A New Method of Detecting Hot Spots in PV Generation System Utilizing AI

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Abstract. Photovoltaic (PV) Generation system is one of the easiest green energy systems to generate small amounts of energy as in houses or for large amounts as in fields. Although PV generation system does not burn fuel for power generation, it does still face some problems regarding heat. One of these problems are called Hotspots. Hotspot is an increase of the cell’s heat in certain conditions and positions. In some cases, the heat can even start a fire. In this study, we propose a new method to detect this hotspot phenomenon in 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 with the main control system. The output will be a flag sent to the main controlling system. Making this system a secondary one, makes it easier to apply in already built PV fields. In near future, the detection of other deficiencies is going to be a major task for this system.

1. Introduction
In this research, we are proposing a new method of detecting hotspot phenomenon within the PV generation system utilizing the Artificial Intelligence. Making the installation of such system relatively easy for most PV generation fields is one of the main goals we have. 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. Utilising the artificial intelligence, we investigate a new detection method that has string current and string voltage as its only parameters to detect the hotspots. Making it totally different technical-wise to 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. Knowing that most of the PV generation fields have current and voltage sensors, the proposed method will not require any new wiring neither new types of sensors or cameras. Which makes the installation and running costs cheaper compared to the existing methods. This became possible as deep learning artificial intelligence analyses the samples of the database we have made.

2. What is hotspot
A hot-spot phenomenon is ordinarily associated with illuminated regions of shaded PV modules that are heated up homogenously [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 shown 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 [5]-[13]. More importantly, it has been found that hot-spots can be produced from low-resistance defects in c-silicon PV cells [14]-[17]. In addition, it has been reported that low-resistance defects usually occur at the edge of cells, intersecting junctions and cracks [17]-[18]-[15]. 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.  

![Figure 1. Actual hotspot.](image)

However, this issue has rarely been discussed. Therefore, we have proposed a new real time hotspot detection method and it worked successfully [19]. However, this time we are working on a new system with an even higher versatility. As we are using the Artificial Intelligence.

3. System diagram  
The system that has been used in this study is shown in Figure 2.

![Figure 2. System diagram.](image)

The system we have used is built 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 then is transferred to PC via USB. After rearranging the (raw data) we feed it to the AI database. Then the AI starts its work. Note that the current system is not real time detection system yet.

4. 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 neural system diagram. Deep learning on the other hand is a subfield of machine learning which is subfield of the artificial intelligence affectively making it sub-subfield of the artificial intelligence. Deep learning is more complicated method comparing to the older learning algorithms. As deep learning does have more layers to interact with data, that is why it is called DEEP learning. The artificial intelligence here tries to function as how the human brain would do which is widely known as neural network. Neural network is shown in Figure 3.

The neural network which is shown in figure 3 is the actual neural network we have built in this study. It is consisted of 3 parts: Inputs, hidden layers and outputs. Input layer and all of the 4 hidden layers are made of 90 nodes which is the number of the variables in the samples the AI analyses. The output layer does have only one node and this node have only two outputs: 1 and 0 which shows if whither the series have 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 amount in which the equation is going to affect the node. In the mean time we have 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.

We have used “Adam” as the solver for our AI. As Adam is stochastic gradient-based optimizer, it works better than other solvers when working on large databases containing thousands of samples [20]. Needless to say, deep learning requires something to learn and analyse. We in this study have a goal of making a pure software detection method which is why we only use the absolute essentials in any PV generation field, current sensor and voltage sensor. Also for making the detection rate higher, we removed the solar radiation density from the equation. As some PV generation field’s solar radiation density sensors have an output once every 5 minutes.

5. About sampling
Deep learning algorithms analyse the samples that has been given trying to find the similarities to make a rule that can cover all the samples. Thus the sampling way 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, we tried to make the detection system as fast as possible and accurate. That is why 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 shown in Figure 4. Learning samples sampling format is shown in Table 1.
Figure 4. Used solar panels.

Table 1. Learning samples sampling format

| hotspot | t1    | V1    | I1    | ........ | t30   | V30   | I30   |
|---------|-------|-------|-------|---------|-------|-------|-------|
| 1       | t1    | V1    | I1    | ........ | t1    | V1    | I1    |
| ........ | ........ | ........ | ........ | .......... | ........ | ........ | ........ |
| 0       | t1    | V1    | I1    | ........ | t30   | V30   | I30   |

The first column of learning samples sampling format (hotspot) column shows whether the sample has an actual hotspot or not. 1 means the sample has 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 1 has 30 (t-V-I) bundles. Starting 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 shown in Table 2.

Table 2. Testing samples sampling format

| t1    | V1    | I1    | ........ | t30   | V30   | I30   |
|-------|-------|-------|---------|-------|-------|-------|
| t1    | V1    | I1    | ........ | t1    | V1    | I1    |
| ........ | ........ | ........ | .......... | ........ | ........ | ........ |
| t1    | V1    | I1    | ........ | t30   | V30   | I30   |

6. Running the program

In this study, we had 180 samples varying in solar radiation densities. The lowest was 298W/m² the highest was 976W/m². As the sampling format in this study does not contain solar radiation density as a parameter. Making sure that this method does get a good score in different solar radiation densities was an important task to complete. Initially all the samples are taken as learning samples. Starting with 30 samples and by using a randomizer 20 of these are changed to test samples by taking away the (hotspot) column. And then all the samples (learning and testing) are given to the AI. After having the output of 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 our threshold to decide if the output is hotspot or not. Considering only the percentages 50% and above as hotspots, using Sigmoid function [21].

7. Results and discussion

The AI outputs are shown in Figure 5.
Having an accuracy as of 82.25% by a mere 160 samples was better than what was expected. Perhaps adding the solar radiation density as a parameter to the formula is going to make the accuracy of the AI higher. But giving that some of PV power generation fields have the output of the solar radiation sensors once every 5 minutes is something not to be forgotten. The hotspot deficiencies which can start an actual fire are not going to wait for 10 minutes to be detected. As 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. Needless to say that increasing the number of the samples is going to make the accuracy higher and possibly making AI reach a level that does not have a noticeable different of whether we had the radiation density as a parameter or not. For having Adam as our solver, we can say that by enlarging the database or by making the samples number in thousands, we can expect even higher detection accuracy from our AI.

8. Future issues
The main goal of this study is to detect the hotspots in PV power generation fields. sacrificing the solar radiation density as a parameter was for 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 we have faced in this study is the low number of solar panels that have had a hotspot. Also increasing the numbers of such panels without having multiple types of solar panels from different makers will not make our AI an AI which can detect hotspots on any panel type. Therefore, having 2 solar panels to make learning samples to use it on 20000 solar panels is not our ideal case. That is why this study hardware part is temporary and just to make sure of the theory. 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 real PV generation field and take the data from the field directly, it would have even higher accuracy due to matching the learning samples with the test samples (real time detection) and due to the numerous amount of the learning samples the AI is going to get. However, before that, we are going to make real time detection system.

9. Conclusion
This study proved that it is possible to detect hotspots monitoring only the current and voltage without using any special sensors by using the AI. Utilizing such possibility can lead to a new cheap yet high end hotspot detection system which is our goal in this study. Having a system based on pure software detection method can makes it spread faster comparing to the hardware (sensors) based one, and by spreading this system and applying it in small and big scales connecting it all with the IoT, we will be able to gather variety of hotspots data and by making it open for researchers from all the world, a new detection method or even a prevention method might be proposed based on this study.

10. References
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