Performance Analysis Of Grid Tie Inverter With Power Limiter To Increase Utility Power Reduction In One Way kWh Meter Circuit

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Abstract. The use of grid tie inverter (GTI) in household electricity is intended to reduce the use of electricity from utilities. The configuration of GTI usually does not use batteries and the excess power from PV will be sent to the grid so that it will substitute utility electricity with electricity from GTI. However, this can occur when follow net metering program by installing an export-import kWh meters (two-way kWh meter) or follow feed in tariff program. If the kWh meter used does not support this capability or not following both program, the electric power of GTI will not substitute power from the utility. GTI with power limiter allows the inverter to work like a GTI in general but does not send excess power to the utility. The excess power from PV can be stored into the battery so that when the power shortage of PV will be substituted with power stored in the battery is not from the utility. In this research, conducted a study of the performance of the GTI with a power limiter and compared it with the GTI without a power limiter that works on an electricity network. The results of the study show that the use of GTI with a power limiter can increase the reduction in power usage from utilities by up to 40%.

1. Introduction
To meet the increasing demand for electrical energy, the use of renewable energy sources, such as solar energy, is increasingly being used. The mechanism of operating power plants that use renewable energy sources will usually work with other power plant to get more stable operation [1]. In solar power plants (SPP), other plants that become complement include electricity sources from utilities. In this configuration, it is possible to conduct electricity trading between SPP and Utilities.

In order to increase interest in implementing SPP, in line with the increasingly competitive prices of components from SPP, the power purchase and sale rules were applied in SPP installations through the mechanism of feed in tariff (FIT) and Net metering. The FIT scheme is tailored to many things ranging from geographical conditions to economic factors with the long-term application of the rules so that it is expected to attract the interests of the private sector and the general public to participate in the program of users of renewable energy sources to meet the electricity needs [2]. In Net metering, an electrical installation that connects the utility needs to be installed in a two-way kWh meter, export-import (ExIm), which will record the amount of power sent to grid (export) or supplied from grid (import). The difference in power between export and import will determine the amount of the bill that needs to be paid to the electricity network operator. The excess power difference cannot be converted
into money value, but can only be used to substitute when electricity production from the sun is decreasing, such as when conditions are cloudy or prolonged rain [3].

Installation of SPP with the FiT mechanism or Net metering must follow the rules and stages that have been set, which is certainly not simple. Installation of SPP actually does not have to always follow the rules of both, by making a long-term contract through the FiT mechanism or replacing the kWh meter with kWh ExIm to follow the Net metering scheme. SPP installation can be done with motivation to reduce power consumption from the network, by ignoring the power sent to the network. This can be done by installing SPP using a grid tie inverter (GTI). At present there is an alternative use of GTI which has the power limiting capability, where the excess power is not sent to the network, but is saved to the battery.

In this research a study on the performance of GTI with power limitation (GTIwL) will be carried out, how it will be compared with GTI without power limiting (GTInL) and what kind of configuration is suitable for use in GTIwL. From this research, it is expected that an alternative PLTS installation scheme can be obtained which is simpler, without having to be complicated by the rules of the FiT mechanism or Net metering.

2. Methodology

2.1 Grid Tie Inverter (GTI)

Configuration of solar power plants (SPP) is generally divided into isolated SPP, and grid connected SPP. The electrical power generated in isolated SPP is only supplied to the load and not connected to the utility grid. To maintain the stability of the electric power system in isolated SPP due to fluctuations in solar radiation, batteries are used, which also function as energy storage. In grid connected SPP, generated electricity power supplied to a utility grid at the same time have functions to maintain electric power stability due to fluctuations in load and solar radiation [4].

The inverter technology used in SPP depends on the SPP configuration used. In isolated SPP, which are not connected to the network, the standalone inverter is used while in grid connected SPP, a grid tie inverter is used [5]. GTnL are equipped with the MPPT (maximum power point tracking), to maximize the conversion of solar energy to electrical energy. However, the GTIwL is not equipped with MPPT, this causes the inverter output power to be set only to supply the load and limit the power delivered to the network. This also causes the GTIwL can work with the battery.

There are several standards that must be met if a distributed generator will be connected to the network, including: IEC 61727 for characteristics of the utility interface, VDE 0126-1-1 for Safety enhancement, IEC 61000 for electromagnetic compatibility, EN 50160 considering the public distribution voltage quality [6].

2.2 Power flow in GTI

Power flow in GTI can be shown in Figure 1. In home solar power plant (HSPP), the output power is connected to the local load before connected to utility grid, so that the power output equation using a GTInL is:

\[ P_{\text{inv}} = P_{\text{Load}} \pm P_{\text{utility}} \] (1)

\( P_{\text{utility}} \) is positive when the inverter sends excess power to the network, while \( P_{\text{utility}} \) is negative when the power from the network supplies power to the load. Equation of inverter output power to inverter input power is stated as,

\[ P_{\text{inv}} = \eta P_{PV} \] (2)

With the MPPT feature, the efficiency of the GTInL can reach almost 95%.

While on GTIwL the inverter output power to the input power of both PV and battery meets the following equation:
3

Figure 1. Power flow in GTI a. Solar Power Plant  b. Home Solar Power Plant

\[ P_{inv} = \eta (P_{PV} \pm P_{Battery}) \]  
(3)

When : \( P_{PV} + P_{Battery} > P_{Load} \) or \( P_{PV} > P_{Load} \), if not use battery, then :

\[ P_{inv} = P_{Load} \]  
(4)

Because \( P_{utility} = 0 \), it's mean that excess power from PV is not sent to the network, as in GTInL. If the above conditions are not met, \( P_{PV} + P_{Battery} < P_{Load} \) then :

\[ P_{inv} = P_{Load} - P_{utility} \]  
(5)

Power from the utility will also supply the load. It can be seen from equation 4 that the output power of GTIwL is like on a standalone inverter, but here the inverter operation is done by connecting the network, if there is no electricity on the network then the GTIwL inverter cannot operate to produce electricity.

2.3 Related research

Several researches related to the development of grid tie inverters, among others, were carried out by Qusay Salem and Jian Xie who developed the Line Current Control Strategy to Control the Real Power Flow at PCC Using H-bridge Inverter. The simulation results show the effectiveness of the proposed control strategy in reducing the real power at PCC to zero during both inductive and capacitive operation modes [7]. Research about a voltage-sensorless control scheme for a grid connected inverter using a disturbance observer (DOB) to control the active and reactive powers of Grid Connected Inverter has conducted by Hyun-Sou Kim and Kyeong-Hwa Kim. By using these techniques, the phase angle of grid voltages can be completely restored even if the phase angle of grid is initially unknown [8]. Mohamed Alswidi et al. developing control system using an adaptive and effective controller for a single-phase single-stage transformerless inverter of PV system to handle uncertain distortion of electrical grid parameters. The simulation results shows, the proposed strategy can handle the variation conditions of grid [9]. Several other researches related to smart meters and their characteristics[10,11], as well as the application of feed in tariffs [12,13] and Net metering [14,15] were examined in the following research.
2.4 Testing Method

In this study measurements of electrical parameters on GTI, both without power limiting (GTInL) or with a power limiter (GTIwL). The measurement is intended to see the performance of each GTI in supplying power to local loads. Measurement of GTInL characteristics is carried out in two conditions, changing load conditions and fixed load conditions. At changing load conditions, measurements are taken on two different radiation conditions. The load used in this test is 5 levels as shown in Table 1.

Table 1. Variation of Load Power

| No. | Load | Power (watt) | Power reading (watt) |
|-----|------|--------------|----------------------|
| 1   | 0    | No Load      | 0                    |
| 2   | 1    | 100          | 90                   |
| 3   | 2    | 200          | 180                  |
| 4   | 3    | 300          | 270                  |
| 5   | 4    | 400          | 360                  |

Meanwhile in the measurement of fixed loads, measured the amount of power that can be utilized by local loads for 24 hours of measurement are carried out. Measurement of GTIwL is measured without battery and with battery. Measurements are made at changing loads and fixed loads, with measurement methods such as on GTInL. A measurement scheme is performed for each type of inverter as shown in Figure 2.

**Figure 2.** Measurement method a. Grid tie inverter b. Grid tie inverter with power limit c. Grid tie inverter with power limit + battery (PM : Power Meter)
On the DC side the measurements are made for current and voltage, while on the AC side it is done using a power meter to measure current, voltage and active power. In a GTIwL, a CT current sensor is added to wire connection to grid. This sensor will limit the power supplies to grid.

3. Result and Discussion

Based on the results of testing on GTInL, the average efficiency of the inverter was 94.8%. Based on the characteristics of the power flow according to Equation (1), it can be seen that, when the power of $P_{PV} > P_{Load}$ the excess power will be deliver to grid. When $P_{PV} < P_{Load}$, the power shortage will be supplied from grid, as shown in Table 2. When operating all day, the amount of energy that can be produced in 1 day is 2.9 kWh with an average power generated during the day of is 297 Watts, as shown in Figure 3.

| PV | INV | Load | PLN | Rad. | Load |
|----|-----|------|-----|-----|------|
| I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | W/m² | Load |
| 14,2 | 23,5 | 333,7 | 1,49 | 221,34 | 326,3 | 0 | 223,4 | 0 | 1,27 | 223,3 | 270,6 | 566 | 0 |
| 15 | 23,5 | 352,5 | 1,55 | 220,13 | 336,4 | 0,4 | 223 | 88,24 | 0,98 | 222,6 | 196,4 | 567 | 1 |
| 15 | 23,5 | 352,5 | 1,56 | 221,19 | 329,3 | 0,82 | 222,5 | 181,2 | 0,69 | 222,5 | 120,4 | 566 | 2 |
| 15,3 | 23,5 | 359,55 | 1,59 | 218,54 | 334,2 | 1,24 | 221,2 | 273,1 | 0,52 | 220,9 | 34,67 | 569 | 3 |
| 15 | 23,5 | 352,5 | 1,57 | 220,69 | 332,1 | 1,67 | 223,5 | 371,4 | 0,68 | 223,5 | -52 | 566 | 4 |

Table 2. Grid Tie Inverter Without Power Limit (Radiation 566-569 W/m²)

![Output Power Grid Tie Inverter no Power Limit](image)

Figure 3. Grid Tie Inverter connect to grid without power limit

Observations on the GTIwL inverter test show in accordance with Equation (3). When the PV power meets to supply power to the load, the power of the PV will be divided into the battery and into the load and a small portion to the grid. However, when the power from PV is insufficient to supply the load, battery will be supply power to the load, according to Equation (3). If the condition of the power from the PV and the battery is insufficient to supply the load, $P_{PV} + P_{Battery} < P_{Load}$, the grid will supply power to the load according to Equation (5). Table 3 and Table 4. shows the contribution of battery to meet the power needs to the load without having to get supplies from the utility.
GTIwL testing without using a battery indicates the inverter output power adjusts to the load power requirements. From the observations made during the test, it appears that even though the radiation is high but when the circuit is connected to a load of 1000 watts the power produced by the inverter is more or less close to the power at the load. Excess power from radiation is not delivered to the grid. However, when the power from PV is not sufficient to supply the load, the power shortage needed to supply the load will be substituted from the utility, as shown in Table 5 and Table 6.

### Table 3. Grid Tie Inverter With Power Limit Using Battery (Radiation 520-540 W/m²)

| BAT | PV | INV | PLN | Rad. Load |
|-----|----|-----|-----|-----------|
| I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | Rad. W/m² | Load |
| 8.1 | 26 | 210.6 | 8.2 | 26 | 213.2 | 0.16 | 218.63 | 2.8 | 0.14 | 221.3 | 2 | 540 | 0 |
| 5.73 | 26 | 148.98 | 9.2 | 26 | 239.2 | 0.61 | 218.28 | 85.9 | 0.63 | 220.8 | 4 | 520 | 1 |
| 3.08 | 26 | 80.08 | 10.6 | 26 | 275.6 | 0.93 | 218.03 | 179.4 | 0.63 | 220.6 | 8 | 535 | 2 |
| 0.46 | 25 | 11.5 | 12.4 | 25 | 310 | 1.32 | 218.55 | 280.5 | 0.63 | 220.9 | 9 | 538 | 3 |
| -2.68 | 24 | -64.32 | 14.2 | 24 | 340.8 | 1.74 | 218.17 | 367.9 | 0.6 | 220.1 | 6 | 551 | 4 |

### Table 4. Grid Tie Inverter With Power Limit Using Battery (Radiation 301-345 W/m²)

| BAT | PV | INV | PLN | Rad. Load |
|-----|----|-----|-----|-----------|
| I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | Rad. W/m² | Load |
| 2.56 | 28 | 71.68 | 2.8 | 28 | 78.4 | 0.17 | 218.15 | 3.7 | 0.23 | 221.2 | 2 | 345 | 0 |
| 1.48 | 28 | 41.44 | 4.8 | 28 | 134.4 | 0.61 | 218.53 | 82.7 | 0.64 | 221 | 5 | 303 | 1 |
| 0.57 | 26 | 14.82 | 8 | 26 | 208 | 0.97 | 219.36 | 184.6 | 0.65 | 221.6 | 4 | 340 | 2 |
| -2.28 | 24 | -55.86 | 10 | 24 | 245 | 1.35 | 219.69 | 280.2 | 0.67 | 221.9 | 6 | 301 | 3 |
| -5.53 | 24 | -132.72 | 11.8 | 24 | 283.2 | 1.77 | 219.87 | 377.1 | 0.67 | 222 | 6 | 310 | 4 |

### Table 5. Grid Tie Inverter With Power Limit No Battery (Radiation 549-550 W/m²)

| BAT | PV | INV | PLN | Rad. Load |
|-----|----|-----|-----|-----------|
| I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | Rad. W/m² | Load |
| 0.2 | 30 | 6 | 0.17 | 221.28 | 3 | 0.21 | 224 | 2 | 552 | 0 |
| 3 | 29 | 87 | 0.62 | 221.58 | 86.2 | 0.65 | 223.9 | 4 | 556 | 1 |
| 7 | 27 | 189 | 0.93 | 221.76 | 181.4 | 0.65 | 224 | 4 | 549 | 2 |
| 12 | 25 | 300 | 1.33 | 221.64 | 284.1 | 0.65 | 224 | 4 | 550 | 3 |
| 17.8 | 23 | 409.4 | 1.88 | 220.69 | 361.4 | 1.15 | 223.1 | 23 | 552 | 4 |

### Table 6. Grid Tie Inverter With Power Limit No Battery (Radiation 45-267 W/m²)

| BAT | PV | INV | PLN | Rad. Load |
|-----|----|-----|-----|-----------|
| I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | I (A) | V(V) | P(W) | Rad. W/m² | Load |
| 0.2 | 30 | 6 | 0.17 | 219.61 | 3.2 | 0.29 | 221.9 | 4 | 150 | 0 |
| 3.2 | 28 | 89.6 | 0.64 | 219.41 | 83.8 | 0.66 | 221.7 | 4 | 174 | 1 |
| 7.4 | 23 | 170.2 | 0.95 | 219.02 | 180.5 | 0.65 | 221.6 | 3 | 267 | 2 |
| 7.6 | 23 | 174.8 | 0.9 | 218.05 | 170 | 0.75 | 221.6 | 97 | 26 | 3 |
| 10.4 | 23 | 239.2 | 1.21 | 219.5 | 227 | 1.05 | 221.2 | 167 | 45 | 4 |
GTIwL testing when operating throughout the day, is only done on GTIwL configuration by using the battery. This is done because GTIwL without a battery will only supply power according to load requirements and when approaching dusk the inverter cannot produce power to supply the load. It can be ascertained that the power utilization of PV is certainly very low. When operating all day using a battery, GTIwL can still operate even though there is no sunlight, as shown in Figure 4.

![Output Power Grid Tie Inverter no Power Limit](image)

**Figure 4.** Grid Tie Inverter connect to grid without power limit

From the results of testing using a battery capacity of 2 x 60Ah and a fixed load of about 90 watts, the power supply to the load can be carried out for almost 17 hours without supplies relief from utilities. The amount of energy utilization from solar radiation is 1.6 kWh. Only 55.69% when compared to the amount of energy produced using GTInL. This can be due to the battery capacity that is used too small which cannot accommodate more electricity generated from PV. When viewed from the ability to supply local loads, GTIwL is able to supply power to local load a greater than GTInL which is only 990Wh, or only 59.96% compared to GTIwL. When using kWh meters that do not have the ability to import power, the excess power sent to the network cannot be used to substitute electrical power supplied from the network at night. When viewed from the characteristics of GTIwL, it can be considered as an alternative of Home SPP configuration that does not overload the utility electricity network, because the excess power produced is not sent to the network.

4. Conclusion
The characteristics of GTIwL are more like a standalone inverter but are connected to the grid, where the power generated follows the power requirements needed by the load. At GTIwL the excess power generated from PV is sent to the grid, in a very small capacity. This causes the use of GTIwL to be more suitable for use in home SPP applications because GTIwL provides a lower power change fluctuation in the grid than GTInL, because at GTIwL it does not send large amounts of power to the grid compared to GTInL.

The use of GTIwL at home SPP installations makes the installation process administratively relatively simple compared to feed in tariffs and net metering because at GTIwL it does not supply large amounts of power to the network which can affect power network stability.

From the results of the study, it appears that the use of GTIwL in home-based solar power plants provides the ability to supply greater local load power, around 40%, compared to GTInL.
Acknowledgments
This work was financially supported by Ministry of Research, Technology and Higher Education of the Republic of Indonesia through grant of Penelitian Unggulan Perguruan Tinggi 2018

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