Design and Performance Analysis of 600 W On-Grid Solar Power Plant System based on Maximum Power Point Tracking (MPPT)

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Abstract. This research aimed to make, test, and analyse the performance of 600 W on-grid solar power plant system based on maximum power point tracking (MPPT). This research used a developmental research method with the ADDIE model that was developed by Robert Maribe Branch. The results obtained data that the average power that was produced and distributed to the PLN grid reached 22.5 W with 95.67% efficiency from the grid-tie inverter usage.

1. Introduction

Electricity is an important element for social, educational, economic and political development of every nation [1]. Electricity need in Indonesia always increases along with the development of technological advances and the increase of public electricity consumption. Based on the data from [2], national electricity production was still dominated by non-renewable energy for 82.64%, consisted of 56.14% coal, 20.2% gas, and 6.3% oil. The usage of renewable energy only contributed for 17.37% from the national electricity production, whereas renewable energy potential is very abundant in Indonesia. Based on [2], the potential of renewable energy reached 442 GW and to date was only implemented for 9.32 GW or less than 3%.

Renewable energy flows are very large in comparison with humankind’s use of energy. Therefore, in principle, all our energy needs, both now and into the future, can be met by energy from renewable sources [3]. Among all types renewable energy source, solar PV sources can have the biggest impact to electrical power generation in the coming years [4]. Solar energy is one of the renewable energies with high potential of 207.9 GW, although the implementation of the solar power plant in Indonesia was only 0.14 GW or around 0.02%. This is very unfortunate considering the importance of renewable energy usage in industrial revolution 4.0 or Society 5.0 to welcome the Sustainable Development Goals 2030 with the main purpose is the usage of carbon-free energy and environmentally-friendly all over the world. Public’s awareness and government’s contribution are needed to realize the implementation of renewable energy in Indonesia such as solar power plant rooftop system, off-grid and on-grid, to improve the role of renewable energy in the national electricity mix.

High costs of installation and maintenance as a result of storage units discourage the use of solar Photovoltaic system for power generation. To reduce these costs, Solar PV systems can be installed without storage units alongside conventional power generation systems [5]. Generally, a PV system is categorized into the stand-alone and grid-connected type. In the global market, a large proportion of PV
solar power is supplied by the grid-connected type. The conventional current control of grid-connected PV system is to supply the maximum available active power from the PV array to the grid [6].

Based on the introduction, research objectives can be formulated as follows: to make, test, and analyse the performance of 600 W on-grid solar power plant system based on maximum power point tracking (MPPT).

2. Related Works

2.1. Grid Connected Solar Power Plant System

Solar panels work best in certain weather conditions, but the weather is changing always, so most panels do not operate under ideal conditions [7]. On-grid solar power plant from the PLN network or often called Grid Connected Solar Power Plant System is a power plant system that utilizes solar radiation to produce electricity, where, true to its name, the system is connected to PLN network by optimizing solar energy utilization through the solar module or photovoltaic. This system is also environmentally friendly and free from carbon emission. Grid-connected solar power plant system is also a Green Energy solution for urban communities, both offices and housing, to reduce electricity bill and add values to the owner.

This solar power plant is ruled in [8], on rooftop solar power plant system by consumers of PT Perusahaan Listrik Negara. The On-Grid Solar Power Plant System can be seen in Figure 1.

![Figure 1 On-Grid Solar Power Plant System](image)

2.2. Grid Tie Inverter

Grid Tie Inverter is a particular type of inverter with different components and specification compared to the standard inverter. A grid tied inverter is a special type of power inverter that converts PV output direct current electricity into alternating current electricity so that one can flow the electricity out into the power grid and actually sell electricity back to the power company [9]. In one-phase system, this inverter has 220-230 VAC output with 50 Hz/60 Hz frequency, pure wave sinus wave, and very identical with PLN network characteristic so it can be transported into the PLN grid. This type of inverter can be used for off-grid and on-grid system and loads with unique characteristic such as AC motor or air conditioning.

Grid-tie inverter is sold in the market with power rating starts from 500 W, 600 W, to up to 1 kW. The specification determines its quality on the grid-tie inverter. The grid-tie inverter quality can be seen from its efficiency, lifetime, and the amount of electricity that can work in high quality
2.3. MPPT (Maximum Power Point Tracking)
A maximum power point tracking algorithm is absolutely necessary to increase the efficiency of the solar panel as it has been found that only 30-40% of energy incident is converted into electrical energy [10]. Maximum power point tracking or MPPT is a system that is used in the grid tie inverter to improve electricity efficiency produced by the solar cell. Maximum power point tracking works by controlling the current and voltage that is produced by a solar cell so that the produced power is optimized. Several factors that influence the MPPT performance are sensor, an algorithm that is used, and the MPPT speed in creating optimized power.

![Figure 3 MPPT Schematic Diagram](image)

3. Method
This research used a developmental research method to create design and performance analysis of 600 W on-grid solar power plant system based on maximum power point tracking. The ADDIE approach model that was developed by [11], consists of the below stages:

![Figure 4. Developmental Stages](image)
Observation and interview related to the performance requirement of on-grid solar power plant system were conducted in the requirement analysis stage. After, the stage was continued with design making of the device and started to compile the required components. The required components among others were 600 W grid-tie inverter, solar panel, digital DC ampere and voltmeter, and digital power meter and other supporters. The design involved box panel design and solar power plant component layout.

After the design stage, the next stage was implementation consisted of tool design and making. All process was done in Mechanical Engineering workshop, Universitas Negeri Yogyakarta.

4. Findings and Discussions
After the on-grid solar power plant making process was done, the next stage was testing that was performed in the Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta on May 18th, 2020.
Testing was performed without connecting the system to the load because it aimed to analyse the power efficiency that was produced by the system. The testing was done by taking the observation data every 10 minutes from 11:50 to 13:20, considering the optimized solar energy during the hours. Table 1 displays the testing results.

| Test Result | Condition | Photovoltaic | PLN | Grid Tie Inverter |
|-------------|-----------|--------------|-----|-------------------|
|             | Luminance (lux) | Temperature (°C) | Voltage (volt) | Current (ampere) | Voltage (volt) | Current (ampere) | Voltage (volt) | Current (ampere) | Output Power (watt) | Input Power (watt) | Efficiency (%) |
| 11.50 | 8770 | 29 | 43.4 | 0.56 | 225 | 226.1 | 0.153 | 21.794 | 50 | 0.63 |
| 12.00 | 7840 | 29 | 42.71 | 0.58 | 225 | 228 | 0.161 | 23.493 | 50 | 0.64 |
| 12.10 | 7350 | 29 | 42.49 | 0.58 | 225 | 229 | 0.153 | 22.073 | 50 | 0.63 |
| 12.20 | 7780 | 29 | 42.71 | 0.58 | 225 | 229.1 | 0.153 | 22.083 | 50 | 0.63 |
| 12.30 | 9860 | 29 | 44.48 | 0.56 | 225 | 227.9 | 0.163 | 23.403 | 50 | 0.63 |
| 12.40 | 7950 | 29 | 42.71 | 0.58 | 225 | 228.6 | 0.153 | 22.035 | 50 | 0.63 |
| 12.50 | 8970 | 29 | 43.81 | 0.56 | 225 | 229.1 | 0.153 | 22.784 | 50 | 0.65 |
| 13.00 | 7860 | 29 | 42.71 | 0.58 | 225 | 227.9 | 0.162 | 23.259 | 50 | 0.63 |
| 13.10 | 7830 | 29 | 42.71 | 0.58 | 225 | 228.1 | 0.153 | 22.336 | 50 | 0.64 |
| 13.20 | 7560 | 29 | 42.49 | 0.59 | 225 | 229.2 | 0.153 | 22.093 | 50 | 0.63 |

Based on Table 1, all components of the on-grid system solar power plant are well-functioned as proved from the stable electricity and follows the basic theory and manual book from the tool components. The grid-tie inverter connected the solar power plant system that was made with the PLN network. The voltage on average was higher than 2 up to 4 V from the PLN voltage. The readable frequency on the power meter was also similar to PLN frequency of 50 Hz while the average power factor (PF) from the system was 0.63.

The electricity average that was distributed to the PLN reached 22.5 W, if the average sunshine was 8 hours, the system produced up to 180 Wh electricity. From Table 1 above can be analysed the efficiency of the utilized grid-tie inverter using the formulation below:

\[ \text{efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \]  

(1)

Where the input power was calculated using the formulation below:

\[ \text{Input Power} = V_{sc} \times I_{sc} \]  

(2)

Table 2, shows the grid-tie inverter efficiency after the analysis.

| Efficiency calculation | Input Power (watt) | Output Power (watt) | Efficiency (%) |
|------------------------|-------------------|-------------------|----------------|
| 24.41                  | 22.08             | 90.46             |
| 24.56                  | 23.49             | 95.67             |
| 24.43                  | 22.07             | 90.35             |
| 24.56                  | 22.08             | 89.92             |
| 25.02                  | 23.4              | 93.54             |
| 24.56                  | 22.03             | 89.73             |
| 24.65                  | 22.78             | 92.45             |
Based on the above data, the maximum power point tracking system in the grid-tie inverter worked by optimizing the input power in the system to produce the most optimized output power. This statement can be seen from the grid-tie inverter efficiency that reached 95.67% with an average efficiency of 91.63%.

5. Conclusion
The 600 W on-grid solar power plant system was successfully made and tested in the Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta. Based on the testing, the solar power plant system that was made could be connected with PLN network. The average electricity that was distributed to the PLN reached 22.5 W, if the average sunshine was 8 hours, the system could produce the electricity up to 180 Wh. Besides, after the analysis, the grid-tie inverted efficiency reached 95.67% with an average of 91.63% efficiency. For the next research, it can be done by adding the Internet of Things (IoT) for monitoring the power and energy consumption used.

6. References

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