String Fault Finding on the Single Axis Tracker Photovoltaic Plant

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Abstract

South Africa has embarked on a journey of increasing renewable energy installations such as solar Photovoltaic (PV) and wind plants mostly in coastal areas. The South African Government has introduced the South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) to ensure a smooth facilitation of a private sector investment into grid-connected renewable energy (RE) generation in South Africa. As a result, the Council for Scientific and Industrial Research (CSIR) has a programme called the Energy Autonomous Campus (EAC) which aims to supply the Pretoria main campus with energy from wind, biogas and solar PV. The first solar PV plant was installed in 2015, connecting 558 kW DC on single axis trackers to the CSIR reticulation. Since that time, the plant has been struck by lightning twice. This paper will demonstrate the diagnostic techniques used to perform string fault finding on the single axis tracker solar PV plant in 2019. The results before, during and after fault finding will be discussed as well as the overall lesson learned during the fault finding process.

Keywords: current; voltage; string; string monitor, combiner box, lightning

1. Introduction

The CSIR has installed nearly two megawatts (MW) of solar PV in a number of systems since 2015: a 558 kW DC single axis tracker, a 203 kW DC dual axis tracker, and 6 rooftop east-west facing solar PV plants with an addition 1161 kW DC. The ground mounted single axis tracker solar PV plant has been struck by lightning twice, judging by the melted junction box covers and damaged bypass diodes following storm events. The first lightning strike happened in January 2019 and damaged more than 20 solar modules. The modules were replaced by spares and efforts are underway to replace the damaged bypass diodes so that the modules can be returned to service. In some cases, the modules may be beyond repair because the junction boxes were severely melted.

The second lightning strike occurred in April of 2019 in a different part of the same single axis tracker plant. The fault was detected the day after a severe storm passed through when some observers working nearby noted a thunder clap. The cloud cover was so heavy that the output of the plant was brought nearly to zero.

This paper will describe the diagnostics and repairs done at the single axis tracker solar PV plant after the lightning strike in April 2019. The results before, during and after fault finding will be discussed as well as the overall lesson learned during the fault finding process.

2. Solar PV Plant description

The Single Axis Tracker solar PV plant is located in Pretoria East at the CSIR campus next to the N4 highway as seen in Figure 1.

Figure 1 Location of a 558 kW DC single axis tracker PV plant

The Single Axis Tracker Solar PV plant capacity is 558 kWp. This plant consists of 8 inverters, 8 combiner boxes and 1800 crystalline silicon solar modules rated at 310 W each. Each string consist of 20 solar modules in series and each combiner box connects 11 or 12 strings in parallel. One home run direct current (DC) cable exits the combiner box leading to the inverter shed on site. Each combiner box is dedicated to one 60 kW AC SMA Inverter. The alternating current (AC) cable from the inverters are connected to the transformer where the 400V AC is stepped up to 11kV.

The strings enter the combiner box, pass through a fuse terminal block, and a surge protection device is connected at this point to prevent a surge from impacting the inverters down the line.

The combiner box brings the output of several solar PV strings together. Each string conductor is connected to a fuse terminal, and the output of the fused inputs are combined onto a single conductor that connects the box to the inverter[1]. The combiner box also houses a surge protector between the output and the inverter. The effects of direct and indirect lightning strike can be catastrophic to the electrical systems, so the surge protector is meant to minimize exposure to the lightning strike. If significant damage is caused to the installation then the operator is faced with high repair costs to the equipment and a loss of revenue as a result of the loss of output[2].

The combiner box also includes two printed circuit boards (PCB) that provide string level monitoring. Each PCB combines the positive conductors of 5 or 6 strings on the input side. One conductor from each PCB carries the current out from the board to the main terminal block that connects to the home run cable. The negative conductors of each string bypass the PCBs so current flows directly from the fused terminal block to the home run cable. If failures occur in individual modules or strings, the fault can be detected by monitoring the output from the web portal. The combiner box consists of string level fuses, a surge protection device (SPD) and a KSM monitoring system[3].

The PV plant equipment specifications is as follows:

- PV module: BYD310Wp
- Inverter: SMA Sunny Tri-power 60
- Transformer: Wegezi 500kVA, 400V/11kV
- Mounting assembly: PIA Solar Single axis tracker
- Pyranometer: SMP10 (ISO 9060 Secondary standard)
- Weather station: Lufft WS600-UMB
- Energy meter: Schneider ION7550

3. Fault Techniques in DC side

The following techniques are used to perform fault finding in the solar PV Plants:

3.1. Visual inspection

This technique is easy and not expensive. Most of the people normally use this technique to check for any obvious damages on the solar PV system before applying any other techniques. During the visual inspection technicians look for melted junction box, blown fuses, cracked modules, disconnect wires and burned back sheets.

3.2. Electrical current–voltage (I-V) measurement (EM) technique

Fault detection based on this technique requires only measurement of electrical signals from the output terminal, such as voltage and current. This technique was used by the CSIR during fault detection using a clamp meter and IV Curve tracer equipment [4].

3.3 A-B Comparison

This technique is used to compare the short circuit current of individual modules and also compare the string current of faulty string with a good string. Check the voltage of individual module to find a faulty diodes and compare with the good modules voltage output. The CSIR used this techniques to be able to detect the fault when measuring both the faulty and good string.

The following techniques are also used to detect the faults at the solar PV plant, but CSIR did not use them.

3.4 Climatic data independent (CDI) technique

This type of technique does not require any measurement of climatic data (solar irradiance, temperature, humidity and wind speed) for fault detection and classification (FDC). This technique uses external devices such as LCR [inductance (L) capacitance (C), and resistance (R)] meters and signal generators for fault detection. In order to detect fault, the response of the PV system is analysed right after injection of each signal[4].

3.5. Comparison between measured and modelled PV system outputs (CMM) technique

The difference between measured and modelled PV system output is used for fault detection. Various predictive models have been used to predict the expected output power of the PV system. [4].

3.6. Ground fault detection and interruption (GFDI) fuse

This fault detection technique uses a fuse. When the ground current is higher than the safe threshold current limit, then the fuse gets melted. If the fuse is opened, then inverter should turn OFF immediately to isolate the PV array from the rest of the power system[4].

4. Types of Faults

Some of the faults that happen at solar PV plants are described below.

4.1 Earth Fault

Earth fault occurs when the circuit develops an unintentional path to ground[5]. Earth Fault is an inadvertent fault between the live conductor and the earth. When earth fault occurs, the electrical system gets short-circuited and the short-circuited current flows through the system. The fault current returns through the earth or any electrical equipment, which damages the equipment[6].

4.2 Bridging Fault

When a low- resistance connection occurs between two points of different potential in a string of modules or cabling, the bridging fault will occur. Insulation failure of cables from animals chewing through cable insulation, mechanical damage, water ingress or corrosion cause these faults[5].

4.3 Open-Circuit Fault

An open circuit fault occurs, when one of the current-carrying paths in series with the load is broken or opened. The poor connections between cells, plugging and unplugging connectors at junction boxes, damaged bypass diode or breaks in wires cause these fault[5].

4.4 Mismatch Fault

When the electrical parameters of one or group of cells are changed from other, the mismatches in PV modules will occur. Mismatch in PV modules occurs when the electrical parameters of one solar cell are significantly altered from those of the remaining devices. These fault results in irreversible damage on PV modules and large power loss. These faults can be classified into permanent and temporary mismatches[5].

4.5 MPPT Fault

MPPT increases the power fed to the inverter from PV array. The performance of MPPT degrades when the failure occurs in the charge regulators. The output voltage and the output power reduces when a fault occurs in the MPPT[5].

5. Fault Description at the Single Axis Tracker

Figure 2 below shows the DC current of 11 strings from combiner box GD800 on the 25th of April 2019. At 11:45 the DC current of all strings started rapidly dropping to zero due to a large storm system that caused the global horizontal irradiance to drop from 110.43 W/m² to 12.71 W/m² in a matter of 15 minutes. Lightning and thunder was reported by observers in the area. After the heavy storm clouds passed, the DC current from all the strings except for one returned to expected output given the variable clouds. The current from “GD800 left I5” producing 0 current, is shown on figure 2.

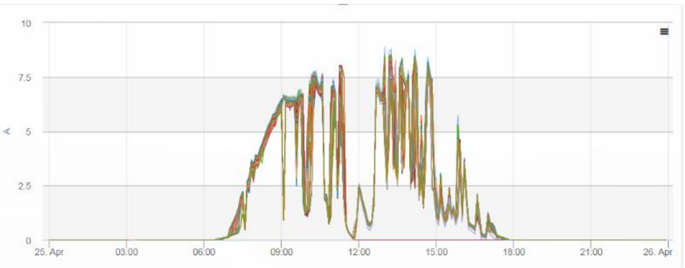

Figure 2 String level DC current on 25 April 2019

The output current remained 0 until the following afternoon when troubleshooting began.

6. Fault finding steps taken at the Single Axis Tracker

The monitoring software was used to detect the fault at GD800 left I5 string. A visual inspection of the string and the junction boxes was conducted. The blown fuse was replaced. The voltage drop across each module was measured to identify potential bypass diode faults. Five modules were identified with low voltage output and tagged for replacement. The module level short circuit current was measured with a DC clamp to ensure the current output of each functional module was matched and performing as expected.

Figure 3 shows the inside of the junction from one of the damaged modules. Three bypass diodes are still intact, but interconnection bridge shows signs of charring.

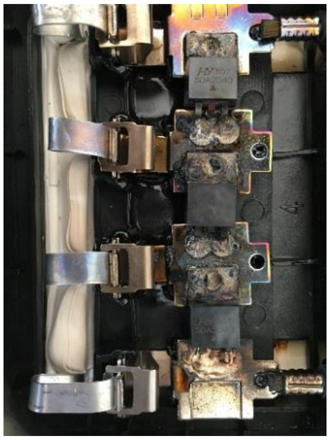

Figure 3 Charring inside the junction box of a damaged module

After the initial inspection was completed, two PV modules were replaced with remaining spare parts and three were bypassed because of a shortage of spares. The string was left with 17 modules in series until more spares could be acquired. This will result with the string producing less voltage than the other strings, but the current should remain the same as the other strings in parallel. The GD800 left I5 string power will be low compared to other strings of the same rating on the same combiner box.

The monitoring system continued to indicate low current of the faulty string, as shown in Figure 4. The string DC current measured only 25-30% of the other strings in the box. A clamp on DC amp meter also measured low current when the string was connected to the combiner box despite the short circuit current of each module measuring fine when measured individually.

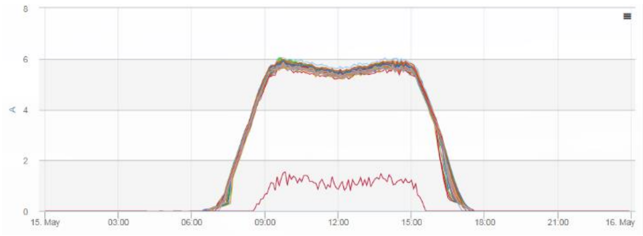

Figure 4 GD800 left I5 string current after two modules were replaced

Figure 5 below shows the DC string current after the remaining damaged modules were replaced on 18 June 2019. Even after the remaining modules were replaced, the DC string current output continued to measure low.

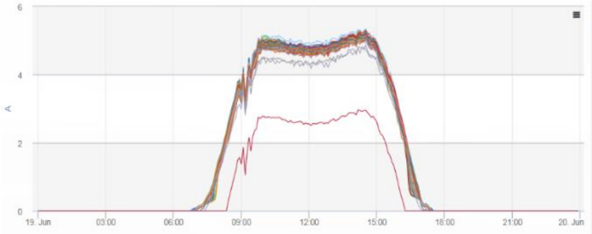

Figure 5 GD800 left I5 string current after all modules were replaced on faulty string

The string current increased to roughly 50% of expected, but still below the DC current produced by the other strings in the same combiner box. Further testing was done on the 21st of June to test the maximum current (Impp), maximum voltage (Vmpp), short circuit current (Isc)and open circuit voltage (Voc) per module using the IC Curve tracer and the results are stipulated on figure 6 below. The results indicate each module was performing as expected.

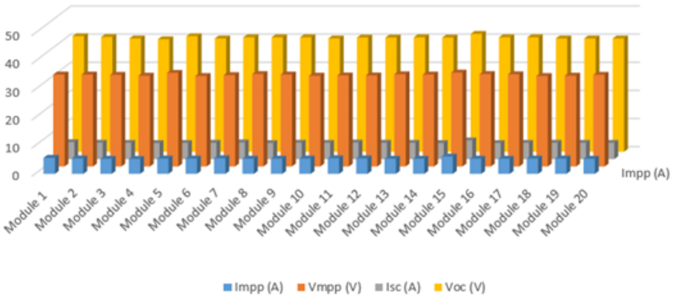

Figure 6 solar modules current and voltages

The cable from the end of the string to the combiner box was tested to check the cable resistance, in case if the cable is faulty and the results showed that the cable does not have any fault

The investigation now shifted toward the combiner box. Figure 7 below shows the picture of the combiner box installed at the CSIR single axis tracker PV plant.

Figure 7 Combiner box

Figure 8 shows a block diagram of a combiner box. Five or six strings are connected to one of two fuse blocks with a dedicated fuse for each string. Both the positive and the negative conductors are fused. The positive conductors from the fuse block are connected to the monitoring system circuit board, five or six strings to each board. The strings are combined in the circuitry of the measurement board and a single cable from each of the two monitoring system circuit boards is connected to the surge protection device. Finally, one positive and one negative home run DC conductors connect the combiner box to the inverter.

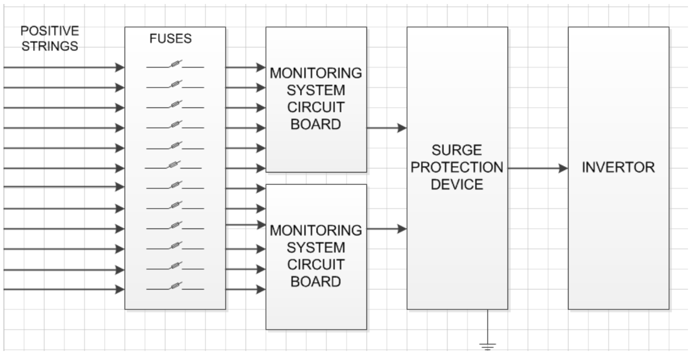

Figure 8 Block diagram of the combiner box

The following methodology was used to test the combiner box[7]:

1. Disconnect the inverter connected to the combiner box
2. Wear the gloves, open the combiner box lid and familiarize yourself with the strings connection and the number of strings per the combiner box and number of modules per string.
3. Measure the current and voltage per string using the multi-meter on the combiner box.
4. Open the fuse holders and perform a visual inspection to check if the fuse is working or not. 1 fuse was found blown and it was replaced
5. Check polarity for all the strings by measuring the voltage differential of the positive end to ground
6. Measure the voltage between the positive and the negative ends at the combiner box. This is perhaps your best indicator to know that all strings are wired correctly.
7. Switch on the inverter
8. Measure the current from the combiner box to the inverter.

After testing the combiner box, we realised that all the measurements are fine. There is nothing showing that there's a fault on the combiner box. When we checked on the monitoring software we realised that there's still a low current on the GD800 left I5 DC string. A further testing was done to check if the fault is in the string monitor inside the combiner box. The string monitor board was replaced with a new string monitor board and all the DC string currents finally matched. Figure 9 shows the GD800 DC power before the string monitor board was replaced, the figures show that the GD800 I5 during fault it was producing less current and the Figure 10 shows the results as displayed on the web portal.

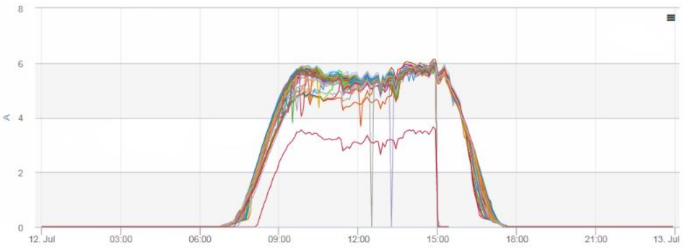

Figure 9 D800 left I5 DC string current (red colour) on the day the monitoring circuit board was replaced.

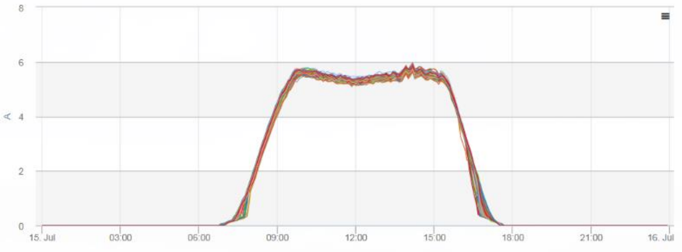

Figure 10 GD800 left I5 DC string currents after the monitoring system circuit board was replaced

7. Conclusion

After replacing the 5 PV modules and burnt fuses, a major fault was the monitoring system circuit board which was giving us false signals, causing delays in determining the root cause of the fault. Further investigation on the monitoring system circuit board still needs to be done. As much as there was no supporting evidence that the lightning caused all the damage, there is a high possibilities that it was lightning that damaged the PV modules, burnt fuses and damaged the monitoring circuit board and the surge protection device (SPD) did not protect the monitoring system circuit board because it is connected before the SPD.

8. Acknowledgement

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