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# Optimizing Component Specifications and Panel Configurations in On-Grid Solar Power Generation system: Guidelines for Maximum, Minimum, and String Count

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## Abstract

*The increasing global emphasis on renewable energy has significantly accelerated the adoption of solar photovoltaic (PV) systems. On-grid Solar Power Generation, which are connected to the public electricity grid, play a crucial role in this transition by providing a sustainable and efficient means of generating electricity. However, the performance and efficiency of such systems depend on the careful selection and configuration of the systems' components. This paper addresses those issues and proposes guidelines for designing the panels and components in order to raise the efficiency in Solar Power Plants. Towards achieving this aim of enhancing the efficiency and reliability of solar power provision, this study has focused on overcoming some of the challenges associated with specifications of components such as maximum and minimum limits, and determination of number of strings. In this solar installation project plan, JAM72S30-550/MR panels and Huawei SUN2000-100KTL-M1 inverters which have the capacity to handle 13 strings of 18 panels per inverter unit have been proposed. In this case, the number of panels installed in a string of the inverter was bane from 5 to 22 to avoid overloading the system, thus ensuring reliability and efficiency. This also helps to provide essential insights on how specifications of solar panels and other components in on-grid Solar Power Plants should be adjusted to enhance the overall efficiency and reliability of the systems. In this research, suggestions have been made to improve the management of solar resources and the efficiency of solar power systems, such as the optimal number of strings and the maximum number of modules per panel.*

***Keywords:** Component Specifications; Solar systems; On-Grid; Panel Configurations; Strings*



## 1. Introduction

Solar power generation systems that rely on solar energy are a way to tackle the worldwide transition to renewable energy. Such systems can employ solar thermal technology or utilize photovoltaic (PV) panels to convert sunlight into electrical energy (Zhao et al., 2022). The deployment of solar power systems promotes energy autonomy, aids in the reduction of greenhouse gases, and lessens the reliance on fossil fuels thanks to its clean and affordable characteristic. With the assistance of technological advancements and declining costs, solar power systems are now easily available and cheap to deploy on a global scale. This is a great move towards sustainable future energies (Mardiyanto et al., 2022). At present, the trend which has taken an upward curve is the integration of renewable energy sources, which can minimize repercussions of global warming. At present, solar photovoltaic (PV) energy systems are seen as one of the most important possibilities. Some countries use the considerable capacities of solar power plants to cover the needs of their regions because this energy source is clean and has low operational costs. It is estimated that in 2019 and 2020 the total amount of electric energy produced throughout the world from solar photovoltaic cells increased by 23% and this number reached 156 TWh. By the year 2050, solar power capacity generation is envisaged to be around 7000 TWh (Abdelilah et al., 2022).

Optimizing the design parameters for an on-grid solar power generation system is very difficult, as it has to meet the needs of various energy components, locations, and energy requirements (Muktiadji et al., 2022). To configure a solar energy system in an efficient manner, proper arrangement of the various components is critical as inefficient arrangement will result in poor energy generation and energy costs, thus affecting the reliability of the entire system. According to recent research, for optimal performance, it is important to choose the system and component arrangement - in a specific order. For instance, Chen et al. (2021) during the study of the optimal design of trigeneration systems, it was revealed that proper distribution of solar energy significantly improves the performance of solar systems. Mehta (2022) discusses the benefits that can be gained from optimizing the operational parameters of solar cells and improving system performance under various circumstances. In addition, the use of high-voltage inverters and proper configuration of photovoltaic panels can significantly reduce electricity costs. (Pahwa et al., 2015). However, characterizing the optimal combination of components - properly shaded solar panels, inverters, and configured wiring - can present challenges of site conditions, electrical energy demand, and complexity of electrical parameters. Inappropriate system deployment can lead to poor energy generation and high expenses as well as reduced system operability. Given these issues, it is critical to improve the efficiency and reliability of grid-connected solar power plants to expand the use of solar energy as a renewable resource.

In recent years, the surge in the quest for renewable energy has resulted in extensive research on the optimization of solar photovoltaic (PV) systems, especially for grid-connected configurations. One of the key areas for such optimization is the orientation and number of solar PV panels and strings and associated components that affect the overall efficiency and economic viability of such systems. Mardiyanto et al. (2022) in this regard, it is worth mentioning that even inexpensive PV elements can reduce electricity expenditure by more than 50% as long as they are arranged in an optimal configuration, and therefore emphasizes the importance of proper choice and arrangement of PV panels and inverters. Similarly, Phelps & Zhou (2021) This research aims to find an optimal threshold of the ratio between the storage and panels comparing various configurations in terms of cost and operation of grid-integrated solar photovoltaic power plants (Seedahmed et al., 2022).

Optimizing the panel configuration becomes a major challenge when it comes to considering various environmental conditions that affect the intensity of solar radiation. Research by Craciunescu & Fara (2023) the study also focused on optimization methods for solving partial shading problems and it was found that fuzzy logic-based control algorithms improve the efficiency of PV modules with respect to erratic weather. The research also pointed out the need to implement adaptive string configurations to reduce environmental impact. Another direction of optimization lies in incorporating hybrid systems to reduce dependence on the power grid and make the overall system more robust. For instance, Ren et al. (2019) this research discusses a hybrid energy system that has been optimally reconfigured to improve its performance through multi-purpose optimization as a solar and geothermal energy source. Similarly, Eghlimi et al. (2021) in this paper discusses the exploration of wind-solar hybrid configurations and their contribution to minimizing power outages and emphasizes the importance of multi-source integration for optimal energy distribution.

Optimizing the inverter, especially the inverter maximum power point tracking (MPPT), would be essential for the estimation of the PV system efficiency in converting solar energy into usable electricity. There has been focus on contemporary events whereby the inverter functionality is improved with the application of complex manipulation algorithms as well as the development of the inverter cooling systems increasing the inverter efficiency and its operational life. For example, Sharma et al. (2023) emphasize the application of advanced power electronics techniques and thermal control technologies for reliable and efficient inverter operation with complex system configurations. Moreover, it has been shown that optimization technologies, including genetic algorithms and machine learning, allow for reduction of losses and control of the variability of renewable energy sources which, in turn, improves inverter performance in solar power systems (L. Li et al., 2019). In addition, the utilization of sophisticated algorithms has enhanced the maximum power point tracking (MPPT) capability that greatly optimizes energy conversion efficiency (Villegas-Mier et al., 2021).

Research in the field of renewable energy has paid particular attention to finding the most suitable storage options, especially in relation to integrating with PV panel configurations. Sultan et al. (2020), the inclusion of advanced optimization algorithms in these artificial systems has improved the efficiency and economy of hybrid systems, integrating PV, wind turbines, and fuel cells for better energy storage in both grid-connected and off-grid systems. Furthermore, Maleki et al. (2020) demonstrates that even with the reliability of the system being maintained, life cycle costs can be maintained at lower levels with the employment of more sophisticated optimization techniques. Additionally, J. Li et al. (2020) discusses capacity configuration models for optimized hybrid PV and energy storage systems, which not only reduce operational costs but can also improve energy conservation and emission reduction, further making the overall economy more viable.

Finally, recent research has tried to improve these various variables by providing recommendations on the selection of components and arrangement of solar panels in Solar Power Plants so that maximum efficiency is ensured. By addressing challenges related to component datasheet specifications, maximum and minimum limits, and determination of the number of strings, this research aims to improve the efficiency and reliability of solar power systems. Therefore, this research provides guidance on factors useful for determining the component specifications and panel configurations of on-grid solar power plants with the aim of improving system effectiveness. Through optimal panel limit settings with an appropriate number of strings, this study contributes to ensuring more effective utilization of solar resources and improving overall solar power system performance.

## 2. Research Methodology

This research uses a research method called descriptive analysis. Descriptive analysis involves collecting the necessary data and then compiling, processing, and analyzing it to describe the investment feasibility of installing a Solar Power Plant project in the industry. Figure 1 below shows the research flow chart on the design of on-grid-type rooftop solar power plants in the industry.

### *2.1 Data Acquisition*

In this study, energy consumption load data in the industry of 3,310,421 kWh is used, and the data is obtained directly from stakeholders in the company as data holders. In addition, this study also used sunlight intensity data at the design location obtained from the Global Solar Atlas application and Peak Sun Hour (PSH) value data obtained through the Meteonorm 8.1 application in the PVSyst application. Solar intensity data at the location of industrial buildings taken through the Global Solar Atlas application can be seen in Table 1.

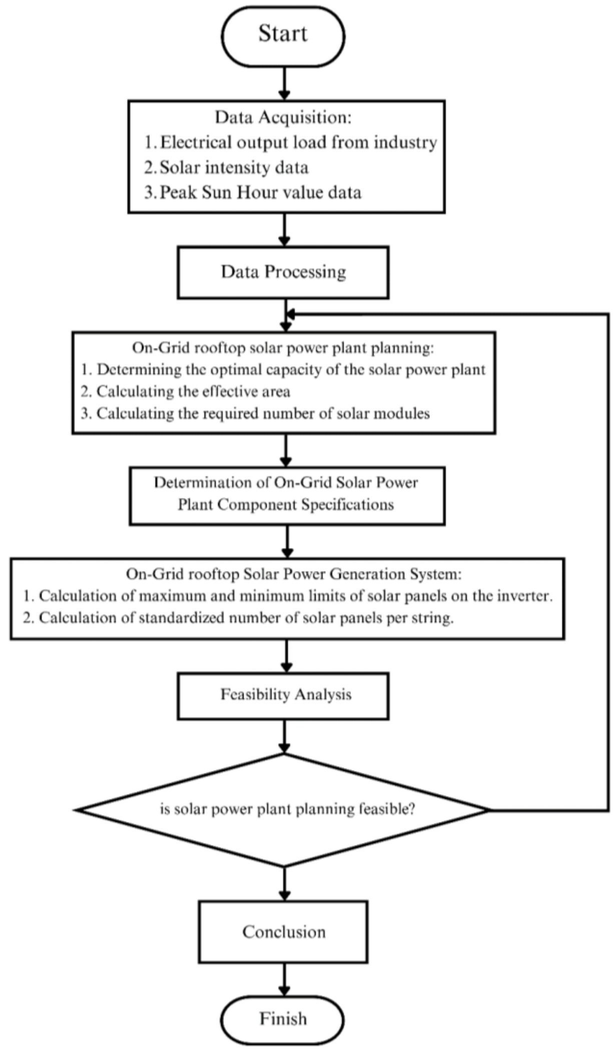


**Figure 1.** Research flow chart

**Table 1.** Solar intensity data at industrial building sites.

| Data | Value |
|---|---|
| *Diffuse horizontal irradiation* (*DIF*) | 2,459 kWh/m$^2$ per day |
| *Direct normal irradiation* (*DNI*) | 3,896 kWh/m$^2$ per day |
| *Direct normal irradiation* (*DNI*) | 3,896 kWh/m$^2$ per day |
| *Specific photovoltaic power output* ($PV_{out}$) | 4,287 kWh/kWp per day |
| *Global horizontal irradiation* (*GHI*) | 5,277 kWh/m$^2$ per day |
| *Global tilted irradiation at optimum angle* (*GTI opta*) | 5,337 kWh/m$^2$ per day |
| *Optimum tilt of PV modules* (*OPTA*) | 20/90º |
| *Air temperature* (*TEMP*) | 25.6 ºC |
| *Terrain elevation* (*ELE*) | 255 |

Peak Sun Hour (PSH) value data is obtained through the Meteonorm 8.1 application by looking at the Global Horizontal Irradiation (GHI) value. Peak Sun Hour (PSH) is an estimate of the time of effective utilization of solar radiation in a day. The GHI value can be seen in Table 2.

**Table 2.** Global Horizontal Irradiation (GHI) values based on Meteonorm 8.1

| **Month** | ***Global Horizontal Irradiation* (GHI)** |
|---|---|
| January | 4.17 kWh/m$^2$/Day |
| February | 4.88 kWh/m$^2$/Day |
| March | 4.62 kWh/m$^2$/Day |
| April | 5.15 kWh/m$^2$/Day |
| May | 5.02 kWh/m$^2$/Day |
| June | 5.30 kWh/m$^2$/Day |
| July | 5.35 kWh/m$^2$/Day |
| August | 5.69 kWh/m$^2$/Day |
| September | 6.02 kWh/m$^2$/Day |
| October | 6.34 kWh/m$^2$/Day |
| November | 5.56 kWh/m$^2$/Day |
| December | 5.15 kWh/m$^2$/Day |
| Average | 5.27 kWh/m$^2$/Day |

### 2.2 *On-Grid Rooftop Solar Power Plant Panning*

In this research, system design is first carried out through the stages of determining the optimal capacity of the Solar Power Plant system. The optimal capacity is the average capacity that can be generated by the Solar Power Plant according to the intensity of sunlight available at the installation site. The optimal capacity of the installed Solar Power Plant system should not exceed the connected power of Perusahaan Listrik Negara (PLN). To calculate the optimal capacity of the Solar Power Plant system, Equation (1) is used.

$$Optimal\ Capacity\ (kWp) = \frac{ET_{daytime}}{PV_{out\ daily}} \quad (1)$$

Where $ET$daytime is daytime energy demand per day (kWh/day). $PVout$ daily is PV output power per kWp based on solar irradiation (kWh/kWp per day). After obtaining the optimal capacity of the Solar Power Plant, the next step is to determine the peak power of the Solar Power Plant system. In this determination, the value of power losses (15% - 25%) is added which can later be caused by PV temperature loss, PV shading loss, dan cable loss in the Solar Power Plant system. The formula used to calculate the peak power of the Solar Power Plant system is Equation (2).

$$Peak\ power\ (kWp) = Optimal\ Capacity + (Optimal\ Capacity \times System\ Loss) \quad (2)$$

If the peak power value of the Solar Power Plant system is known, the next step is to determine the effective area. This effective area is a special area used for the placement of solar modules so that it can be adjusted between the area of solar modules and the roof area in the industry. In calculating the effective area, data is used in the form of solar module efficiency values (% per m2). The formula for calculating the effective area can be written as Equation (3) below.

$$Area\ (m^2) = \frac{Peak\ Power}{Eff} \quad (3)$$

Where Eff is solar module efficiency (21.3%). After the effective area is known, the number of solar modules used in the design along with the type of circuit used is calculated. The formula used to determine the number of solar modules used is as follows Equation (4).

$$Number\ of\ Module = \frac{Optimal\ Power}{P_{Out}} \quad (4)$$

Where $P_{Out}$ is output power value per solar module (550 Wp).

### 2.3 *On-Grid Solar Power Plant Component Specifications*

In this On-Grid Solar Power Plant Installation project, several important components will be used, each selected based on its specifications to ensure optimal system performance. The specifications of the components used in the installation are detailed as follows, providing an overview of each element's capacity, efficiency, and compatibility with the overall system design. These specifications play an important role in achieving the desired energy output and reliability of the system, which is further discussed in terms of its performance under operational conditions.

- ***JAM72S30-550/MR Solar Panel***

This project uses Monocrystaline solar panels with JA solar panel brand with type JAM72S30-550/MR (Table 3). because its cross section can absorb light more efficiently than other solar cell materials. About 15% of the efficiency gained when sunlight is converted into electricity is owned by this solar cell material. This percentage is a considerable figure when compared to other solar cell materials. The physical characteristics of this type of monocrystalline solar cell are octagonal in shape and darker in color.

**Table 3**. Datasheet of JAM72S30-550/MR Solar Panel

| **Subject @STC** | **Value** | **Symbol** | **Unit** |
|---|---|---|---|
| Rated Maximum Power | 550 | Pmax | W |
| Open Circuit Voltage | 49.90 | Voc | V |
| Maximum Power Voltage | 41.96 | Vmp | V |

| Subject @STC | Value | Symbol | Unit |
|---|---|---|---|
| Short Circuit Current | 14.00 | Isc | A |
| Maximum Power Current | 13.11 | Imp | A |
| Module Efficiency | 21.3 | - | % |
| **Subject @ NOCT** | **Value** | **Symbol** | **Unit** |
| Rated Maximum Power | 416 | Pmax | W |
| Open Circuit Voltage | 46.68 | Voc | V |
| Maximum Power Voltage | 39.43 | Vmp | V |
| Short Circuit Current | 11.17 | Isc | A |
| Maximum Power Current | 10.55 | Imp | A |

Figure 2 is an example of the JAM72S30-550/MR On-Grid PV Solar Panel used in this project.

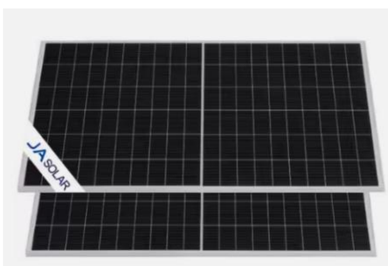


**Figure 2**. JAM72S30-550/MR Solar Panel.

- ***Huawei SUN2000-100KTL-M1 Inverter***

A DC-to-AC voltage converter device widely used in On-Grid solar power plant applications. The GTI solar power system will supply the generated power to the load, in case of overload, the generated power will be transmitted to the grid (Muktiadji et al., 2024; Muktiadji et al., 2022). If the power is not enough to supply the load, the grid will also supply power to the load. For this reason, the GTI will work if it is connected to the power grid, if the power grid is down, the GTI will stop working. Figure 3 is an example of the Huawei SUN2000-100KTL-M1 On-Grid inverter used in this project.


**Figure 3.** Huawei SUN2000-100KTL-M1

The following is the datasheet of the Huawei inverter that will be used (Table 4).

**Table 4.** Datasheet SUN2000-100KTL-M1 Huawei

| Model Name | Value | Unit |
|---|---|---|
| **Input DC** | | |
| Max. input voltage | 1100 | V |
| Max Current per MPPT | 26 | A |
| Max Short Circuit Current per MPPT | 40 | A |
| Start-up voltage | 200 | V |
| MPPT Operating voltage range | 200-1000 | V |
| Nominal Input Voltage | 720V @480Vac, 600V @400Vac, 570V @380 Vac | V |
| Number of MPP Trackers | 10 | |
| MPPT number/Max. input strings number | 20 | |
| **Output AC** | | |
| Rated output power | 100 | kW |
| Max. apparent output power | 110 | kVA |
| Max. output power | 110 | kW |
| Nominal Output Voltage | 480V/400V/380V, 3W+(N)+PE | V |
| Rated AC grid frequency | 50Hz / 60 HZ | Hz |
| Nominal Output Current | 120.3A @480V, 144.4A @400V, 152.0A @380V | |
| Max. output current | 133.7A @480V, 160.4A @400V, 168.8 A @380V | |
| Adjustable Power Factor Range | 0.8 Leading…0.8 Lagging | |
| Max. Total Harmonic Distortion | <3 | % |

- ***Installation Safety of Solar Power Generation Systems***

In the installation of solar power generation systems in Industrial buildings, there are several electrical safety mechanisms used to protect system components from potential damage caused by excessive current loads (Table 5). The application of these safety devices is critical in maintaining the integrity and longevity of the solar power system and can prevent failures and faults. These safety components are selected based on their capacity to more effectively perform overcurrent protection and other electrical hazards. A comprehensive list of safety devices used in installations is listed below, along with their respective roles in protecting PV system components, these measures are further discussed regarding their performance and compliance with industry standards.

**Table 5.** Installation Safety of Solar Power Generation Systems

| Component Name | Function |
|---|---|
| *Miniature Circuit Breaker* (MCB) | As a protection and circuit breaker in the event of an overload or short circuit. This MCB has a maximum value of 63 A. |
| *Molded Case Circuit Breaker* (MCCB) | The function of the MCCB is similar to the MCB, which acts as a protection and circuit breaker when an overload occurs. However, the MCCB has a maximum capacity of up to 1000 A. |

### 2.4 On Grid Solar Power Generation System Planning

Based on the type of circuit in the installation of Solar Power Plants in this industry requires the calculation of the maximum and minimum limits of solar panels to inverters, and strings in accordance with the regulations. Strings are a series of solar panels connected in series. The following are the formulas for the maximum and minimum limits of solar panels against inverter strings in Equations (5) and (6).

$$maximum\ limit\ of\ solar\ panels = \frac{V_{\max Input}}{Voc}$$

$$\sum Voc = N_{PV} \times Voc \quad (5)$$

$$minimum\ limit\ of\ solar\ panels = \frac{V_{\min Input}}{V_{mpp}}$$

$$\sum Voc = N_{PV} \times V_{mpp} \quad (6)$$

Where Vmax input is Maximum inverter input voltage. Voc is Open circuit voltage. Vmin input is Inverter start up voltage. Vmpp is Maximum power point voltage (V). The following are the steps to find the string pv in equation (7).

$$\sum Voc = N_{PV} \times Voc$$

$$\sum I_{mpp} = I_{mpp}$$

$$\sum String = V_{Start} < \sum Voc < V_{max}\ dan\ I_{mpp} < I_{max} \quad (7)$$

Where ∑Voc is Total open circuit voltage. NPV is Number of solar panels. Voc is Open circuit voltage. ∑String is Total strings used. Vstart is Minimum voltage at inverter input. Vmax is Maximum voltage at the inverter input. Impp is Maximum current generated by solar panel. Imax is Maximum current input to the inverter (A). In determining the number of strings there are 2 conditions, namely the minimum voltage of the inverter input is smaller than the open circuit voltage of the panel and smaller than the maximum voltage of the inverter input. In addition, the current generated by the solar panel is smaller than the maximum current of the inverter input. If the string on the MPPT is fully charged, it is strung parallel and fixed on the condition that the current generated by the solar panel is smaller than the maximum current of the inverter input. This causes the input current in the inverter to increase, so the formula requirement is as follows in equation 8.

$$\sum I_{mpp} = I_{mpp} + I_{mpp} \quad (8)$$

If the value of the panel current is smaller than the maximum inverter input current, no current losses occur. If the solar panel current is greater than the inverter input then current losses occur, so that the current that comes out will become heat in the inverter. The last stage in this design is to determine the layout/mounting system for solar modules. This determination is adjusted by looking at the position of the roof slope of the building, the direction of the building towards the equator, and the type of bracket used. The mounting system aims to maintain the position of the solar module so that it does not move and direct it to the desired position. The mounting system itself includes several components such as brackets consisting of T / L feet, adjustable tilt, tile hook and so on, as well as mounting components consisting of rail, rail joiner, end clamp, mid clamp, and so on.

### 2.5 Feasibility Analysis

At this stage, the feasibility analysis of the On-Grid Solar Power Plant design results is carried out. The feasibility analysis of the design of this on-grid rooftop Solar Power Plant includes an analysis of technical aspects, economic aspects, and environmental aspects. The technical aspect includes the calculation of energy generated by the Solar Power Plant. Equations (9), (10), and (11) are formulas used to determine the energy production of Solar Power Plants.

$$P_i = P_{max} - (P_{max} - losses) \quad (9)$$

$$P_{out} = P_i \times PSH \quad (10)$$

$$Energi\ yield = P_{out} \times 365\ day \quad (11)$$

Where P_max is maximum power of solar module. *Losses* is total loss in efficiency (%). P_i is power produced minus losses (watt). *PSH* is Peak Sun Hour (kWh/m2/hari). *Pout* is energy produced by solar power plant (kWh). After calculating the energy produced by the Solar Power Plant, the performance ratio can be calculated. The performance ratio is used to determine the performance of the Solar Power Plant within a certain period. A good performance ratio range from 70-90%. Equations (12), (13), and (14) are the formulas used to calculate the performance ratio value.

$$H_{tilt} = PSH \times 365\ day \quad (12)$$

$$Ideal\ Energy = P_{max} \times number\ of\ solar\ modules \times H_{tilt} \quad (13)$$

$$Performance\ Ratio = \frac{energy\ production\ output\ of\ Solar\ Power\ Plant}{Ideal\ Energy} \quad (14)$$

Where $H_{tilt}$ is length of solar irradiation time for 1 year (h/year). $P_{max}$ is maximum power of solar module (Wp).

## 3. Result and discussion

### 3.1 *Discussion of On-Grid Rooftop Solar System Design*

#### 3.1.1 *Determining the Optimal Capacity of the Solar System*

The data shows that 3,310,421 kWh is the overall energy consumption load of the industry. Meanwhile, the average daily daytime irradiation value (PVout) is 4.287 kWh/kWp according to Table 1 data from the Global Solar Atlas application. Equation (1) was used to calculate the optimal capacity of the solar PV system.

$$Optimal\ Capacity(kWp) = \frac{average\ daytime\ daily\ energy}{PV} = \frac{3{,}310{,}421\ \text{kWh}}{4.287\frac{\text{kWh}}{\text{kWp}}} = 772{,}200\ kWp$$

#### 3.1.2 *Calculating the Peak Power of the Solar System*

The ideal capacity value of rooftop solar power plants and potential system losses (15-25%) are considered in the peak power calculation. A loss value of 25% is applied in this design. Equation (2) is used to calculate the peak power of the system.

$$Peak\ power\ (kWp) = 772{,}200\ kWp + (772{,}200\ kWp \times 25\%) = 772{,}200 + 193{,}050 = 965{,}250\ kWp$$

#### 3.1.3 *Calculating the Effective Area*

The calculation uses the peak power value of the Solar Power Plant system and also the efficiency of the solar module. In this design, the solar module with the Solar brand type JAM72S30-550/MR with a capacity of 550 Wp has an efficiency value of 21.3%. The effective area where the solar module is placed can be calculated using Equation (3).

$$Area\ (m^2) = \frac{Peak\ Power(kWp}{solar\ module\ efficiency} = \frac{965{,}250kWp}{\frac{0{,}213}{m^2}} = 4533.10\text{m}^2$$

#### 3.1.4 *Calculating Solar Module Requirements*

The calculation of solar module requirements uses the peak power value of the rooftop Solar Power Plant system of 44,117 Wp and also the output power value per solar module of 410 Wp. The need for solar modules in PLTS can be calculated using Equation (4).

$$Number\ of\ Module = \frac{Optimal\ Power}{P_{Out}} = \frac{772{,}200Wp}{550Wp} = 1{,}404\ solar\ modules$$

#### 3.1.5 *Calculating the maximum and minimum limit of solar panel to inverter*

In this design, solar modules totaling 1,404 units are needed. Furthermore, it is necessary to calculate the maximum and minimum limits of solar panels to the inverter, a good string is used. String is a series of solar panels connected in series. This solar panel produces an open circuit voltage (Voc) of 49.90 V and the maximum power point voltage is 41.96 V. The maximum and minimum limits of solar panels to string inverters can be calculated in Equations (5) and (6).

$$maximum\ limit\ of\ solar\ panels = \frac{V_{\max Input}}{Voc} = \frac{1100}{49.90} = 22.05\ panels$$

$$Voc = Many\ PV\ x\ Voc$$
$$Voc = 22\ panels\ x\ 49.90\ V$$
$$Voc = 1{,}097.8\ V$$

From the calculation, the Voc value of 22 panels is 1,097.8 V. This result has met the standard at the maximum input inverter of 1100 V. However, the MPPT voltage range is 200-1000 V, so 1000 V <1,097.8 V which can cause the MPPT to be damaged. This is because the voltage generated exceeds the MPPT voltage.

$$minimum\ limit\ of\ solar\ panels = \frac{V_{\min Input}}{V_{mpp}} = \frac{200}{41.96} = 4.75\ panels$$

$$Vmpp = Many\ PV\ x\ Vmpp$$
$$Vmpp = 5\ panels\ x\ 41.96\ V$$
$$Vmpp = 209.8\ V$$

From the above calculations, the Vmpp value of the 5 panels is 209.8 V. This result is also in accordance with the standard inverter and MPPT of 200 V. However, this can cause the performance of Huawei's SUN2000-100KTL-M1 inverter to not be maximized.

### *3.1.6. Determination of Standard Compliant Solar Panel Strings*

In this string calculation using JAM72S30-550 / MR solar panels with a total of 1,404 modules of the monocrystalline type (Figure 4). This solar panel produces an open circuit voltage (Voc) of 49.90 V and the maximum current released is 13.11 A. In this case it is known that the minimum and maximum voltages required by the inverter are 200 V and 1100 V. So that the following calculation is obtained. In order for the voltage value to match the voltage value of the inverter and MPPT, the following calculation is obtained.

$$Ideal\ number\ of\ solar\ panels = \frac{V_{MPPT}}{Voc} = \frac{900}{49.40} = 18\ panels$$

$$Vmpp = Many\ PV\ x\ Voc$$
$$Vmpp = 18\ panels\ x\ 49.90\ V$$
$$Vmpp = 898.2\ V$$

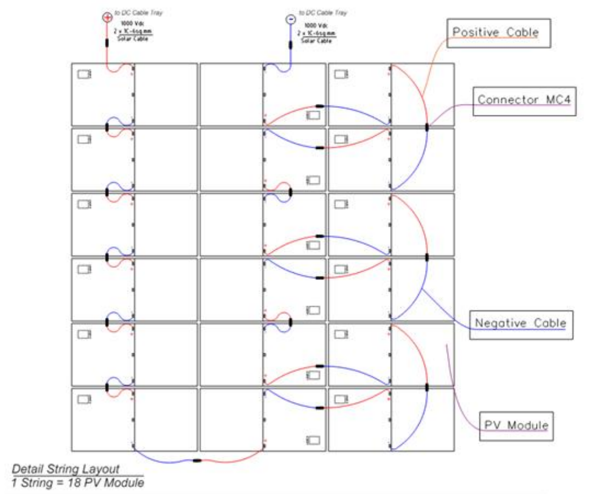


**Figure 4.** Detail String Layout

The total voltage when open circuit (Voc) is 898.2 V. After that, calculate the number of strings.

$$\text{Number of Strings} = \frac{Total\ PV}{number\ of\ PVs\ each\ String}$$
$$\text{Number of Strings} = \frac{1{,}404}{18}$$
$$\text{Number of Strings} = 78\ \text{String}$$

So, the number of strings used in the project of installing On-Grid Solar PV in this Industrial building is 78 strings which requires 6 Huawei SUN2000-100KTL-M1 Inverters, with each Inverter there are 13 Strings with many PVs each string is 18 pcs (Table 6).

**Table 6.** DC Input Terminal Connections

| Inverter: SUN2000-100KTL-M1 | | | | | PV Module: JA SOLAR JAM72S30-550/MR | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of String: 6 pcs | | | | | No of PV Module: 1404 / 78 String | | | | |
| Total Output: 600kW | | | | | Total Power: 772.2 kWp | | | | |
| **Inverter 1** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** | **Inverter 2** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** |
| I1-M1-PV1-18 | 18 | 18 | A | 9.9 | I2-M1-PV1-18 | 18 | 18 | B | 9.9 |
| I1-M2-PV2-18 | 18 | 18 | A | 9.9 | I2-M2-PV2-18 | 18 | 18 | B | 9.9 |
| I1-M3-PV3-18 | 18 | 18 | A | 9.9 | I2-M3-PV3-18 | 18 | 18 | B | 9.9 |
| I1-M4-PV4-18 | 18 | 18 | A | 9.9 | I2-M4-PV4-18 | 18 | 18 | B | 9.9 |
| I1-M5-PV5-18 | 18 | 18 | A | 9.9 | I2-M5-PV5-18 | 18 | 18 | B | 9.9 |
| I1-M6-PV6-18 | 18 | 18 | A | 9.9 | I2-M6-PV6-18 | 18 | 18 | B | 9.9 |
| I1-M7-PV7-18 | 18 | 18 | A | 9.9 | I2-M7-PV7-18 | 18 | 18 | B | 9.9 |
| I1-M8-PV8-18 | 18 | 18 | A | 9.9 | I2-M8-PV8-18 | 18 | 18 | B | 9.9 |
| I1-M9-PV9-18 | 18 | 18 | A | 9.9 | I2-M9-PV9-18 | 18 | 18 | B | 9.9 |
| I1-M10-P10-18 | 18 | 18 | A | 9.9 | I2-M10-PV10-18 | 18 | 18 | B | 9.9 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Inverter: SUN2000-100KTL-M1 | | | | | PV Module: JA SOLAR JAM72S30-550/MR | | | | |
| Number of String: 6 pcs | | | | | No of PV Module: 1404 / 78 String | | | | |
| Total Output: 600kW | | | | | Total Power: 772.2 kWp | | | | |
| **Inverter 1** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** | **Inverter 2** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** |
| I1-M1-PV11-18 | 18 | 18 | A | 9.9 | I2-M1-PV11-18 | 18 | 18 | B | 9.9 |
| I1-M3-PV12-18 | 18 | 18 | A | 9.9 | I2-M3-PV12-18 | 18 | 18 | B | 9.9 |
| I1-M10-PV13-18 | 18 | 18 | A | 9.9 | I2-M10-PV13-18 | 18 | 18 | B | 9.9 |
| **Total 13 String** | **234** | | **128.7** | | **Total 13 String** | **234** | | **128.7** | |
| **Inverter 3** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** | **Inverter 4** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** |
| I3-M1-PV1-18 | 18 | 18 | A | 9.9 | I4-M1-PV1-18 | 18 | 18 | B | 9.9 |
| I3-M2-PV2-18 | 18 | 18 | A | 9.9 | I4-M2-PV2-18 | 18 | 18 | B | 9.9 |
| I3-M3-PV3-18 | 18 | 18 | A | 9.9 | I4-M3-PV3-18 | 18 | 18 | B | 9.9 |
| I3-M4-PV4-18 | 18 | 18 | A | 9.9 | I4-M4-PV4-18 | 18 | 18 | B | 9.9 |
| I3-M5-PV5-18 | 18 | 18 | A | 9.9 | I4-M5-PV5-18 | 18 | 18 | B | 9.9 |
| I3-M6-PV6-18 | 18 | 18 | A | 9.9 | I4-M6-PV6-18 | 18 | 18 | B | 9.9 |
| I3-M7-PV7-18 | 18 | 18 | A | 9.9 | I4-M7-PV7-18 | 18 | 18 | B | 9.9 |
| I3-M8-PV8-18 | 18 | 18 | A | 9.9 | I4-M8-PV8-18 | 18 | 18 | B | 9.9 |
| I3-M9-PV9-18 | 18 | 18 | A | 9.9 | I4-M9-PV9-18 | 18 | 18 | B | 9.9 |
| I3-M10-PV10-18 | 18 | 18 | A | 9.9 | I4-M10-PV10-18 | 18 | 18 | B | 9.9 |
| I3-M1-PV11-18 | 18 | 18 | A | 9.9 | I4-M1-PV11-18 | 18 | 18 | B | 9.9 |
| I3-M3-PV12-18 | 18 | 18 | A | 9.9 | I4-M3-PV12-18 | 18 | 18 | B | 9.9 |
| I3-M10-PV13-18 | 18 | 18 | A | 9.9 | I4-M10-PV13-18 | 18 | 18 | B | 9.9 |
| **Total 13 String** | **234** | | **128.7** | | **Total 13 String** | **234** | | **128.7** | |
| **Inverter 5** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** | **Inverter 6** | **String** | **PV Qty** | **Orien** | **Capacity (kWp)** |
| I5-M1-PV1-18 | 18 | 18 | B | 9.9 | I6-M1-PV1-18 | 18 | 18 | A | 9.9 |
| I5-M2-PV2-18 | 18 | 18 | B | 9.9 | I6-M2-PV2-18 | 18 | 18 | A | 9.9 |
| I5-M3-PV3-18 | 18 | 18 | B | 9.9 | I6-M3-PV3-18 | 18 | 18 | A | 9.9 |
| I5-M4-PV4-18 | 18 | 18 | B | 9.9 | I6-M4-PV4-18 | 18 | 18 | A | 9.9 |
| I5-M5-PV5-18 | 18 | 18 | B | 9.9 | I6-M5-PV5-18 | 18 | 18 | A | 9.9 |
| I5-M6-PV6-18 | 18 | 18 | B | 9.9 | I6-M6-PV6-18 | 18 | 18 | A | 9.9 |
| I5-M7-PV7-18 | 18 | 18 | B | 9.9 | I6-M7-PV7-18 | 18 | 18 | A | 9.9 |
| I5-M8-PV8-18 | 18 | 18 | B | 9.9 | I6-M8-PV8-18 | 18 | 18 | A | 9.9 |
| I5-M9-PV9-18 | 18 | 18 | B | 9.9 | I6-M9-PV9-18 | 18 | 18 | A | 9.9 |
| I5-M10-PV10-18 | 18 | 18 | B | 9.9 | I6-M10-PV10-18 | 18 | 18 | A | 9.9 |
| I5-M1-PV11-18 | 18 | 18 | B | 9.9 | I6-M1-PV11-18 | 18 | 18 | A | 9.9 |
| I5-M3-PV12-18 | 18 | 18 | B | 9.9 | I6-M3-PV12-18 | 18 | 18 | A | 9.9 |
| I5-M10-PV13-18 | 18 | 18 | B | 9.9 | I6-M10-PV13-18 | 18 | 18 | A | 9.9 |
| **Total 13 String** | **234** | | **128.7** | | **Total 13 String** | **234** | | **128.7** | |

### *3.2 Feasibility Aspect Analysis*

Analysis of feasibility aspects includes technical aspects. In this technical aspect, the calculation of the electrical energy production of rooftop solar power plants is carried out. In practice, not all solar radiation received by solar modules is converted into electrical energy. This happens because of the power losses in the components used in Solar Power Plant. With a power loss of 25%, the following is the calculation of the solar module output power (Pi) using Equation (9).

$$Module\ Power\ Out\ (P_i) = solar\ module\ power - (solar\ module\ power \times 25\%)$$

$$= 550\ Wp\ -\ 137.5$$

$$= 412.5\ Wp$$

$$P_i = Module\ Power\ Out \times Number\ of\ Modules$$

$$= 412.5\ Wp\ \times\ 1.404$$

$$= 579.15\ kWp$$

The output power that has been generated is multiplied by the Peak Sun Hour (PSH) value shown in Table 2. At the installation location of the rooftop solar power plant, the average PSH value per year is 5.2 kWh/m2/day and the lowest is 4.1 kWh/m2/day in January. To determine the amount of net energy produced by the on-grid type rooftop solar power plant per day, the following Equation (10) is used. Calculation of net energy per day with the lowest PSH value within one year.

$$P_{out} = Pi\ \times PSH = 579.15\ kW\ \times\ 4.1\ kWh/m2/day$$

$$= 2{,}372.415\ \text{kWh}/day$$

$$\eta = \frac{2{,}372.415 kWh/day}{3{,}310.421 kWh/day} = 0.89 \; or \; 89\%$$

Based on the calculation, it is known that with the lowest PSH value in January or during the rainy season, the Solar Power Plant can only provide 89% of the total power needed by the industry every day. This means that the existing power shortage is supplied by PLN electricity. Meanwhile, with an average PSH value per year, the Solar Power Plant can provide 109.9% of the power. This means that the Solar Power Plant can meet the needs of all power in the lighting sector in the industry and can make cost savings of 3,310,421 kWh / day. The energy generated by the Solar Power Plant per year can be calculated by Equation (11) below. Calculation of net energy with the lowest PSH value within one year,

$$\begin{aligned} Energi\ yield &= Pout \times 365\ day \\ &= 2{,}372.415\ kWh \times 36 \\ &= 865{,}931.475\ kWh/year \end{aligned}$$

Net energy calculation with average PSH value per year,

$$\begin{aligned} Energi\ yield &= Pout \times 365\ day \\ &= 3{,}011.580\ kWh \times 36 \\ &= 1{,}099{,}226.7\ kWh/year \end{aligned}$$

From the calculation, it is found that the Solar Power Plant can produce energy of 865,931.475 kWh / year with the lowest PSH value throughout the year and 1,099,226.7 kWh / year with the average PSH value per year. Furthermore, from the results of the solar power plant energy for 1 year, the performance ratio can be calculated to determine the performance of the solar power plant, in this design using the lowest PSH value. The performance ratio can be calculated using Equations (12), (13), and (14) below.

$$Htilt = PSH \times 365\ day$$

$$= 4.1\ h \times 365\ hari$$

$$= 1{,}496.5\ h/year$$

$$deal\ Energy$$

$$= Pma \times Number\ of\ Solar\ Modules \times Htilt$$

$$= 550\ Wp \times 1{,}404\ unit \times 1496.5 \frac{h}{year}$$

$$= 1{,}155{,}597{,}300\ Wh/year\ or\ 1{,}155{,}597.3\ kWh$$

$$Performance\ Ratio = \frac{Energy\ Yield(kWh)}{Ideal\ Energy(kWh)}$$

$$= \frac{865{,}931.475\ kWh/year}{1{,}155{,}597.3\ kWh/year} = 0.76\ or\ 76\%$$

Based on the calculation of the performance ratio, the result is 76%, this is in accordance with the performance ratio reference standard which is between 70% - 90%.

### *3.3 Discussion*

This study successfully designed an optimal On-Grid Rooftop Solar Power Plant system concerning a total lighting load of 3,310.421 kWh and a daily average irradiation of 4,287 kWh/kWp. This project utilizes several components such as JAM72S30-550/MR solar panels, Huawei SUN2000-100KTL-M1 inverters, and MCCB. The calculations show that the optimal capacity of the solar power generation system is 772,200 kWp, which is increased to 965,250 kWp after taking into account the system losses of 25%. With a solar module efficiency of JAM72S30-550/MR Solar of 21.3%, an area of 4,533.10 m² is required for the installation of this system. The solar module requirement is 1,404 units, with an ideal number of strings of 78, and each string consists of 18 panels.

Further calculations include the maximum and minimum limit of solar panels against the inverter, which shows that the ideal number of panels is 22 units for the maximum limit and 5 units for the minimum limit, resulting in a total string of 78 with each string consisting of 18 panels. Next, an analysis of the feasibility aspects was conducted by considering the technical aspects. In the technical analysis, the rooftop Solar Power Plant's electrical energy production is calculated by considering a power loss of 25%, resulting in a module output power of 412.5 Wp, which is then multiplied by the Peak Sun Hour (PSH) value to get the net energy produced. The calculation results show that at the lowest PSH, the solar power plant can fulfill 89% of the total daily power demand, while at the average PSH, it can fulfill up to 109.9%. The energy generated per year varies, with the lowest value reaching 865,931.475 kWh and the average value at 1,099,226.7 kWh. To evaluate the performance of the solar power plant, the performance ratio was calculated and resulted in a value of 76%, which is within the reference standard of 70% - 90%, indicating that this On-Grid Rooftop Solar PV system meets the requirements of good efficiency.

## 4. Conclusion

The purpose of this research is to develop panel layouts and component specifications in an on grid solar power generation system. This research highlights the importance of proper inverter selection and wiring arrangement to maximize power production by studying the critical components. An on-grid rooftop solar power generation system has been designed considering a total lighting load of 3,310,421 kWh, and a daily average irradiation of 4,287 kWh/kWp. In this project, the components used are JAM72S30-550/MR solar panel, Huawei SUN2000-100KTL-M1 inverter, and MCCB. The optimal capacity of the solar power generation system was calculated to be 772,200 kWp and the figure was adjusted to 965,250 kWp to account for 25% system losses. The efficiency rate of the solar modules is estimated at 21.3% & therefore, an area of 4,533.10 m² will be required for the installation of the system. The total number of panels to be used is 1,404 and the ideal number of strings is 78 with each string consisting of 18 panels. The methodology used has provisions for system designers and construction engineers to be able to identify working strategies for selecting the desired solar panels and inverters for on-grid systems. The results emphasize the importance of modifying component selection by considering shifting operational and environmental variables to maximize efficiency and reliability.

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