Inverter design at photovoltaic for distributed generation networks

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Abstract. The photovoltaic generator is a renewable energy generator and this generator can be used as a DG because it is an environmentally friendly generator and can be stored close to the load because it does not cause pollution to consumers who are near the plant. Photovoltaic generator requires an inverter to convert the voltage generated by PV (DC voltage) to the voltage needed by the grid (AC voltage). In this study, the data obtained is the planning of DG installation in Karimunjawa. However, there is no harmonics calculation in the network. So that requires the design of an inverter in order to analyses the harmonic generated and the effect of harmonics on the grid. Not only inverters, this generator also needs a boost converter because the voltage generated by PV is insufficient to convert into a 400 Volt AC voltage. The inverter will use the PWM technique which will convert the DC voltage to AC and use an LC filter to refine and reduce the harmonic generated by the inverter. Simulation in this research is to found value of the component in LC filter and Boost Converter. After that the circuit will connect to the grid for analysis harmonic on the load.

1. Introduction
The basic concept of Distributed Generation (DG) is a relatively small capacity generator unit located near to the point of power consumption or load. The application of DG technology in power systems can produce many benefits both from the grid and the demand side [1]. Some of the benefits include increasing network reliability, reducing losses in the transmission network, providing better supporting voltage and improving power quality. DG is also able to reduce greenhouse gas emissions by providing clean and efficient energy [2,3]. This clean energy is obtained from several DG system plants, such as electricity from wind, biomass, photovoltaic, geothermal, and hydropower [4].

Distributed generation that uses PV as a generator or uses other Direct Current (DC) generators, of course requires an inverter to convert DC voltage to Alternative Current (AC) so that it can be interconnected into a grid [5]. However, this process will certainly cause harmonics that have a negative impact on power levels [6]. And harmonics cause serious problems such as: (1) Harmonics will damage the protective equipment, this will have an effect on the reliability of a security system and also the protection relay. (2) Equipment on the power system will be easily damaged. (3) harmonics will harm electrical equipment thereby reducing the economic life of such equipment. Therefore, harmonics must be detected, analyzed and filtered so that all problems caused by harmonics can be minimized [5].

The emergence of this harmonic problem is caused by most DG technology using an electronic power converter to control the power supplied by the PV generator [7]. This research focuses on designing...
inverters, simulating and analyzing the effects of interconnected photovoltaic (PV) units in existing network distribution systems. The inverter design will use the Matlab application while the Distributed Generation (DG) photovoltaic integration into the existing PLN network will be simulated using the Digsilent application.

2. Method

![Simulation flowchart.](image)

From Figure 1 explains the work flow of this research. In the beginning to determine the boost converter component, one must first perform calculations to determine the boost converter component first. Then simulated using the matlab application (Simulink) to see the output voltage generated after going through an inverter. If the voltage still does not reach 400 volts as desired. Then the boost converter calculation will be re-done until the desired voltage appears, then connect with the LC filter to see the harmonics generated. If the harmonics generated are still not suitable, the LC filter must be recalculated.

After determining the LC filter and boost converter components. Research will be conducted by linking the circuit with the transformer. Then recheck harmonics and the resulting voltage. If the harmonics generated do not match what is desired, the LC filter and boost converter calculations will be carried out again. If the results are in accordance with the desired results, then connected with the load. To again see the voltage and harmonics caused by increased load. Then re-fix if there are still voltages and harmonics that are not in accordance with the standards.

After these steps have been carried out, the circuit will then be tested by changing the load current so that it can see to what extent this sequence is working. then do an analysis of the circuit to see the characteristics of existing harmonics if interconnected into the network. In interconnecting into the
network is done using the Digsilent application because this application is easier to do interconnection. After that, observe the results obtained to determine the effect on the network.

3. Result and discussion
The information needed in this study to design the boost converter and inverter can be seen in table 1. This information was the design of photovoltaic in Karimunjawa.

| No | Data Name             | Magnitude |
|----|-----------------------|-----------|
| 1  | Primary Voltage       | 400 Volt  |
| 2  | Secondary Voltage     | 20,000 Volt|
| 3  | Primary Nominal Current| 1293 Ampere|
| 4  | Secondary Nominal Current| 52 Ampere |
| 6  | PV DC Voltage         | 587.9     |
| 7  | Load PV Load 1 PV System | 897 kW    |

Information obtained from PT. Quadrant that will be entered into the formulas and used as input to the Boost converter, Inverter and LC filter components. First of all, this test is done without using a Boost converter but the results obtained from the inverter are not sufficient to generate the 400 Volt voltage as needed. Therefore, a boost converter is needed to increase the input voltage so that the output voltage can be 400 volts as needed. Furthermore, to change from DC voltage to AC voltage requires an inverter circuit. The inverter used in this study is an inverter (2 level) with an IGBT switch and uses PWM as an IGBT regulator. This design uses a PWM frequency of 20,000 Hz with a reference voltage and a carrier voltage of 1 Volt. The overall circuit image (Boost converter, inverter and LC filter) can be seen in Figure 2. From the Figure there is a component called Powergui, this is a simulation regulator and a place to analyze the waves generated from each scope. Powergui does not include the existing components, but only the complement provided by the Simulink application (Matlab sub application).

The circuit that has been made or designed in addition to the components of the boost converter series, inverter and LC filter, there are also breakers, transformers and loads. These additional components will be used to analyze the characteristics of the chain and determine the value of the component if the desired load is 1293 Ampere.

![Figure 2](image-url)  
**Figure 2.** The circuit used in research.

By using a boost converter, the transient state voltage generated by the inverter will decrease. This voltage is smaller than without using a boost converter. Although this situation only occurs a few seconds during transients, it can minimize damage or age of using the equipment. While the use of a two-level inverter will further reduce the harmonics produced compared to a 1-level inverter. And LC filter that will refine the voltage, so that the harmonics generated are still in the standard IEEE 519.
In this simulation, in the beginning all breakers contained in Figure 2 will be opened or in an open state so that the circuit connection with the transformer and the load are separated. Next will determine the value of the boost converter and LC filter components contained in the circuit so that the resulting voltage is around 400 Volts and the resulting harmonics in accordance with the provisions of IEEE 519. For the value of harmonics and the resulting voltage can be seen in table 2. In table 2 number 1 is the output of the inverter without using an LC filter so that the harmonic produced is very large at 68.8%. Then the harmonics will be repaired further by using the LC filter. The boost component values and LC filter in this condition can be seen in table 3 number 1. After being repaired, the resulting THD becomes smaller at 4.24% and the resulting voltage is 405.2 Volts (see table 2 number 2).

| No | Condition | Parameter | Value       |
|----|-----------|-----------|-------------|
| 1  | Harmonics and Voltage Filters Before Installing LC filter | Voltage | 403.1 V     |
|    |           | THD       | 68.8%       |
| 2  | Harmonics and Voltage resulting from Repairs without Load and Transformers | Voltage | 405.2 V     |
|    |           | THD       | 4.24 %      |
| 3  | Harmonics and Voltage Conditions After Put Transformer | Voltage | 0.004368 V  |
|    |           | THD       | 104.47 %    |
| 4  | Stress and Harmonization Condition Results after Repair | Voltage | 399 V       |
|    |           | THD       | 0.47 %      |
| 5  | Results Before Repairs Using Load | Voltage | 215.3 V     |
|    |           | THD       | 0.43 %      |
| 6  | Results of Improvements After Concerning Load | Voltage | 401.8 V     |
|    |           | THD       | 0.42 %      |

Furthermore, the repaired sequence will be linked to the transformer. But breaker 1, which connects to the load, remains opened. The result is the harmonics increase to 104.47% and the voltage drop becomes very small (see table 2 number 3), further improvements must be made with the component values obtained listed in table 3 number 2. The results of this improvement result in harmonics returning down to small at 0.47% and the voltage being 399 Volts (see table 2 number 4).

After making improvements, the circuit will be connected to load or breaker 1 in a closed state. The burden given will be in accordance with the data provided by PT. Quadran is 1293 Ampere on the inverter or primary side. After connecting to the load, a voltage drop occurs but the harmonics produced do not change much (see table 2 number 5). Furthermore, improvements were made to the component values as shown in table 3 number 3 so that the improvement values obtained were better, namely the resulting harmonics to 0.42% and the resulting voltage was 401.8%. These results will then be used as the final value that will be used because it suits the needs of the current value of 1293 ampere and a voltage of 400 volts.
Table 3. The value of the component used.

| No | Condition                                      | Name of Component | Value               |
|----|------------------------------------------------|-------------------|---------------------|
| 1  | Repairs before installing the transformer and load | Boost Converter   | Duty Cycle 0.488695652 |
|    |                                                |                   | L (Henry) 0.143676522 |
|    |                                                |                   | C (Farad) 1.69981E-08 |
|    |                                                |                   | L (Henry) 109.8726115 |
|    |                                                |                   | C (Farad) 5.76941E-11 |
|    | Repairs after the transformer is attached and before the load is attached | Boost Converter   | Duty Cycle 0.241290323 |
|    |                                                |                   | L (Henry) 0.070939355 |
|    |                                                |                   | C (Farad) 0.000249074 |
|    |                                                |                   | L (Henry) 8.4975E-05  |
|    |                                                |                   | C (Farad) 7.45984E-05 |
| 3  | Value Repair Components After There Is Load     | Boost Converter   | Duty Cycle 0.488695652 |
|    |                                                |                   | L (Henry) 0.143676522 |
|    |                                                |                   | C (Farad) 0.038118261 |
|    |                                                |                   | L (Henry) 8.4975E-05  |
|    |                                                |                   | C (Farad) 7.45984E-05 |

Furthermore, to determine the characteristics of the series that have been made, an analysis of changes in load on the circuit will be carried out. The results obtained from the change of load can be seen in table 4.

Table 4. Information about harmonic and voltage when load change.

| No | Load current (Ampere) by the inverter | THD   | Vrms  |
|----|---------------------------------------|-------|-------|
| 1  | 1298                                   | 0.42% | 401.8 |
| 2  | 1107                                   | 0.42% | 402.7 |
| 3  | 1008                                   | 0.43% | 403.1 |
| 4  | 907.8                                  | 0.43% | 403.6 |
| 5  | 407.7                                  | 0.43% | 404   |
| 6  | 707.5                                  | 0.43% | 404.3 |
| 7  | 606.9                                  | 0.43% | 404.7 |
| 8  | 506.2                                  | 0.44% | 405   |
| 9  | 405.3                                  | 0.44% | 405.4 |
| 10 | 304.2                                  | 0.44% | 405.7 |
| 11 | 203                                    | 0.44% | 406   |
| 12 | 101.6                                  | 0.44% | 406.3 |
| 13 | 50.83                                  | 0.53% | 406.6 |
| 14 | 35.89                                  | 1.01% | 406.1 |
| 15 | 10.14                                  | 1.28% | 405.6 |

From the results of load testing it can be seen that the greatest harmonic generated is 1.28% when the load current beside the inverter is 10.14 Ampere. This is still below the applicable standards. For the record the initial voltage when the load is 10.14 Ampere has a very large peak but after a few seconds the voltage will return to normal.

After inputting the harmonic value into the Digsilent application, the harmonic generated on the side of the grid is very small at 0.02% this is because the number of harmonics from order 1 to 100 is 0.02%. To see the value of harmonics on the load can be seen in Figure 3. From Figure 3 it can be seen that the
harmonics at the load are still very small. The greatest harmonic load is 0.00187525%, so this is still in accordance with the standards set by the IEEE 519.

Figure 3. Information about harmonic on the load side.

4. Conclusion
After simulating and analyzing the results in the previous chapter, there are some conclusions. The conclusions are as follows:

- The boost converter and LC filter component values obtained from this design have the following values; For the boost converter component, the duty cycle value is 0.488695652, the inductor value is 0.143676522 Henry and the capacitor value is 0.038118261 Farad. As for the LC filter, the inductor value obtained is 8,4975E-05 Henry and the capacitor value is 7.45984E-05 Farad.
- When load is changed, the harmonics on the side of the inverter (Used Matlab application) only change with a very small range that is from 0.42% to 1.28%. This is still under the IEEE 519 standard.
- Harmonics on the load side generated by photovoltaic interconnection with systems (Used Digsilent application) is very various kinds but the greatest harmonic generated on the load side is 0.00187525%.

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