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Modelling and analysis of rooftop PV as an energy optimization of flat roof and gable roof mounting system

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Abstract
Photovoltaic (PV) systems are designed for both communal and self-installation. PV systems are intended for both communal and standalone installations. Installation is required not only in industry and commerce, but also in the growth of energy potential at Universitas Jenderal Achmad Yani. The focus of this research is rooftop PV modelling and analysis at Universitas Jenderal Achmad Yani. Because the ground mounting system could not be done due to limited land, a rooftop solar power-producing system was created. Data gathering is done as part of unique research that takes into account numerous technological criteria for efficiency. System analysis conducted by modelling and simulation, which will make use of a variety of tools linked to this PV system. Data was gathered from similar studies while accounting for numerous technological variables such as modelling and efficiency. K2Base system was used to model flat roofs with concrete roof types and gable roofs with tile roof types. The mounting type, wind load, truss load, and ballast were all taken into account in the design. This article also calculates PV panel configurations and component capacities. There are many different panels that can be constructed from each model. With a maximum roof area of 837.52 m^2, 33 to 350 PV panels may be used. The number of inverters is changed to provide outputs of 10 kW, 25 kW, and 50 kW based on the calculations' findings. With differences in autonomous days, the number of batteries obtained has an average of more than 200 batteries.

Keywords:
Flat-Roof;
Gable-Roof;
K2Base System;
Rooftop Photovoltaic System;

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INTRODUCTION

According to the Paris Agreement and the most recent Intergovernmental Panel on Climate Change (IPCC) reports, considerable decarbonization is required, with global emissions needing to be zero by 2050 or soon thereafter to prevent costly negative emissions [1]. The potential for solar power generation is 207.9 GW, with an average power generation potential of 3.77 kWh per day or 1377 kWh per year for every 1 kWp (kilowatt peak) solar panel installed [2][3]. The rooftop PV user sector's potential usage of solar power generation is expected to reach 2981 MW [4]. The government said that the total installed capacity of rooftop solar panels had only reached 18 MWp as of October 2020 [5]. In general, the policy promotes maximizing clean energy use, reducing petroleum use, optimizing natural gas and new energy use, coal as the principal source of national energy, and nuclear energy as a last resort. Data from the Ministry of Energy and Mineral Resources (MEMR) indicated that the national electrification ratio has reached 98.86% as of September 2019, an improvement of roughly until 0.56% from 98.3% in December 2018.

Table 1. Literature Reviews on Rooftop Mounting PV Simulation

Literature	Roof Type	Location	Proposed Design	Total Power Generated (kWp)
C. Ban et al., 2017 [6]	Gable roof	Gyeongsangbuk, South Korea	The five variants of type of PV installation	94.08 – 104.6
Baumgartner, 2017 [7]	Flat Roofs	Winterthur, Switzerland	Mechanical mounting and performance	100
N. Mohajeri et al., 2018 [8]	Flat & shed, gable, jip & pyramidal, gambler & mansard, Cross corner gable & hip, and Complex.	Proposed in Geneva, Switzerland	Roofs are classified based on their useable area for PV installation and their ability to gather solar energy.	none
H. Rusiana, et al, 2020 [9]	Monopitch Roofs	Cimahi, Indonesia	Modelling and Design for Dept. Electrical Engineering Laboratory for Rooftop PV Systems.	265

In recent years, the electrification rate has risen to 14.5%. In addition to creating a utility grid and employing energy-efficient solar lighting for places without power[10] and combined PV-green roof systems [11][12]. An archipelago nation with many provinces and areas with high potential for renewable energy is Indonesia. contains a range of resources that can be used to address electrical needs and start the transition to environmentally and sustainably produced energy [13][14]. Indonesia is one of the countries pledged to cutting pollution emissions by 29% by 2030, as stated in the president's statement at the Paris Agreement. This is supported by Presidential Regulation No. 22 of 2017, which intends to enhance the position of renewable energy by 23% by 2025 and 31% by 2050 [15].

According to DKI Jakarta data, this statistic leads the way with 516 users, followed by West Java (397 users) and Banten (395 rooftop PV users). Rooftop PV has a total installed capacity of roughly 4.92 MW. Based on PT. PLN (Persero) consumption, households with 1,404 customers and the commercial sector with up to 120 users have the largest consumption of rooftop PV [16]. Furthermore, rooftop PV is used by 34 government facilities and 18 social services. Meanwhile, only four industrial customers employ rooftop PV. From December 2018 to June 2020, total installations totalled 26885 units, with an average of 1,415 units each month. Based on data from the Ministry of Energy and Mineral Resources and the backing of ministerial regulations, an additional increase was the installation of 63 Rooftop PV with a capacity of 300 kWh at the Pertamina Gas Station (PGS) owned by PT. Pertamina (Persero) [17]. Based on this context, numerous studies connected to Rooftop PV system research will be carried out in 2017, including an explanation of the study of PV system features by comparing the results of simulations and tests on 1.6 kWp Rooftop PV [18]. Then, at the Electrical Engineering Laboratory, optimizing the angle on 1 kWp PLTS, Rooftop Design, and in the next year, design and research were carried out to satisfy the energy needs of the PV Rooftop design power at the Electrical Engineering Laboratory in 2020 - 2021 by [9]. According to Article 5, the rooftop PV system's capacity is limited to a maximum of 100% and is defined by the entire capacity of the inverter. Article 6 further explains the percentage export kWh regulation. The net metering scheme refers to this export-import kWh [19].

Table 1 shows research related to rooftop PV installations and accompanying considerations with nearby modelling findings from the literature analysis. This paper will discuss how modelling from the various backgrounds discussed above, the research conducted includes the design, calculation, and design of rooftop PV mounting systems for energy absorption optimization in diverse buildings at Universitas Jenderal Achmad Yani. The specific objectives of this study include estimating and analyzing the daily energy potential required in each building under consideration, calculating and analyzing the required solar panel capacity by taking into account the rooftop area in each building, and analyzing the needs of each building. The number of rooftop PV system components and the amount of backup energy provided by the battery if it is a hybrid-connected [20]

The following is the structure of the next section of this article. Part II outlines the research strategy provided in the process of method and calculating site characteristics to the design of each building's component capacity, which is described further in this chapter. Part III describes the model and the simulation equations that underpin it in order to support the investigation. Part IV examines each rooftop PV requirement in relation to the rooftop design and mounting method. Finally, in Part V is the conclusions based on the test results and discussions conducted based on the system modeling are proposed.

METHOD

The method used in planning rooftop PV on grid is carried out in numerous stages and cannot be separated from diverse references from existing references, as illustrated in Figure 1 by a flow chart that describes the planning process in the rooftop PV on grid research method. Figure 1 depicts a flow schematic of the existing rooftop PV system that will be developed to meet electricity needs. Based on the results of the study, it has been determined that adding PV via a ground-mounted system is not feasible due to space constraints. A rooftop solar power system of this type is entirely feasible. Data was collected in numerous regional buildings on campus as part of a unique research. This stage of system design takes into account a variety of technical elements such as system reliability, system efficiency, and so on.

Collecting existing data on energy usage, the thesis data collection approach in conducting research by expanding on previous study. Energy potential such as solar irradiation data kWh/m^2/year, total electrical energy load at Universitas Jenderal Achmad Yani, Cimahi, West Java, Indonesia is required in the data gathering process. Second, data on determining features and selecting component specifications for PV system design and design utilizing software.

Site Location and Meteo Data

Rooftop PV planning is based on numerous criteria, including the size of the land, the absence of solar irradiance obstacles, and complete technical documents to be utilized as planning references. The Google Earth tool aids in determining the coordinates of the building's location. This campus building's coordinates are -6.887512,107.526843, as depicted in Figure 2. So that the meteorological data parameters can be utilized to calculate the average data on this site. This location's solar irradiance is measured once a year using NASA's Surface Meteorology and solar energy.

This meteo data provides the amount of irradiation including solar irradiation that reaches the top layer of the Earth's atmosphere by taking into account solar irradiation that reaches the surface directly without obstacles will affect the temperature in solar panels with attenuation from the atmosphere and clouds or reflected irradiation from the surrounding environment so that the total irradiation is contained in Global Irradiation (GHI) with an irradiation value that is a combination of Direct, Diffuse, and Albedo irradiation. The annual irradiance 9.96 kWh/m^2, temperature 23.71°C, and wind speed 3.29 m/s at this location is loaded into the software for further use in the simulation.

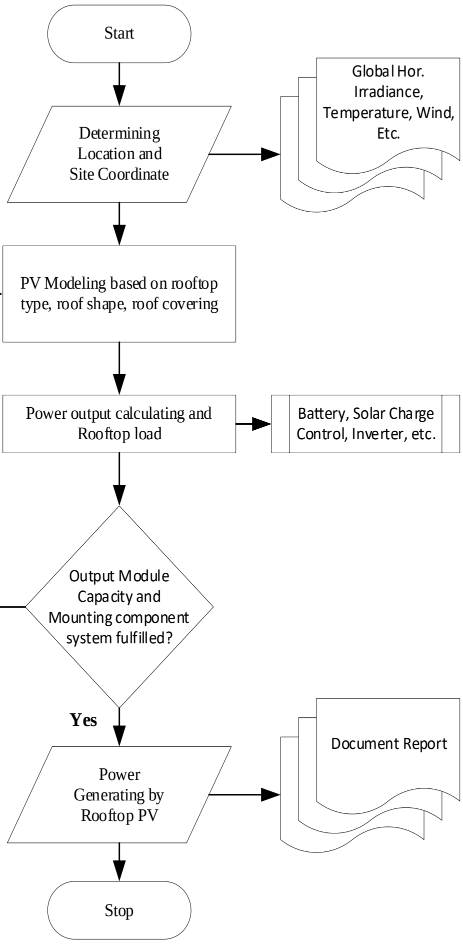


Figure 1. Rooftop PV modelling and analysis flowcharts

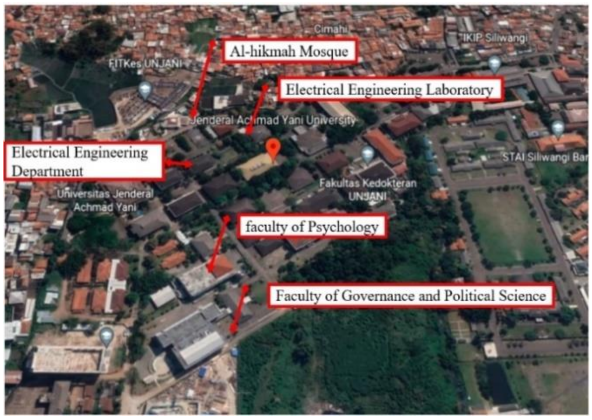


Figure 2. Several Building Locations in Universitas Jenderal Achmad Yani

Solar energy that reaches the earth's surface is classified into three types. Diffuse radiation is energy or sunlight that reaches the earth's surface due to scattering or absorption by clouds, whereas albedo rays are energy or solar radiation that reaches the earth's surface but is partially reflected by water, plants, or other objects. In the software simulation, this albedo will be around 20%. Direct radiation rays are those that reach the surface but suffer scattering or reflection losses (beams). The average amount of radiation received in a year. For several activity's on this research as presented in Figure 2.

Building Existing Load

The daily load required for each building is determined by conducting a daily energy survey for typically one week and then calculating the total load and the length of consumption in one day or 24 hours. The load is determined based on the existing load's condition or capacity, taking into account the type and type of each load, as well as the time of use or operation, using (1), where power is multiplied by working hours in one day so that there is energy (Wh).

$$Power\ x\ Time = Energy \quad (1)$$

According to the survey results, the total amount of daily energy consumed by each building at the Al-Hidayah Mosque (AM) is 72286 Wh. The Electrical Engineering Department (AAD) requires 104.822 Wh each day. The total daily energy utilized in the Electrical Engineering Laboratory (EEL) is 128224 Wh, the survey results at the Faculty of Social and Political Sciences (FSPS) are 892476 Wh, and the total daily energy consumed in Psychology (FPSI) is 1009230 Wh, which is reached by calculating the total existing load and the length of time the load is used in one day or 24 hours describes by Figure 3.

Regulations and Metering Schemes

As an electric energy distribution firm, PT. PLN (Persero) has policies and procedures in place to ensure compliance with relevant regulations. The cost of parallel connections for industry can be calculated by (2),

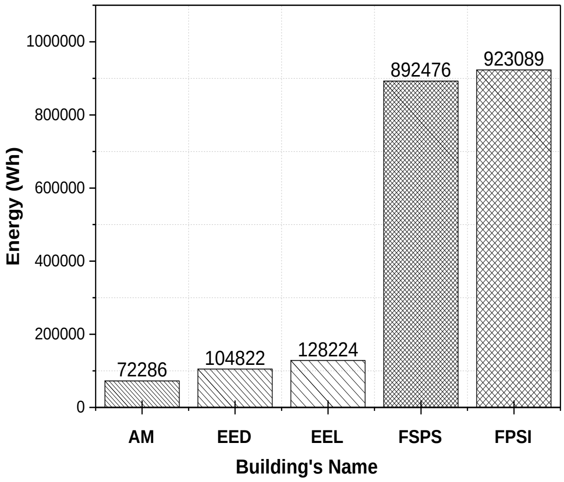


Figure 3. Each Building's Total Energy (Wh)

$$Cap._{Charge} = Inst_{PV_{Cap}} \times 5Hour \times Elec\_tariff \quad (2)$$

the electricity tariffs are determined in accordance with Minister of Energy and Mineral Resources Regulation No. 28: 2016 on Electricity Rates Provided by PT. PLN [21] using (3).

$$Residential._{feed} = 0.65 \times Energy_{Export} \quad (3)$$

The residential feed-in tariff is 0.65 times the energy export, installed inverter capacity cannot exceed existing PLN power, and solar integrators must be certified by the Ministry of Energy and Mineral Resources. However, currently the latest provisions and regulations of the feed-in tariff selling price of electricity from residential PV is 100%, in 2021 [21] by,

$$Residential._{feed} = 1.00 \times Energy_{Export} \quad (4)$$

Net-metering is an electricity-user service in which electricity is generated by customers from generators that match location criteria and delivered to local distribution facilities. This service system is used to compensate customers for the electrical energy generated by utilities. The customer only submits a two-way request form (kWh Ex-imp) to PT. PLN when requesting net measurement. The basic principles of employing net meters for rooftop PV systems are governed by several legislation.

The first is by Directors Regulation 0733.K/DIR/2013, dated November 19, 2013, regulating Customer Use of PV Electrical Energy. Both SPLN D5.005-1: 2015, 13 May 2016, and SPLN D5.005-1: 2015, 13 May 2016, are Technical Specifications for Interconnection of PLTS Systems for Low Voltage Distribution (LV). This specification outlines the requirements for connecting a PV system with a capacity of up to 30 kWp to a low voltage network. Article 5 on electrical transactions specifies four items that consumers should be aware of (5) is used to calculate customer power credit transactions at the end of the month if referee to feed-n tariff 100%.

$$Elec\_Bill_{(kWh)} = Tot\_Imp_{(kWh)} \times 100\%\ Exp_{(kwh)} \quad (5)$$

The total kWh for export is the number of kWh that the customer exports to PLN and records in the Export kWh meter, while the volume of kWh that the customer imports from PLN is recorded in the Import kWh meter.

PV Characteristic Calculation

The input data for designing and simulating the rooftop PV system on the program is as follows as listed in Table 2. The main parameters of the solar panels utilized have a capacity of 250 Wp, however for comprehensive specifications of the working current and voltage, please refer to the manufacturer's customized nameplate on the market.

Table 2 shows the specs for the solar panels used in this investigation. To determine the characteristics, apply the equation to determine or calculate the fill factor (ff) of the solar panel based on the specifications in Table 2, followed by the maximum power (P_{max}) and efficiency (η) of the AMB-250W solar panel, the si-mono type using (5). Because the value of ff (0.7 - 0.8) closely satisfies the criterion, the maximum power when utilizing (6) is as follows,

$$ff = \frac{Vmp\,.Imp}{Voc\,.Isc} \quad (5)$$

$$Pmax = Isc\ x\ Voc\ x\ ff \quad (6)$$

the efficiency of the PV panels (η) is thus as follows with the module area specification based on Table 2 the specifications of the solar panels used in the K2 Base System using Eq. (7) as follows,

$$Ef_{mod}\ (\eta) = \frac{Isc\,.Voc\,.ff}{Area\ (m^2)\,.Irradiance} \quad (7)$$

PV panel characteristics are required to assess the performance of the PV panels that will be employed.

Component Capacity

The calculated number of PV panels results differ from the simulation results. The calculated value is the ideal amount required to meet each building's daily energy needs. Meanwhile, the ideal value in the K2 Base System software simulation is determined by the available roof area.

The following is the outcome of employing a mathematical equation to calculate the number of PV panels. We can use the following (8) - (9) to calculate the peak power of a single building's PV module,

Table 2. K2 Base's PV Panel Epecification

Parameters	Information
Manufacture's	A.M.P Solar
Technology	AMB-250 W, Si-mono
PV Panels Dimension	1650 x 988 x 35.0 mm
Open Circuit Voltage (V_{OC})	37.8 V
Short Circuit Current (I_{SC})	8.70 V
Max. Power Voltage (Vmp)	31.5 V
Max Power Current (Imp)	1.94 A
Max Power at STC	250 Wp

$$kWpeak\_PV = \frac{Energy\_day}{Av.\_Irr} \quad (8)$$

to look for solar modules and determine their effective area using the calculation below by,

$$Area\ (m^2) = \frac{kWp}{REff.\ PV\_Module} \quad (9)$$

The number of inverters can be assumed to be maximum and minimum. This list is based on the efficiency of the design of the manufacturer/supplier that appears on the inverter nameplate. With changes in customer demands, various characteristics of PV inverters have been required for battery charging control[7]. The capacity of an inverter can be measured and calculated using the following (10)[19].

$$N_{inv.} = \frac{Pout_{PV}}{\eta_{inv.} \times Cap_{inv}} \quad (10)$$

Autonomous days must be examined in order to establish the number or length of time the system can work and operate well under adverse conditions or when there is no sun for one week. The system calculates battery energy requirements using (11), (12), and (13),

$$E_{Batt.} = E_{day} \times Oto._{day} \quad (11)$$

$$Cap._{Batt.} = \frac{E_{Batt.}}{Volt_{E_{Batt.}}} \quad (12)$$

$$\Sigma._{Batt.} = \frac{Cap._{Batt.}}{I_{H_{Batt.}}} \quad (13)$$

where battery energy requirements are determined based on autonomous days at 3, 4, and 5 days.

Modelling and Simulation

In this modelling study, the roof method is used on various Universitas Jenderal Achmad Yani buildings and is simulated using the K2 Base System software and based on potential and meteorological data based on the General Achmad Yani University coordinates to the type of roof photovoltaic installation system selected, the type of gable roof and flat roof. Figure 4 and Table 3 depicts the flow of actions carried out in this study, taking into account parameters such as the size of the land, the absence of solar irradiance impediments, and the comprehensive technical documentation to be utilized as planning references. The first stage involves modelling meteorological data, followed by PV construction that modifies the slope and kind of roof, and finally roof mouting simulations to compute the capacity of each requirement in this design [8][22]. Based on actual data and current conditions, the design and simulation on the concrete roof model (all contained in the new building) and tile roof (old building model) were chosen as the basis of the layout model given in Table 3. The most significant installation type for both types is raised, with the PV module oriented in the form of a landscape.

The design deviations are adjusted to the real situation. Building height, roof slope (for gable roofs), roof area, and wind load during operation are all important considerations for both types. Meanwhile, the module specs utilized in Table 3 are stored in the software's manufacturing data.

Comparison Flat Roof and Gable Roof Model

Two kinds of flat roof and gable roof mounting systems are proposed in this study. All of these proposals are modeled using open-source K2 Based System software. According to the survey results, flat roofs are ideal for a variety of surfaces including concrete [23], green roof, gravel, or even trapezoidal sheet metal. In this case, there are three buildings with concrete cast standards with installation angles ranging from 0 to 45°. While there are two buildings with gable roof models (EED and EEL). The K2 installation technology is appropriate for various types of corrugated roofs that often employ tiles (without metal) that are more conventional and widespread in Indonesian buildings such as residential types.

This program will allow installation on corrugated mode, or typical roof tiles, which is similar to the flat roof type standard, provide several variables and types of civil constructions in buildings. Wind will generally affect rooftop PV installations if the building height is greater than 200 meters, hence this standard should offer criteria dynamically.

Table 3. Rooftop Modelling Design by K2Base Systems Simulation

Eurocode Design	Roof Type	
	Flat Roof	Monopitch/Gable Roof
Roof Covering, Sheet Material	Membrane Bitumen Concrete Gravel Green roof	Tile Trapezoidal Seam Metal Corrugated
Module Arrays	D-Dome 6.10 S-Dome 6.10 S-Dome 6.15	Minifive Multirail MiniRail MK2 K2 BasicRail Multi, Mini, MiroRail Insertion Minifive
Module Layout	Complete Roof Module array	Complete Roof Module array
Installation Type	Paralel Elevated	Paralel Elevated
Module Orientation	Potrait lanscape	Potrait lanscape

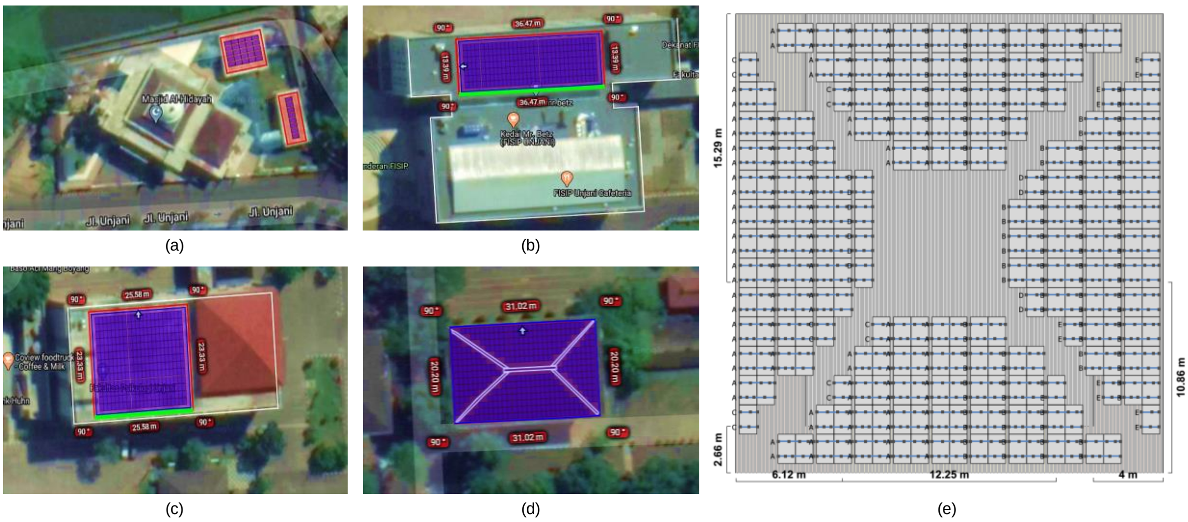


Figure 4. Simulation Rooftop PV using K2 Base; a) Al-Hidayah Mosque (AM), b) Faculty of Social and Political Science (FSPS), c) Faculty of Psychology (FPSI), d) Department of Electrical Engineering (EED) and e) base rail of Electrical Engineering Lab. (EEL)

In this simulation (tuned to the climate and existing conditions), the pressure of the snow accumulation can be ignored or snow load is assumed to be 0.00 kN/m^2 [24]. The simulation will shows the total weight of materials (in kg) based on the simulated Bill of Materials (BOM) Table, which includes sockets, stainless steel clips, cable clamps, rail mats, mounts and couplers [25].To guarantee appropriate ballast calculation, the coefficient of friction should be validated by the Designer or Installer by reading the guidelines from the D-Dome R2-Coefficient of Friction document [26], which can be found in the technical information part of the website for values on popular roof types. The solar fastener SolidRail system can be used with reference to the K2 system under standard roof requirements on slopes of 5 – 75° [27, 28, 29, 30].

RESULTS AND DISCUSSION

PV systems play a significant function as a solar energy source. The working parameters of the PV characteristics can be discovered by modelling the panel specifications (see Table 2). Current to voltage (I-V) ratings, which include short circuit current (I_{SC}), voltage open circuit (V_{OC}), and voltage to PV output power, are used to verify working qualities. The PV panel characteristic all working maximum power based on solar irradiation (1000 W/m^2) and ideal solar panel temperature (25°C or 77°F). This PV module has the same effective area as the modelling results, namely 1.63 in Table 2, and an efficiency of 15.3%. The current-voltage curve demonstrates that the maximum working conditions at current are exactly proportional to the irradiance, the maximum current operating point is attained, and the voltage continues to fall to zero. As a result, the voltage in working conditions will be lower. This maximum voltage, like the battery, is determined by each cell in the panel. However, if the solar irradiation conditions and environmental temperature are not too hot, part of the maximum operating voltage will increase. It should be noted that if the ambient temperature exceeds the STC value, the PV power will fall, but the voltage will grow under maximum conditions when the temperature is between 18°C and 23°C, provided the light intensity is good and high. Solar panel attributes are inextricably linked to other losses.

The optimal angle can be calculated using the amount of irradiation received. In this example, the solar panel is built at a 15° angle to match the structure's roof. The direction and speed of the wind will have an effect on the roof PV installation system. PV positioning will also have a significant impact on shadowing. Shading can have a (near) or (far) affect. The orientation of the field must match that stated in the "Orientation" section. The area must be large enough to house the PV mini-grid. Shadows may affect the maximum operational power generated. The simulation includes the effects of shading and un-shading.

The K2 Base System software is used to simulate and model this research, which is specifically developed to determine the amount of energy that can be utilized by roof-type PV panels, both buildings and dwellings, as presented in Figure 4. This software not only assists in the selection of PV panels, but it also calculates racking and mounting methods. The initial stage of modelling a rooftop PV system using the K2 Base System is to understand that rooftop PV is intended to fulfill the supply of power, lighting in buildings, and supporting core equipment in buildings. The mounting system for the rooftop PLTS used is open-source software, namely the K2 Based System. This means that it is generally accessible and user friendly. The first stage begins with determining the type of roof, this type consists of gable roofs, flat roofs, and monopitch roofs, then determines the roof covering, the height of the building and the roof angle. We enter the wind speed (m/s) from the meteo data as a mechanical load parameter in the design of a rooftop solar power plant.

The K2 Based System software determines the distance between the panels, and for the roof surfaces of structures and buildings in this study, it is separated into two categories: flat cast roof surfaces and sloping roof surfaces, as in general. Rooftop PV is intended to serve electrical loads, illumination in buildings, and support essential building systems. The choice of the roof type, panel spacing, roof slope, and mounting rail type for the installation system is critical since it will decide how much weight is created in the rooftop PV system, so the estimated load that the building must withstand. The K2 Based System software determines whether or not a load must be carried by snow. However, because there is no snow in Indonesia, we presume zero or no snow.

The electrical demands for the Al-Hidayah Mosque Building are divided into two PV arrays, which are located on the roofs of the male and female ablution areas. In addition to meeting the needs of mosque lighting and loudspeakers, energy is also used for illumination and water pumps. The design employed makes use of a flat roof or a flat surface of the structure to reduce shade. Using the design and simulation outlined in the session. Previously, the area and number of PVs could be calculated or estimated by simulation. The roof type of one structure cannot be paired with another. As a result, the flat roofs of the Psychology Building, the Social Sciences Building, and the Mosque were chosen oneddas the appropriate location for a rooftop PV system.

The PV panel rack system is held together by the fastening parts. Stainless steel fasteners are used in humid areas where corrosion is more likely. Even though the mounting structure is built of steel or aluminum alloy material, failure or damage may occur if the stress specification is exceeded. The force per unit area is used to define stress. When the pressure (P) is normal and evenly distributed across the cross-sectional area (A), the normal stress will be the same. K2 Base system for flat roof mounting methods is suited for a wide range of including concrete, bitumen, surfaces, green roofs, foils, and even trapezoidal sheet metal. The simulation also offers the maximum pressure of the insulating equipment (protective mat), also known as the dead load system (see Table 6) column 5 in kN/m^2, which differs from the total weight of the material (kg) as shown in Table 4.

Mounting Systems and Utilized Energy

Elevations can be either single-sided or double-sided. The mounting angles range from 0 to 45°. The use of strong rails on concrete roofs makes installation easier for technicians. Screws are not required for installation on concrete roofs; only components intended for it are required as depicted in Figure 5. A steep slope angle, as shown in Figure 6, for example, is advantageous in very rainy areas because it helps the rain to drain off better.

In areas where there is a lot of snow, a flatter angle of inclination is utilized more often: the sliding down of the snow is more controlled this way. The timeless shape of the gable roof can be aided slightly by the addition of skylights or dormers, which are available with or without overhang. Architects provide a variety of contemporary styles and combinations. Furthermore, photovoltaic systems are typically well-installed. The Electrical Engineering Building contains 350 PV panels and an 837.52m^2 usable roof space as listed in Table 5.

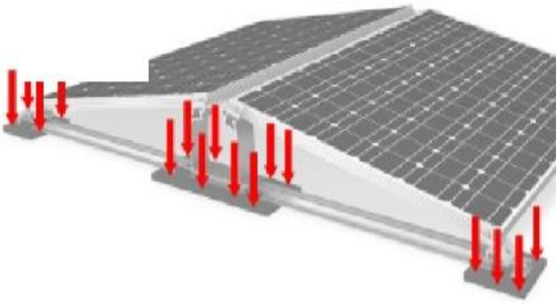


Figure 5. D-Dome Mounting Systems

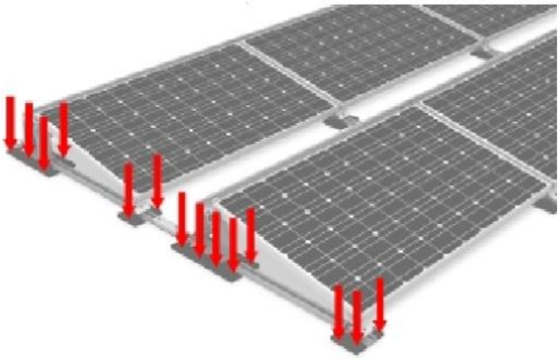


Figure 6. SolidRail Mounting Systems

Meanwhile, the Al-Hidayah Mosque has only 33 solar panels covering a total area of 131.58m^2.

Figure 7b shows the more the space utilized, the more solar panels that can be mounted on a building's roof, and the greater the quantity of power that can be generated by rooftop PV. The following are the results of estimating the roof area of the building and the quantity of output electricity that the PV system can generate. The Peak Power (kWp) in Table 5, second column calculated using Eq. (8) will have a much smaller value because it is adjusted to the average irradiance at 9.96 kW/m^2 compared to the power that can be generated (this value will be large) if the conditions STC. The mechanical load of each building is shown in Table 7 depending on the area of the solar panel used. Each mechanical load weight is similar since the specs utilized are adjusted to Table 2 as the PV Panel's nameplate parameter.

Component System's Result

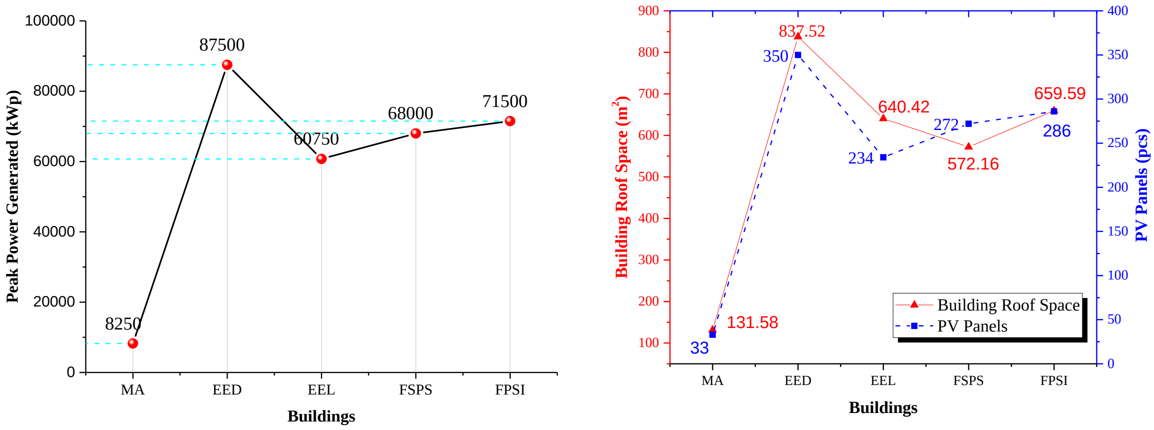
The appropriateness of the roof area is determined by the PV panels installed on the roof and is given in m^2. The calculated number of solar panels results differ from the simulation results. The calculated value is the ideal amount required to meet each building's daily energy needs. Meanwhile, the ideal value in the K2 Base System software simulation is determined by the available roof area. Following the completion of the modelling and calculation operations, the specification model is inserted in line with the K2-Based System software-based rooftop PV design, and the model from the simulation results for rooftop PV is produced (Figure 7a).

Table 8 compares the number of PV panels required, yet the area is insufficient. As a result, the quantity of solar panels is insufficient for the Psychology Building and the FSPS Building. However, for EED 350 PV panels, export to 220VAC/50Hz grid using Grid-tie Inverter calculated in further specification is possible.

There are two portions based on the results of determining the number of inverters (Figure. 7a).

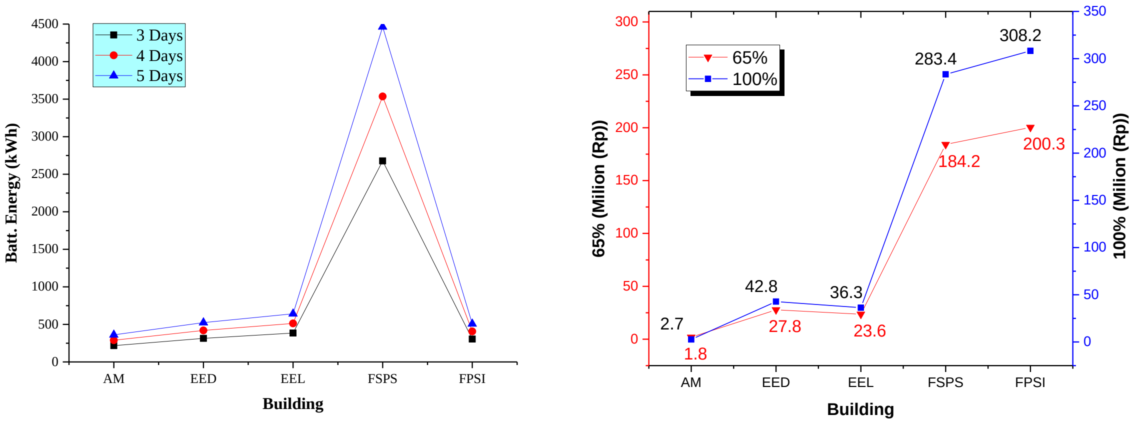
The following equation can be used to compute and determine inverter capacity, for example, in the Al-Hidayah Mosque using a 10 kW inverter, while for larger buildings utilizing 2 - 3 inverters with a capacity of >25 kW. The system calculates battery energy requirements using (11) - (12), where battery energy requirements are determined based on autonomous days at 3, 4, and 5 days, as given in Table 8. Figure. 8a depicts the required quantity of batteries based on the chance of an autonomous day extreme, such as when there is no sun for 3-5 days in a row. The graph next depicts the demand for various battery specifications on the market, namely 12 to 100Ah. Table 9 presents the calculations (2) – (4), with references to prior and most recent ministerial rules. Column 1 (Table 9) calculates the PV contribution to actual load based on the energy characteristics of the survey findings per day shown in Figure 3.

Meanwhile, the optimum contribution based on the modelling of the roof area and PV quantity is substantially bigger when the adjustment factor (1.1) and the average Peak Sun Hour (PSH) in Indonesia of roughly 4.67 hours per day are taken into account. One of the new regulations provisions is to compare the export hour (kWh) of electricity from 65% to 100% shows in Figure. 8b where the FPSI has far better support to the grid.



(a) (b)

Figure 7. Simulation Result; a) Peak Power (kWp) Generated, b) Roof Area of a Building vs. Number of PV Panels



(a) (b)

Figure 8. a) Battery Energy in kWH for each Building, b) Comparison of Feed in Tariff Export to the Grid

Table 4. K2 Base's Mounting Simulation Result

Building	Roof Type	Mounting System	Velocity Pressure	Weight Tot.
Al-Hidayah Mosque (AM)	Flat roof	S-Dome V10	0.303 kN/m^2	108.8 kg
Electrical Eng. Dept. (EED)	Gable roof	Solid Rail	0.017 kN/m^2	1044.3 kg
Electrical Eng. Lab. (EEL)	Gable roof	Solid Rail	0.021 kN/m^2	684.7 kg
Fac. of Soc. and Pol. Sci. (FSPS)	Flat roof	D-Dome V10	0.417 kN/m^2	604.5 kg
Psychology (FPSI)	Flat roof	D-Dome V10	0.417 kN/m^2	662.7 kg

Table 5. K2 Base's PV Generated Simulation Result

Building	Potential Power (kWp)	Rooftop Area (m^2)	PV Panel (Pcs)	PV Array
Al-Hidayah Mosque (AM)	8.250	131.58	33	2
Electrical Eng. Dept. (EED)	87.500	837.52	350	1
Electrical Eng. Lab. (EEL)	60.750	640.42	234	4
Fac. of Soc. and Pol. Sci. (FSPS)	68.000	572.16	272	3
Psychology (FPSI)	71.500	659.59	286	4

Table 6. K2 Base's Mechanical Simulation Result

Building	Weight/panel (kg)	Weight Mounting Sys. (kg/m^2)	Total Dead Weight (incl. ballast)
Al-Hidayah Mosque (AM)	20	1.63	0.14 kN/m^2
Electrical Eng. Dept. (EED)	20	1.63	1.14 kN/m^2
Electrical Eng. Lab. (EEL)	19	1.5	0.12 kN/m^2
Fac. of Soc. and Pol. Sci. (FSPS)	20	1.63	1.13 kN/m^2
Psychology (FPSI)	20	1.63	0.13 kN/m^2

Table 7. Rail Component Simulation Result

Building	Roof Covering	Rail Arrays	Roof Layout	Additional Rail Material
Al-Hidayah Mosque (AM)	Concrete	Mini-Rail	Complete Roof	Recycled Rubber
Electrical Eng. Dept. (EED)	Tile	Mini-Rail	Complete Roof	Ultralight (Aluminium)
Electrical Eng. Lab. (EEL)	Tile	Mini-Rail	Complete Roof	Ultralight (Aluminium)
Fac. of Soc. and Pol. Sci. (FSPS)	Concrete	Mini-Rail	Complete Roof	Recycled Rubber
Psychology (FPSI)	Concrete	Mini-Rail	Complete Roof	Recycled Rubber

Table 8. Component Capacity Calculation Result

Building	Number of Inverter (Pcs with Max. η 98%)			Number of Battery with Autonomous (Day)		
	10 kW	25 kW	50 kW	2	3	5
Al-Hidayah Mosque (AM)	1	-	-	181	241	300
Electrical Eng. Dept. (EED)	-	-	2	262	349	437
Electrical Eng. Lab. (EEL)	-	3	-	694	926	1157
Fac. of Soc. and Pol. Sci. (FSPS)	-	3	-	223	295	373
Psychology (FPSI)	-	3	-	253	338	423

Table 9. PV Contribution and Export Tarif

Building	Electrical Export (kWh)		Electrical Bill	
	Actual PV Contribution per day	Potential PV Contribution per day	65% (Rp)	100% (Rp)
Al-Hidayah Mosque (AM)	16.7	38527.5	1,810,249.26	2,784,998.87
Electrical Eng. Dept. (EED)	24.22	408625	27,841,378.34	42,832,889.75
Electrical Eng. Lab. (EEL)	29.63	283702.5	23,645,355.08	36,377,469.36
Fac. of Soc. and Pol. Sci. (FSPS)	206.24	317560	184,219,541.06	283,414,678.56
Psychology (FPSI)	213.31	333905	200,341,280.39	308,217,354.45

CONCLUSION

The following conclusions can be drawn based on the design results based on surveys, calculations, and simulations of the Rooftop PV System model that is modelled, simulated, and compared in accordance with the research objectives: The Electrical Engineering Building contains 350 PV panels with a total usable roof surface of 837.52 m^2 simulated using the K2 Base System software, while the laboratory has 243 PV panels with a roof area of 640.24 m^2. Al-Hidayah Mosque has 25 and 8 solar panels, for a total of 33 solar panels with a total area of 131.58 m^2. Then, at FPSI and FSPS Building, there are 286 and 272 PV panels, respectively, with roof areas of 659.59 m^2 and 572.16 m^2. According to the results of the calculation of the number of inverters that correspond to a 50kW output, the Electrical Engineering Department Building has two inverters, while the EEL, FPSI, and FSPS Buildings each have three inverters with a 25kW output. While it is much smaller, a mosque has one inverter with a capacity of 10kW. The number of batteries with the shortest autonomous (5 days) produced 1157 for the EEL Building, 300 for the Al-Hidayah Mosque, 437 for the EED, 423 for the FPSI, and 373 for the FSPS Building. The Al-Hidayah Mosque requires just 181 batteries for the maximum autonomy (3 days), whereas the other three buildings require more than 200 batteries with variations. This value is not absolute the more batteries that may be used, the higher the cost and investment. This system's design is not fixed; it can still vary based on the needs of the user and the planning party, and it is adjusted to the budget provided. The amount of electrical energy (kWh) exported or transmitted from the Rooftop PV customer installation system to the network system of the Electricity Supply Business License holder or PT PLN (Persero) recorded on the import-export kWh meter, and according to the new regulation in 2021, the maximum amount obtained from exports is >300 million rupiahs. However, this study can provide an outline of how rooftop PV can assist lower conventional generation costs while also helping to cut carbon emissions.

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REFERENCES

[1] J. Donker and X. Van Tilburg, “Three Indonesian Solar-powered Futures: Solar PV and Ambitious Climate Policy,” *ECN.TNI Report Ambition to Action,* 2019, Germany, doi: 10.13140/RG.2.2.17465.31847.

[2] NN, “Policy Instrument: General National Electricity Plan (RUKN) 2019 - 2023,” *Climate Policy Implementation Check,* 2023.

[3] NN, “Renewable Energy in Indonesia,” *Traction Energy Asia*, 2019.

[4] R. M. Nasir and R. Dalimi, “Evaluation of the Strategy for the Implementation of Solar Power Plants in Indonesia Using SWOT Analysis,” in *International Conference of Social Research with Multidisciplinary Approach (ICSRMA)*, Galaxy Science, Oct. 2021, pp. 13–24. doi: 10.11594/nstp.2021.1202.

[5] NN, “Akselerasi Pengembangan PLTS Atap Kejar Target Bauran EBT,” *Kementrian Energi dan Sumber Daya Mineral*, pp. 1–4, 2022,

[6] C. Ban, T. Hong, K. Jeong, C. Koo, and J. Jeong, “A simplified estimation model for determining the optimal rooftop photovoltaic system for gable roofs,” *Energy Build*, vol. 151, pp. 320–331, 2017, doi: 10.1016/j.enbuild.2017.06.069.

[7] F. Baumgartner, "Photovoltaic (PV) balance of system components," *The Performance of Photovoltaic (PV) Systems*, pp. 135-181, 2017, doi: 10.1016/B978-1-78242-336-2.00005-7.

[8] N. Mohajeri et al., “A city-scale roof shape classification using machine learning for solar energy applications,” *Renew. Energy*, vol. 121, pp. 81–93, 2018, doi: 10.1016/j.renene.2017.12.096.

[9] H. R. Iskandar et al., z, “Design of Solar Power Plant for Electrical Engineering Department Laboratory,” *2019 2nd International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, Indonesia, 2019, pp. 145-150, doi: 10.1109/ICHVEPS47643.2019.9011041.

[10] O. T. Winarno, Y. Alwendra, and S. Mujiyanto, “Policies and strategies for renewable energy development in Indonesia,” in *2016 IEEE International Conference on Renewable Energy Research and Applications*, 2017, vol. 5, pp. 270–272, doi: 10.1109/ICRERA.2016.7884550.

[11] T. Baumann, D. Schär, F. Cariget, A. Dreisiebner, and F. Baumgartner, “Performance analysis of PV green roof systems,” in *32nd European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2016)*, 2016, pp. 1–5, doi: 10.4229/EUPVSEC20162016-5CO.14.3.

[12] M. Cossu et al., “Solar light distribution inside a greenhouse with the roof area entirely

covered with photovoltaic panels," *Acta Hortic*., vol. 1182, pp. 47–55, 2017, doi: 10.17660/ActaHortic.2017.1182.5.
[13] M. Stocks, A. Blakers, C. Cheng, and B. Lu, "Towards 100% renewable electricity for Indonesia: The role for solar and pumped hydro storage," in *2019 International Conference on Technologies and Policies in Electric Power and Energy*, TPEPE 2019, 2019, pp. 1–4, doi: 10.1109/IEEECONF48524.2019.9102581.
[14] S. Singh et al., "Optimization of Rooftop PV System Deployment for LV Distribution Network," 2021, doi: 10.1109/SeFet48154.2021.9375688.
[15] NN, International Renewable Energy Agency, Abu Dhabi: IRENA, 2020.
[16] S. Dwiatmoko, A. Nagel, and J. Windarta, "Soaking up the Sun: Solar Energy Optimization during Pandemic, Study Case at Micro, Small and Medium Enterprises (MSME) Rattan Crafts Center in Trangsan Village, Sukoharjo, Central Java," *Jurnal Riset Teknologi Pencegahan Pencemaran Industri*, vol. 13, no. 1, pp. 12–19, Jun. 2022, doi: 10.21771/jrtppi.2022.v13.no1.p12-19.
[17] NN, "Minister of Energy and Mineral Resources Regulation Number 49 of 2018 concerning Use of Rooftop Solar Power Generation Systems by Consumers of PT. PLN (Persero)." Jakarta, pp. 1–18, 2018.
[18] H. R. Iskandar et al., "Prototype development of a low cost data logger and monitoring system for PV application," *2016 3rd Conference on Power Engineering and Renewable Energy (ICPERE)*, Yogyakarta, Indonesia, 2016, pp. 171-177, doi: 10.1109/ICPERE.2016.7904864.
[19] H. R. Iskandar et al., "Optimal Design of Rooftop PV Systems for Electrical Engineering Department Laboratory," in *2021 3rd International Conference on High Voltage Engineering and Power Systems, ICHVEPS 2021*, 2021, pp. 349–354, doi: 10.1109/ICHVEPS53178.2021.9601097.
[20] NN, "Regulation of The Minister of Energy and Mineral Resources ff the Republic of Indonesia Number 50 of 2017 on Utilization of Renewable Energy Sources For Power Supply By the Blessings of Almighty God Minister of Energy And Mineral Resources Of The Republic Of Indonesia," *The Minister of Energy and Mineral Resources,* 2017.
[21] NN, "Minister of Energy and Mineral Resources Regulation No. 26 of 2021 on Rooftop Solar Power Plant Connected to the Electricity Network of the Holder(s) of the Electric Power Supply Business License for Public Interest," *Indonesia Legal Alert*, Sep. 2021.
[22] H. X. Li, Y. Zhang, D. Edwards, and M. R. Hosseini, "Improving the energy production of roof-top solar PV systems through roof design," *Build. Simul*., vol. 13, no. 2, pp. 475–487, 2020, doi: 10.1007/s12273-019-0585-6.
[23] V. M. Joshima, M. A. Naseer, and E. Lakshmi Prabha, "Assessing the real-time thermal performance of reinforced cement concrete roof during summer- a study in the warm humid climate of Kerala," *J. Build. Eng*., vol. 41, no. May, p. 102735, 2021, doi: 10.1016/j.jobe.2021.102735.
[24] G. Zhang et al., "CFD Simulations of Snowdrifts on a Gable Roof: Impacts of Wind Velocity and Snowfall Intensity," *Buildings*, vol. 12, no. 11, pp. 1–19, 2022, doi: 10.3390/buildings12111878.
[25] NN, "ANSI/UL 2703 Overview & Module Listing," *PanelClaw*, no. 2. pp. 8, PanelClaw, Inc., 2019
[26] K2 Base Systems, "D-Dome Railless System Assembly Instructions." K2 Base Systems, pp. 1–24, 2022
[27] D. R. Armanda & P. Pawenary, " Plans for upgrading existing conventional 150 kV substations into digital substations in Sulawesi - Indonesia, accompanied by financial studies," *SINERGI*, vol. 27, no. 2, pp. 249-260, 2023, doi: 10.22441/sinergi.2023.2.013
[28] M. I. Malik, A. Adriansyah, A. U. Shamsudin, "Techno-Economic Analysis Utilization of On-Grid Solar Photovoltaic Systems in Improving Energy Efficiency in Manufacturing Industries", *Journal of Integrated and Advanced Engineering (JIAE)*, vol. 3, no. 2, pp. 101- 110, 2023, doi: 10.51662/jiae.v3i2.96
[29] M. Iqbal, E. Ihsanto, A. B. Mohammednour, "Improvement of output voltage from shading interference on solar cell using a reflector system," *Journal of Integrated and Advanced Engineering (JIAE)*, vol. 2, no. 2, pp. 70-76, 2022, doi: 10.51662/jiae.v2i2.39