is the energy demands of the estimated loads, N is the quantity of loads, P is the power rating of loads, h is usage hours per day of the loads.

$$E_t = \sum_{i=1}^{n} E_{loadi} \quad \text{Eq.2}$$

where E_t is the algebraic sum of energy demands, i is the lower bounds of summation and n is the upper bounds of summation.

2.4 GCPV system algorithm

According to the International Energy Agency (IEA), there are various parameters were developed for analyzing the performance of GCPV systems. The performance indices were defined as final yield, performance ratio, capacity utilization factor, system efficiencies, and system losses, environmental and economic analysis. These parameters will automatically be generated by using PVsyst software.

2.4.1 Battery Bank sizing

In order to determine the battery size, we must first determine how long the battery can supply the source before it drains. Eq. 3 presents the equation for the battery's capacity in Ah [4].

$$B_{cap} = \frac{E_t \times AD}{V_{DC} \times DOD \times \eta} \quad \text{Eq.3}$$

where, B_{cap} is battery capacity in Ah, E_t is total energy demands, AD is the autonomous day, V_{DC} is the nominal voltage of the battery, DOD is the depth of discharge for the battery and η is the efficiency of the battery.

2.4.2 System yield

In general, yields indicate the amount of energy (kWh) produced for every kWp of module capacity typically over the year. System yield can be divided into two where final yield (Y_F) and reference yield (Y_R). The final yield, (Y_f) is defined as the total AC energy generated by the PV system over a specified period divided by the installed PV system rated output power. It indicates how many hours per day the PV system must run at full power to produce the same amount of measured energy [10].

$$Y_f = \frac{E_{AC}}{P_{PV,rated}} \quad \text{Eq.4}$$

where E_{AC} is total AC energy generated from PV system in kWh and $P_{PV,rated}$ is the output power of the system in $kW_{p.}$

The reference yield, Y_R can be calculated as follows:

$$Y_R = \frac{H_T}{H_R} \quad \text{Eq.5}$$

2.4.3 Performance Ratio

Performance ratio, (PR) describe the quality factor that measures the performance of the PV system. The measured performance ratios can be calculated using the formula [1]:

$$PR = \frac{Y_f}{Y_r} \times 100\% \quad \text{Eq.6}$$

where Y_f is the final yield and Y_r is reference yield, both are in kWh/kWp. These parameters are depending on the location of the system.

2.4.4 Capacity utilization factor

The capacity utilization factor, (CUF) is a method of presenting the energy delivered by an electric power generating system [1]. The annual capacity factor of the PV system is given by the equation below:

$$CUF = \frac{E_{AC}}{P_{PV,rated} \times 365days \times 24hours} \quad \text{Eq.7}$$

where E_{AC} is the total AC energy generated from the PV system in kWh and $P_{PV,rated}$ is output power of PV system in kW_p.

2.4.5 Array and system energy losses

The array operation losses, L_A which highlight the array's inability to fully utilize the available irradiance [11]. The difference between the reference yield and the array yield is the array capture losses. The equation is as follows:

$$L_A = Y_R - Y_A \quad \text{Eq.8}$$

where, Y_R is reference yield and Y_A is the array yield.

The system losses, L_S are caused by the inverter losses in converting the DC power output from the PV to AC power [11]. It is written as follows:

$$L_S = Y_A - Y_F \quad \text{Eq.9}$$

where, Y_A is the array yield in kWh/kWp and Y_F final yield in kWh/kWp.

2.4.6 Environmental Analysis

The emission of Carbon dioxide, CO_2 were evaluated by considering environmental factors. The average CO_2 factor in Malaysia is 0.585 tCO_2/MWh [12]. Thus, amount of carbon dioxide that was saved on an annual basis was calculated:

$$CO_2 = 0.585 \times E_{AC}\ (metric\ tons) \quad \text{Eq.10}$$

where, E_{AC} is Total AC energy generated from the PV system, (kwh).

3. Results and Discussion

This chapter presents the study's analysis. The PV software was used to produce the result. Meteorological data, energy yield, performance ratio, system efficiency, and losses were all examined. Then, a comparison study of GCPV systems without and without batteries was presented.

3.1 Meteorological data analysis

Table 1 shows the annual average solar irradiation and other performance parameters at the site monthly. The average solar irradiation was 1645.6 kWh/m^2. The highest solar irradiation was 160.0 kWh/m^2 in March, and the lowest was 115.5 kWh/m^2 in December. Malaysia is said to have two peak seasons, one during the rainy season (December - February) and the other during the summer season (June - August). It can be verified based on the simulated results because the lowest value of solar radiation occurred during the rainy season, while the highest value occurred during the dry summer period.

Table 1: Monthly average performance parameters

Month	GlobHor kWh/m^2	T_Amb °C	GlobEFF kWh/m^2
January	141.4	26.57	141.8
February	148.6	27.07	148.0
March	160.0	27.39	156.4
April	143.4	27.31	137.8
May	139.5	27.99	131.8
June	125.1	27.41	117.8
July	138.2	27.41	130.2
August	142.5	27.26	136.3
September	137.4	26.81	133.5
October	136.3	27.26	134.2
November	117.9	26.49	117.3
December	115.5	26.67	115.4
Year	1645.7	27.14	1600.5

3.2 Comparison of GCPV system with and without battery storage

The comparison of system sizing under both conditions is shown in

Table ***2***. Technically, the PV panel and inverter utilised are the same. The only difference between this system and others is the presence of a battery. As a result, from the PVSYST software simulation, a reasonable total number of batteries is required for the system. The battery offered is a lead-acid battery. In addition, the battery must be able to hold an electrical charge for 5 days. The photovoltaic battery must have a sufficient power supply for charging and charging the battery. Based on the result, the minimum rejection (SOC) achieved was 20%. The SOC tells the user how long the battery can last before it needs to be charged or replaced.

Table 2: System sizing comparison

Description	GCPV without battery	GCPV with battery
PV model	TSM-DE18M-(II)-480	TSM-DE18M-(II)-480
Modules	757 strings × 19 in series	757 strings × 19 in series
Mounting type	Fixed Tilt	Fixed Tilt
Nominal power (W_p)	480	480
Number of PV modules	14383	14383
Nominal Power (STC), (kWp)	6904	6904
Voltage at Pmpp, (Vmpp)	727	727
Current at Pmpp, (Impp)	8631	8631
Module area, (m^2)	34365	34365
Inverter Model	SUN2000-100KTL-M1-480Vac	SUN2000-100KTL-M1-480Vac
Nominal power (kWac)	100	100
Number of inverters	54	54
Total power (kWac)	5400	5400
Operating voltage (V)	200 - 1000	200 -1000
Pnom ratio (DC:AC)	1.28	1.28
Battery Model	__	BAE Secura Block Solar 12V 3 PVS 210
Number of batteries	__	200 in series ×100 in parallel
Min. Discharging SOC, (%)	__	20.0

Stored energy, (kWh)	__	32064
Voltage, (V)	__	2400
Nominal Capacity, (Ah)	__	16700

3.5 Comparison of performance ratio and energy production

A comparison between a GCPV system with energy storage and a GCPV system without energy storage is shown in Table 3. System performance, annual energy output, and credibility in storing surplus energy are among the components that will be assessed.

Table 3: Comparison of GCPV performance with and without a battery

Type	GCPV system without Battery	GCPV system with Battery
Performance Ratio (%)	77.77	77.93
Yearly energy production (GWh/year)	9.0	8.8
Energy injected to grid (GWh/year)	8.817	-
Energy to user (From solar)	Unlimited	8843 MWh
Energy to user (From grid)	-	28439
Stored energy	-	32064 kWh

Based on the table above, the performance ratio differs slightly in both situations. GCPV systems with batteries outperform GCPV systems without batteries. According to NREL, the usual performance ratio for a new PV system is only 77%, and the system's performance is expected to deteriorate with time. Next, when the GCPV is not connected to the battery, the total annual energy produced by the system is greater. The dissipation of the energy produced can be caused by battery degeneration. Furthermore, the amount of energy exported to the grid varies greatly. While the system is disconnected from the battery, 8817 MWh/year is exported to the grid, but no energy is injected into the grid when the system is linked to the battery. Since power is generated for self-consumption, and any surplus cannot be sent to the grid.

3.6 Comparison of system losses

Table 4 presents a comparison of system losses between GCPV systems with and without batteries. According to the table, the difference between the two systems is minor. However, energy injected into the user in a GCPV system with a battery was determined to be more than energy injected into the user in a GCPV system without a battery. The greater the system losses, the less energy generated. As a result, losses in GCPV systems without batteries are larger than losses in GCPV systems with batteries.

Table 4: Comparison for system losses

Description	GCPV system without Battery	GCPV system with Battery
Global incident in coil plane, (%)	0.10	0.12
IAM factor on global, (%)	2.60	2.62
Module degradation loss, (%)	3.80	3.80
PV loss due to irradiance, (%)	0.80	0.83

PV loss due to temperature, (%)	9.50	9.54
Light induced degradation, (%)	2.00	2.00
Mismatch loss, (%)	3.90	3.80
Ohmic wiring loss, (%)	1.00	0.97
Inverter loss, (%)	1.60	1.57

3.7 Comparison between environmental analysis

Table 5 compares the environmental impact of GCPV systems with and without batteries. Therefore, the total generated emission in the GCPV system with battery is more than the total generated emission in the GCPV system without battery. Carbon emissions have a tremendous impact on the world since they are the GHG with the greatest amounts of emissions in the atmosphere. As a result, a larger number of tCO_2 is bad for the ecosystem which contributes to global warming and climate change.

Table 5: Comparison in the emission system lifespan

Item	GCPV system without Battery	GCPV system with Battery
Module ($kgCO_2/kWp$)	1713	1713
Supports ($kgCO_2/kg$)	4.40	4.40
Inverters ($kgCO_2$/Units)	436	436
Total generated emission, (tCO_2)	138994.9	139274.4

4. Conclusion

To conclude, all objectives had been proven successful. A GCPV system performance with and without battery energy storage located at Universiti Tun Hussein Onn, Malaysia was determined. This project's findings and approach clearly explain how a solar PV plant functions in real life. PVsyst was used to successfully simulate the GCPV system. Therefore, the system is working well since the performance ratio reached 77%, which is standard in a new performance ratio. Following that, the second aim was effectively determined. According to the findings, the battery type BAE Secura with a nominal voltage of 12V and a capacity of 167Ah is the best size for storing excess energy. Therefore, 32064.0kWh of energy may be conserved while also reducing power waste. Finally, a comparison of GCPV connected to the battery and GCPV disconnected from the battery was performed. Both conditions offer advantages and disadvantages. However, because it is self-consumption, a GCPV connected to a battery cannot export energy to the grid. Thus, without energy storage, the system will lose over 3000kWh of generated energy.

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