Investigation of PV solar panel I-V characteristics for real-time hot-spot detection system

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This paper proposes an investigation about the PV solar panel I-V characteristic to find a way to distinguish between normal cells and hot-spot cells depending on the changes of the panel output current. The current changes will help to design the real-time hot-spot detection system. In case if partial shadowing is applied to the PV panel, the system is equipped with a DSP to give an immediate judgment if hot-spot arises from one of the cells or not. From the experimental results, it is clarified that the hot-spot cells can be determined by calculating the current rate depending on the difference in the current divided by the short circuit current.

Keywords: Hot-spot, Detection system, Real-time, DSP, PV solar panel, DC-DC converter

I. INTRODUCTION
I-A. General
Currently, a feed-in tariff system requiring utility providers in Japan to purchase the maximum amount of electricity generated by non-residential photovoltaic power systems is being implemented, and the production of photovoltaic modules and the number of installations has been increasing rapidly. Accordingly, the number of failures has also increased. From reports on the causes of the failures, it is understood that many faults are a result of the hot-spot phenomenon. This is a phenomenon in which the entire or part of the cell becomes hot when partial shadowing occurs. If the partial shadowing continues for a long period of time, the temperature of the cell rises and causes deformation in the surface resin with the risk that the cell will break and burn in some cases. While there are methods for measuring temperature, such as using an infrared camera, for the purpose of checking for hot-spots, the measurement instruments are expensive, and a lot of time and effort is required. Therefore, the authors previously investigated the hot-spot phenomenon based on crystal defects and the simple hot-spot detection method.\(^1\)\(^2\) In the present study, based on these findings, we present an investigation to detect the hot-spot phenomenon in real-time based on analyzing the effect of partial shadow on the PV panel I-V characteristics.\(^3\)

I-B. Hot-spot Phenomenon
Hot-spot heating occur when a cell in a string of series connected cells is negatively biased and dissipates power in the form of heat as shown in Figure 1 instead of producing electrical power. This happens when the current produced by given cell is lower than the string current. This can occur when the cell is shaded, or simply generates less current then the panel. Shading part of a PV panel has a very dramatic effect on its I-V curve. Shading even a very small fraction of the panel may result in a very reduction of the panel power. Partial shading can be occurred by utility poles, chimneys, trees, parts of

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other buildings. About 15% of reported failure cases of PV solar cell system in Japan were due to panels’ malfunction.

II. HOT-SPOT DETECTION METHOD

II-A. Experiments

Table 1 shows the specification of KIS’s PV solar panel Model number GT133 at 25°C and 1000W/m².

| PV solar Panel Model number: GT133 |
|------------------------------------|
| Maximum power                      | 50W  |
| Maximum voltage                    | 20.5V|
| Maximum current                    | 3.35A|
| Operation voltage                  | 16.4V|
| Operation current                  | 3.05A|

Figure 2 shows the panel constitution. The panel consists of 34 cells separated to two clusters, and two bypass diodes. The two bypass diodes are connected in parallel to the two clusters respectively.

As a preparation step, hot-spot cells of the used panel were determined by shadowing each cell of the panel individually and observing the changes in the output current. Two cells were determined to be hot-spot cells.

![Fig. 1. Example of hot-spot cells by infrared camera.](image)

Figure 3 is the experiment configuration. I-V 400 PV panel analyzer (made by HI Instruments) were used to measure the output current and voltage of the panel and the collected data were converted into graphs for investigating in the I-V characteristics of the hot-spot cells and distinguish them from normal cells. Many experiments were applied to the panel in different solar radiation intensity and in variety shadow situations.

![Fig. 3. Experiment configuration.](image)

Figure 4 shows the different shadows applied to the hot-spot cells (pointed in red) of the panel. Also, the same cases of shadowing were applied to normal cells to observe the difference between all the cases and collect many results for comparison.

II-B. Results

Shadowing a cell or a part of it has a direct impact on the current path inside the panel. Figure 5(a) shows the current path in no shadowing condition.
The current flows normally through the two clusters while the bypass diodes are in OFF state. Therefore, shadowing a normal cell, which reverse leakage current is small, turns it into a large resistance which leads the whole current to skip the string of series connected cells in the cluster of shaded cell to flow through the bypass diode as illustrated in Figure 5(b).

Figures 6 and 7 show the I-V characteristics of the panel when normal and hotspot cells are shaded respectively in small shadow, 1 cell shaded, 2 cells shaded and big shadow conditions. When normal cells are shaded, the I-V characteristics shows a sudden drop in the current as in Figure 6 because the bypass diode of the cluster of shaded cell is turned ON.

On the other hand, the hot-spot cell is turned into a small resistance under the shadowing condition and the whole current is leaked through the cluster of shaded cell while the bypass diode is in OFF state as illustrated in Figure 5(c). The lost power is dissipated to heat and formed the hot-spot phenomenon.
small shadow conditions, the inclination is similar but the amount of flowing current is different. The reason is considered to be the resistance value is approximately equal but the size of the coverage area determines the amount of flowing current. For 2 cells shading condition, the resistance value becomes larger and accordingly the flowing current decreases. We relied upon the current inclination of all conditions to differentiate between normal cells and hot-spot cells.

III. INVESTIGATION OF DETECTION CRITERION

This system is based on calculating the current difference between the two points 10 and 15 volts divided by the short circuit current to regard the changes in the solar radiation intensity and this equation is named current change rate.

\[
\text{Current change rate} = \frac{I_{10} - I_{15}}{I_0} \quad (1)
\]

Table 2 shows the result of the current change rate for the I-V characteristics of normal cells and hot-spot cells when partial shadowing is applied. According to the results of current change rate in Table 2, if the result of the current change rate equation becomes 0.1 and over it means there is a hot-spot cell in the measured PV solar panel but if the result does not exceed 0.1, it means the PV solar panel is function properly.

IV. CONCLUSION

This paper investigates the PV solar panel I-V characteristic for a PV generation system as a first step to build a system that can detect the hot-spot phenomenon in real-time. From the experimental results, the hot-spot cells can be detected by the current change rate regardless of difference of the solar radiation intensity.

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