Simulation Investigation of Solar PV Rooftop Design at Faculty of Engineering-*Universiti Malaysia Sarawak* Building, Malaysia

Yanuar Z. Arief
[1]*Dept.of Electrical and Electronic Eng., Faculty of Engineering Universiti Malaysia Sarawak (UNIMAS)*
94300 Kota Samarahan, Sarawak, Malaysia
ayzulardiansyah@unimas.my

[2)]*Dept. of Electrical Engineering, Faculty of Engineering & Information System Jakarta Global University (JGU),*
16412 Depok, West Java, Indonesia

Anatassia Lampai Anak Abut
Dept. of Electrical and Electronic Eng., Faculty of Engineering Universiti Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan, Sarawak, Malaysia
64796@siswa.unimas.my

Naemah Mubarakah
Department of Electrical Engineering Universitas Sumatera Utara (USU)
Medan, Indonesia
naemah@usu.ac.id

Yulianta Siregar
Department of Electrical Engineering Universitas Sumatera Utara (USU)
Medan, Indonesia
Julianta_srg@usu.ac.id

Hamzah Eteruddin
Dept. of Electrical Engineering, Faculty of Engineering Universitas Lancang Kuning (UNILAK),
28265 Rumbai, Riau, Indonesia
hamzah@unilak.ac.id

Hendri Masdi
Dept. of Electrical & Electronic Engineering Faculty of Engineering Universitas Negeri Padang (UNP)
Padang, West Sumatra, Indonesia
hendri@ft.unp.ac.

***Abstract*—Renewable energy is increasingly employed as a substitute for conventional energy due to its detrimental environmental effects. Various forms of renewable energy, such as solar, wind, biomass, and geothermal energy, are commonly utilized. Given Malaysia's consistently hot and humid climate, solar energy has gained significant traction in the country. The recent rise in solar farm installations and rooftop solar systems is particularly notable. Rooftop solar systems, particularly suitable for urban settings due to their installation on building rooftops without requiring additional space, were the focus of a project aimed at designing a rooftop solar system for the Faculty of Engineering buildings at UNIMAS. The design and evaluation of a grid-connected PV system were conducted using PVSyst 7.2 software, with climate data collected through Meteonorm 8.0 Power demand, determined with Fluke 435 power analyzer, guided the sizing of the PV system. The simulation involved varying types of solar panels to identify the most efficient for the PV system's performance. Inverter specifications remained consistent throughout the simulation. Results revealed that, to fulfill the building's power demand, a 105kW PV system with 525 Si-Mono 200Wp 24V panels and nine 9.0kW inverters exhibited the highest Performance Ratio, leading to the selection of this design for the project.**

Keywords—Solar PV Rooftop, PVSyst 7.2 software, Meteonorm 8.0 Power Demand, power analyzer, inverter, solar PV performance.

I. INTRODUCTION

In Sarawak, solar energy accounts for only 25% of the total energy demand, with the remaining 75% fulfilled by other sources [1-5]. Sarawak Energy Berhad (SEB), a power utility in Sarawak, Malaysia, focuses its solar power installations primarily on rural areas like Lubok Antu. Since 2014, Sarawak Energy's Corporate Social Responsibility (CSR) Solar projects have brought benefits to nine longhouses in the Batang Ai region. In 2019, SEB successfully provided solar-powered electricity to 31 households in Rumah Bada, Nanga Talong at Batang Ai, Lubok Antu [6-8]. This RM1.45 million initiative, initiated in June 2018 and concluded in May 2019, is depicted in Fig. 1, featuring an aerial view of the Rumah Bada longhouse and its solar powerhouse.

In recent times, there has been a notable increase in the interest surrounding the assessment of solar potential on urban rooftops [9]. Rooftop solar photovoltaic (PV) systems present a viable alternative to solar farms in metropolitan regions. Unlike solar farms, which demand substantial land for panel placement, rooftop solar installations require no additional land. Despite solar farms being favored by investors due to promising financial returns, their negative environmental impacts are often overlooked. These large-scale installations pose threats to expansive agricultural landscapes and compete for limited land resources with other renewable energy alternatives, such as bioenergy feedstock systems [10]. The practicality of rooftop solar PV becomes evident in urban areas, where the installation of solar panels doesn't necessitate additional land.

The main objective of this study is to design a rooftop solar PV system at the Faculty of Engineering Building, Universiti Malaysia Sarawak (UNIMAS) including the quantity and specifications of solar panels and inverters as well as evaluation of the performance of energy generation by solar PV systems using PVSyst software.

2023 7th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM) | 979-8-3503-8552-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/ELTICOM61905.2023.10443211

Fig. 1. Picture of the Rumah Bada Longhouse and its solar PV systems [6].

II. Method

A. *Measuring of Power Demand at FENG's Building.*

The conducted study is mainly focused on doing simulation which requires a few software to collect all needed data. PVsyst 7.2 and Meteonorm 8.0 are the software that will be used and discussed in this section. Generally, *PVsyst 7.2* software is used to simulate and monitor the performance of the designed rooftop solar PV. Meanwhile, Meteonorm 8.0 is used to collect climate data that may affect the performance of the designed rooftop solar PV system. The energy demand was determined by measuring the Faculty of Engineering UNIMAS buildings' power consumption using power analyzer equipment. Thus, the Fluke 435 power analyzer was used for power consumption measurement. Fig.2 depicts the block diagram of the methodology for collecting the required data in this study.

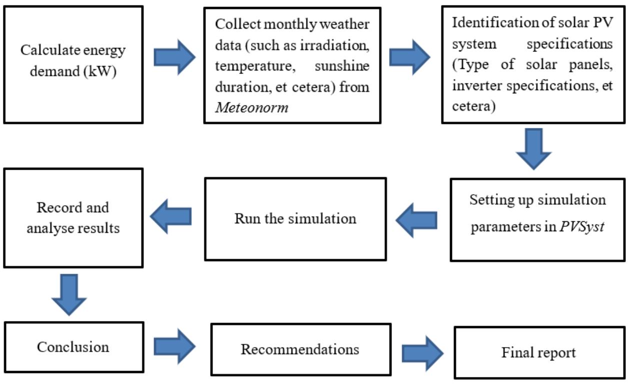


Fig. 2. Block diagram of the study's methodology.

The measurement was conducted in the Faculty of Engineering UNIMAS (FENG's) power source room for two days at different peak hours. The first measurement was conducted on Wednesday (25/05/2022) at 3.15 p.m. The second measurement was conducted on Thursday (26/05/2022) at 11.00 a.m. Fig. 3 shows the configurations of power measurement at the Faculty of Engineering main power distribution board.

Fig. 3. Complete connections of power measurement at FENG's main distribution board.

Tables 1 and 2 show the power consumption measurement on those two days. These measurements that were conducted for two days show that the highest power consumption of FENG's buildings was 209.14 kW. Hence, it was concluded that the power demand of FENG's building is approximately 210 kW. This value was used in the determination of the PV system's sizing in the design.

TABLE I. POWER MEASUREMENT ON 25/5/2022 (WEDNESDAY) AT 3.15 P.M.

Parameters	L1	L2	L3	Total
Real Power (kW)	77.26	57.54	46.53	181.33
Apparent Power (kVA)	80.81	74.42	54.71	212.68
Reactive Power (kVAR)	24.50	47.80	29.01	101.45
Power Factor	0.96	0.77	0.85	0.85

TABLE II. POWER MEASUREMENT ON 26/5/2022 (THURSDAY) AT 11.00 A.M.

Parameters	L1	L2	L3	Total
Power (kW)	83.32	73.86	52.96	209.14
Apparent Power (kVA)	84.89	87.28	58.22	233.98
Reactive Power (kVAR)	21.62	47.35	24.55	93.69
Power Factor	0.97	0.85	0.91	0.89

B. *Collecting climate data using Meteonorm 8.0 software*

The Climate data for the Faculty of Engineering, UNIMAS was collected based on its specific coordinate which is 1.5°N/ 110.5°E. Fig. 4 shows a graph captured from Meteonorm 8.0 which shows sun radiation from January to December at FENG, UNIMAS. Meanwhile, Fig. 5 shows a data table that consists of actual values of sun radiation. The main parameter that was monitored in this simulation was global radiation (kWh/m^2). According to [11], global radiation is referred to as the entire short-wave radiation from the sky falling onto a horizontal surface on the ground. It encompasses both direct solar radiation and diffuse radiation caused by reflected or dispersed sunlight. The global radiation is at its highest under a clear sky. The maximum global radiation determined here is the maximum value of global radiation per hour at the selected height. These data were imported to *PVSyst 7.2* software for PV system simulation and evaluation

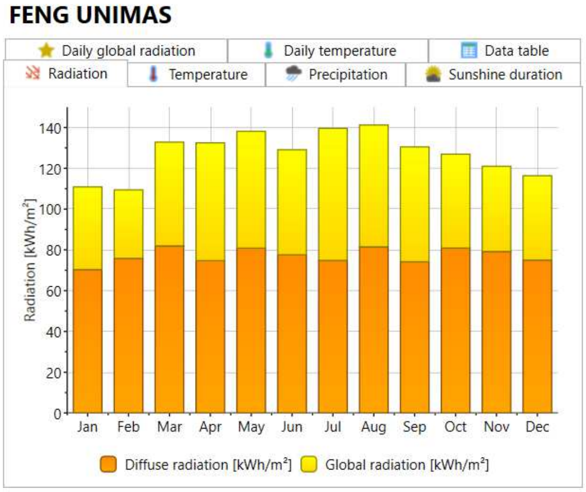
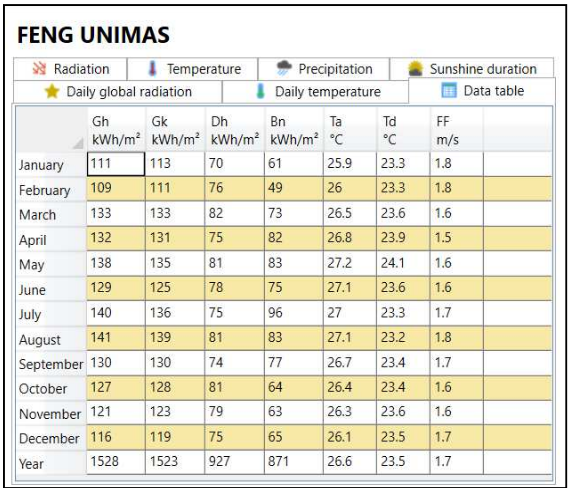


Fig. 4. Sun radiation at FENG's building UNIMAS obtained from Metenorm 8.0 software.


FENG UNIMAS

Radiation | Temperature | Precipitation | Sunshine duration | Daily global radiation | Daily temperature | Data table

	Gh kWh/m²	Gk kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	111	113	70	61	25.9	23.3	1.8
February	109	111	76	49	26	23.3	1.8
March	133	133	82	73	26.5	23.6	1.6
April	132	131	75	82	26.8	23.9	1.5
May	138	135	81	83	27.2	24.1	1.6
June	129	125	78	75	27.1	23.6	1.6
July	140	136	75	96	27	23.3	1.7
August	141	139	81	83	27.1	23.2	1.8
September	130	130	74	77	26.7	23.4	1.7
October	127	128	81	64	26.4	23.4	1.6
November	121	123	79	63	26.3	23.6	1.6
December	116	119	75	65	26.1	23.5	1.7
Year	1528	1523	927	871	26.6	23.5	1.7

Fig. 5. The climate data was obtained from Meteonorm 8.0 software.

C. Design of Rooftop PV System for FENG's UNIMAS

Fig. 6 depicts a simplified schematic diagram that has been implemented in this research. This schematic diagram was obtained from *PVSyst 7.2* software itself. It involved three components which were the PV array, inverter, and user. PV array consisted of solar panels that were connected as a complete power-generating unit. The quantity of the connected solar panels was determined based on how much power should be supplied by the PV system. Then, the PV array was connected to the inverter. The inverter was used to convert the DC produced by the PV array into AC before distributing AC to the user. A user was at the end of the schematic diagram which means the user was the load and receiver of AC. The user could be any electrical appliances in FENG's UNIMAS buildings such as computers, lights, fans, electrical equipment, air conditioners, etc.

A possible case may happen where the generated power might be excessive and not fully used by FENG'S buildings. The power may be returned to the grid as the PV system in this research was grid-connected. Thus, there was an arrow that went out to the grid in the schematic diagram. Another possible situation is the generated power may not sufficient for FENG's buildings especially at night. Hence, backup power may be supplied from the grid which explains the incoming arrow to the user.

Sizing of the PV system was done based on the power demand of FENG's buildings. As the proposed PV system was grid-connected, the PV system is aimed to supply 50% of the power demand while another 50% would be supplied by the grid. The sizing of the PV system is 105 kW.

A few modules of solar panels with different specifications were simulated to determine the best specifications in order for the rooftop solar PV to generate the maximum power. The specifications that were being considered in this study were the material's types of solar panels, its watt peak, and voltage. There were four types of solar panels used in this research which were Si-Mono and Si-Poly with each type having two variations of watt peak and voltage; 200Wp 24V and 300Wp 32V. The irradiation effect's characteristics of each solar panel are obtained from PVSyst software. Table 3 shows the types of solar panels used as well as the number of modules in series, the number of strings, and total number of solar panels that will be used in the PV system.

The selection of inverter in this study was done by ensuring *the Pnom ratio* in *PVSsyst 7.2* software is between 1.25 and 1.30. *The Pnom ratio* is defined as the ratio of installed PV power to the *Pnom* (AC) of the inverter [12]. There were nine inverters with a nominal AC power of 9.0kW used in the simulation. Such quantity and specifications were decided as the Pnom ratio using this configuration was 1.296 which was acceptable in the range.

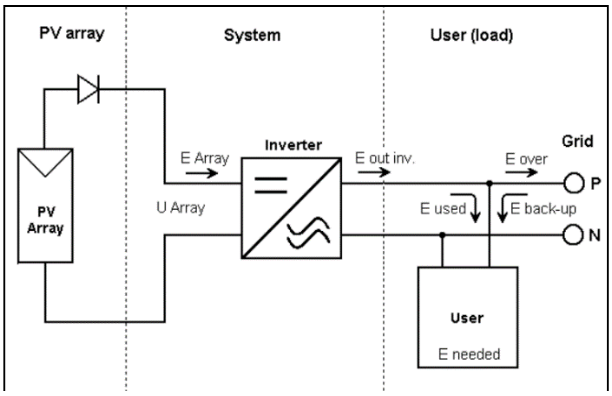


Fig. 6. The Simplified schematic diagram of the PV system.

TABLE III. QUANTITY OF SOLAR PANELS BASED ON THEIR TYPES.

Material Types of Solar Panel	Watt Peak and Voltage	Number of Modules in Series	Number of Strings	Total Number of Solar Panels
Si-Mono	200Wp 24V	21	25	525
Si-Poly				
Si-Mono	300Wp 32V	14	25	350
Si-Poly				

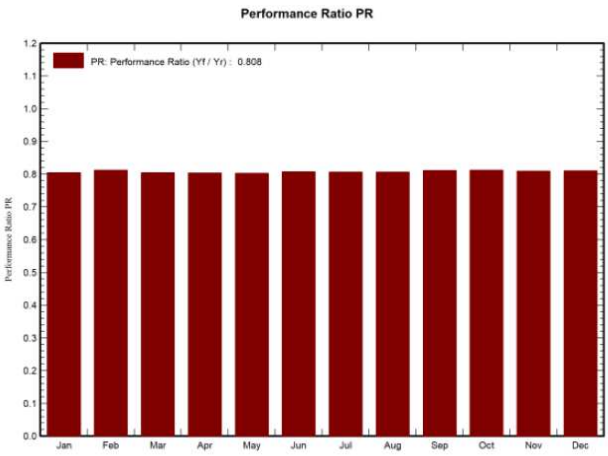
III. Results and Discussion

PV system in this research was simulated using four types of solar panels which were Si-Mono 200Wp 24V, Si-Mono 300Wp 32V, Si-Poly 200Wp 24V, and Si-Poly 300Wp 32V. The simulations were conducted using PVSyst 7.2 software. From each simulation, three aspects were monitored which were Performance Ratio (PR), normalized production and loss factors as well as losses in the system which was displayed in the loss diagram.

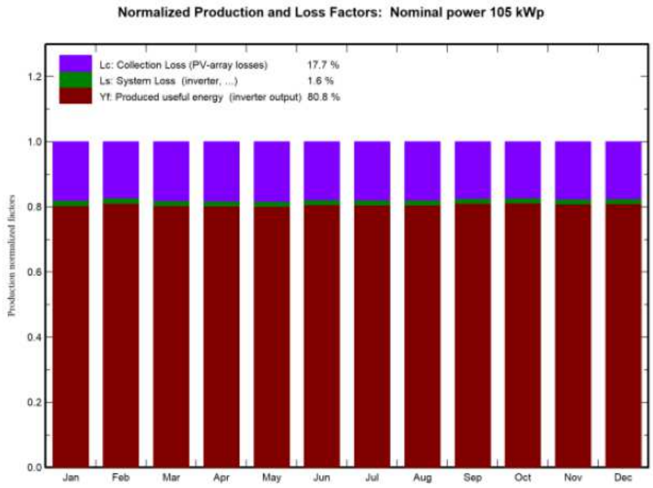
Khalid et. Al [13], describes *PR* as a percentage of energy available for export to a grid after considering energy loss and consumed energy in the operation process. Multiple environmental factors such as degradation and soiling cause energy loss. They also added that *PR* is a unitless quantity that has acquired widespread acceptability for judging PV system performance worldwide. The greater the *PR* of the system, the better its performance in comparison to comparable systems under identical climatic circumstances. *PR* which was obtained from *PVSyst 7.2 software* was displayed using a graph throughout one year; from January until December. *PR* of the PV system is the mean of *PR* for one year.

Based on [12], normalized production and loss factors graphs included produced useful energy (Yf), system loss (Ls), and collection loss (Lc). Yf which is also known as final system yield is described as the ratio of the system's final or real energy production to its nominal DC power. Ls is the difference between Ya (the effective yield as measured at the output of the array) and Yf, which includes inverter loss in grid-connected systems. Meanwhile, Lc is the difference between Yr and Ya which includes thermal, wiring, module quality, mismatch and IAM losses, shading, dirt, MPP, regulation losses, as well as all other inefficiencies. Losses within Ls and Lc were displayed in detail in the loss diagram for a year.

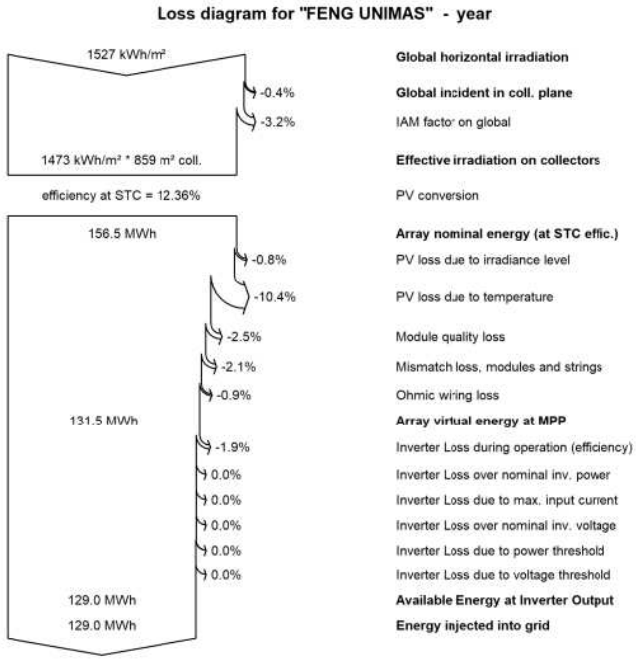
Fig. 7 shows the PV system performance when the solar panel used was Si-Mono 200Wp 24V design.



(a)



(b)



(c)

Fig. 7. PV system performance when solar panel used was Si-Mono 200Wp 24V (a) PR (b) Graph of normalized productions and loss factors (c) Loss diagram per year.

A. *Comparison of PV System's Performance with Different Solar Panel Designs.*

Based on all graphs that had been simulated for all PV panel designs, the values of PR, Ls, Lc, and PV loss due to temperature were tabulated in Table 4 for comparison. The values were tabulated according to the types of solar panels used in the PV system. From Table 4, it can be seen that the *PR* for each type of solar panel was approximately **0.8**. Khalid et. Al [13], mentioned that a PV system has good performance when its *PR* is **0.8** and above. Thus, this indicates the proposed system in this research has good performance and produces efficient power output.

TABLE IV. COMPARISON OF PV SYSTEM'S PERFORMANCE WITH DIFFERENT TYPES OF SOLAR PANEL DESIGNS

Type of Solar Panel	Performance Ratio (PR)	Collection Loss (Lc)	System Loss (Ls)	PV Loss due to Temperature
Si-Mono 200Wp 24V	0.808	17.7%	1.6%	10.4%
Si-Mono 300Wp 32V	0.798	18.7%	1.5%	11.5%
Si-Poly 200Wp 24V	0.792	19.3%	1.5%	11.1%
Si-Poly 300Wp 32V	0.800	18.5%	1.5%	11.1%

There were slight differences in *PR* when different types of solar panels were used in the PV system design. Solar panels with specifications of 200Wp 24V used 21 modules in series and 25 strings which means 525 solar panels were used in the PV system design. Meanwhile, solar panels with specifications of 300Wp 32V used 14 modules in series and 25 strings which means only 350 solar panels were used. Solar panels with specifications of 200Wp 24V have a greater number of modules to meet the power demand of the system. The difference in the number of solar panels was as such due to different specifications of watt-power. The higher the watt-power of solar panels, the lesser the number of modules would be. However, when *PR* was compared between the same material of solar panel with different watt-power, there was no obvious relationship between the number of modules with PR value. Si-Mono 200Wp 24V gives a higher *PR* (0.808) compared to Si-Mono 300Wp 32V (0.798). Contrarily, Si-Poly 200Wp 24V gives lower PR (0.792) compared to Si-Poly 300Wp 32V (0.800). The inconsistency in these results shows that the number of solar panels does not have any significant effect on the performance of the PV system design. The PV system produces the desired output as long as the number of solar panels provides enough power to meet power demand.

Another comparison was PR value when different types of materials with the same specifications were used. With the same specifications which was 200Wp 24V, both Si-Mono and Si-Poly solar panels had the same number of total modules used in the PV system. Yet, Si-Mono solar panel gives higher PR than Si-Poly. The use of Si-Mono provides PR of 0.808 while Si-Poly was 0.792. This difference indicates that different materials of solar panels have different efficiency. Specifically, Si-Mono has higher efficiency compared to Si-poly. According to Ameur et.al [19], monocrystalline cells have an efficiency of 15%–24% while polycrystalline cells have an efficiency of 13%–20%. Furthermore, Qazi [20] states that monocrystalline cells have a slightly greater efficiency of 15–22% compared to conventional polycrystalline cells.

Next is the discussion of the losses that occur in the PV system. Lc and Ls were obtained from a graph of normalized production and loss factors while PV loss due to temperature was extracted from the loss diagram. Although there were other losses described in the loss diagram, loss due to temperature was analyzed as it had the highest value compared to other losses in the loss diagram. Table 4 depicts that Si-Mono 200Wp 24V has the lowest value for Lc and loss due to temperature which were 17.7% and 10.4%, correspondingly. Meanwhile, it has the highest Ls which was 1.6% and its difference with other types of solar panels was only 0.1%. The difference can be considered insignificant as the value was very small. A small value of losses depicts that the system had produced output power that was almost similar to the input power. In other words, the PV system has high efficiency.

To conclude this discussion, Si-Mono 200Wp 24V gives the best performance of the PV system with a *PR* of 0.808. It also had the least Lc. Ls and loss due to temperature compared to the other types. Thus, it was fair to say that Si-Mono 200Wp 24 was the most suitable for the Rooftop PV system design of FENG's UNIMAS buildings.

B. Cost Reduction Analysis

The cost reduction estimation was conducted to identify how the proposed PV system helps reduce the cost of electricity bills for FENG's building. The electricity rate that was used in the calculation was obtained from Sarawak Energy Berhad's official website [21]. FENG's buildings fall into the tariff category of C1-commercial buildings. The electricity tariffs can be seen in Figure 4.9. The value rate per unit used in the calculation was RM0.30 as the maximum power demand of FENG's buildings per day was 201kW which is above 20, 000 units.

In the usual situation, power supplied to the buildings by the grid would be 210kW per day which was the power demand of FENG's buildings. To calculate electricity usage for one month by FENG's buildings, electricity usage per day was multiplied by 30 days. Later, the total electricity bill was obtained by multiplying the total electricity usage per month by RM0.30. The total electricity bill when power is supplied by the grid is RM189, 000.

The same method would be used to calculate total electricity bills when the PV system is involved in providing the power demand to FENG's buildings. However, the maximum power provided by the grid would be only 50% of power demand as another 50% has been supplied by a PV system. From the calculation found that the total electricity bill has been reduced to RM94,500. From these calculations, the presence of a PV system to supply 50% of power to meet the power demand of FENG's buildings does reduce the electricity bills to 50%.

IV. CONCLUSION

This project aimed to design a rooftop solar PV system at the Faculty of Engineering Building, UNIMAS. The PV system was designed as a grid-connected system to meet 50% of power demand. Simulation using PVSyst 7.2 software was conducted to simulate the design of a PV system with multiple types of solar panels. Climate data from Meteonorm 8.0 was exported into *PVSyst 7.2 software* as sun radiation data were used in evaluating the PV system. Important parameters in PV system evaluation were the Performance Ratio (PR), the graph of normalized productions and loss factors as well as the loss diagram. In the loss diagram, PV loss due to temperature was extracted as it recorded the highest value among other losses.

Based on the four simulations that had been conducted, it was found that Si-Mono 200Wp 24V gives the best performance to the PV system as its PR was 0.808. In addition, the PV system has the lowest Lc and loss due to temperature which were 17.7% and 10.4%. Meanwhile, it has the highest Ls which was 1.6% and its difference with other types of solar panels was only 0.1%. considered insignificant due to the very small value. To conclude this project, the appropriate design of the rooftop PV system in the Faculty of Engineering's UNIMAS Building is Si-Mono 200Wp 24V with a total quantity of 525 solar panels and nine inverters with such specifications; nominal AC power of 9 kW and frequency of 50/60 Hz.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Higher Education, Malaysia for the financial support under the Fundamental Research Grant Scheme (FRGS/1/2022/TK07/UNIMAS/02/3) and *Universiti Malaysia Sarawak* (UNIMAS) for facilitation and support in completing this research work.

REFERENCES

[1] A. Mikhaylov, "Geothermal Energy Development in Iceland," *International Journal of Energy Economics and Policy,* vol. 10, no. 4, pp. 31-35, 2020.

[2] F. E. Abrahamsen, S. G. Ruud and A. Gebremedhin, "Moving Toward a Sustainable Energy System: A Case Study of Viken County of Norway," *Energies,* vol. 13, no. 22, 2020.

[3] "Malaysian Investment Development Authority (MIDA)," 23 June 2021. [Online]. Available: https://www.mida.gov.my/mida-news/malaysia-aims-31-re-capacity-by-2025/. [Accessed 2 November 2021].

[4] The Star, "Largest Solar Park in Malaysia Starts Operation," 5 December 2018. [Online]. Available: https://www.thestar.com.my/business/business-news/2018/12/05/largest-solar-park-in-malaysia-starts-operation/. [Accessed 3 January 2022].

[5] M. Tabassum, S. Abul Kashem and M. B. M. Siddique, "Feasibility of using Photovoltaic (PV) technology to generate solar energy in Sarawak," in *2017 International Conference on Computer and Drone Applications (IConDA)*, Kuching, 2017.

[6] "Sarawak Energy's Batang Ai Solar Project Receives Sustainability & CSR Malaysia Award," Sarawak Energy, 7 January 2021. [Online]. Available: https://www.sarawakenergy.com/media-info/media-releases/2021/sarawak-energys-batang-ai-solar-project-receives-sustainability-csr-malaysia-award. [Accessed 5 November 2021].

[7] S. Sharma, K. K. Jain and A. Sharma, "Solar Cells: In Research and Application- A Review," *Materials Sciences and Applications,* vol. VI, no. 12, 2015.

[8] A. M. Bagher, M. M. A. Vahid and M. Mohsen, "Types of Solar Cells and Application," *American Journal of Optics and Photonics,* vol. 3, no. 5, pp. 94-113, 2015.

[9] M. Fogl and V. Moudry, "Influence of vegetation canopies on solar potential in urban environment," *Applied Geography,* vol. 66, pp. 73-80, 2016.

[10] K. Calbert and W. Mabee, "More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in Eastern Ontario, Canada," *Applied Geography,* vol. 56, pp. 2019-221, 2015.

[11] M. AG, J. Remund, S. Muller, M. Schmutz, D. Barsotti, P. Graf and R. Catin, "Meteonorm 8 Handbook Part II: Theory," Meteotest AG, 2021.

[12] PVSyst, "General Description of the PVSyst Software, "2022. [Online].Available: https://www.pvsyst.com/help/general_descr.htm. [Accessed 17 January 2022].

[13] A. M. Khalid, I. Mitra, W. Warmuth and V. Schacht, "Performance ratio – Crucial parameter for grid connected PV plants," *Renewable and Sustainable Energy Reviews,* vol. 65, pp. 1139-1158, 2016.