The modelling of photovoltaic power plant connected to the grid related to loading capability

I Hajar*, S Azzahra and A Yogianto

Electrical Engineering Department, Sekolah Tinggi Teknik PLN, Menara PLN, Jl. Lingkar Luar Barat, Duri Kosambi, Cengkareng, Jakarta Barat 11750

*lbnu.hjr@gmail.com

Abstract. Solar Cell performances as a power plant do not only convert energy, so that electricity is generated, but in the study of power systems it becomes a major element that has an important role in the study of power systems. As a power system element, the Solar Cell acts as an element of electricity generation in this study modelled as a PV system and connected to the network, so it must meet the requirements of the electric power network operation. Through MATLAB / SIMULINK modelling and simulations, a 100 kW peak Solar Cell power plant has been modelled to connect to the network. From the simulation and analysis obtained, this Solar Cell model shows that the connected load affects the voltage condition but does not affect the frequency. The load power factor also affects the network, namely with a lower load power factor, it affects the voltage on the network.

1. Introduction

Currently, photovoltaic (PV) power plant is increasingly developing its application, it is not only on an off-grid but it can also connect on-grid. Operation of photovoltaic power plant connected to the grid, originally only has a capacity of hundreds kilowatt, that is power system of a small island, but now it can reach thousand kilowatts capacity. The increasing photovoltaic connected to the grid will affect the operation of power systems, especially the distribution of power system [1-4], because generally photovoltaic it connected to the grid through low voltage of 380 volts or medium voltage of 20 kV.

Power system studies with the photovoltaic power plant connections is no longer adequate, if it is needed only as a point of the distribution network, but is needed as an analysis study for more details on the analysis of electrical power system.

In the power system analysis includes the analysis for the power system stability, in addition it requires the right model of power plant, it also needs the complete parameters of the power plant. In this research the power plant model that is made is not yet with the complete system parameters. But the photovoltaic power plant model is made with level of irradiance constantly, inverter with voltage control system, and filter for high harmonic, with using MATLAB/Simulink software for modeling the system.

2. Basic theory

2.1. Solar panel
Solar panel of the photovoltaic power plant is structured from modules which is circuited in series to get dc voltage requiring the inverter. Series circuit of the modules is called as string.
The number of modules of the string are adjusted to the minimum and maximum voltage at the input of the inverter, in order for the electricity plant to be able to operate reliably and continually.

To get the required capacity of the plant, the string structure is made of circuit in parallels so that the ability of the plant’s current can meet the specified capacity.

The structuring element of a module is the solar cell. A solar cell that structures a module is a current source that the rate depends on the irradiation that illuminates the modules. The bigger the solar irradiance is, the bigger the power resulted in the modules. In addition to dependence of irradiance, it also depends on the temperature of the modules. The bigger the temperature of the modules is, the lower the power can be resulted from the modules.

2.2. Radiation effect at the solar module
Performance of the solar module is very dependent on solar irradiance, the higher the irradiance is, the bigger the resulted current of the solar cell is, so that the power produced by the solar module is also getting bigger [4].

2.3. Temperature effect at the solar module
Solar cells will operate optimally if the cell temperature remains normal (at 25 °C), an increase in temperature higher than normal temperature of the solar cell will reduce the voltage of the solar cell. Every increase in temperature of the solar cell by 1 °C (from 25 °C), will reduce the voltage by about 0.4%, while the power generated will be reduced twice (2x) fold to increase the cell temperature per 10 °C [4].

2.4. Voltage source converter / inverter (VSC/VSI)
The inverter is known for the two types of operating which are voltage source converter / inverter (VSC/VSI) and current source inverter (CSI) [5].

As a source of the electricity plant’s power, the voltage source inverter (VSI) is used, because this source is expected to supply power with a constant voltage. As a voltage source converter, it is known to change dc power to ac power in a various way, which is basically related to commutation and voltage switching.

The inverters commonly used today are inverters with pulse width modulation (PWM) which is an inverter with work being set forcibly or regulated. In this inverter is not used thyristor as a primary component of the inverter, but it is used the IGBT (Insulated Gate Bipolar Transistor).

DC voltage that entrance to the inverter is chopped with high and graded frequency, a sinusoidal voltage is obtained from the sum of several rectangular waves.

![Diagram block of Inverter with Pulse Width Modulation (PWM)](image)

**Figure 1.** Diagram block of Inverter with Pulse Width Modulation (PWM).

On using inverter, there are some specifications which are need to be considered that is included:
- Input voltage of inverter
- Input current of inverter
- Output voltage of inverter
- Output power of inverter
- Output frequency
- Output voltage variation
- Output frequency variation
- Efficiency of inverter
- Regulatory / control capabilities
- Harmonic content of voltage and current

2.5. The electric power network
The electric power network contains of network conductor of SUTT (High Voltage Power Line) or cable with voltage system of 20 kV. At the system of 20 kV, the medium voltage power line can be formed by a radial network or loop network.

In general, the load that is supplied by the distribution network is an inductive load. The consumers with the inductive load, operating to the network require a requirement that there is no voltage drop that exceeds the limit.

Electrical power plant connected to the electrical power system is regulated by the Grid Code, while connected to the distribution system is regulated by the Distribution Code [5]. At present with development of renewable energy plants that vary in output, require a requirement for varied electrical power plants still need to be equipped, especially to maintain system stability.

In addition to the voltage and frequency meeting network requirements, the electrical power plant with converter devices also needs attention of the Total Harmonic Distortion (THD) condition.

The Total Harmonic Distortion declare the content of the total harmonic in a voltage, that is:

\[ \text{THD} = \sqrt{\frac{\sum V_i^2}{V_b}} \times 100\% \]

where:
- \( V_i \) = magnitude of the harmonic voltage to i, i = 2 and so on.
- \( V_b \) = voltage in the basic frequency

Based on SPLN code about harmonic, is determined that the THD of the allowable voltage of 5% [4].

3. Research method

3.1. Model design
Before the simulation is done, the first step is to design a model of plant that contains the model of the solar panel, inverter model and is also completed with a control system and a model of network. Based on the specifications of each capacity, it can be designed as a power plant as follow:
3.2. Simulation

After a model is designed, the model is then run creating a simulation.

First, the solar panel model is examined by looking at the output power produced in a fixed irradiance mode with the temperature changed at two values, then the output power is seen at a fixed temperature with the irradiance changed.

The next step, after making sure that the solar panel works according to plan, check the work of the inverter before and after the low frequency filter.

After ensuring that the output voltage of the inverter before and after the filter output is as planned, a parallel operation and loading simulation of the photovoltaic power plant is carried out. In general, the load on the network is an inductive load, therefore inductive loading is carried out in stages and the network conditions are seen at a certain capacity.

If the network conditions, especially in the condition of the voltage which exceeds the limit is too low, then increasing the network capacity is carried out.

4. Results and discussion

4.1. Model testing

Model testing is carried out in stages starting from solar panel testing, output of inverter testing and testing to the network with loading.

In testing for the panel with fixed irradiance of 1000 W/m² and modul temperature of 25°C, the capacity of solar panel is obtained according to the design as shown in the following figure,
Figure 3. Output power of solar panel with irradiance of 1000 W/m².

At the output of the inverter before the filter, the alternating voltage is obtained with the shape of the quadrilateral copped as a result of the square waves’ sum, as shown in the following figure,

Figure 4. Output voltage of the inverter.

Furthermore, with the operation connected to the network, the photovoltaic power plant is loaded gradually starting from 5 kVAR, 10 kVAR and 20 kVAR. The voltage obtained on the network and THD is as follows:

Figure 5. Voltage on the network with inductive load of 5 kVAR.
By monitoring the voltage on the network, the frequency of about 50 Hz with the inter-phase voltage of 19.2 Volt are obtained, thus they are still meeting the network requirements at the medium voltage.

![Figure 6. Voltage THD at Inductive Load of 5 kVAR.](image)

From monitoring the voltage through a harmonic recorder, the THD of 1.41 % at a steady state condition is obtained with resistive load of 90 kW and inductive load of 5 kVAR. This shows that the operation of a photovoltaic plant using this inverter is still meeting harmonic limits determined by electricity network [2], that is with a maximum limit of the THD which is 5 %.

![Figure 7. The network voltage of 20 kV with inductive load of 10 kVAR.](image)

From monitoring the network voltage, it can be seen that the network frequency is around 50 Hz with a large inter-phase voltage of 18.9 kV, thus it is still meeting the network requirements at the medium voltage.

![Figure 8. Voltage THD at Inductive Load of 10 kVAR on the side of 20 kV.](image)
Monitoring for THD on the side of the transformer output with a larger inductive load of 10 kVAR is relatively not too large adding to the magnitude of the harmonics. This is indicated by the THD value which is 1.96 %. By this THD value, the operation of a photovoltaic power plant still meets the network requirements.

![Figure 9. Voltage on the Network of 20 kV at Inductive Load of 20 kVAR](image)

From the simulation results, it can be seen that even though the network frequency is around 50 Hz, the inter-phase voltage is 17.5 kV. With the inter-phase voltage equal to this value, which exceed the limits of $-10\%$ (18 kV), the operation with a load of 90 kW and an inductive load of 20 kVAR is not permitted, unless there are capacitors or capacities of the systems greater than 2 MVA.

![Figure 10. Voltage THD at inductive load of 20 kVAR on the side of 20 kV.](image)

Monitoring the voltage THD on the 20 kV side shows that the THD value remains within the limit required ($<5\%$) which is around 1.55 % [3].
Figure 11. Voltage on the network of 20 kV, 4 MVA, inductive load of 20 kVAR.

From monitoring the network voltage, it can be seen that the network frequency is about 50 Hz and the large inter-phase voltage is 20.3 kV. Therefore, they meet the network requirements for the medium voltage network. Even though the load inductive is 20 kVAR, this load able to be served with a 4 MVA capacity system.

Figure 12. THD of voltage with inductive load of 20 kVAR, 4 MVA capacity system.

From the results on monitoring THD, it can be known that the voltage of THD in a steady condition is not more than 1.45 %. This value is showing that the operation of Photovoltaic power plant can meet the requirements of the THD for the network.

5. Conclusion

The modeling and the simulation of the photovoltaic power plant with capacity of 100 kWs connected to the network can be concluded as following:

- The solar panel model can meet the specification required namely the output voltage of 485 to 500 Vdc, the output power of 100 kW on irradiance of 1000 W/m² and module temperature of 25 °C.
• The inverter model constructed can meet the network specification namely with the output voltage of inter-phase of 380 V, frequency of 50 Hz, and the output from 380 V/20 kV transformer is becoming 20 kV inter-phase voltage.

• Photovoltaic Power Plant Model connected to the network that is designed can meet the resistive load required with voltage, frequency, and THD in which meet the limits on the provision of connection to the PLN power grid.

• This model of photovoltaic power plant can meet the limit of inductive load requirements at 2 MVA system capacity, up to the load of 90 kW, 10 kVAR or the power factor of 0.99.

• This model of photovoltaic power plant can be loaded with a larger inductive load with the increase of system capacity, at 4 MVA system, the load can reach 90 kW, 20 kVAR, or power factor of 0.976.

References
[1] Soni S 2014 Solar PV plant model validation for grid integration studies (Tempe (AZ): Arizona State University)
[2] Cahyawatto D N 2015 Distributed Generation: Study on Converter Modeling on PV Grid Connected System under Islanding Phenomena Clean Energy System
[3] Gorgan B, Busoi S, Tanasescu G and Notingher P V 2015 PV plant modeling for power system integration using PSCAD software In 2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE) 753-758
[4] Keyhani M M M D A 2010 Integration of Green and Renewable Energy in Electric Power System (Wiley and Son, Inc.)
[5] Schimpf L E N G 2008 Grid Connected Converters for Photovoltaic, State of the Art, Ideas for Improvements of Transformerless Inverter (Norwega: Norwegian University of Science and Technology, NTNU)