Fault Diagnosis And Troubleshooting On 2.1kW Grid-Connected Photovoltaic Power System In UiTM Pulau Pinang

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Abstract. Grid-connected photovoltaic power systems always have a connection to a utility grid via a suitable inverter because a PV array only produces a DC power. This paper presents fault diagnosis and troubleshooting on 2.1 kW grid-connected photovoltaic power system in UiTM Pulau Pinang as a case study network. Grid-connected PV systems has a solar panels that produced a power needed in the day time, however the electricity supplied ongoing by distribution network operator during day night or whenever the solar panels produced low electricity because changes of weather (cloudy or rainy day). The case study network was selected because of a fault frequently occur and make the system unstable. The functionality of the case study network has been tested and troubleshooting has been carried out to identify the cause of the problems. Troubleshooting process had been done on the DC and AC side of the system by creating a troubleshooting table. The DC side of the system free from a fault, as proved by all the equipment in a good condition and PV array able to produce desired output voltage. The fault was occurred in the AC side of the system. The inverter has failed to produce desired output.

Keywords. Grid-connected PV system, photovoltaic (PV), PV faults, troubleshooting

1. Introduction
A photovoltaic (PV) system is a power system designed to supply usable solar power by means of solar energy. This system used solar panel to absorb and convert sunlight to electricity. The solar PV industry begin to popular and rapidly develop whenever the world facing an oil crises in 1970s. Low cost in solar PV generation is one of the main reason rapid development of PV industry[1]. The use of solar PV system has grown significantly in Malaysia after Renewable Energy Act gazette in 2011[2]. The use of the renewable energy to generate electricity such as solar system will reduce greenhouse gas emissions to the environment.

Nowadays, grid-connected PV system mostly used rather than off-grid or stand-alone system. A grid-connected PV power system is a renewable electricity generating power system using solar energy that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and a grid connection equipment’s. Stand-alone PV system normally used for small residential and commercial rooftop. Unlike stand-alone PV power systems, a grid-connected system
rarely includes battery bank, because they are very expensive. The grid-connected PV system will supply the excess power that is not being used by the connected load to the utility grid.

The grid-connected PV power system in UiTM Pulau Pinang has a power of 2.1kW that consist 12 PV modules in a series connection. The PV modules applied for the case study has a maximum power of 175 W with the model name NT-RSE3E. A voltage and current are 35.4 V and 5 A respectively at maximum power of the module. These 12 series connected PV modules connected to Growatt 3000MTL inverter for conversion of DC to AC voltage before delivered to the grid system. Growatt 3000MTL inverter has an input voltage range from 100V to 500V maximum. If the inverter received a voltage between the given range, it would convert to 240 V AC source and deliver to the grid system.

Upon analysing the characteristic of the fault on the case study network during monitoring process, an indicator light at the inverter turn red showing that the system is in a fault condition and it display ‘No AC Connection’. Therefore, troubleshooting process was conducted to search for a location of the fault that make the system malfunctioning. The troubleshooting table was created to troubleshoot the grid-connected PV system which consist of DC and AC side.

The objectives of this project are to test the functionality of the 2.1kW grid-connected photovoltaic power system in UiTM Pulau Pinang and identify the cause of malfunction of the system. Lastly, to identify the solution needed to fix the problem in the system.

In PV solar system, like any others electrical system, the lifespan of the system is shortened if the system is not well maintained[3]. Fault detection and diagnosis methods are indispensable for the system reliability, operation at high efficiency, and safety of the PV plant[4]. Therefore, it is very important to study the types of fault that might occur in PV system and a troubleshooting methods to make sure the system operate efficiently.

Faults in the PV system can be identified in two sides of the system which is DC and AC side and, the interface between these two parts are DC/AC inverter that connected to the grid[5]. The faults that may occur in DC side of the grid-connected PV system are fault in PV array, earth or grounding fault, bridging fault, open circuit fault, mismatch fault and fault in cables. Meanwhile, the faults in the AC side of the system occurs on the inverter and unbalanced voltage or grid outage for AC part. The AC output power will become low and DC output power remains the same when there is a fault in the inverter[5]. The classification, simulation, and discussion of all possible faults in both the AC and DC side of a grid-connected PV system are represented in[5].

Fault analysis in solar PV arrays is a fundamental task to increase system reliability, efficiency, and safety[6]. Faults in the PV system may cause damage PV modules or cables, as well as lead to DC arching hazard and even fire risks without proper protection. Two type of faults inside PV arrays usually cause overcurrent back feeding into the faulted modules are line to line and ground faults[6]. A PV array ground fault is an electrical pathway between one or more array conductors and earth ground[7]. Ground or earth fault occurs when the circuit develops an unintentional path to ground. In order to protect the array during ground fault event, a ground fault protective device (GFPD) is used to detect ground faults current[7]. Line to line fault also known as bridging or short circuit fault in the PV system exists when there is accidental connection occur between two different potential points in the string of PV array or in cables.

Several research works have been proposed to detect and diagnose PV system faults. For instance, authors in[8] suggest a diagnostic method based on I-V characteristic analysis and Artificial Neural Networks (ANN). This method allows the detection and localization of faults occurring in PV cells, PV modules, PV strings, and bypass diodes. Fault diagnosis method for PV system based on operating voltage-window has been proposed in[9]. In this method, it is only based on the measurement of operating voltage of PV strings and ambient temperature. The Grid Connected PV System Troubleshooting Tree is proposed by authors in[3]. This troubleshooting tree gives better periodic maintenance and preventive maintenance. In addition, minor faults are repaired at the time of periodic maintenance and better solar array output is obtained.

This paper presented a design of case study, 2.1kW grid-connected PV power system using MATLAB Simulink and troubleshooting process of 2.1kW grid-connected PV power system in UiTM Pulau Pinang. The system is designed same as the grid-connected PV power system in UiTM Pulau Pinang to analyze the system performance and comparing the result after troubleshooting/repairing process.
2.0 Methodology

Figure 1 shows the process flow of research methodology in order to indicate overall methodology of the project. It On the early stage, literature study has been taken into main consideration of the research on the grid-connected PV power system and to study the type of faults that might occur in the PV system. MATLAB Simulink is used to model the system design of 2.1kW grid-connected PV power system and analyses the system performance. After the simulation process completed, a test on the PV system will be conducted on the case study network by measuring output voltage of main components which is PV array, surge protection device (SPD), and inverter. Troubleshooting process has been carried out on the grid-connected PV system to find the location of the faults and a solution to fix the problem. whenever, the location of the faults has been identified, repairing process will be conducted to make the system fully operated. the final step taken, by analysing the system performance and comparing the new system updated with previous system.

![Figure 1: Process Flow of Research Methodology](image1)

![Figure 2: Grid Connected PV System Troubleshooting Flowchart](image2)

2.1 Grid Connected PV System Troubleshooting Flowchart

Figure 2 shows the Grid Connected PV System Troubleshooting Flowchart which is the process to troubleshoot the grid-connected PV system.

2.2 Troubleshooting

Troubleshooting process is a process or procedure to identify the exact location of the faults that might occur in the grid-connected PV system.
2.2.1 Faults in DC Side

The faults that might occur in DC side of the system are names as solar array fault, earth or grounding fault, short circuit fault, open circuit fault and mismatch fault.

a) Solar Array Fault

Perform visual inspection of the PV array to check if there is any kind of blockage such as shading or dirt on the module that prevents sunlight to be absorbed by the PV array. Usually, visual inspection is the first step in deciding whether further tests should conducted on PV module[10]. After that, check for any loose wires on each connections of the system. If there is any loose wire, tighten the connections using spanner and screwdriver. The output voltage reading for all PV string need to be checked using digital multimeter and identify if any of the strings give low output reading. When the faulty string is identified, the flawed module can be identified by covering each module and observe the changes in the voltage reading.

b) Earth or Grounding Fault

Earth or grounding fault can be identified using two methods: by measuring the voltage and insulation resistance.

i. Identify the fault types by Measuring the Voltage

Before measuring the voltage to troubleshoot grounding fault, the inverter must be disconnected from the supply. Next, use digital multimeter to measure voltage between positive terminal to ground potential, negative terminal to ground potential and positive to negative terminal. There is a ground fault occur in the system if the value of voltage reading between positive terminal to ground and negative terminal to ground is approximately equal to the voltage reading between positive to negative terminal. The location of the ground fault can be determined via the ration of two measured voltage. If the ground fault cannot be identified by measuring the voltage, measuring the insulation resistance should be necessary.

ii. Identify the fault types by Measuring the Insulation Resistance (IR)

To measure the insulation resistance, the theoretical value of the insulation resistance needs to be calculated for each string or the exact value can be obtained from datasheet of the PV module. Disconnect the inverter from any supply before setting up the short circuit device at the PV strings and then connect the IR tester device by setting the test voltage. The test voltage must be not exceeding the maximum PV modules voltage. Record the value of the insulation resistance and compared with value given from datasheet. Repeat the same step for others string. If there is a different of insulation resistance reading of the string compared to the datasheet value, it means that ground fault occurs in that string.

c) Short Circuit and Open Circuit Fault

This type of fault occurs when a disconnection problem appear in the PV string or more[11]. To detect this type of fault, perform visual inspection at every cable to check the insulation of the cable for mechanical damage, water ingress or corrosion. Then, check the connection between PV modules, connectors at junction box or breaks to identify if there are breaks in cable or the insulation of the cables. Lastly, check for any loose wires at every connection of the system. If there is any loose wire, tighten the connection using spanner and screwdriver.

d) Mismatch Fault

When the electrical parameters of one or group of cells are changed from other, the mismatches in PV modules will occur[5]. Therefore, perform visual inspection of the PV array to check if there is any kind of blockage such as shading or dirt on the module that prevent sunlight to be absorbed by the PV array.
After that, check the output voltage reading for all PV string using digital multimeter and identify if any of the strings give low output reading. Then, check the solder bond between the cell and contacted ribbons if there is any soldering damage. Lastly, check if there is discoloration, delamination and transparent layer crack of the PV modules.

2.2.2 Faults in AC Side
Two types of fault might occur in AC side of the inverter; inverter and grid fault which is unbalanced voltage or grid outage.

a) Inverter Fault
Troubleshooting process for inverter fault need to be done using digital clamp meter. Measure the DC input voltage and AC output voltage using this device. The AC output voltage must be at 240V and 50Hz as this system connected to utility grid. If the inverter cannot produce 240Vac, check for blown fuse, tripped breaker and broken wires of the inverter. Replace all blown fuse, circuit breakers and broken wires of the inverter.

3.0 Results and Discussions
The simulation results consist of two part which is the simulation results of PV array and simulation results of 2.1 kW grid-connected PV power system.

3.1 Simulation
The 2.1 kW PV array system was implemented in MATLAB Simulink as shown in Figure 3. The type of PV array that being used in this simulation was Sharp NT-175U1. The PV array modules can produce maximum and minimum power, 175W and 157.5W respectively. This PV modules was chosen for the simulation because its nominal ratings were same with Sharp NT-R5E3E that used in UiTM Pulau Pinang grid-connected PV system. The nominal ratings of these two modules was tabulated in Table 1. In this simulation, the PV array was set to 12 modules in series connection which was same as the case study network. The irradiances and temperature were set to 1000 W/m² and 25ºC respectively which was the Standard Test Condition (STC) for PV array. The output voltage of the PV array in this simulation is 501.71V while the exact value is 465V.

![Figure 3: Simulation Diagram of 2.1kW PV Array System.](image-url)
Table 1: Nominal Ratings of NT-R5E3E and NT-175U1.

|                     | NT-R5E3E (UiTM) | NT-175U1 (Simulation) |
|---------------------|-----------------|-----------------------|
| Power               | 175W            | 175W                  |
| Open circuit voltage (Voc) | 44.4V          | 44.4V                 |
| Short Circuit Current (Isc) | 5.4A           | 5.4A                  |
| Voltage at Point of Maximum Power (Vmp) | 35.4V          | 35.4V                 |
| Current at Point of Maximum Power (Imp) | 5A             | 5A                    |
| Weight              | 17kg            | 16kg                  |

3.2 2.1kW Grid-Connected Photovoltaic Power System

The 2.1kW grid-connected PV power system was designed using MATLAB Simulink as shown in Figure 4. The PV array was connected to inverter to convert to desired AC voltage and frequency to be delivered to the grid. The inverter then delivered 2.1kW of power to the grid.

The irradiance was measured using Hand Pyranometer 4890.20 to get the exact irradiance that received by PV array. The irradiance reading was taken at 10:00, 12:00, 14:00 and 17:00 to analyse the output voltage of PV array throughout the day. The irradiance reading was taken on 11 November 2019. The irradiance reading and PV array output voltage was tabulated in Table 2. It shows that the PV array output voltage increased when irradiance reading increased. Then, the irradiance data was transferred to the simulation to get the output voltage of the PV array and the inverter. Figure 5(b) shows the output of PV Array that varied from 425V to 280V. The output voltage of PV array in the simulation was a bit lower than the exact value that was measured using digital multimeter as shown in Table 2. This output voltage then enter the inverter as input and converted to AC voltage. The Growatt 3000MTL inverter that being used in UiTM grid-connected PV system have input range from 100V to 500V. This means that the inverter can convert the PV array output voltage to AC voltage to be delivered to the grid for the whole day. Figure 5(c) shows that the output voltage of the inverter that is 240V. This output then delivered to the grid.
Table 2: Irradiance and PV Array Output Reading

| Time  | Irradiance (W/m²) | PV Array Output Voltage (V) |
|-------|------------------|-----------------------------|
| 10:00 | 692              | 448                         |
| 12:00 | 985              | 467                         |
| 14:00 | 766              | 459                         |
| 17:00 | 423              | 305.4                       |

![Figure 5](image-url)  

(a) Irradiance, (b) PV Array Output Voltage, (c) Inverter Output Voltage.

3.3 Troubleshooting

In order to troubleshoot the 2.1kW grid-connected PV system in UiTM Pulau Pinang, troubleshooting table is created to list down all the equipment that need to be troubleshoot and to record the results of the troubleshooting process. Table 3(a) and 3(b) shows the troubleshooting table for DC and AC side of the system.
Table 3: (a) DC Side Troubleshooting table, (b) AC Side Troubleshooting Table.

| Name                                      | Condition/Reading          | Name                                      | Condition/Reading          |
|-------------------------------------------|----------------------------|-------------------------------------------|----------------------------|
| Cleaned PV modules (dirt, bird dropping,  | In good condition.         | Cleaned inverter                         | External and internal of   |
| fungus)                                   |                            |                                           | inverter clean.            |
| PV array structure                        | In good condition.         | No insects inside inverter                | No                         |
| Trees and shading                         | No shading.                | Cable connection inside inverter          | In good condition          |
| PV array cabling (mechanical or electrical | No mechanical or electrical| All fuses and circuit breaker operate     | Fuse blown                 |
| damages)                                  | damages detected.          | correctly                                  |                            |
| Cables connection (tightness and corrosion)| In good condition.         | Cabling from Inverter to Grid             | In good condition          |
| PV array output voltage                   | 465V                       | DC input voltage of inverter              | 465V                       |
|                                           |                            | AC output voltage of inverter             | 0Vac                       |

The equipment used to perform this troubleshooting process was digital multimeter, digital clamp meter, set of screwdriver, spanner and plier. After performing troubleshooting process, the DC side of the system was operating in good condition. There was no fault occur on the DC side of the system. The PV array was clean from dirt, bird dropping, or fungus as shown in Figure 6(a). Its structure also in good condition. There was no cracking or bending detected when performing the visual inspection of the PV array. Figure 6(b) shows the output voltage of the PV array is 465V, so it means the PV array was in good condition and can produce desired output voltage. All the PV array cabling were free from mechanical or electrical damages and the cables connection was in good condition as shown in Figure 6(c). It can be concluded that no faults occur in the DC side of the PV system.
In the AC side, the inverter was not producing output. When troubleshooting the inverter, the inverter was clean and all cable connection inside the inverter was in a good condition. There was no disconnected cable or loose cable connection but the fuse inside the inverter has blown. The fuse had been replaced with higher rating fuse that was 20 A/500 V. Its original fuse rating was 20 A/250 V. After replacing the fuse and connected the inverter to the grid, there was spark inside the inverter and the AC breaker tripped. After inspections, all cabling from inverter to the grid was in good condition. There were no mechanical or electrical damages that leads to short circuit fault and the grid voltage also in good condition that was 240 Vac. This can be concluded that the inverter has failed and need to contact Growatt Sdn. Bhd. customer service for further repairing process.

4. Conclusions
This paper presented all procedures of troubleshooting process for DC side and AC side of the grid-connected photovoltaic power system. The 2.1kW grid-connected photovoltaic power system in UiTM Pulau Pinang is simulated and analysed using MATLAB Simulink. In order to get accurate result of the simulation, the irradiance reading is taken throughout the day and the reading was used in simulations to analyse the output voltage of PV array and output voltage of the inverter. For the troubleshooting process, it can be concluded, there were no fault occur in the DC side of the system. All equipment in the DC side was in good condition and the PV array can give desired output voltage. The fault was occurred in the AC side of the system which is the inverter has failed. Growatt Sdn. Bhd. Customer service need to be contacted for further repairing process to make the grid-connected photovoltaic power system in UiTM Pulau Pinang works again. In order to make the 2.1kW grid-connected photovoltaic power system in UiTM Pulau Pinang works again, only the inverter need to be troubleshoot. After the system works again, scheduled maintenance should be done in order to prevent the system from malfunctioning and the system can operate for longer time. The maintenance should be done at least once in a month.

5. Acknowledgement
The authors gratefully acknowledge to Universiti Teknologi MARA, Cawangan Pulau Pinang, specifically Faculty of Electrical Engineering for the facility that has been provided to complete this project and their support along the journey to accomplish this research.

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