Development of Real-Time Hotspot Detection System Utilizing Artificial Intelligence in PV Generation System

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Photovoltaic (PV) Generation system is one of the easiest renewable energy systems to generate either small amounts of energy for usage in households or for large amounts as utilized in fields. Although PV generation system does not burn fuel for power generation, some problems exist regarding heat. One of these problems is called Hotspots. A Hotspot is an increase in the cell’s heat in certain conditions and positions. In some cases, the heat can even ignite a fire. In this study, we propose a new method to detect this hotspot phenomenon at an early stage. The proposed method utilizes Artificial Intelligence (AI) as the main detection system. In fact, we were able to detect the hotspot with an accuracy of 82.25% using only two parameters, string current and string voltage. This system is a secondary system to be used in conjunction with the main control system. The output will be a flag sent to the main controlling system. Designing this system as secondary one, makes it easier to apply in already constructed PV fields. The findings illustrated the detection of hotspots with an accuracy rate of 82.25% using only two parameters, namely string current and string voltage. Thus the findings from this study provides a basis for the future development of a system which provides an overall evaluation for solar panels including hotspots and degradation.

Keywords: AI, Hot spot, PV generation system

I. INTRODUCTION

In this research, a new method of detecting hotspot phenomenon in the PV generation system utilizing Artificial Intelligence is proposed. Making the installation of such a system relatively easy for most PV generation fields is a crucial aim in this study. The detection system is mostly pure software, which makes the method easier to implement and less costly. The detection software consists of deep learning algorithms. Utilizing artificial intelligence, the application of a new method incorporating both string current and string voltage as its only parameters employed to detect the hotspots. This method totally differs technically from the existing method (thermography based). As the current and the solar radiation density are strongly correlated, we are able to a certain degree conject the solar radiation density with a level of accuracy that satisfies the AI. With full knowledge that most of the PV generation fields have current and voltage sensors, the proposed method will not require collectively any new wiring neither new types of sensors or cameras. This guarantees both cheaper installation and running costs in comparison to existing methods. This became possible as deep learning artificial intelligence analyses the samples of the database we have made.
II. WHAT IS HOT SPOT

A hot-spot phenomenon is ordinarily associated with illuminated regions of shaded PV modules that are heated up homogenously.\textsuperscript{1-4} It has been determined that, when PV modules operate under partial shading conditions (PSCs), both the shaded and illuminated regions simultaneously work at a reverse bias. In such cases, the illuminated regions can be treated as loads that heat up as a result of consuming power generated by a minor reverse current. An actual hotspot is depicted in Figure 1. It is well known that the high temperatures resulting from the hot-spot phenomenon often lead to irreversible cell destruction and accelerate the rate of thermal degradation. Therefore, in recent decades, a number of studies have investigated the generation of hot-spots.\textsuperscript{5-13} More importantly, it has been found that hot-spots can be produced from low-resistance defects in c-silicon PV cells.\textsuperscript{14-17} In addition, it has been reported that low-resistance defects usually occur at the edge of cells, intersecting junctions and cracks.\textsuperscript{15, 17, 18} These defects are associated with high conductivity that occurs in conjunction with a reverse bias and enables a high and prolonged reverse current flow through the defective regions. Hence, the defective regions heat up abnormally compared to the minor reverse current generated by the hot-spot phenomenon. From a safety point of view, hot-spots resulting from low-resistance defects are definitely more severe. 60°C is considered the upper critical safe operating point of solar panels. More than 60°C in a single point on a cell is considered a hotspot. However, this issue has rarely been discussed. Therefore, we have proposed a new real time hotspot detection method and it worked successfully.\textsuperscript{19} Moreover, this study will bring a new system with an even higher versatility, such as the control with Artificial Intelligence.

III. SYSTEM DIAGRAM

The system that has been used in this study is depicted in Figure 2. The system is composed of hardware and software. The study itself is the software part. The hardware part is just to start the experiment. As hardware part: we have connected 2 solar panels in series connection and it is connected it to a MPPT (Maximum Power Point Tracking) device connected to an electric load. The reason we have used MPPT device here is that almost every PV generation system starting from house scale up to mega PV generation field uses the MPPT method to maintain high output level. The PV string voltage and string current in this experiment were measured with oscilloscope. The software part: The data from the oscilloscope is then transferred to a PC via USB. After rearranging the raw data, this is fed to the AI database where the AI commences its work. However, at this point the system is not operating in real time yet.

IV. DEEP LEARNING ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) is a program which is built to work in a similar way to the human mind which is usually shown as a neural system diagram. Deep learning on the other hand is a subfield of machine learning which is subfield of the artificial intelligence. Deep learning is a more complicated method comparing to the older learning algorithms. As deep learning contains more layers to interact with data, it is coined called DEEP learning. The artificial intelligence attempts to function in the same manner.
as human brain would do which is widely known as neural network. Neural network is depicted in Figure 3.

The neural network which is shown in Figure 3 is the actual neural network we have built in this study. It consists of 3 parts: Inputs, hidden layers and outputs. Input layer and all 4 hidden layers are made of 90 nodes denoting the number of the variables in the samples that the AI analyses. The output layer has one node and this node has only two outputs: 1 and 0 which shows if whether the series has a hotspot or not. The nodes in the figure means the data and the connections shows equations that affects the data on the next nodes. Each line has its own weight. The weight means the extent to which the equation is going to affect the node. Currently there is a single node on the output layer. However, we are going to extend that layer and have more nodes to show some other deficiencies of the solar panels within the series.

The study utilized “Adam” as the solver for our AI. As Adam is a stochastic gradient-based optimizer, it works better than other solvers when working on large databases containing thousands of samples. In order to meet the aim of implementing a pure software detection method which is why we only use the absolute essentials in any PV generation field, namely current sensor and voltage sensor were utilized. Finally, to increase the detection rate, the solar radiation density was removed from the equation. Generally, some PV generation field’s solar radiation density sensors have an output of once every 5 minutes.

V. ABOUT SAMPLING

Deep learning algorithms analyse the samples to detect similarities in order to make a rule that can cover all the samples. Thus the sampling method has a huge and direct effect on the output accuracy of the AI. One of our main goals here is to make an AI which can detects the hotspots by monitoring the string current and string voltage only. As hotspot can occur within minutes depending on the conditions, the authors attempted to make the detection system as fast as and as accurate as possible. For this reason the sampling rate is set to 2 samples per minute. Every sample is 30 seconds long. For sampling we have used 2 of 50W silicon-based solar panels in series connection as depicted in Figure 4. Learning samples sampling format is depicted in Table 1. The first column titled ‘Hotspot’ indicates whether the sample contains an actual hotspot or not. 1 denotes that the sample has a hotspot and 0 means it does not. The next column (t1) is the time in seconds. (V1) is string voltage [V]. (I1) is string current [A]. The number 1 here is the seconds. The table has 30 (t-V-I) bundles. Staring from (t1-V1-I1) and ending with (t30-V30-I30). Testing samples sampling format is similar to learning samples sampling format excluding (hotspot) column as the AI is going to make one. Testing samples sampling format is depicted in Table 2.

VI. RUNNING THE PROGRAM

In this study, we had 180 samples varying in solar radiation densities. The lowest was 298W/m² the highest was 976 W/m². As the sampling format in this study does not contain solar radiation density as a parameter. Ensuring this method does gets a good score in different solar radiation densities was an important task to complete. Initially all the samples were taken as learning samples. Starting with 30 samples and by using a randomizer 20 of these were changed to test samples by removing the (hotspot)
column. Following, all the samples (learning and testing) are given to the AI. After receiving the output from the AI, the AI is formatted then given a new set of samples which is consisted of the previous samples all as learning samples + 30 new samples. After converting 20 of the learning samples to testing samples, the AI analyses it and gives back the output and then the steps are repeated. Until the samples reached 180 samples (20 testing and 160 learning). The AI gives the outputs in percentage, we have used 50% as threshold to determine if the output is hotspot or not, using Sigmoid function.21

VII. RESULTS AND DISCUSSION

The AI outputs are depicted in Figure 5. Having an accuracy rate as of 82.25% from a mere 160 samples was better than expected. The addition of the solar radiation density as a parameter to the formula may make the accuracy of the AI higher. However, considering that some of PV power generation fields gain output of the solar radiation sensors once every 5 minutes must be considered. Hotspot deficiencies which can ignite an actual fire can’t wait for 10 minutes to be detected. The fastest possible if possible way would be by using 2 measurements 1 every 5 minutes to wait for the solar radiation sensor output of the field. Sacrificing the boost in accuracy for higher sampling rate is one of the features of this study. Increasing the number of the samples is going make the accuracy higher and possibly making AI reach a level that does not have a noticeable difference of whether we had the radiation density as a parameter or not. Utilizing Adam as our solver, we concur that by enlarging the database or making the samples number in thousands, we can expect an even higher detection accuracy from our AI.

VIII. REAL TIME DETECTION SYSTEM DIAGRAM

The system used for real time detection is depicted in Figure 6. With respect to hardware: 2 PV panels were connected to a MPPT device connected to electric load. A current sensor right after the panels and voltage sensor on the PV string are connected to Arduino and finally to a PC. SC stands for Sensors Circuit. Regarding the software part: The Arduino takes the real time data from the sensors and sends it to the database on PC. Then the AI start to analyse these data to check whether it has a hotspot or not. Afterwards the AI send it to Arduino and Arduino gives an output of 5[V] if the AI send hotspot flag. The software cycle is 49[s] long. It is already proven in other research22 that the dangerous hotspots do not form within the first 60[s] of the onset of hotspot. Thus it is safe to say the 50[s] cycle is within the safe

![Figure 6. Real Time detection system diagram.](image)
Real time hotspot detection cycle phases are depicted in Figure 7. Real time hotspot detection can be divided into 3 phases. Phase 1: Arduino reads sensors output for 30[s] and feed it to AI database in real-time. Phase 1 is 30[s] long. Phase 2: AI analyses the data searching for hotspots. Phase 2 is 10[s] long. Phase 3: Arduino takes AI output as a figure and analyses it, reshaping the result to 0 and 5[V]. The accuracy rate of Arduino figures analysis was 100% in all of the 80 tests. When phase 3 ends, the cycle ends and hotspot flag state changes if needed to match the result. Every cycle is 50 [s] long. Cycles are unrelated to the next nor the previous cycles. However, Phase 3 is only used in this experiment to give a visual output in oscilloscope. Therefore, for practical usage in solar farms, phase 3 is not needed, as the results can be taken directly from the AI. Saving 10[s] each cycle by skipping phase 3. Therefore, even in the worst case scenario, if the hotspot begins when phase 1 ends, it can be detected within 50 [s]. Phase 2 (of a cycle) + Phase 1 (of the next cycle) + Phase 2. Thus, real time detection system is practical in real usage as it can detect hotspots in less than 60[s]. Arduino, Sensors Circuit and MPPT are depicted in Figure 8.

IX. RUNNING IN REAL TIME

Real time operating output is depicted in Figure 9.

As shown in Figure 9. The system has already been tested for 3 different situations. The grey area (60s~97s) shows the partial shadow pattern. The system did not raise a hotspot flag. The red area (155s~196s) shows hotspot pattern. The system has differentiated between the hotspot and the normal shadow and has raised a hotspot flag. The delay between the flag and the actual occurrence of the hotspot was due to the length of the software cycle - 50[s]-. The delay length is not a problem in this system, as hotspot does not reach dangerous levels within 50[s]. The white area shows the normal operation of the PV. Therefore, no hotspot flag is expected.

X. FUTURE IMPLICATIONS

The main goal of this study was to detect the hotspots in PV power generation fields. Sacrificing
the solar radiation density as a parameter making the system usable in PV generation fields. As in some fields, the solar radiation density sensors give an output once every 5 minutes, and this system requires an input every 1 second. However, the main technical problem faced in this study is the low number of solar panels that had a hotspot. Therefore, having 2 solar panels to make learning samples to be used on 20000 solar panels is not ideal case. However, in near future, we are planning to connect this AI to the IoT (Internet of Things). If we are able to get this AI connected to a real PV generation field and take the data from the field directly, it would have even a higher accuracy rate due to matching the learning samples with the test samples and due to the numerous amount of the learning samples the AI is going to receive. As real time system has already been constructed, the next step will be making self-learning system. For coming PV generation age, it may change from our AI to the AI which can detect hotspots on any panel type.

XI. CONCLUSION

In this research, we detected hotspot in PV generation system using only current and voltage sensors utilizing AI with an accuracy rate of 82.25%. Hotspots were detected in real time with a 50[s] long detection cycle to make sure the detection took place within the safe zone. It could lead to a cheaper yet high end hotspot detection system which is our goal. Having a system based on pure software detection method can makes it spread faster in comparison to the hardware (sensors) based one. By applying this system on a small and big scales connecting it all with IoT, we will be able to gather variety of hotspots data. Furthermore, by making it open-source for researchers from all the world, it may provide an impetus for the creation of a new detection or even a prevention method.

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