Planning of Photovoltaic (PV) Type Solar Power Plant as An Alternative Energy of the Future in Indonesia

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Abstract

Indonesia receives a lot of sunlight throughout the year. This then causes large profits to be obtained with the Development of a Solar Power Plant Planning (PLTS) that uses a photovoltaic (PV) system. This research then aims to look at how the use of PV systems as a solar power generation system becomes alternative energy in the future. The approach used in this research is a qualitative approach through a literature study of various previous studies and studies that discuss the planning of PV-type solar PV in Indonesia. This study found that the PLN network can be integrated and benefit PLTS that are on-grid and use solar modules. Then various public facilities with a flat surface and wide enough can be a good enough place to be a PV type PV mini-grid. Then the ratio of power that PLN has issued for PJU is 76.66%, while the ratio of solar panels is 23.3%. Unfortunately, the main ingredients for making PV mini-grid are still imported, which makes it challenging to develop PV-type PV mini-grid.

Keywords: *PLTS on-grid, PLTS off-grid, PLTS, Photovoltaic (PV).*

A. INTRODUCTION

The electrical energy supply is still primarily supported by coal and fuel oil, which significantly pollutes the environment. In this case, the need for energy in the industrial era 4.0 is an alternative energy that is clean, environmentally friendly, and renewable (Shahsavari & Akbari, 2018), where the potential for renewable energy is shown in Table 1 below.

Table 1. Renewable Energy Potential

Renewable energy	Potential
Hydropower	75,000MW
Geothermal	29,164 MW
Biomass	49,810 MW
Solar power	112,000 GWp = 89,600 MW

Of the total electric potential generated by renewable energy from hydropower, geothermal, and biomass which is 153,974 MW, only 33.52% can be installed as a national power plant. The installed capacity of national power plants, fossil-fueled and those using renewable energy, up to mid-2015 was 51,620 MW. Solar power can generate up to 112,000 GWp, equivalent to 89,600,000 MW (Sayed et al., 2021).

Indonesia has a good intensity of solar radiation throughout the year because it is located on the equator and in the equatorial area. The equator is the central region that divides the globe into northern and southern parts. This position causes the availability of sunlight almost all year round in all aspects of Indonesia except during the rainy season and when thick clouds block the sun's rays. Based on the solar insolation map, the territory of Indonesia has the potential for solar electricity of 4.5 kW/m2/day. This is undoubtedly very potential to be utilized in meeting electrical energy needs considering several problems associated with fossil fuel power generation (Nguyen et al., 2021).

Most parts of Indonesia have a long-term average intensity of sunlight that has the potential to generate electricity equivalent to more than 1,600 kWh per square meter. This means that the potential for developing solar energy in Indonesia is tremendous, especially in Nusa Tenggara and East Java. Especially for the Nusa Tenggara area, the construction of PLTS can be a priority alternative to overcome the shortage of electricity supply in the area (Al-Zoubi et al., 2021).

PLTS is a renewable energy-based power plant recommended for electricity in remote rural areas, where sunlight is abundant, and fuel is relatively expensive but difficult to obtain. The main reasons for using PV mini-grid technology are as follows: (1) abundant and free energy sources; (2) energy sources are available in place and do not need to be transported; (3) relatively small operating and maintenance costs for the PV mini-grid system; (4) does not require frequent maintenance and can be carried out by a trained local operator; and (5) environmentally friendly, because there are no harmful gas emissions and waste (Aien & Mahdavi, 2020).

The utilization of solar energy for solar power has been done for a long time, but its application is still limited to small power systems. Why is that, and what are the reasons? To get an idea of the PV mini-grid planning, research was conducted under the title: "A Study on Planning for Photovoltaic (PV) Solar Power Plants as Future Alternative Energy in Indonesia."

B. LITERATURE REVIEW

1. Solar Power Plant (PLTS)

Solar Power Plant (PLTS) is a generator that converts solar energy into electrical energy as an environmentally friendly alternative energy source (renewable energy). According to Furqani & Mangapul, solar cells, or what is often referred to as photovoltaic cells, come from the English language, namely photovoltaic. Photovoltaic comes from two words, namely "photo," which means light, and the word "volt," is the name of the unit of electric voltage. A solar cell is a semiconductor device with a large surface consisting of a series of "p" and "n" type diodes, which can convert solar energy into electrical energy. Solar cells rely on the photovoltaic effect to absorb solar energy and cause current to flow between two oppositely charged layers (Guven & Samy, 2022).

The main difference between solar cell panels is the material of the solar cells. The most commonly used solar cell material is crystalline silicon which consists of (1) polycrystalline, a bluish crystalline material with light blue and dark blue spots (where this type is most widely used in small-scale solar power plants) with an efficiency of about tens of percent; (2) monocrystalline is a crystalline material that has better efficiency, but is relatively more expensive (this type can be recognized by its plain bluish color without spots); (3) thin layer of amorphous silicon is silicon that is slightly dark black which is commonly used in very low power consumption devices such as calculators. The efficiency of this type is the lowest, around 3-5%. The advantage of amorphous silicon is that it is affordable but not as efficient as crystalline silicon solar cells (Klugmann-Radziemska & Kuczyńska-Łażewska, 2020).

Solar radiation energy can be converted into direct current using thin layers of pure silicon (Si) or other semiconductor materials. At this time, silicon is the most widely used material. Silicon is an element that is abundant in nature. For use as a semiconductor, silicon must be purified to a very high degree of purification. At absolute zero (0oK), all covalent bonds are intact and complete. When the temperature rises, the atoms will experience a state of thermal vibration. These vibrations, which increase with temperature, can disrupt some of the covalent bonds (Singh & Agrahari, 2019).

Disruption of covalent bonds in semiconductor crystals at ordinary ambient temperatures has several significant effects on the electrical properties of the crystals and is essential in explaining the photovoltaic effect (Brozena et al., 2019).

A study conducted by Alifyanti & Tambunan regarding regulating the voltage of a 1000 Watt solar power plant (PLTS) found that when a collision occurs, the energy of photons is transferred to the electrons in the solar cell atoms, which are semiconductor materials. With the power obtained from the photons, the electrons break away from the regular bonds of the semiconductor material and become an electric current that flows in the existing electrical circuit. By releasing from the bond, the electron causes the formation of a hole (Liu et al., 2022).

In general, the construction of photovoltaic consists of three parts, namely: (1) the radiation receiving layer; (2) the layer where the charge separation occurs due to photoinduction; and (3) the contactor layer (Kanan et al., 2020).

Photovoltaic quality depends on the efficiency of the photovoltaic work. If photovoltaics has good efficiency, the power generated will be maximized, and the losses will be more minor. Photovoltaics with high efficiency and small losses can be called good photovoltaics. Photovoltaic efficiency is influenced by several things, including solar insolation (I), photovoltaic collector area (Ac), and collector power (IV) max owned by photovoltaic (Fan et al., 2021).

The efficiency value of a solar module is highly dependent on the Peak Sun Hour (PSH) value. PSH is very subjective depending on environmental characteristics, including the duration of sunlight and the brightness index in a place (Rutty et al., 2020).

The maximum power produced by solar panels is measured by the amount of Watt peak (Wp), whose conversion to Watthour (Wh) depends on the intensity of sunlight hitting the panel's surface. Furthermore, the power released by the solar panel is the panel power multiplied by the length of irradiation. For example, a solar panel with a capacity of 50 Wattpeak is exposed to the sun with maximum intensity for 8 hours, the power generated is 50 times 8 Watthour or 400 Watthour. This much power can be used to power 4 25 Watt lamps for 4 hours or a 40 Watt black and white television for 10 hours. The solar cell panel's total electricity output (wattage) is proportional to the operating voltage multiplied by the operating current. Solar cell panels can produce currents with different voltages. This is in contrast to batteries, which produce current from a relatively constant voltage (Grossi et al., 2021).

The performance curve, called the I-V curve, can show the output characteristics of solar cell panels. I-V curve shows the relationship between current and voltage. Most I-V curves are given in Standard Test Conditions (STC) of 1000 watts per square meter of radiation (or one peak sun hour) and 25 degrees Celsius/77 degrees Fahrenheit solar cell panel temperatures (Reddy & Narayana, 2022). For information, STC represents optimal conditions in a laboratory environment. The I-V curve consists of 3 essential things, namely:

a. Maximum Power Point (Vmp and Imp)
   On the I-V curve, the Maximum Power Point (Vmp and Imp) is the operating point, where the maximum output/output generated by the solar cell panel is under operational conditions. In other words, Vmp and Imp can be measured when the solar cell panels are loaded at 25 degrees Celsius and radiated at 1000 watts per square meter. In the above curve, the voltage at 17 volts is Vmp, and Imp is 2.5 amperes. The maximum wattage is determined by multiplying Vmp and Imp, so the maximum wattage for STC is 43 watts (Raj & Gupta, 2021).
b. Voltage Open circuit (Voc)
   Voltage Open Circuit (Voc) is the maximum voltage capacity achieved without current (current). On the IV curve, the Voc is 21 volts. The power at the time of Voc is 0 watts. The VOC of solar cell panels can be measured in the field under various conditions. When buying a module, it is highly recommended to test the voltage to see "whether the voltage matches the factory specifications". When testing the voltage with a digital multimeter from the positive terminal to the negative terminal. Open Circuit Voltage (Voc) can be measured in the morning and evening (Singhal et al., 2021).
c. Short Circuit Current (Isc)
   Short Circuit Current (Isc) is the maximum output current of a solar cell panel that can be output (output) under conditions with no resistance or short circuit. The I-V curve above shows an approximate current of 2.65 Ampere. The power on the Isc is 0 watts. Short circuit current can be measured only when making a direct connection between the positive and negative terminals of the solar cell panel (Musanga et al., 2018).

C. METHOD

This research is literature research conducted as an activity to collect information relevant to the topic that is the object of research. The data collection technique was carried out by studying several articles about PV mini-grid. The data analysis technique used is to describe the data and information in the form of sentences that are easy to understand as an effort to obtain answers to the problems studied related to several feasibility studies on PLTS in Indonesia. The journals reviewed are associated with PV mini-grid, both on-grid and off-grid types.

D. RESULT AND DISCUSSION

1. Photovoltaic Solar Power Plant (PLTS PV)

There are two types of PLTS: photovoltaic (PV) and solar thermal. PLTS PV uses solar panels that can directly convert solar power into electricity. Meanwhile, solar thermal PLTS collects heat from the sun to heat large amounts of liquid to produce steam which is then used to turn turbines to generate electricity. The simple working principle of PLTS solar thermal is used in household water heaters (usually installed on the roof of the house and used to heat bath water).

PV-type solar power plants are currently more popular with a much larger market size than solar thermal PLTS. This is mainly due to the technical limitations of PLTS solar thermal, which causes the installation location to be in certain places with direct irradiation (not flexible). Then economically, it can only be installed on a large scale above 20 MW (it cannot be installed with a distributed system of PV mini-grid models).

Photovoltaic systems start with modules/panels that convert solar energy into electricity. The electric current generated at this stage is still in the form of direct current (DC). Furthermore, the inverter converts DC electric current into alternating current (AC) so that electric current can be supplied and used further (through a transformer according to the desired voltage, if needed).

The fuse box shares some of the electric currents for household use or own generation. The system can be equipped with a battery to store excess electrical energy that has not been used or distributed. However, the investment value for battery components is currently very high, so it can make a solar power plant uneconomical, especially a small-capacity solar power plant. Therefore, many solar power plants do not use batteries and directly distribute all the electricity generated after deducting their own use.

The system uses a meter to record the electricity distributed from PLTS to the grid or grid. If PLTS uses its network to distribute electricity to households, the network used is called off-grid. Meanwhile, if PLTS uses networks from other power companies, such as PT. PLN (Persero) in Indonesia, the network used is called on-grid. The number of electricity distributed (recorded on the meter) becomes the basis for calculating electricity sales from PLTS, where sales are obtained by multiplying the quantity of electricity supplied recorded on the meter by the FIT.

It should be noted that the meter is usually installed as close as possible to the network (on-grid), so a solar power plant needs to pay attention to the distance between the generating area and the network point where the meter is installed or called the point of connection (POC). The farther the distance, the greater the investment value that PLTS must provide to build a link from the generator to the POC, and the greater the risk of “evaporating” the plant’s electricity generated during the journey to the POC. The rule of thumb for this electricity “shrinkage” or “evaporation” is 5% (the distance from the generator to the POC is about 10 km).

The Ministry of Energy and Mineral Resources of the Republic of Indonesia, in its book entitled Solar Power Plant Installation, explains that PV is the most widely developed renewable energy power generation system by countries in the world because it has internationally recognized advantages. These advantages include: (1) there are pretty several manufacturers (large and small scale) that can provide quality products ranging from solar panels, inverters, electrical balance systems, and monitoring systems to technical construction and procurement services; (2) PV mini-grid-related product lines that continue to grow; (3) there has been a continuous development of testing protocols and international standards; (4) the downward trend in the prices of the main components (solar panels, inverters); (5) increased technical understanding of service providers; (6) development of reliable modeling and number of solar data sources; and (7) increasing trust of international financial services institutions on the bankability of PV mini-grid projects.

On-grid PLTS is a PLTS system connected to the PLN distribution network by optimizing the energy from solar panels to produce as much electrical power as possible. This system will reduce household electricity bills and provide added value to the owner. On-grid PLTS is a system that works directly on solar panels. This system technology does not use batteries, and the electricity generated is used for various purposes. The electricity produced is AC electricity, so this on-grid solar panel system can be applied together with the PLN distribution network. This on-grid solar power plant system is suitable for housing by utilizing the roof as a space to absorb solar energy. If installed in conjunction with PLN, this system will reduce electricity costs.

The application of the on-grid PLTS system can be run simultaneously with the PLN electricity system. In this system, the PLN electricity network acts as a distributor or liaison for electric current from solar panels fed to the load. During the day, electricity can utilize electrical energy from sunlight. At night, because there is no sunlight causing no electricity production from solar panels, it can use electric current from PLN. For large-scale PLTS, the PLTS system is generally connected to PLN grids on the 20 kV Medium Voltage (TM) side using a step-up transformer.

The advantages of using an on-grid PLTS system are as follows: (1) with an integrated monitoring system, you can find out the electricity generated by PLTS and monitor its use; (2) reduce the amount of electricity bills by producing their own electricity without worrying about the increase in PLN electricity tariffs; (3) the energy produced is clean and environmentally friendly energy because it is sourced from the sun; (4) by utilizing free energy from the sun to produce electrical energy that can be used anytime and anywhere as long as the sun shines on the place; (5) the construction of the PLTS system is very fast compared to other power plants, an average of 6 months the PV system can produce electricity; (6) the PLTS system is easy to operate so it does not require special skills to operate this system; (7) this generator system is very practical and does not have moving components (motors), so that routine maintenance of this system is more accessible than conventional generating systems; (8) do not use fuel, either gasoline or diesel so that the monthly operating costs become cheaper; and (9) PV components have a relatively long technical life (25 years) so that this PLTS system is quite reasonable (economically) if it is built as an alternative to renewable power plants.

Photovoltaic (PV) is a technology that functions to convert or convert solar radiation into electrical energy directly. PV is usually packaged in a unit called a module. A solar module consists of many solar cells arranged in series or parallel. What is meant by solar is a semiconductor element that can convert solar energy into electrical energy based on the photovoltaic effect.

In general, the working mechanism of the on-grid PV mini-grid system begins with solar panels that capture sunlight into electrical energy. Electrical energy from a series of modules (arrays) is collected in an array junction box with a DC power supply. From the junction box, an on-grid inverter converts DC electricity into AC electricity. This on-grid inverter also regulates the voltage and current from the solar module so that optimal energy harvest occurs. The electrical energy output from several inverter units is collected by the connector block and the AC switchboard safety/Interconnection Panel, which is also connected to the existing distribution panel. To be connected to the PLN network, a transformer is needed to adjust the inverter output voltage to be the same as the PLN network voltage.

2. **Equipment in Solar Power Generation**

The general specifications of the leading PV mini-grid equipment can be explained as follows:

a. Solar Module

The solar module is composed of Polycrystalline Silicone cells assembled into one module to produce optimum power.

Figure 1. Solar Module

b. String Combiner Box

The string combiner box is a DC voltage system panel that contains a separator switch and a fuse. Also equipped with surge arresters on both positive and negative buses to anticipate power surges. The inverter is a collector of the entire array before the electricity is converted from DC to AC type.

Figure 2. String Combined Box

c. Grid Inverter
   A grid inverter is a device that converts direct current (DC) from PV arrays into alternating current (AC) on the load/grid side. The Grid Inverter is integrated with MPPT so that it can convert energy from PV optimally. The AC power output can be single-phase or three-phase.

Figure 3. Grid Inverter

d. Distribution Panel
   The distribution panel is an interconnection box liaison between the inverter output, grid, and load. The AC Switchboard is placed outdoors, while the distribution panel is indoors. On the distribution panel, there is also a monitor for voltage, current, frequency, power, and energy generated by PV and distributed to the grid and the load.

Figure 4. Distribution Panel

e. Monitoring System
The monitoring system is for energy data generated by the PV Array. The monitoring system displays and records electrical and meteorological data from the PV mini-grid (such as ambient temperature and solar radiation).

Figure 5. Monitoring System

f. Meteorological Sensor
Meteorological sensors are equipment for collecting environmental and meteorological data around PLTS in the form of temperature and solar radiation.

Figure 6. Meteorological Sensor

g. Photovoltaic (PV) Cable
Photovoltaic (PV) cables and power cables are tailored to the generator's needs, consisting of DC and AC cables.

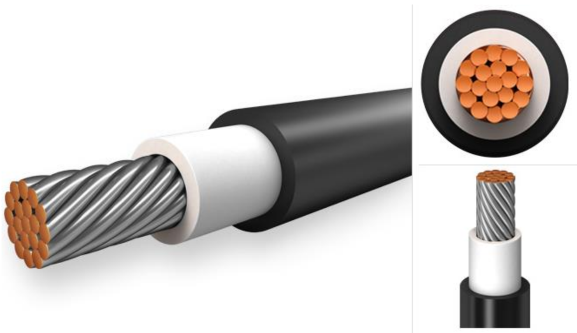

Figure 7. Photovoltaic (PV) Cable

h. Grounding System
The grounding system is an equipment grounding system made using copper rods, whose primary function is to support safety in operation and maintenance.

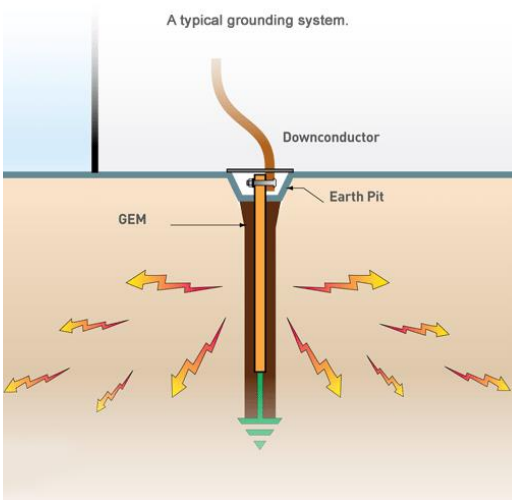

Figure 8. Grounding System

i. Power Transformer

Power transformer/power transformer functions to change the voltage level. For the on-grid PLTS system, a 380/20kV transformer is used to be able to connect to the medium voltage PLN 20 kV network.

Figure 9. Power Transformer

3. **Previous Research Related to Solar Power Generation**

Related to PLTS, a lot of research has been done by various parties, as explained as follows:

a. Naim and Wardoyo (2017), conducted a study entitled "*Rancangan Sistem Kelistrikan PLTS on Grid 1500 Watt dengan Back Up Battery di Desa Timampu Kecamatan Towuti*". In his research, he explained that the Photovoltaic (PV) used were six units with a capacity of 250 Wp each; solar charge controller (MPPT technology which is efficient in battery charging) with a capacity of 1500 Watts; 2 x 100 Ah and 2 x 60 Ah wet AKI combined in series and parallel with a voltage of 24 Volts and a charge capacity of 160 Ah; Pure Sine Wave inverter with a capacity of 1500 Watts and a disc type kWh meter that can move or rotate left and right or forward and backward (Naim & Wardoyo, 2017).

b. Besides being easy to operate, it does not mean that PLTS is without problems. Kumara conducted a study entitled "*Pembangkit Listrik Tenaga Surya Skala*

Rumah Tangga Urban dan Ketersediaannya di Indonesia" which found the main obstacle to PLTS is that the main components of PLTS still have to be imported, even though other components are already available in the country (Kumara, 2012).

c. In the context of utilizing solar power technology, Sihombing and Kasim conducted research entitled "*Perencanaan Sistem Penerangan Jalan Umum dan Taman di Areal Kampus USU dengan menggunakan Teknologi Tenaga Surya (Aplikasi di Areal Pendopo dan Lapangan Parkir)*", with panel component materials consisting of solar modules, battery chargers, batteries, controllers, and LED lights, found that: Hi-power LED-based street lighting lamps are very bright, energy-efficient and long-lasting. The use of solar power PJUs is very efficient when compared to PJUs sourced from PLN electricity. Then the comparison of the power issued by PLN for general lighting is 76.66%, while with solar panels using 12 Ah batteries, it is 23.3% (Sihombing & Kasim, 2013).

d. To function optimally, solar power plants need to be well designed. With research entitled "*Analisis Desain Sistem Pembangkit Listrik Tenaga Surya Kapasitas 50 WP*", Ramadhan, Diniardi, and Mukti made a PLTS with a capacity of 50 WP, with the following materials and procedures: (1) the tools used are solar cells, to converting solar radiation into electrical energy (photovoltaic process); (2) so that solar energy can be used at night, during the day the electrical energy produced is stored in a battery controlled by the regulator; (3) the output of the regulator is directly connected to the inverter to convert the DC to AC; (4) the position of the photovoltaic is controlled automatically so that it always faces the sun so that it can capture the sun's rays optimally. With these materials and procedures, the study found that the average PLTS output power reached 38.24 Watt, and the current obtained was 2.49 A (Ramadhan et al., 2016).

e. In contrast to the four studies above, Hikmawan and Suprayitno conducted a study entitled "*Bangun Lampu Penerangan Jalan Umum (PJU) menggunakan Solar Panel Berbasis Android*". This research resulted in a design of a Street Lighting Tool (PJU) controlled by Arduino and uses a solar panel as a voltage source and light sensor. The light sensor will work and read the intensity of sunlight. During the day, the sensor provides input to the Arduino so that the lights automatically turn off; at night, the sensor provides input to the Arduino so that the lights turn on. PJU can also be controlled using an Android Gadget via the Bluetooth Module HC-05. The result is that the lights automatically turn on and off according to the light sensor readings, and the communication between the Arduino Microcontroller and the Android Smartphone, with the help of the HC-05 Bluetooth Module, can function correctly. The problem with this tool is that the Arduino microcontroller can only receive commands from an Android Smartphone with a maximum distance of 15 meters. Therefore, a solution is needed so that the microcontroller can accept orders from anywhere and is not limited by the distance from the android smartphone (Hikmawan & Suprayitno, 2018).

f. To increase the capacity of PLTS, Suriadi and Syukri conducted a study entitled "*Perencanaan Pembangkit Listrik Tenaga Surya (PLTS) Terpadu menggunakan Software PVSYST pada Kompleks Perumahan di Banda Aceh*", suggesting: (1) that for planning a solar power plant (PLTS) in housing, it is necessary to pay attention to the capacity of each PV mini-grid component; (2) it is necessary to calculate for household electricity distribution needs of 26.927 kWh per day using PVsyst software. The materials used are a solar module with a capacity of 200 Wp, 30 units of battery with a capacity of 100 Ah, a charge regulator (BCR) battery with a current capacity of 500 A, and an inverter with a power capacity of 12 kW. Research proves that this PLTS system can serve ten houses, each with a connection power of 6 A (Syukri, 2010).

g. The performance of the inverter as an essential part of PLTS also needs to be known. The research entitled "*Analisis Produksi Energi dari Inverter pada Grid-connected PLTS 1 MWp di Desa Kayubihi Kabupaten Bangli*", was conducted by Bagus Kumara, and Ariastina. Bagus, Kumara, and Ariastina analyzed the Grid-connected 1 MWp PLTS Kayubihi using 50 inverter units with a capacity of 20 kW each. This study aims to determine the performance of the inverter and the effect of the position of the string array on the PV mini-grid energy production. Energy production analysis in PLTS Kayubihi is carried out by mapping the percentage of energy production from each inverter, then the inverter with the highest rate of energy production is selected as a reference to assess the performance of the other 49 inverters. The analysis also pays attention to the location of the string array connected to the inverter and is based on the conditions at the location of the PLTS installed. The research concludes that the 44-E5 inverter of 17,827 kWh generates the highest energy production, and the lowest is the 8-D3 inverter of 8,898 kWh. The inverter with the most increased average energy production is the inverter 44-E5 at 72.47 kWh/day, and the lowest is the inverter 11-C5 at 39.26 kWh/day (Nathawibawa et al., 2016).

E. CONCLUSION

On-grid PLTS using solar modules can be combined with the PLN network to produce electricity that is environmentally friendly and emission-free (a Green Energy solution for cities). The application of the on-grid PLTS system integrated with the PLN electricity system is very beneficial because, during the day, it can utilize electrical energy from sunlight, and at night, it can use electrical power from PLN. Commercial buildings or extensive public facilities with a flat roof surface (not blocked from sunlight) are ideal for developing solar energy facilities (PLTS).

On-grid PLTS can be applied in housing/offices (with a 1-phase/220V power system), so for: (1) a PV mini-grid with a capacity of 1300Wp needs a roof area of 8 m2 with an estimated average power output of 160 kWh/month; (2) a system capacity of

5500 Wp requires a roof area of 32.5 m2 which will produce 660 kWh/month; and (3) large scale (factories, buildings, hotels) that require a capacity of 20 kWp, requiring a roof area of about 130 m2 with an estimated average power of 2400 kWh/month. The main obstacle to the development/utilization of PLTS is that the main components of PLTS still have to be imported, even though other components are already available in the country.

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