Control of Solar Power Plants Connected Grid with Simple Calculation Method on Residential Homes

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Abstract: One of the most compatible renewable energy in all regions to apply is solar energy. Solar power plants can be built connected to existing or stand-alone power grids. In assisting the residential electricity in which there is a power grid, then a small scale solar energy power plants is very appropriate. However, the general constraint of solar energy power plants is still low in terms of efficiency. Therefore, this study will explain how to control the power of solar power plants more optimally, which is expected to reactive power to zero to raise efficiency. This is a continuation of previous research using Newton Raphson control method. In this study we introduce a simple method by using ordinary mathematical calculations of solar-related equations. In this model, 10 PV modules type of ND T060M1 with a 60 Wp capacity are used. The calculations performed using MATLAB Simulink provide excellent value. For PCC voltage values obtained a stable quantity of approximately 220 V. At a maximum irradiation condition of 1000 W / m², the reactive power value of Q solar generating system maximum 20.48 Var and maximum active power of 417.5 W. In the condition of lower irradiation, value of reactive power Q almost close to zero 0.77 Var. This simple mathematical method can provide excellent quality control power values.

Keywords: solar, control, power

1. Introduction
Now, electrical energy needs is something to be fulfilled. The need for electric energy has moved closer to the primary needs of some people or groups, as well as in national issues. Various efforts doing by Indonesia in meeting the needs of various energy sources, the improvement of all aspects for each source of energy. Renewable energy sources is one of the energy sources that currently occupy the first position as an alternative energy. So the development of power plants with renewable energy is highly recommended in the acceleration of national development. The power plants on a medium or small scale, scattered or centered following the wisdom of local resources.

One source of renewable energy that is very flexible to be built anywhere is solar energy. Indonesia’s geographical condition is very supportive for the construction of solar energy power plants on a large scale or even small. The common obstacle faced is the efficiency of solar panels that are still low. Efforts to improve efficiency have been largely undertaken by previous researchers [1] [2]. Research has also been done by author using the Newton Raphson method in optimizing the flow of active power from solar energy generation to PLN network or load [3]. Design system built on the residential scale and connected to the grid (PLN network). The aim is to maximize the power flow in the previous review of the buy-back system [4]. This research will continue the previous research but by introducing a more simple and easy to understand control method. By utilizing simple mathematical calculations to produce a system control that still gives maximum results.

The design of solar energy generation system connected to the grid will be simulated with MATLAB.
1.1. System Description

Photovoltaic (PV) systems are devices that convert solar energy into electrical energy. PV consists of several solar cells, which each cell is connected to another in series or parallel to form a series of PVs commonly called PV modules [5]. The maximum operating efficiency of a solar cell depends on the maximum power point (MPP) of the PV system. In its operation, PV performance is strongly influenced by local climatological conditions (environmental temperature and solar radiation) and electrical parameters (short circuit current, open circuit voltage, PV cell temperature, MPP, etc.) [5] [6] [7]. The characteristics of PV systems are not very linear because they are influenced by external factors (environment). Solar irradiation, temperature and wind velocity are the major environmental factors affecting PV [6].

To build a solar power plant (PLTS) system are used a single phase inverter. Single-phase inverters are used as DC voltage converters into AC for load fulfillment and connection to the grid by using SPWM technology. Control of SPWM to set output voltage to have frequency according to fundamental frequency of load. The output voltage waveform can be seen from Figure 1 above.

For PLTS system connected grid where PLTS is connected to grid through inverter without battery. These systems can be classified as small systems, such as residential roof systems or connected to large grid systems. In the case of PLTS inverter connection with the grid, then the voltage and frequency should be in sync. Interactive inverters with the network not only the power condition of the PLTS output but are assured that the PLTS output is synchronized with the PLN network.

1.2. Optimization of PLTS Systems Connected Grid

The PLTS inverter is connected through a transformer with an equivalent impedance L at the PCC point. The phase and voltage magnitude of the inverter is controlled to regulate the active and reactive power of the PLTS inverter supplied to the grid. The real power of inverter the PLTS is equal to the output power of the array PV minus the inverter losses due to the energy balance between the DC input and the inverter PV AC output [10]. And the average output power of the PV inverter to the grid is described by equation (2) below. From the equation the Inverter PLTS output voltage can be controlled. With the output of the inverter is affected by the modulation index according to equation (1). This control system can be analog system or with microprocessor. This control system produces waveforms and amplitude and phase waveform regulation to control the power flow between the PLTS and the grid. The grid interfaced with a PV inverter, controlled voltage or controlled current, has a bidirectional power flow potential. Not only supplying local loads, but also can export active and reactive power overload to the grid. A control system approach is needed to reduce some error in power transfer due to synchronization error, which can make the inverter overload [9]. The simple interface of a grid connected inverter with a first order filter can be shown in Figure 3 below.

PLTS systems in grid-connected residential homes are designed using circuits such as Fig. 4 Controls are performed so that the accumulated energy absorbed from the grid within a given time range is zero. By knowing the characteristic pattern of the output of PLTS system and the house load, it can be calculated controlling so that the total power of PLTS can meet the load in certain period, so there is only temporary borrowing / storage of electrical energy in the grid system. The amount of energy supplied from the grid for the residential load and the amount of power supplied by the PLTS system to the grid is controlled for the same total value in a given period.

2. Method

In this system used 60W peak solar module as much as 10 pieces and planned to supply a residential house with 450VA installed power.
Table 1. Electro Optical Characteristic SHARP ND T060M1

| Parameters               | Symbol | Min | Typ. | Unit | Condition                      |
|-------------------------|--------|-----|------|------|-------------------------------|
| Open circuit voltage    | Voc    | —   | 22.0 | V    | Irradiance: 1000 W/m²         |
| Maximum power voltage   | Vpm    | —   | 17.4 | V    |                               |
| Short circuit current   | Isc    | —   | 3.90 | A    |                               |
| Maximum power current   | Ipm    | —   | 3.45 | A    | Module temperature: 25°C      |
| Module power            | Pₘ     | 57  | 60   | W    |                               |
| Module efficiency       | ηₘ     | —   | 11.36| %    |                               |

The modeling of solar panels in the MATLAB simulation is modeled based on a series of solar cell equivalents. By modeling the component of current source and diode as a controlled DC current source. The control system used for the PLTS system based on the power system flow equations connected to the PLTS grid.

For the system control system of PLTS using equations (2) and (3) we obtain the values of α and mₐ by determining that the constant Vpcc value of 220 and Xₐ is the reactance of the system channel connecting the inverter terminal with the grid and load terminals (L and transformer). By wanting the reactive power of the PLTS system to close to zero, the value of Q in equation (3) is made zero. The equations P and Q are the equations of the functions of α and mₐ which have the roots of the equations at certain α and mₐ values. At the root values, P and Q are optimum as desired. Calculation of the root value by means of completion of substitution. From equation (3), the value of P is set as the desired maximum P value, according to the PV array
output and the output of the PLTS system must meet the synchronization requirement that is the voltage and frequency value equal to the grid network [9]. The $\alpha$ and $m_a$ control equations are described below.

$$P_{\text{max}} \alpha X_{\text{pwm}} \sin$$  \hspace{1cm} (4)

With $\alpha$ is the ratio of the transformer used 60/230. Then the equations (6) and (7) are used as equations to control the sinusoidal signal SPWM gate inverter. The value of $X_L$ constant used is $\approx 10.04407446$ ohm. This value is calculated using equations (5) and (7) by inputting manual-controlled initial simulation data for some variations of load and irradiation. Here is a complete series of simulation models of PLTS systems connected to a single phase grid at home (Figure 6).

![Figure 2. Simulink Circuits of PLTS Connected Grid System](image-url)

Seen that the absorbs, supplies and also neutral conditions on the grid. When the output power of the PLTS system exceeds the load requirement, the grid will absorb it, while when the output of the PLTS system approaches the same as the load requirement, the grid also supplies or absorbs with a value close to zero. This means that at the time the house load is filled by the PLTS system without add with the grid. But when the PLTS system conditions are changed to insufficient load demand, the grid returns as a supplier.
3. Result and Discussion
The purpose of solar panel modeling is to achieve the IV curve similar to the graph given on the solar panel manufacturer's data sheet. The more precise the value, the better the model. From the simulation results obtained curve characteristics of solar panel models are almost the same and in accordance with the desired results. The IP-V curve corresponds to the theory of solar panel characteristics. Solar panel modeling is said to be successful by looking at the output characteristics of the modeling. Such as testing performed by previous studies [1][5].

![Figure 3. Curve of IP-V Characteristics of Solar Panels](image)

The voltage value of Vm and Im current at module maximum power is almost the same as indicated by SHARP NDT060M1 solar panel manufacturer. Where the maximum power Pmax 63.87 W and the maximum current Im 3.65A at a voltage of 17.51 Volts. The characteristics of IP-V simulation results shown by Figure 7. Next on the test, the system is fed irradiated inputs as well as residential loads that change. In Figure 9. The simulation test results, the power output of the PLTS system is proportional to the irradiation input value. It is

![Figure 4. The Power Flow Curve of Irradiation and Load Systems Changes](image)

The output waveform of the PLTS system for each irradiation variation can be seen in the figure below. From the current waveform and voltage can be the work area of each system. Where for the side of the PLTS system, the current and voltage wave are in phase, as well as the home side load waveform. As for the grid side, voltage and current waveforms can be in phase and different phase 180o according to whether the grid conditions absorb or supply power in the system. In this experiment it is clear for each working of PLTS connected grid system. The conditions under which the grid becomes a supplier and absorber for a certain time. The flow of power that occurs is as in Table 2 below.
Table 2. Power Flow of PLTS System Connected Grid with Irradiated and load Changed

| No | Irradiation W/m² | Home Load | Vpcc (Volt) | Active Power P (W) | Reaktif Power Q (var) |
|----|------------------|-----------|-------------|-------------------|----------------------|
| 1  | 1000             | 100W 10Var| 220.6       | 417.5             | -317.2               |
|    |                  |           |             | 100.3             | 20.48                |
|    |                  |           |             |                   | -10.46               |
|    |                  |           |             |                   | 10.02                |
| 2  | 600              | 200W 20Var| 220         | 226.1             | -26.32               |
|    |                  |           |             | 199.8             | -0.7744              |
|    |                  |           |             |                   | 20.75                |
|    |                  |           |             |                   | 19.98                |
| 3  | 500              | 300W 30Var| 219.7       | 170.2             | 128.9                |
|    |                  |           |             | 299.1             | -7.904               |
|    |                  |           |             |                   | 37.8                 |
|    |                  |           |             |                   | 29.9                 |

In this system, PLTS system is designed using topology without DC-DC converter and without battery storage. So the system control is applied to the inverter. The selection of a simple topology and with simple system control to be applied to a residential house with a PLTS grid connected system. Cost savings and components by reducing battery and DC-DC converter. While the control by using MPPT can cause rise in PCC point voltage, so it will damage in the inverter and also the grid network. Then the designed control system must be able to keep the PCC voltage constant but still deliver maximum power to the system. This designed control system keeps the inverter working area always close to being an inverter unity, so the possibility of inverter being loaded or acting as a bidirectional converter is very small. Using equations (5) and (7) has been tested for some experiment mode conditions by the calculation of the equation roots substituted. From the test results can be said that the control system works quite well. The voltage at the PCC point approaches a stable value of 220Volt. For the reactive power of the PLTS system as shown in Table 2, the maximum value of the PLTS system Q on the test is 24.64Var. The values are still tolerable. While the maximum value of P active power of PLTS system at irradiation 1000 W / m² is 419.2W. Although small of the maximum value given on the topheet is 60Wx10 = 600 W. This decrease in the maximum value of power is due to losses in the inverter to balance the input DC and AC output. By looking at the reactive power and phase phases and the voltage of the PLTS system, the active power supplied is the maximum power of the existing system after the reduction of the interface circuit of the PLTS system.

4. Conclusion

Simulation modeling for controlling solar power systems connected to the grid at home by using simple mathematical methods can work well. Point voltage PCC systems can be kept constant ≈220 Volts. In a maximum irradiation condition of 1000 W / m², the reactive power value of Q solar generating system is maximum 20.48 Var and maximum active power of 417.5 W. In the lower irradiation conditions the reactive power Q value is almost close to 0.77Var. This control method is simple so it can be applied easily. This method is not only at home but is also suitable for other small-scale generators as it provides excellent quality power control values.
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