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COST-EFFECTIVE ENERGY MANAGEMENT SYSTEMS STRATEGY IN OPTIMIZATION OF PHOTOVOLTAIC FOR GRID-CONNECTED SYSTEM

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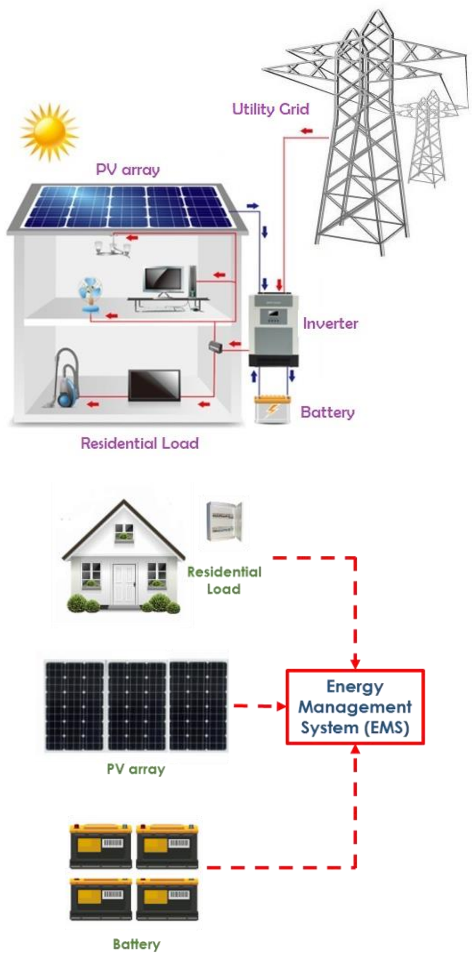
Graphical abstract



Abstract

Renewable Energy Source (RES) based Distributed Generation (DG) like Photovoltaic (PV) is widely integrated into the distribution network, particularly for residential. With proper planning, the installation of optimal PV in the network is capable of minimizing the dependency on the power grid generation. However, the optimum use of solar energy has been limited by the weather and the load variation. At the particular time, the generated PV output is not fully utilized during the minimum load. The excessive generation of PV power occurs and causes an increase in the cost of electricity consumption. Therefore, the purpose of this paper is to optimize the PV size for the grid-connected system considering the Battery Energy Storage System (BESS) and the proper Energy Management System (EMS) Strategy in order to reduce the grid power consumption. BESS is introduced to store the excess PV power generated during peak hours, while the cost-effective EMS strategy is proposed to ensure the RES is fully employed. The number of PV panels is optimized using Particle Swarm Optimization (PSO) technique. The implementation of PSO in optimising PV size can reduce the number of PV panels by 21% compared to the conventional method.

Keywords: Renewable energy, PV generation, energy management system, optimization, energy storage system

Abstrak

Penjana Teragih (DG) berdasarkan Sumber Tenaga Diperbaharui (RES) seperti Fotovoltaik (PV) disatukan secara meluas ke dalam rangkaian pengedaran, terutama untuk kediaman. Dengan perancangan yang tepat, pemasangan PV optimum dalam rangkaian mampu meminimumkan pergantungan pada penjanaan grid kuasa. Walau bagaimanapun, penggunaan tenaga suria yang baik telah dibatasi oleh cuaca dan variasi beban. Pada masa tertentu, output PV tidak digunakan sepenuhnya ketika beban dalam keadaan minimum. Penjanaan tenaga PV yang berlebihan berlaku dan menyebabkan kenaikan kos penggunaan elektrik. Oleh itu, tujuan jurnal ini adalah untuk mengoptimumkan saiz PV untuk sistem yang disambungkan ke grid dengan mempertimbangkan Sistem Penyimpanan Tenaga Bateri (BESS) dan Strategi Sistem Pengurusan Tenaga (EMS) yang tepat untuk mengurangkan penggunaan kuasa grid. BESS diperkenalkan untuk menyimpan lebihan kuasa PV yang dihasilkan pada waktu puncak, sementara strategi EMS yang menjimatkan kos dicadangkan untuk memastikan RES digunakan sepenuhnya. Bilangan panel PV dioptimumkan menggunakan teknik pengoptimuman Kumpulan Zarah (PSO). Pelaksanaan PSO dalam mengoptimumkan saiz PV mampu mengurangkan bilangan panel PV sehingga 21% berbanding kaedah konvensional.

Kata kunci: Tenaga boleh diperbahrui, penjanaan PV, sistem pengurusan tenaga, pengoptimuman, sistem penyimpanan tenaga

1.0 INTRODUCTION

The penetration of photovoltaic (PV) technology into the distribution network receives high attention among several Renewable Energy Sources (RES) due to the clean, quiet, highly efficient and requires low PV module cost [1][2]. The deployment of PV is capable of reducing the high dependency on the power grid. In the distribution network, the PV system is commonly implemented using two types of feeding methods, either the Direct Feed or the Indirect Feed. The Direct Feed feeding system is the system adopted in the Feed-in-Tariff (FiT) where the connection point is located at Distribution Licensee's Grid. In 2016, Net Energy Metering (NEM) scheme is introduced in Malaysia to improve the FiT scheme. The NEM scheme adopted an indirect approach where the connection point is located within the consumer system without connecting to the Distribution Licensee's Grid directly [3] as shown in Figure 1. Throughout this scheme, the customer will consume first the energy produced by PV and any excess energy will be exported to the electricity utility.

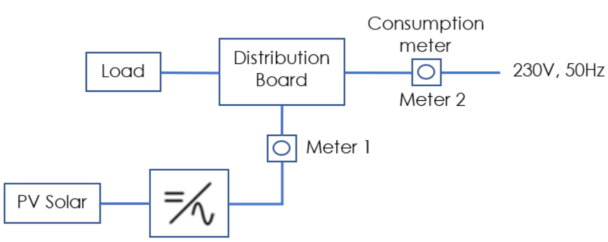


Figure 1 Indirect feed connection system

Due to the advantages of PV, many researches are conducted on the PV solar distributed generation (PV-DG) sizing and allocation. An inexpensive and fast method that provides the most accurate solution is required in PV planning. Thus, the metaheuristic optimization methods are preferable with different objectives as carried out in references [4][5]. Authors in [4] concentrated on planning the PV-DG locations in distribution networks using biogeography-based optimization algorithms by utilising loss reduction sensitivity factors with varying load variations and bus voltage limits. Paper [5] proposed an optimization application for the location and size of renewable DG units via the firefly algorithm in order to minimise losses and boost the voltage profile while increasing the overall system's efficiency and dependability. Paper [6] suggested Flower Pollination Algorithm (FPA) to reduce power loss, increase voltage profile, and increase power supply by optimizing PV locations and sizes. While authors in [7] addressed optimal PV planning including the PV position and its capacity in order to minimise the power losses and improve the voltage profiles as well as a power factor. They also comply with the technical aspects using Particle Swarm Optimization (PSO) algorithm. The other advantage of the metaheuristic optimization method is, that method can provide effective solutions in solving problems that require dynamic and restrictive handling [8].

Nevertheless, papers [4]-[7] did not take into account the nature of PV output power and the inability to use its power during the night peak hours in their PV size optimization planning. The different pattern between residential energy consumption and PV production is the main challenge and it has prevented the optimal utilization of solar energy [9]. In a residential area, the electricity consumption is low during peak PV production time, which is during the day. Consequently, for the Indirect feed method, excessive PV power is generated and it flows into the grid hence a large amount of energy from the grid is still required to meet the demand [10]. This matter is a part of concern to be considered to ensure the benefits can be realized.

Therefore, the Battery Energy Storage System (BESS) is a valuable solution for this major issue as introduced by authors in [11]-[13]. The BESS is integrated into the PV system to store excessive PV power. The optimal utilization of PV power output can be achieved while gaining economic benefits from the operating system [14]. However, the generated electricity from the grid during peak consumption hours is still not addressed in their study.

In the context of BESS installation, the accurate State of Charge (SoC) and an effective charge/ discharge monitoring process, and their regulations are the main factors to be emphasized. The authors [15] state that the effective maximum and minimum SoC levels are 95% and 40%, respectively. However, this study has limitations. Reducing battery usage has increased the overall cost of the system, even though it can maximize the battery life [16].

To manage the BESS effectively, a proper strategy of the Energy Management System (EMS) becomes an essential component [17]. The EMS is required to monitor and control the energy flow while satisfying the load requirement and optimum use of BESS in to achieve the target objective like the minimum electricity grid. The PV output variations, the grid status and the battery SoC are to be addressed in the monitoring and controlling process. Authors in references [15],[18]-[20] emphasized the use of EMS for the PV grid-connected system with BESS in a residential area. However, the detailed BESS criteria in Energy Management System (EMS) for PV generation is not adequately discussed.

Authors in references [21][22] propose a framework for coordinating day-ahead optimization planning and real-time operation of energy storages to supply designated power to the grid during peak-load hours. Regrettably, these current strategies did not consider the future nature of RES and does not forecast electricity generation under various weather conditions. Considering the abovementioned issues, several factors need to be addressed in the PV-based DG optimization planning. While the BESS and EMS are important, they are not properly planned in any previous studies in RES optimization planning.

Hence, the main objective of this paper is to optimize the number of PV panels for grid-connected PV systems considering BESS and EMS strategy, in order to reduce the electricity grid consumption. The battery is introduced to store the excessive PV power while the cost-effective EMS strategy is proposed. The EMS strategy takes energy consumption and economic analysis into consideration. Thus, it is able to increase energy efficiency and maximize energy saving [23]. The optimal PV size is determined using the PSO algorithm. This is due to the capability of PSO to optimize the solution faster and provide a high efficient solution for dynamic and constraint problems compared to Genetic Algorithm (GA) and other conventional algorithms [21][24].

The paper is organized as follows: Section 2 presents the methodology; Section 3 describes the result and discussion. While, Section 4 concludes the study.

2.0 METHODOLOGY

2.1 Eco-Effective Ems Strategy

The EMS is responsible for monitoring and regulating the generated PV electricity, the SoC battery, the load power and the energy consumed from the grid. EMS has predicted and provided long-term availability and overall energy generation of RES to fulfil the demands of consumers within the grid-connected system [8]. To control load demand and power flow within the grid connection, RES was designed. The EMS structure of this paper which is focusing on the Indirect Feed System of PV residential generation hybrid with BESS is shown in Figure 2. Solar PV has provided energy to the BESS and supplied energy for residential loads through the inverter [25]. BESS is also connected to the hybrid inverter and has stored energy from solar PV panels or discharged for load demand. Thus, residential loads are supplied by the grid, solar PV, or a BESS.

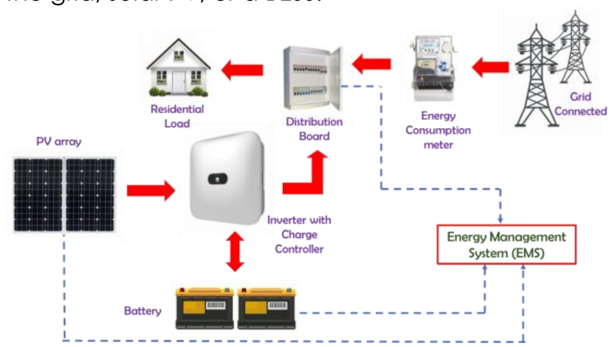


Figure 2 The PV residential generation hybrid with BESS

Figure 3 shows the flowchart for the implementation of the EMS strategy for this system. The flowchart describes the step-by-step process of energy distribution and it is repeated every hour in a week which gives 168 repetitions in total.

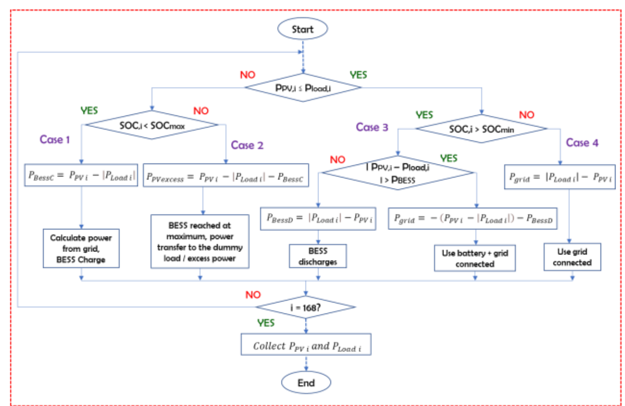


Figure 3 Energy management flowchart

The primary goal is to provide the load with PV and BESS as much as possible. Thus, the condition of PV power and load status is assessed every hour to store the excess PV power in the BESS. Despite this, battery life should be emphasized due to the high cost of batteries. As a result, the setting of the SoC level is important in the EMS strategy. Based on the flowchart, there are 4 situations for EMS strategy for various concepts that have occurred during a day. For purpose of developing an effective EMS strategy, the PV power ($P_{PV,i}$), load power ($P_{Load,i}$), SoC_i, minimum SoC (SoC_{min}), and maximum SoC (SoC_{max}) at each hour i are all evaluated. The following instances are given:

i. Case 1, [$P_{PV,i} > P_{Load,i}$ and $SoC_i < SoC_{max}$]: The PV power exceeds the load power at hour i, which the load is supplied by the PV power. In this case, the SoC_i at that hour is less than the maximum SoC, allowing for the excess PV power to charge the BESS. SoC is monitored hourly until it exceeds the maximum SoC value.

ii. Case 2, [$P_{PV,i} > P_{Load,i}$ and $SoC_i \geq SoC_{max}$]: For this case, due to the PV power being greater than the load power at hour i, the PV power is used to supply the load. When the SoC_i is greater than the maximum SoC, it indicates that the BESS has reached its maximum capacity. Therefore, there is an excess of PV power.

iii. Case 3, [$P_{PV,i} \leq P_{Load,i}$ and $SoC_i > SoC_{min}$]: When the PV power is less than the load power and the SoC value is greater than the minimum SoC at hour i, there are 2 possibilities, first, the BESS will supply to the load or second, BESS uses the available capacity along with the grid to supply the load. The amount of excess PV power remaining after it has been supplied to the load is determined to be either greater or less than the SoC at that hour.

iv. Case 4, [$P_{PV,i} \leq P_{Load,i}$ and $SoC_i \leq SoC_{min}$]: In this case, the PV power is less than the load power and SoC at that hour is less than the minimum SoC at hour i. This shows the BESS at minimum state does not able to supply the load. Thus, the load is supplied by the grid.

To prevent battery degradation, the minimum SoC should be at 20%-30% and the battery efficiency at 90% [26]. In this paper, SoC_{min} and SoC_{max} are equal to 20%-30% and 90% respectively as shown in Equation 1 and Equation 2.

$$SoC_{min} \leq SoC_i \leq SoC_{max} \quad (1)$$

$$20\% - 30\% \leq SoC_i \leq 90\% \quad (2)$$

2.2 PV Power

PV output power is calculated on an hourly basis because of the difference in radiation where the weather does not remain constant for 24 hours. In this study, the daily irradiation data is collected for 1 year from a solar farm in Pasir Mas, Kelantan and the PV output power is determined using Equation 3. Figure 4 shows the variation of PV power for a week.

$$P_{PV}(kWh) = \frac{\text{irradiation } (Wh/m^2)}{1000\ (W/m^2)} \times \text{power panel (kW)} \quad (3)$$

2.3 Load Variation

The one-year hourly load demand at residential in Shah Alam is collected and processed. Load data was taken from a smart meter study of a residence in Shah Alam Selangor Malaysia.

2.4 BESS Capacity

The amount of storage capacity that should be delivered to the load is very important to be determined. The BESS capacity is necessary to store excess PV power during peak-hour PV and supply to the residential load throughout the off-peak hours of PV. Therefore, the size of the BESS is determined by the amount of load required by off-peak hour PV for one day. The off-peak hours PV are defined between hours 00:00 until 08:00 and 05:00 until 23:00. In calculating the BESS capacity, the day that has the lowest solar irradiance is selected. The total residential demand when the off-peak hours of PV power production of that day are 30 kWh. Hence, the battery capacity, C_{BESS} used in this paper is 780 Ah with a voltage of 48 V.

2.5 Problem formulation

In this paper, the variable to be optimized is a number of PV panels in order to obtain minimum power generated from the grid while satisfying operational constraints.

A. The total power generated from the grid is calculated using Equation 4.

$$f = \min \sum_{i=368} P_{grid,i} \quad (4)$$

Where :

$P_{grid,i}$ = Output power from the grid at hour i

B. Power balance constraint is satisfied using Equation 5.

$$\sum P_{Load,i} - P_{PV,i} - P_{BESS,i} - P_{grid,i} = 0 \quad (5)$$

C. The Power limit of PV size is set to between 1 kW - 40 kW.

2.6 Implementation of PSO in Optimizing PV Size Considering EMS Strategy

The focus of this study is to optimize the number of PV panels considering EMS by using the PSO approach. The size of BESS is predetermined since the application of BESS in a grid-connected system is not crucial as in an off-grid system. The implementation of PSO is the best method for minimizing the electricity consumption from the grid. The PSO algorithm depends on the segment of the population to identify the optimum solution [27][28]. This PSO optimizes the efficiency of predicting uncertainty and was used for optimization problems as part of this paper. The key steps are summarized in the algorithm below [29][30]:

Step 1: Define Objective Function
Step 2: PSO Parameters
Step 3: Initialization of Position and Velocity
Step 4: Function Evaluation (EMS Strategy)
Step 5: Compute pbest and gbest
Step 6: Update Particle Velocity and Position
 Handling Boundary Constraints
Step 7: Store Best Value

The EMS is PSO-based and is applied to optimize the number of PV panels while managing the energy transfer from PV solar, BESS and the main grid to the load demand. Figure 4 shows the flowchart of PSO implementation. EMS is applied in the optimization problem after the initialization of the parameter and swarm position has been ascertained. PV panels of varying sizes will be selected at random from a predefined range and will generate PV power. Power comparisons are evaluated hourly as in an EMS flow chart for PV power, load power and current SoC. The power grid consumption has been calculated based on the fitness of each particle. After updating the particle velocity and position to store the best value, PSO will provide the optimal PV size.

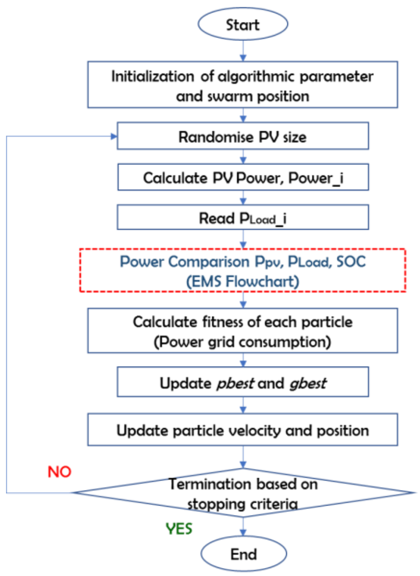


Figure 4 PSO flowchart

3.0 RESULT AND DISCUSSION

In this section, the 24 hours analysis is firstly carried out to observe the impact of three different weather conditions which are sunny-day, cloudy-day and rainy-day on PV power output production, power generated from the grid and the soc of the BESS. After that, the analysis of 168 hours is conducted. In addition, the impact of adjusting the SoC level in the EMS strategy on electricity grid consumption cost is investigated. Next, the effectiveness of the implementation PSO based EMS in optimizing the PV size is examined by applying the result obtained in designing the PV panel configuration. The PV panel configuration based on PSO is then compared to the configuration designed using the method approved by Malaysia Sustainable Energy Development Authority (SEDA).

3.1 PV Power Output for Different Weather Conditions

The collected irradiance data for 1 year is processed and is divided into three conditions, which are sunny-day, cloudy-day and rainy-day conditions. The sunny day is chosen based on the day that has the highest irradiance in a year and the day with the lowest irradiance is represented as a rainy day. While the day with mean irradiance is selected to express a cloudy day. Hence, the irradiation samples of 14 March 2020, 14 July 2020 and 1 December 2020 are utilized to represent PV power output during a sunny day, cloudy day and rainy day, respectively. Figure 5 illustrates the variation in load demand and PV output power in different weather conditions. In this case, the graph depicts the difference in peak hour PV and the peak hour of residential load. Due to the difference in peak hour, the excessive power of PV, $P_{PVexcess}$ has occurred. This shows that the EMS is necessary to ensure that PV is optimally utilized.

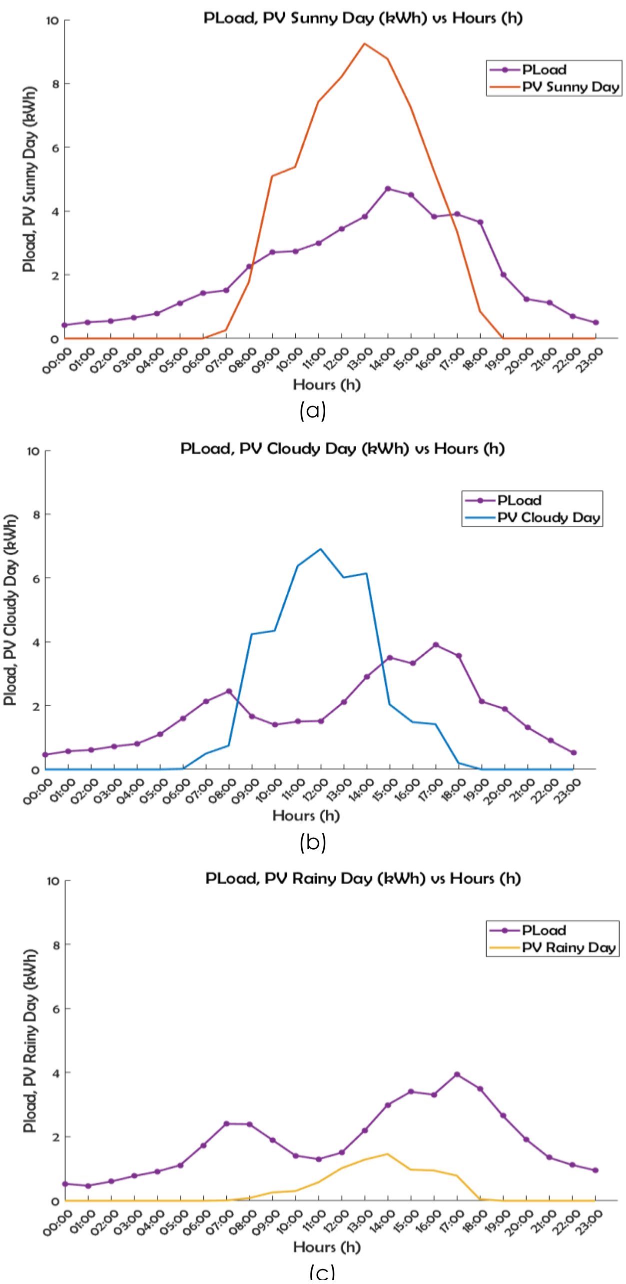


Figure 5 PV output power and load demand variations in different weather conditions a) sunny day b) cloudy day c)rainy day

3.2 Cost-Effective EMS for Different Weather Conditions

The maximum PV power generation only occurs within 4 hours, and it shows that the EMS is important for the effective and systematic control of the power flow. To analyse the impact of the EMS on energy distribution, the system is simulated for 24 hours under 3 different weather conditions. The PV output power was calculated using a sample 10 kW PV panel. For simplicity, the same size of PV panel is applied for all weather conditions.

Figure 6 shows the 24 hours energy patterns for the grid, PV, and BESS during the sunny day after the EMS is implemented.

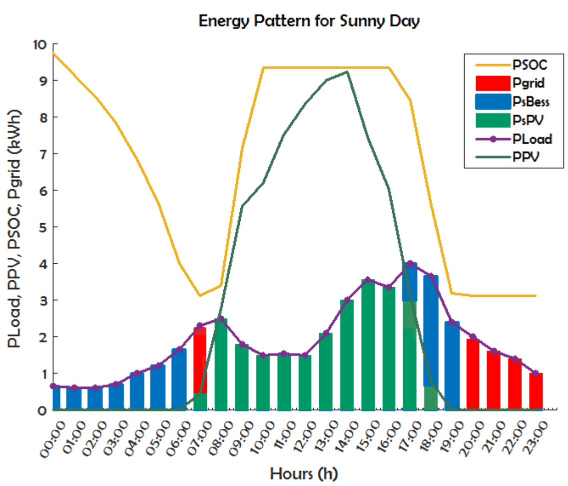


Figure 6 Energy pattern for Sunny Day

BESS capacity is initially set to 100%, considering the full capacity of BESS at the time of the commencement. Assuming that the initial SoC is 100% at t = 00:00, the BESS capacity after supplying the load is 9.75 kWh as shown in the PSoC curve. This indicates that BESS has discharged up to SoC_{min}, which is from t = 00:00 until t = 06:00, due to off-peak hour PV. At t = 07:00, the irradiation begins to increase, but not sufficient to supply the load. To meet the load requirements at that time, P_{grid} were required. According to the graph, the PV power is produced between hours 08:00 to 16:00. During this period, the PV power output is greater than the load consumption. Hence, the load is solely supplied by the PV system and the excessive PV power is used to charge the battery, which is at a SoC_{min}, 30% of its total capacity. With the EMS strategy appointed, BESS charged the battery up to its SoC_{max}, which is 90% of its capacity. During the peak hour load which is from 17:00 until 19:00, a small amount of PV output is generated. At that moment, the BESS is activated to ensure that sufficient power to the load is supplied. The BESS is discharged until it reaches the SoC_{min}. The PV power is not produced during the night peak hours, which is from 20:00 until 23:00. In addition, the BESS has reached the SoC_{min} level. Therefore, the power from the grid is utilized to supply the load.

Figure 7 illustrates the energy pattern for a cloudy day. The peak hour of the PV system is from hours 09:00 to 14:00, proving that the PV has supplied the load and the excess PV power has charged the BESS, which is in the SoC_{min} state. Even on cloudy days, BESS can still be charged to SoC_{max} guided by EMS strategy. However, because of the cloudy days, BESS was discharged earlier than usual due to low irradiation, between hours 15:00 to 17:00. It is indicated that SoC_{min} is in a fixed state at t = 18:00 and that BESS is no longer supplying the load. The grid provided power to the residential load until the hours of 23:00.

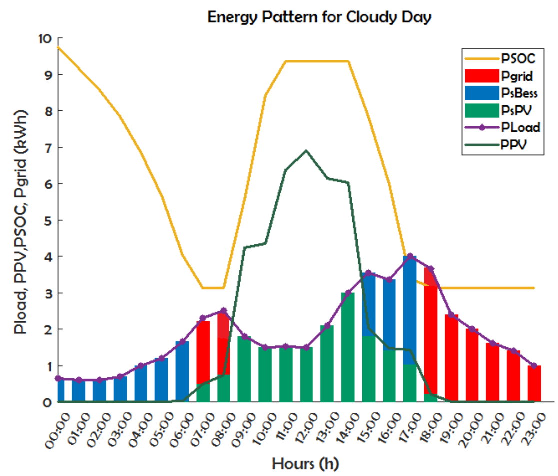


Figure 7 Energy pattern for cloudy day

The energy pattern for a rainy day is depicted in Figure 8. According to the graph, the PV power curve cannot entirely meet the load's demand due to low irradiation, electricity demand surpasses PV power. At t = 00:00, the initial SoC is 100% and BESS has discharged up to SoC_{min} at t = 07:00, which is 3.12 kWh of the BESS capacity. Due to the EMS implementation, the PSoC curve indicates that SoC_{min} is in a fixed state from t = 07:00 until t = 23:00. PV power is incapable of charging the BESS and supplying the load, power is supplied by the grid until the end of the day.

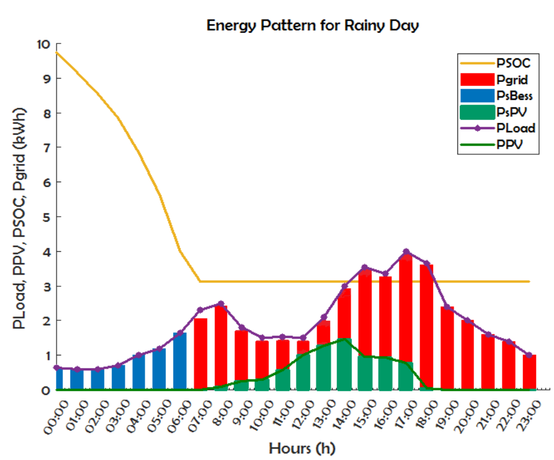


Figure 8 Energy pattern for rainy day

Table 1 indicates the summaries of EMS strategy implementation for different weather conditions. PV power produces more energy on a sunny day than it does on a rainy day, which produces only 7.74 kWh of PV power per day. The PV power is insufficient due to low irradiation; thus, grid power has been fully utilised. As a result of three weather conditions in Malaysia, rainy days were unable to give an adequate supply to the load or charge the BESS. On a sunny day, PV generated 66.45 kWh more energy than the load requirement, due to BESS inability to accommodate the excess PV, the P_{grid} was used minimally. PV can only produce 40.43 kWh for cloudy days, which is lower than the load demand. Nevertheless, the BESS can store and supply excess PV. The P_{grid} is used for fulfilling load demands which are not supplied by BESS at peak load hours. Hence, on both sunny and cloudy days, the EMS strategy was effectively applied.

Table 1 Summary of EMS strategy implementation for different weather conditions

Type of energy (kWh)	Sunny Day (kWh)	Cloudy Day (kWh)	Rainy Day (kWh)
P_{PV}	66.45	40.43	7.74
$P_{BESSDis}$ (kWh)	13.52	13.52	7.28
$P_{BESSCharge}$ (kWh)	6.24	6.24	0

3.3 Effect of SoC and P_{grid}

Figure 9 illustrates the SoC for a sunny day, cloudy day, and rainy day. Due to low radiation on a cloudy day, the power stored in the battery, $P_{SoCDiss}$ started discharging earlier at t = 01:00.

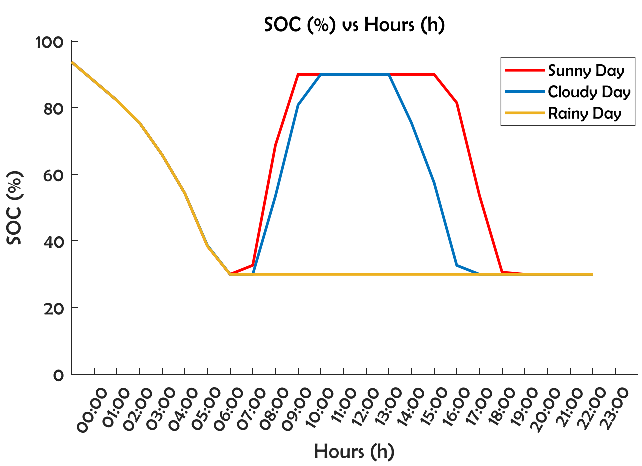


Figure 9 SoC for sunny day, cloudy day, and rainy day

Compared to cloudy and sunny days, rainy days consumed the most grid power due to low radiation. The P_{grid} and the excessive PV power output, $P_{PVexcess}$ for all conditions are summarized as tabulated in Table 2. The power grid consumption on rainy day is 30.56 kWh which is higher than the power consumed on sunny day, 6.91 kWh and on cloudy days, 14.24 kWh due to low solar radiation. However, PV power output during a sunny day causes high $P_{PVexcess}$ compared to a cloudy day and rainy day.

Table 2 Total P_{grid} and $P_{PVexcess}$ for sunny day, cloudy day, and rainy day

Day	P_{grid} (kWh)	$P_{PVexcess}$ (kWh)
Sunny Day	6,91	35.06
Cloudy Day	14.24	16.36
Rainy Day	30.56	0

Figure 10 shows the different patterns for SoC_{min} 20% and 30%. To prevent battery degradation, the SoC_{min} should be between 20% and 30% of the total capacity. The different values of SoC_{min} have resulted in a reduction of the amount of grid power connected as shown in Table 3. In conclusion, the SoC determination has influenced the use of power from the grid.

Table 3 P_{grid} for difference SoC_{min} 20% and 30%

Day		P_{grid} (kWh)	Difference (kWh)
Sunny Day	SoC_{min} 20%	4.89	2.02
	SoC_{min} 30%	6.91	
Cloudy Day	SoC_{min} 20%	12.15	2.08
	SoC_{min} 30%	14.23	
Rainy Day	SoC_{min} 20%	29.53	1.03
	SoC_{min} 30%	30.56	

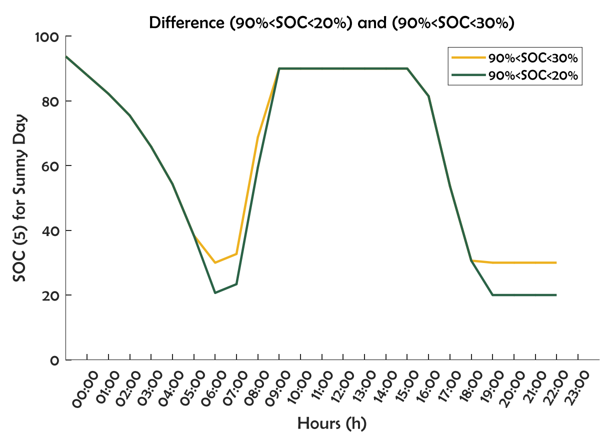


Figure 10 Difference SoC_{min} 20% and 30%

3.4 Cost-Effective EMS for One Week

Figure 11 depicts the energy usage pattern for residential use over the week. An average daily load used is 45 kWh. Data analysis for one week revealed that the amount of grid usage was 82.39 kWh, with a PV panel size of 10 kW and a battery capacity of 780Ah.

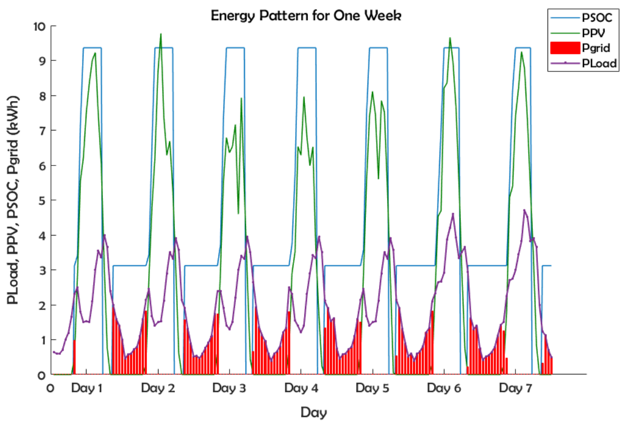


Figure 11 Energy pattern for one week

3.5 Implementation of PSO

The objective of optimal power is maximizing the utilization of renewable energy sources while minimizing the cost of grid-connected generation. This is accomplished through the integration of EMS strategy and PSO. The simulation results demonstrate that PV measurement is suitable for reducing the cost of grid connection for residential loads for one week. Figure 12 depicts the optimal result obtained through simulation. The Best P_{grid} value represents the minimum power consumption from the grid, while the Best Size value represents the PV panel of this system.

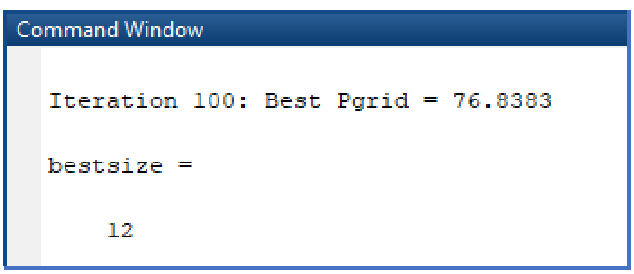


Figure 12 Optimum result by simulation

The objective function is to minimize the electricity consumption from the main grid. It is estimated that the total energy consumption from the grid connection amounts to RM 32.66 per week, which is equal to P_{grid} 76.8383 kWh multiplied by the tariff cost, which is RM 0.425 per kWh.

PSO is a widely used metaheuristic optimization technique for maximizing the use of renewable energy to achieve a more efficient energy management system. The advantages of PSO have minimized the PV configuration in ensuring that the solar energy generated is not wasted and is utilized to the greatest extent possible. Besides, the ideal PV size for residential load, BESS, and SoC limits have been selected for this system, as well as relatively low grid-connected costs.

3.6 PV Configuration Optimization

Based on the testing and commissioning solar photovoltaic system by SEDA, the solar panels have reached the appropriate I_{mp} and V_{mp} under irradiance of 350 W/m^2 – 1000 W/m^2. Therefore, the optimum radiation for charging is 350 W/m^2 and above, which indicates that the best time to charge the battery is between 10:00 and 15:00 hours. Table 4 shows the comparative analysis for determining the PV configuration.

Referring to the SEDA method, the PV configuration design should consider the PV Open Circuit Voltage, and Maximum Power Current, I_{mp} to measure the number of panels for each string. The 385 Wp Monocrystalline Solar Module and Hybrid Solar Inverter PH3000 Series (9-12 kW) data-sheet is used in this analysis to design the PV configuration at residential. The result shows that 14 strings with a total of 42 panels are required for this particular equipment specification. In contrast, the optimum 12 kW of PV size obtained from the optimization process only requires 11 strings with 33 panels of 385 Wp Monocrystalline modules. Using the 33 panels as per optimization is adequate to achieve minimum generation cost. If 42 panels per SEDA is used, the minimum generation cost can be accomplished but produces high excess PV production. In other words, the PV with 42 panels is considered to be oversized.

Table 4 Comparative analysis for determining the PV configuration

Method	Description
Conventional	1. Approximate BESS charging = 6 H 2. I charging = 130 A 3. From datasheet, I_{mp} = 9.58 A 4. Maximum no. of string = 14 string 5. Based on Hybrid solar inverter, PV open circuit = 145 V_{DC} No. of panel/string = 3 panel/string 6. Total no. of panels = 42 panel
PSO	1. From simulation, PV sizes = 12 kW 2. By using 385 Wp solar module, no. of panel = 32 panel 3. No. of string = 11 string 4. Total no. of panels = 33 panel

A comparison of the analysis performed using PSO and conventional methods is shown in Table 5. In comparison to the conventional method, which is 16.2 kWh, the PSO method produces a PV panel value of 12 kWh. The Pg obtained using the PSO approach was higher, at 76.8383 kWh, than it was using the conventional process, which produced Pg at 71.3668 kWh. By using the conventional method, the Pg value is lower due to the larger PV panel, hence producing more excess power. Consequently, the PSO method shows a 12 kWh PV panel is optimum and produces good Pg and excessive power.

Table 5 Analysis using the PSO method and conventional method

Method	PSO	Conventional
$P_{grid\ (kWh)}$	76.8383	71.3668
$P_{Excessive\ (kWh)}$	272.3612	444.4842

3.7 Project Installation at Residential

Based on site investigation, the maximum number of PV panels required to install solar PV on a 45 kWh residential load with a 780 Ah BESS capacity and 48 V is 14 strings x 3 panels, which equals 42 panels for the entire system. From the simulation result, PSO determined the optimal solution as a 12 kW PV panel with a minimum of 76.8383 kWh power grid. The results of 12 kW PV panels, only 33 Monocrystalline 385 Wp solar panels to be used. Therefore, using the optimization method, 9 number of panels can be saved, and the cost is reduced. In this analysis, it is demonstrated that the EMS with the proposed optimization has been able to improve RES performance in order to reduce the cost of the grid connection.

4.0 CONCLUSION

The optimal PV size planning for a grid-connected system is presented. The research for an optimal PV size that incorporates effective EMS and BESS using PSO is considered viable. The BESS has been used to store the excess PV energy, whereas the EMS strategy can manage energy requirements by utilizing the appropriate PV size, BESS capacity, and SoC limits. PSO has been effectively executed by providing an optimal PV size in order to reduce the cost of electricity connected to the grid. In minimizing the grid generation cost, the implementation of PSO and EMS in optimizing the PV size can reduce the number of PV panels by 21% compared to conventional methods. PV with a capacity of 12 kW has minimized the total amount of energy consumed by the power grid by 76.8383 kWh for one week. As a result of the PSO optimization, PV configurations for residential applications can be economically viable when PV systems are integrated with BESS. EMS strategies have reduced energy consumption and analyzed the economy for savings opportunities. As a result, it is capable of increasing energy efficiency and maximizing energy savings.

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