Microgrid Development Using a Grid Tie Inverter

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Abstract

The use of renewable energy sources (RES), especially photovoltaic (PV), to meet the demand of electrical energy has been getting a great deal of attention as an alternative solution to electrical energy deficit problems. RES are being applied in power systems in a variety of configurations including microgrid systems. One of the characteristics of a microgrid is capability to supplying power to grid when there is an excess power to supply local load. This research examines the chances of saving power consumption from grid using power converters grid tie inverter (GTI) in a microgrid configuration. The test is done by using a zero load and power distribution methods. Test results show grid tie GTI capable of supplying electrical power to grid up to 98% of the input power converter. In the microgrid configuration power usage from grid can be reduced up to 91%, which should be supplied from the grid to load.

Abstrak

Pengembangan Jaringan Listrik Mikro Menggunakan *Grid Tie Inverter* (GTI). Penggunaan sumber energi terbarukan (SET), khususnya photovoltaic (PV), untuk memenuhi kebetuhan energi listrik semakin menjadi perhatian sebagai salah satu alternatif solusi permasalahan defisit energi listrik. Penerapan SET pada sistem pembangkit listrik dilakukan dalam berbagai konfigurasi antara lain sistem jaringan listrik mikro/JLM (*microgrid*). Salah satu karakteristik JLM antara lain mampu mensuplai daya ke grid jika terjadi kelebihan daya untuk mensuplai beban lokal. Penelitian ini mengkaji peluang penghematan penggunaan daya listrik dari grid/PLN menggunakan konverter daya *grid tie inverter* (GTI) dalam konfigurasi JLM. Pengujian dilakukan dengan menggunakan metode beban nol dan distribusi daya. Hasil pengujian menunjukkan konverter daya GTI mampu mensuplai daya listrik ke jaringan hingga 98% dari masukan daya konverter. Pada konfigurasi JLM penggunaan daya dari grid/PLN dapat dikurangi hingga 91% dari daya yang seharusnya disuplai grid/PLN ke beban.

Keywords: architecture of microgrid, grid tie inverter (GTI), microgrid, Photovoltaic (PV)

1. Introduction

The use of renewable energy sources (RES) to meet electricity demands is gaining a considerable amount of attention, as it appears to be a solution to the problem of electricity energy deficits, especially for areas that are difficult to reach by electric networks. Various developments related to RES utilization are continuously made, from the optimization of energy resource utilization to the development of power conversion systems and electric generation system architecture. The application of RES in electric generation systems is performed in various configurations, from the simplest systems such as the utilization of solar cells in solar home systems (SHS) to its application in microgrid systems.

The production of electric power from RES, such as solar power generation, varies depending on the solar energy source that is received at that time. This leads to problems in the quality of power generated, especially if it is connected to a grid system viewing solar power generating stations as negative loads because it has characteristics that are associated with energy source fluctuations that are uncontrolled [1]. This problem can be addressed by adding another generation system that is more controlled; for instance, energy storage systems (batteries) can be added or hybrid systems can be formed by adding diesel generators or micro turbines [2].

Microgrid system implementation provides many advantages both from the user and the electric utility provider. From the user's side, the application of a

microgrid that is connected to a grid can improve network quality, reduce emissions, and reduce the cost incurred by the user. The implementation of distributed generation systems with microgrid ability from an electric utility provider can reduce power flow on lines of transmission and distribution, thus reducing losses and costs for network development. Microgrids can also reduce the network load to meet the electricity demand and help to fix the network if a fault occurs [3]. The implementation of microgrid systems can also assist in improving emissions and the threat of climate change.

Many countries have developed microgrids because they offer many advantages such as better power quality and being more environmentally friendly. In addition, there is economic potential, as it is an opportunity to utilize waste heat from engine generators using combined heat and power (CHP). A microgrid system using RES is going to be an alternative power system in the future. Of course, such a system requires an operating mechanism and a sophisticated control system to make a reliable and efficient network, and this can all be done by the microgrid [4]. In general, while it can be applied as a solution to electricity in remote areas, microgrid technology can also be used as an electrical solution in urban residential complexes, offices, schools, and other places.

In this research, besides conducting a review of microgrids, the grid tie inverter (GTI) is also tested as a microgrid component. GTI power converter devices have the ability to change DC power into AC power. Output power is generated to supply local loads and grids.

2. Methods

Architecture of a microgrid. Microgrid power systems operate at a low voltage distribution and have several distributed energy resources. Microgrid systems also have the ability to operate when connected to (on grid) and when disconnected from a grid (off grid/islanded) [5].

As shown in Figure 1, the microgrid structure consists of several types of distributed energy resources (DER), such as solar panels, wind turbines, microturbines, and thermal power plants, each in the form of distributed generation (DG), including energy reserves from batteries (distributed storage/DS).

The microgrid electrical connection point, which is connected to the low-voltage network, at the point of common coupling (PCC) is connected to DG, DS, and loads, which consist of several types of loads such as residential homes, commercial buildings, school campuses, and industrial complexes.

As a new paradigm of power systems, there are still many obstacles to the implementation of microgrid

technology. Unfavorable government policies and the public's limited understanding of microgrids have become obstacles in applying microgrid technology. Different characteristics of conventional grid power with a microgrid can be seen in Table 1.

Grid tie inverter (GTI). Inverter power systems can be grouped into inverters for standalone systems and inverters for grid connected systems. In a standalone system (off grid), the inverter is not connected to the network. The electric power generated is consumed only for a local load. This means that the electrical PV-generated power is not all converted to electricity, but only partially in accordance with the needs of the load. The GTI is an inverter that works connected to the grid. PV-generated power is completely converted to electricity. Partialy consumed by the local load, if there is excess power will be delivered to grid. However, if there is no power from the grid, the GTI cannot work. A block diagram of a GTI is shown in Figure 2 [6]. Some of the DC-AC converters of GTI, among others, include *Zeta-Cuk based inverters*, *Full-bridge buck-boost inverters*, *Side-by-side boost converters,* and *Z-source boost inverters* [7].

Maximum power point tracking (MPPT). In power converter systems for solar power, to get maximum power use, the MPPT method is used. In accordance with the characteristics of solar panels/PV, as shown in Figure 3, the maximum power from the solar panels will be obtained in accordance with the working voltage maximum power point (MPP).

In Figure 3, the MPP values appear to change according to the solar radiation values and the temperature at that time. At a solar radiation of $300 W/m^2$ with temperature T = 330 K, the MPP obtained at a working voltage of solar cell voltage = 12 V. When solar radiation increases to $600 W/m^2$, the working voltage changes to about 11 V. The working point of solar panels is also affected by the environment and temperature. At lower temperatures the working point increases, as shown in Figure 3.
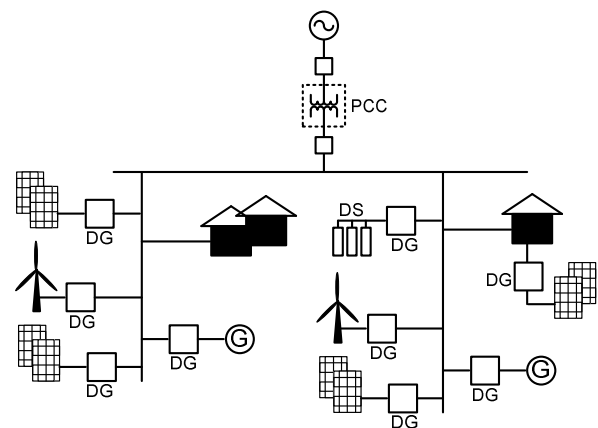

Figure 1. Architecture of a Microgrid

Table 1. Conventional Grid Power Vs Microgrid

Performance Measure	Traditional Grid Power	Microgrid
Cost	In most U.S. locations, the effective delivery of grid power costs between 6 and 15 cents/kWh.	Well-designed microgrid projects with good fuel cost/availability can be under 10 cents per kWh; thus, some are less costly than grid power in certain locations.
Fuel Efficiency	Delivered grid power is 30–50% efficient depending on the mix of power plants used.	A microgrid with CHP can be 70–90% efficient. Without CHP, a microgrid may be less efficient than traditional grid power.
Reliability	Grid power is, on average, 99.97% reliable. No single DG technology without redundancy can beat this performance.	A microgrid with a bulk system as backup achieves higher reliability than the bulk system alone and usually at a lower cost than upgrading the bulk system's reliability. A microgrid alone is not as reliable as traditional power without the use of costly redundancy.
Emissions	Modern natural gas combined cycle power plants pollute less than fuel oil/diesel DG engine units.	Fuel cells and renewable energy systems used in DG have little or no emissions and pollute much less than most grid sources. Natural gas DG sources pollute less than coal fired traditional grid generation.
Security	Damage to a few major transmission lines can cause regional blackouts affecting millions of customers.	Severe damage to a microgrid affects thousands of customers at most.
Construction Constraints	It is difficult to build new lines and substations.	Microgrids can be a solution to overloaded and constrained T&D systems, but they also have their own pollution, noise, and other zoning issues.

(a)

(b)
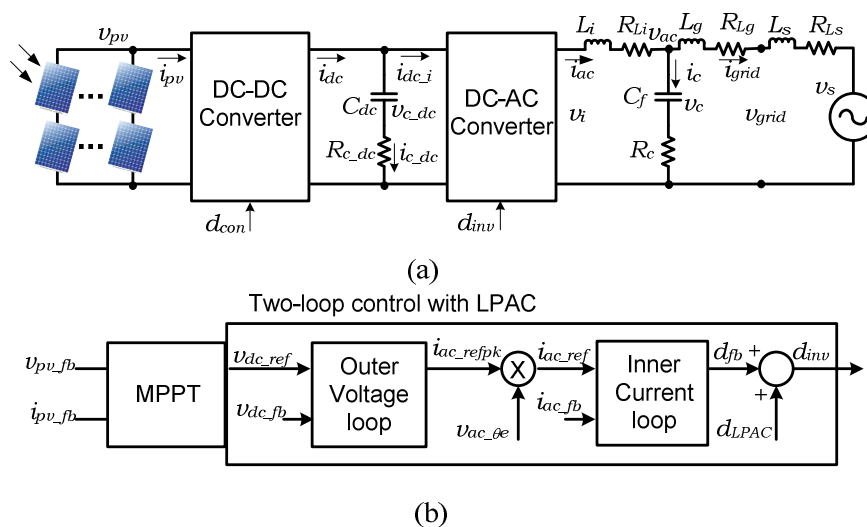
Figure 2. a) GTI Configuration, b) Block Diagram of GTI Model

There are several methods of MPPT that can be used to get a working voltage corresponding to the MPP in order to have maxim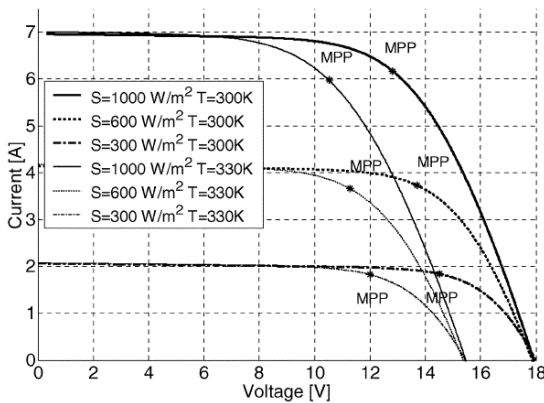um power, including perturb and observe (P & O) and incremental conductance (INC). The MPPT method using the P & O algorithm is widely used because it is easier to implement. However, this

algorithm has several drawbacks, such as oscillations in steady conditions around the MPP and a slow response in the event of solar radiation changes.
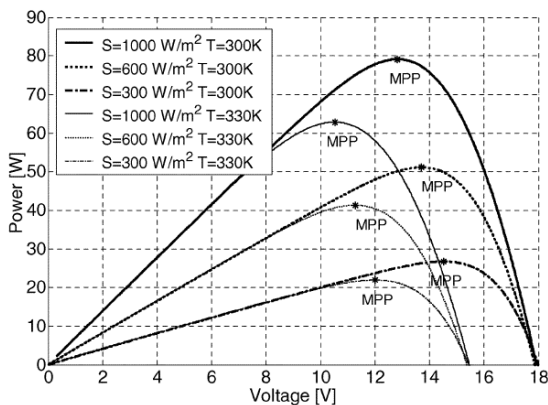
The P & O algorithm is based on the following criteria: if the operating voltage of the PV array is disturbed, and if increased power is obtained in a particular direction, the operating point has moved toward the MPP, and therefore, the operating voltage must be changed in the same direction [8].

There are three techniques that can be used to resolve the P & O algorithm: reference voltage perturbation, reference current perturbation, and direct duty ratio perturbation [9].

Meanwhile, for the INC method, the operating voltage at the terminals of the PV array is always adjusted to the MPP voltage based on the addition of another conductance voltage on the PV array [10]. This method based on the calculation of the power gradient toward voltage at the MPP is 0, and the gradient is positive if it is on the left of the MPP and negative if on the right [11].

Besides the two methods described above, several methods can be used to obtain the operating MPPT point of the PV array, such as parasitic capacitance, voltage based peak power tracking, and current-based peak power tracking [12].

Methods of Testing GTI. Test activity intended to determine characteristics of GTI to be applied to microgrid. In addition to studying the mechanisms of grid interconnection, there are three stages of testing, which are: 1) Characteristics of GTI with zero load, 2) Characteristics of GTI with a local load, 3) Characteristics of GTI power distribution when connected to the grid.

The loading characteristics of GTI were examined to determine the relationship between output power and input power that can be generated by GTI. In these testing activities, a GTI has been given an input DC voltage source that can be set at the output voltage.

Tests were carried out in two stages, without a local load and with a local load. Testing without a local load means the output of GTI is directly connected to the grid and then measure the dc input power and AC power supplied to the grid. Tests performed with a local load to do to see sharing mechanism of power generated by GTI toward power supplied to the grid.

GTI testing with a local load was intended to look at the behavior of GTI in supplying output power generated to a local load and a grid.

(a)

(b)

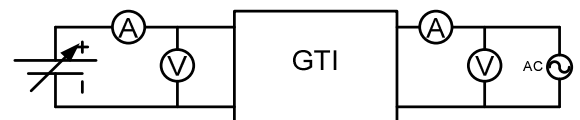**Figure 3. Characteristics V-I (a) and V-P (b) of PV**

Figure 4. Testing Circuit of GTI without a Local Load

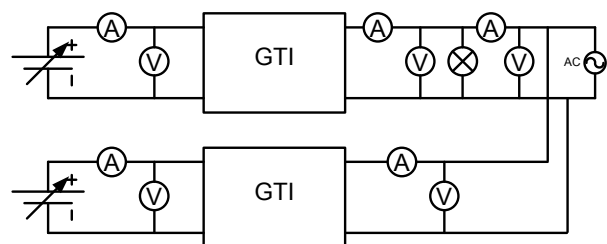**Figure 5. Testing Circuit of GTI with a Local Load**

Figure 6. Testing Circuit of Two Parallel GTIs Connected to a Grid and a Local Load

The test results show that when output power was less than the power required by a local load, the load power was supplied by the GTI and grid. On the other hand, when the GTI power exceeded the load power, the excess GTI power was supplied to the grid.

Two parallel GTIs connected to a grid were tested to look at the power-sharing mechanism of each GTI. The test started by connecting one GTI to the grid with a local load added and doing power measurements from the GTI and from/to the grid. Furthermore, the second GTI was connected to the grid and each GTI and grid's power distribution was measured.

3. Results and Discussion

The GTI test results without a local load with a DC regulator slide 16 A/220 Vdc (GTI connected to the the grid) showed that when the input voltage reached 14.8 V, the GTI began supplying a maximum power of 131 W to the grid, as shown in Table 2.

GTI doing MPPT process in order to get the maximum power that can be supplied by means of internal loading to obtain optimum power can be supplied. It can be seen from the behavior of the GTI and output voltage of the DC voltage source that changes the value of the initial voltage to a final voltage value.

The measurement result shows when the input power is 133 W, then 131 W is supplied to the grid. This indicated nearly 98% of the input power converter, is supplied to the grid. This means, the electrical power which is supplied to the network, can be used to substitute the grid electric power usage, when there is no supply of energy sources to generation. So the cost for grid electricity consumption can be reduced.

As shown in Table 3, when the GTI output power was only 40 W while the load power consumption reached 85 W, then a portion of the power (46 W) to the load was obtained from the grid. The excess power between the supply and the load is likely due to the accuracy of measuring devices. Table 3 also shows that when the GTI output power was 116 W, surpassing the power at the load, which was only 85 W, of the rest of the GTI power was supplied to the grid (29 W).

The test results of two parallel GTIs connected to a grid are shown in Table 4. It looks that with power load of 170 W while GTI1 power of 122 W power deficit supplied by grid at 55 W. When GTI2 ran, the power supply from the grid was reduced because a portion of the power to the load was supplied by GTI2.

The measurement results of GTI output voltage are shown in Figure 7. The GTI output was in accordance with the gridvoltage output. Measurements of power power were performed on the inverter, load, and line outputs to thegrid. Measurement began by activating the GTI without being connected to thegrid, it marked by value of grid = 0 W power, as shown in Table 4.

Test results using the local loads and microgrid configuration, From 170 W power required by loads, is only 14 W loads power supplied from the grid, it indicates that, using a microgrid configuration electrical power requirements to the loads which should have been supplied from the grid, can be reduced up to 91%.

**Table 2. GTI Connected to a Grid without a Local Load**

DC input				AC (Inverter)			AC (grid)
V_{awal} (V)	V_{akhir} (V)	Arus (A)	P_{in} (W)	V inv (V)	I inv (A)	P inv (W)	V grid(V)
16.5	12.8	0.52	6	208	0.05	2	207
17.38	13.7	0.5	7	208	0.05	3	207
17.4	13.8	0.53	7	207	0.05	3	207
20.52	13.9	1	14	207	0.1	8	207
22	14.8	8.97	133	208	0.6	131	208
24	15.04	7.92	116	208	0.53	108	207.4

Table 3. GTI Connected to a Grid with a Local Load

P_{inv} (W)	P_{load} (W)	P_{grid} (W)	V_{inv} (V)	V_{load} (V)	V_{grid} (V)
19	85	65	211	210	209
40	85	46	211.6	211	210
116	85	-29	212.5	211.9	212

Table 4. Measurement of a GTI Microgrid

P_{GTI1} (W)	P_{GTI2} (W)	P_L (W)	P_{grid} (W)
0	0	0	0
122	0	170	55
120	40	170	14
120	40	0	-158
0	0	0	0
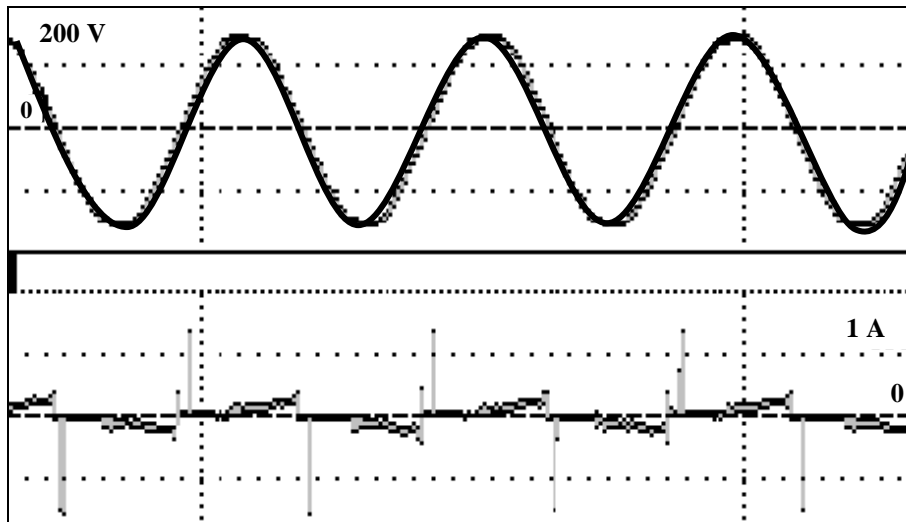
Figure 7. Output Voltage of GTI when Connected to a Grid

When there was no power supplied to the load (load disconnected), then the power from both GTIs was supplied to thegrid. The minus sign indicates the direction of the power flow toward the grid. When the source of the grid was disconnected (isolated/islanding), as can be seen in Table 4, grid power = 0 W, then both GTIs again produced no output power. The measurement results show that the total power was not balanced, which can be due to the fact that the measurements at each output were performed using different tools.

4. Conclusions

The output power of a GTI is influenced by its input voltage; the greater the input voltage, the greater the output power. With MPPT ability, a GTI will deliver the greatest possible power to supply to a grid.

A GTI will operate if connected to a network. When there is no power from a grid the GTI will stop delivering power to the grid. Although linked to a local load, the local load will be off. When it is connected to the grid and the load local, the GTI will supply power to the local load and excess power will be distributed to the grid. Conversely, if less power needs to be supplied

to the load, the power requirement will be met from the GTI, and its shortcomings will be obtained from the grid.

When operations of more than two GTIs are connected to a grid, then both GTIs will meet the power demand of a local load. Owned excess power will be supplied to the grid. Conversely, if both GTIs are not able to meet the power needs of the load, the grid will meet the power shortage.

From this phenomenon if GTIs are applied to a microgrid so that one microgrid consists of several GTIs, power sharing between GTIs will occur, so that one GTI can supply its own power to the local load of other GTIs that have power deficits to meet the needs of their local loads.

The measurement result shows, when zero load test, indicated nearly 98% of the input power converter, is supplied to the grid. This means, the electrical power which is supplied to the network, can be used to substitute the grid electric power usage, when there is no supply of energy sources to generation. So the cost for grid electricity consumption can be reduced. Test results using local loads and microgrid configuration

shows, that using a microgrid configuration, electrical power requirements to the loads which should have been supplied from the grid, can be reduced up to 91%.

Acknowledgements

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