International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

A New Design for Smart Photovoltaic Module with Fault Detection Properties

Mouhamed Aghiad Raslan[a]*, Ertugrul CAM[b]

[a,b]*Department of Electrical and Electronics, Faculty of Engineering, Kırıkkale University, Kırıkkale, 71450, Turkey*

[b]*prof. Dr. Department of Electrical and Electronics, Faculty of Engineering, Kırıkkale University, Kırıkkale, 71450, Turkey*

[a]*Email: aghiad006@gmail.com*

[b]*Email: cam@kku.edu.tr*

Abstract

Solar power places the third in the renewable energy around the world. To provide such power, huge Photovoltaic (PV) plants are manufactured and installed all over the world. In such plants, faults occur in different stages of the electrical generation process. This paper proposes a new design of a smart PV module that detects and locates faults in the essential material of the PV plants, the PV module. For this aim, Hall Effect sensors have been connected to each substring in a PV module to provide real-time readings from the substrings. These readings have been processed by an algorithm that detects faults and differentiate the normal overall shading from the abnormal shading cases on the PV module. these substrings are designed to be demountable on the PV module for replacement if a sever permanent damage happens. Detecting and locating such faults with this design can save both, time and cost in the repairing process, and early maintenance in such cases provides a longer lifespan of a PV module.

Keywords: Photovoltaic module; Smart PV panels; Fault detection in PV modules; Hall Effect Sensor.

----

* Corresponding author.

1. Introduction

The demand for electrical power is increasing continuously. Countries over the world are trying to find alternative methods to produce electrical power. In these days the fossil fuel is the main reliable source to produce such power. However, it has several disadvantages from polluting the atmosphere to expensive costs with increased demands [1]. Renewable energy has become an alternative to fossil fuel and has been growing vastly in the past few years. Especially the photovoltaic power plants, they became more reliable and more efficient. Solar power plants have produced 505.5 GW (direct current) of the world's total power production in the year 2018 [2]. This significant growth of solar power was accomplished by the increased reliability, safety and efficiency of the photovoltaic systems. The main title of the reliability of a system is the continuous production of power in a Grid-Connected Photovoltaic (PV) system. To achieve that, faults are to occur in such systems should be detected early and eliminated as fast as possible. To this time, engineers and experts have been developing methods and algorithms to automate these plants by detecting faults that occur in the system whether it is in the DC-AC inverter units [3], the Maximum Power Point Tracking (MPPT) Unit [4], partial shading [5], dust effects [6], Line-Line faults in PV arrays and Line-Ground faults [7]. Hotspots are a common phenomenon in PV systems. They were discovered in 1969 and still present until this day [8]. They occur in photovoltaic cells because of a series of faults in the single PV module. It most commonly occurs in partial shading cases, where a PV cell or several PV cells in a PV module are shaded. The shaded PV cell operates at reverse-bias which makes the PV cell consume the power instead of generating it which leads the PV cell to operate under high temperatures, and that is how a hotspot is formed. Hotspots may cause a severe permanent damage to the PV cell. Therefore, detecting the hotspots on early stages may prevent the permanent damage of a PV cell [8,9]. Detecting these kinds of faults requires a delicate fault detection algorithm and sometimes it requires an intervention by a human to locate the faulty component in the PV module. According to Kim and his colleagues an algorithm has been developed to detect hotspots, it states that using several resistors, coupled in parallel and series, and capacitors coupled in parallel with a substring of a PV module can help detect hotspots occurrence in one PV cell. When hotspots occur, a series of changes in the AC current of the capacitors that can be detected and locate the faulty substring. This technic proves that detecting hotspots is possible using 2 different frequencies, one for detecting the changes in the AC impedance (the capacitive impedance) and the second to detect the changes in the DC impedance [10]. In this work, a new smart PV module design is proposed that helps in fault detection. This approach is developed to allow detecting faults that occurred on substrings bases, where hotspots affect the substrings whether its occurrence is caused by partial shading, dust or soiling, or interconnection failure. In addition, it can provide real-time data about each substring's current value. Also, an algorithm is applied along with this technic to provide a continuous inspection and the location of the faulty substring and to avoid false alerts. The PV module is designed to have demountable substrings where maintenance operations become easier when a permanent damage happens in the PV substring. replacing one substring instead of replacing a complete module is surly cost-effective and saves time. In this experiment, a PV module is coupled with Hall Effect Sensor (HES) on each substring. The Hall Effect sensor measures the magnetic field of the current produced from each substring and transmits the readings to a microcontroller. The given data from the microcontroller are entered into MATLAB script to provide readable readings, these readings are processed by an algorithm to detect faults when they occur. The advantage of using Hall Effect sensors is that the sensor's circuit is electrically disconnected from the PV module's circuit and only they are only connected magnetically. This provides a discrete measurement for the system and the sensor provides the data without being interrupted by the electrical faults that might occur in the PV module. The contribution of this design is to provide an easy and fast maintenance process when a permanent damage occurs in one or more PV cells. In addition, the proposed smart PV module detects malfunctions in real-time, which require an intervention to avoid permanent damage of the PV module. These faults such as hotspots have significant effects on a PV cell, and it increases the degradation of that PV cell significantly, hence decreasing its lifespan [11]. In this paper the effectiveness of the smart PV module will be tested while several fault tests are performed. The data collected from the smart PV module during the tests provides a better understanding of the efficiency of this design.

2. Materials and methods

2.1. PV Module design

The proposed PV module design consists of several separate substrings mounted on a PV panel and connected in parallel or series (as desired). The PV cells in a substring are connected in series and encapsulated to prevent any damage from the surrounding environment and permanently adhered to a hard back-sheet to provide stiffness to the substring. Then each substring is mounted to the panel using connectors and locks to hold the substring in place. After mounting the substrings, a tempered glass with anti-reflection coating is placed above the substrings and enclosed by the frame as seen in Figure 1.

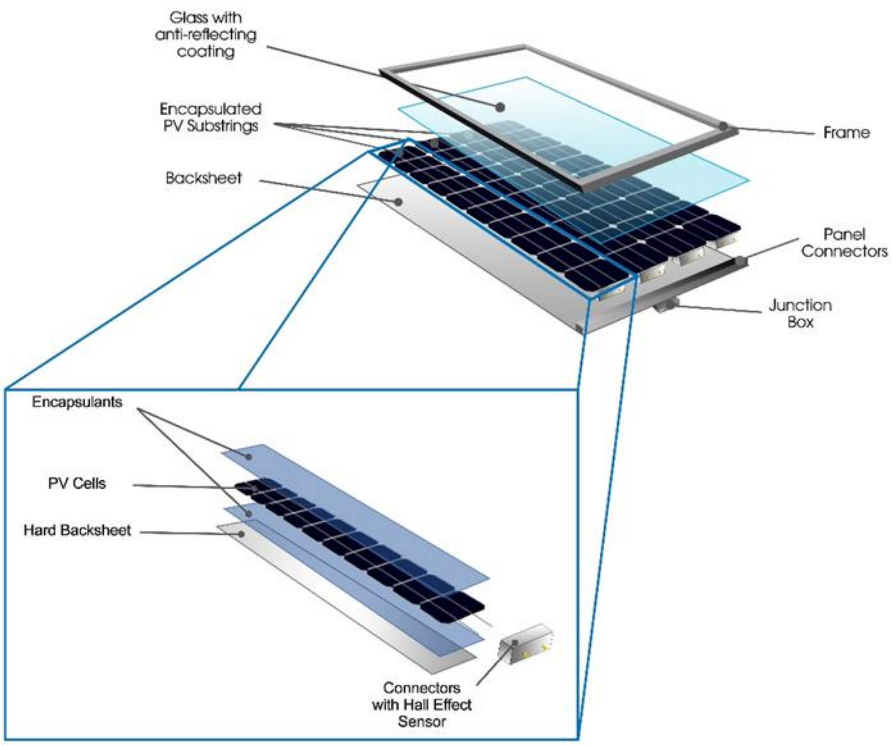

Figure 1: The design of the PV module

The connectors at the end of each substring contains the Hall Effect Sensor (HES) which is connected in series with the substring's output. Then the connectors are slid into the panel connectors providing the electrical connection for the substring and the HES. The panel connectors are connected to the junction box where bypass diodes can be mounted to each substring and the PV module. In addition, a microcontroller is placed in the junction box with WiFi transmitter and connected to the Hall Effect Sensors. The microcontroller receives analog data from the sensors and converts them into digital data, then it transmits the data to the workstation where the processing phase starts, as shown in Figure 2.

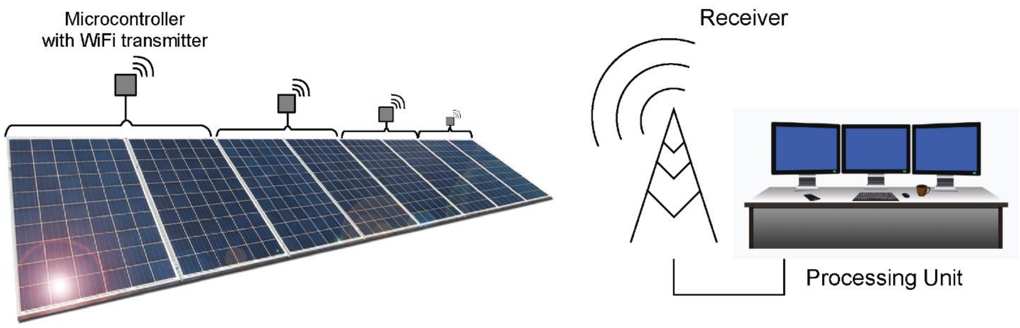

Figure 2: Smart PV system

2.2. Detectable faults and simulation

A fault can be easily detected but the aim of detecting a fault is eliminating it. To locate a fault, several algorithms are used in a Grid-Connected Photovoltaic (GCPV) system. Faults might occur on the AC side or on the DC side of the system. In this work, faults occurring in the DC side are studied and a special algorithm is placed to locate the fault. A PV module is constructed for this study, it has 3 substrings with Hall Effect Sensors connected in series with each substring. Figure 3 shows the electrical diagram of the studied PV module. The bypass diode is connected in parallel with each substring to prevent a complete power loss when partial shading occurs.

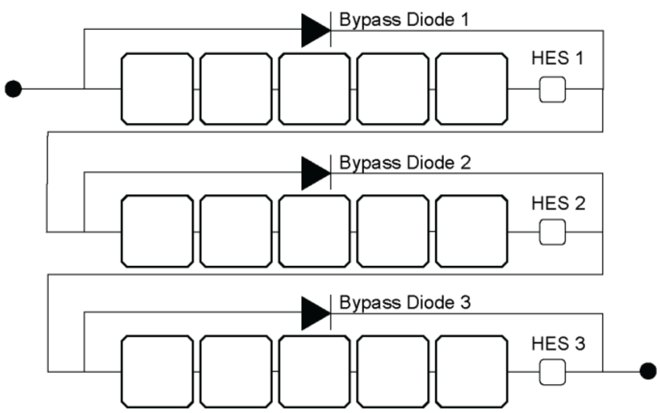

Figure 3: PV Module's diagram

2.2.1. Encapsulant discoloration test

The discoloration of the PV module affects the efficiency of the PV module [12]. The discoloration is caused by the degradation of a PV cell over the time, while some PV cells degrade faster than others due to external factors, such as climate conditions, delamination, poor module packaging and installation …etc. Commonly, the main factors of discoloration are UV light, high temperature, and high humidity [13]. In an experimental situation that was implemented to observe the effects of the discoloration on the electrical characteristics of the PV cell [13], the results show that the effect on the PV cell is severe and the efficiency of the maximum power of a PV cell had dropped significantly. The new design of the PV module will be tested to detect such faults. To simulate the PV discoloration, one PV cell will be shaded by a transparent yet tinted paper, it simulates the characteristics of the faulty PV cell. Figure 4 shows the PV module with the shaded PV cell.

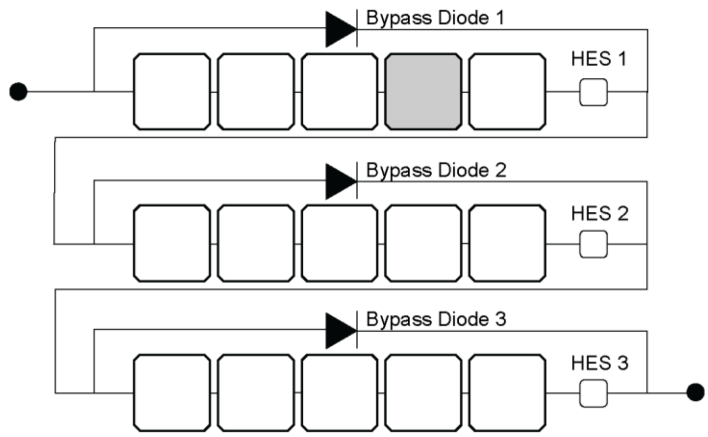

Figure 4: PV module discoloration test

2.2.2. Partial shading test

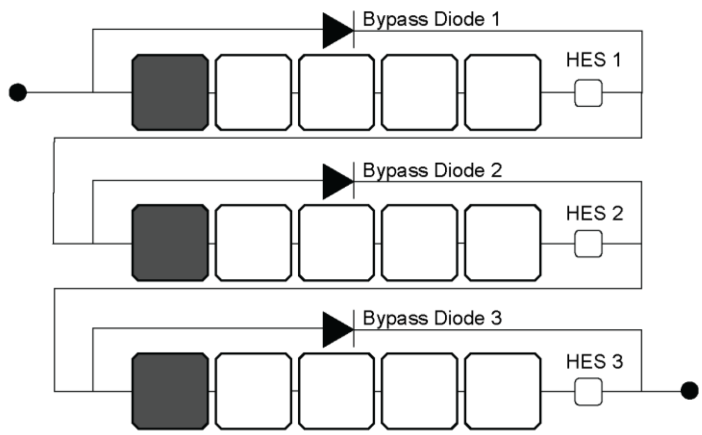

Figure 5: Partially shaded PV module

Partial or total shading affects directly the efficiency and the output power of a PV module. Partial shading may cause hotspots in the shaded part of a PV module and that may shorten the lifespan of the shaded PV cells. In addition to the power loss when partial shading occurs [14]. When partial shading occurs in a PV module, the current drops significantly before a voltage drop occurs. Detecting and locating the current drop in the shaded substrings or PV cells can be helpful in eliminating the shading factor (if possible) and that prevents the power loss. To test the new PV module, all substrings will be shaded partially. Only one PV cell will be shaded from each substring at the same time. Figure 5 shows the diagram of the partially shaded PV module.

2.2.3. Interconnection failure test

PV modules operate under severe weather conditions sometimes. In most cases, they operate under high temperatures. In some cases, they operate in a humid climate during all seasons. All these factors increase the degradation of a PV module and decrease the lifespan of a PV cell. In harsh conditions, the first to be affected are the solder-joints which might wear and separate the interconnection alloy and that causes the separation of the interconnections of the PV cell and it causes increments in the resistance of the series connections between the PV cells in a module. Increasing the resistance leads to excessive heating in a PV module and losses in the output power. In addition to generating hotspots in the PV cells and arcing of the interconnection’s solder-joints which causes to burn the back sheet of the module [9,15]. To simulate such faults, the main impact of an interconnection failure is an increment in the substring’s resistance. Adding a resistor in series with the substring or disconnecting one ribbon might simulate this failure. For this test, one ribbon is disconnected from the PV cell to measure the impact of the interconnection failure on the output power. Figure 6 shows the PV module’s diagram with the simulated interconnection failure test with R_c representing the lack of conductivity in the disconnected ribbon.

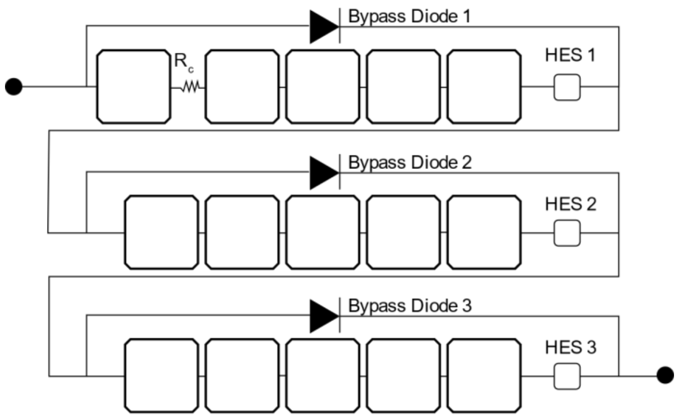

Figure 6: Interconnection failure simulation diagram

2.2.4. Dirt or object shading test

In this test, a small object will be placed above the PV module. This object will cover a small portion of a PV cell where it is hard to be detected by typical fault detection means. This test aims to observe the sensitivity of the new design in detecting malfunctions in the PV module. The shaded part of the PV module is illustrated in Figure7.

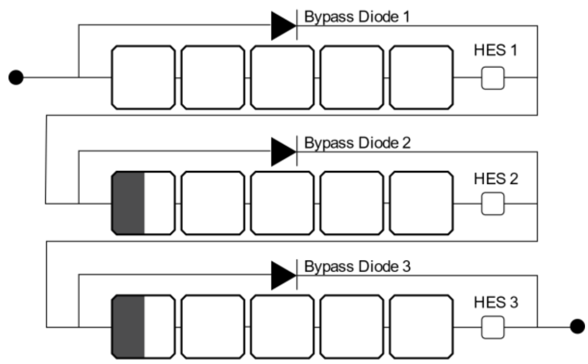

Figure 7: Dirt or object shading test

2.3. Algorithm

The algorithm is developed to detect faults in the substrings of the PV module and faults in the PV modules in a power plant. To achieve accurate results, sub-algorithms work simultaneously within the main algorithm to detect faults on substring-bases and PV-module bases. The faults that may occur in a PV plant are divided into two sections, substring faults and PV module faults. Each section has its own algorithm that detects the intended faults. Afterwards, they work simultaneously to detect the fault in the PV power plant. For the purpose of this study, we will be concentrating on detecting faults on substring levels to test the accuracy of the proposed design. At the beginning, all data are being collected from Hall Effect sensors and converted into readable values, such as Amperes, to be used later by the sub-algorithm. The threshold (ϴ) in this system is the value that the system depends on to decide whether a substring is faulty or not. It is defined by the user or a special algorithm or an AI that depends on Neural Network Learning algorithms or it could be a percentage between the substring’s values. It is not a fixed number due to the wide variety of PV cell types, qualities and efficiencies. Afterwards, the Faulty Substring Detection algorithm takes place in recognizing a fault in one or more substrings. This algorithm processes the data collected from the Hall Effect sensors directly to detect a fault occurring in a substring. It depends on comparing two values of substrings, δ_{Max} and δ_s, and compare the result with a threshold that was defined previously. Where δ_{Max} is the greatest measurement in Amperes of a substring at a certain time in a PV module, and δ_s is the current value in Ampere of the other processed substring in the same PV module. Comparing the difference between the two substrings and the threshold gives the advantage of detecting the fault faster and more reliable, as the threshold value could be adjusted for each PV module, and assuming that the irradiance levels are equal upon one single PV module. In the workflow of the algorithm, the average current of each PV module is calculated to form a new set of data that will be used later by another algorithm and by the Maximum Power Point Tracking unit MPPT. The goal of forming such data set is to define the partially or completely shaded PV modules which are covered by dirt accumulation and soiling. This part of the algorithm will not be covered in this paper as the main focus is the detectable faults by the new design. Figure 8 shows the used algorithm along with the sub-algorithms.

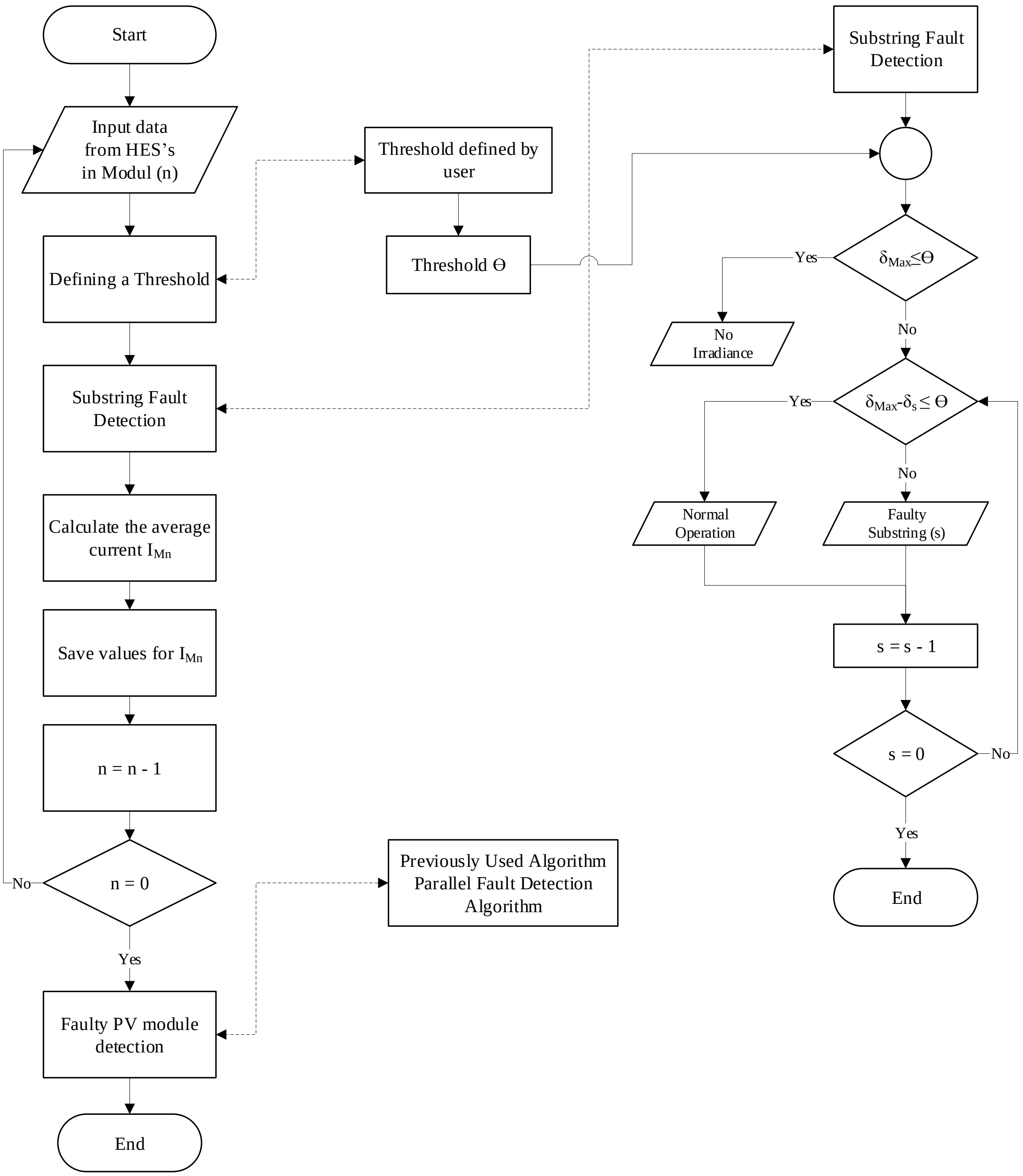

Figure 8: Fault detection algorithm for the proposed design of PV module

Where:

n: PV module's number

I_{Mn}: the average of the (n) PV module's current.

Ɵ: substring's fault threshold.

δ_{Max}: Greatest substring's current value in PV module (n).

s: Substring's number.

δ_s: Substring's current

3. Results

After carrying out the intended tests, the results are obtained from each Hall Effect Sensor measuring the short-circuit current of each substring, as the previously proposed algorithm processes the substrings' current values.

3.1. Encapsulant discoloration test

Figure 9 shows the impact of the encapsulant discoloration on the PV module and the response of the sensors to that fault.

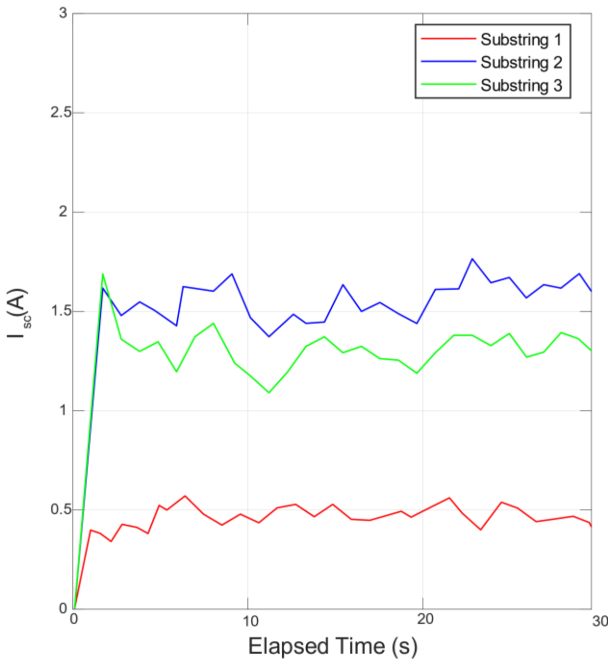

Figure 9: Encapsulant discoloration test results

The difference between the defected substring and the normal substring is quite significant and it could be detected by the algorithm, where differences between the δ_{Max} and δ_1 are greater than 60%, hence these types of faults can be detected and eliminated due to the demounting property of the substring in the proposed design.

3.2. partial shading test

Figure 10 shows the impact of partial shading on the PV module and the response of the sensors to this fault.

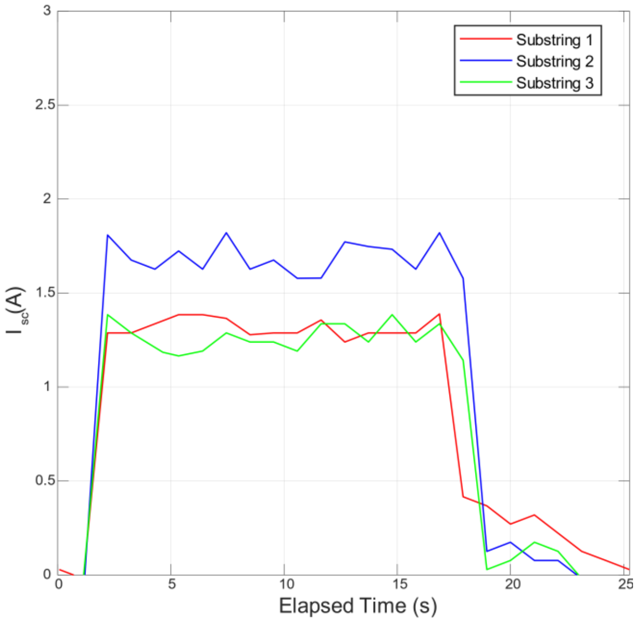

Figure 10: Partial shading test results

When partial shading occurs in the system, the substring fault detection algorithm cannot detect significant differences between the substring's values. However, other fault detection algorithms could be used and the readings from the sensors can locate the partially shaded PV module. As the current average of the PV module I_{M1} has dropped significantly in this case.

3.3. interconnection failure test

Figure 11 shows the impact of an interconnection failure in the PV module and the response of the sensors to this fault.

When disconnecting one ribbon from the PV cell, the overall resistance increases in the substring, the sensor of the substring detects the differences. This test simulated a real-life disconnection due to hotspots with weak connection solder joints, mechanical stress on the PV module or corrosion.

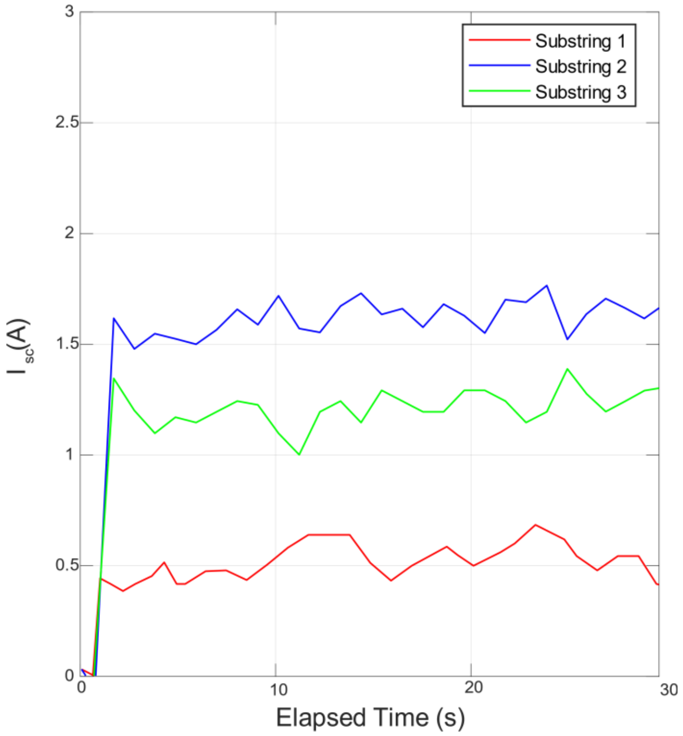

Figure 11: Interconnection failure test results

3.4. Dirt or object shading test

In this test, the substring fault detection algorithm could detect the fault because the current drop is significant. Figure 12 shows the significant drop of the current in substring 2 and substring 3 when a small portion of a PV cell is shaded. This type of shading leads to more significant effect of hotspot on the PV cell [16].

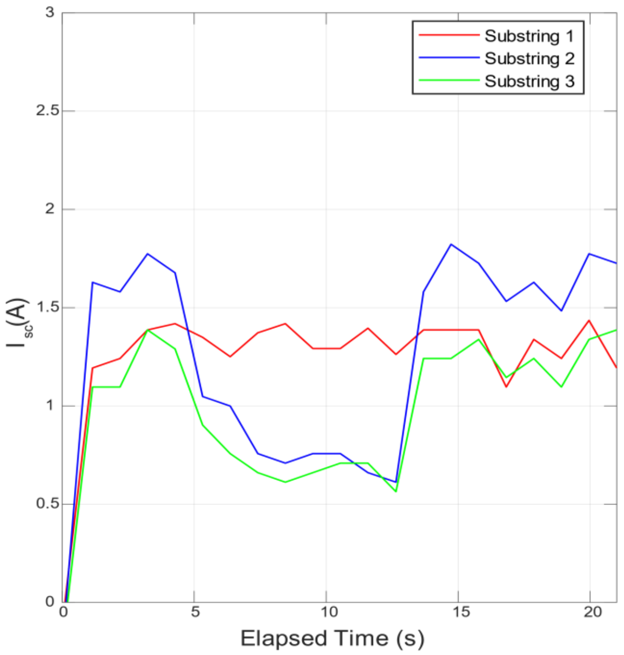

Figure 12: Dirt or object shading test results

4. Conclusion

Detecting faults in PV plants is a delicate process especially when it comes to locating the fault. Most of the times faults start small and get exaggerated quickly or over time. Detecting and locating such small faults helps fixing the faulty component and saves both time and money. When permanent faults occur, with the proposed design of the PV module, substrings could be replaced instead of replacing the PV module(s) and that saves both, cost and time. Most of the previous typical methods cannot detect small faults that occur in a PV module. such small faults become more significant over time, such as hotspots, they can significantly reduce the lifespan of a PV cell which leads to almost completely faulty substring in a PV module [17]. Especially when a small object or dirt blocks a portion of a PV cell, it may affect the output of the substring that is connected to, as shown in Figure 12. A major advantage of this design is detecting and locating the faulty substring when permanent faults occur, then manufacturers can replace a single substring without the need to replace the whole module. Using Hall Effect sensor to detect the fault in a PV module allows us to detect any current-related faults, to prevent greater damage and increase the lifespan of a PV module. The efficiency of this method and the cheap price of these sensors gives it another advantage to replacing old PV modules with more practical modules with accurate fault detection means.

References

[1]. G. M. Masters, Renewable and Efficient Electric Power Systems. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2004.

[2]. H. E. Murdock, Renewables 2019 Global Status Report Collaborative, no. July. 2019.

[3]. A. Karabiber, C. Keles, A. Kaygusuz, and B. B. Alagoz, "An approach for the integration of renewable distributed generation in hybrid DC/AC microgrids," Renew. Energy, vol. 52, pp. 251–259, 2013, doi: 10.1016/j.renene.2012.10.041.

[4]. J. Qi, Y. Zhang, and Y. Chen, "Modeling and maximum power point tracking (MPPT) method for PV array under partial shade conditions," Renew. Energy, vol. 66, pp. 337–345, 2014, doi: 10.1016/j.renene.2013.12.018.

[5]. R. Eke and C. Demircan, "Shading effect on the energy rating of two identical PV systems on a building façade," Sol. Energy, vol. 122, pp. 48–57, 2015, doi: 10.1016/j.solener.2015.08.022.

[6]. F. Mejia, J. Kleissl, and J. L. Bosch, "The effect of dust on solar photovoltaic systems," Energy Procedia, vol. 47, pp. 2370–2376, 2014, doi: 10.1016/j.egypro.2014.03.251.

[7]. A. Dhoke, R. Sharma, and T. K. Saha, "An approach for fault detection and location in solar PV systems," Sol. Energy, vol. 194, pp. 197–208, 2019, doi: 10.1016/j.solener.2019.10.052.

[8]. J. Solórzano and M. A. Egido, "Automatic fault diagnosis in PV systems with distributed MPPT," Energy Convers. Manag., vol. 76, pp. 925–934, 2013, doi: 10.1016/j.enconman.2013.08.055.

[9]. A. Triki-Lahiani, A. Bennani-Ben Abdelghani, and I. Slama-Belkhodja, "Fault detection and monitoring systems for photovoltaic installations: A review," Renew. Sustain. Energy Rev., vol. 82, no. October 2017, pp. 2680–2692, 2018, doi: 10.1016/j.rser.2017.09.101.

[10]. K. A. Kim, G.-S. Seo, B.-H. Cho, and P. T. Krein, "Photovoltaic Hot-Spot Detection for Solar Panel Substrings Using AC Parameter Characterization," IEEE Trans. Power Electron., vol. 31, no. 2, pp.

1121–1130, 2016, doi: 10.1109/TPEL.2015.2417548.

[11]. A. E. Brooks, D. Cormodel, A. D. Cronin, and E. Kam-Lum, "{PV} system power loss and module damage due to partial shade and bypass diode failure depend on cell behavior in reverse bias," in 2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC), 2015, pp. 1–6, doi: 10.1109/PVSC.2015.7356290.

[12]. N. C. Park, J. S. Jeong, B. J. Kang, and D. H. Kim, "The effect of encapsulant discoloration and delamination on the electrical characteristics of photovoltaic module," Microelectron. Reliab., vol. 53, no. 9-–11, pp. 1818–1822, 2013, doi: 10.1016/j.microrel.2013.07.062.

[13]. A. Bouaichi et al., "Experimental evaluation of the discoloration effect on PV-modules performance drop," Energy Procedia, vol. 119, pp. 818–827, 2017, doi: 10.1016/j.egypro.2017.07.107.

[14]. I. Hadj Mahammed et al., "Outdoor study of partial shading effects on different PV modules technologies," Energy Procedia, vol. 141, pp. 81–85, 2017, doi: 10.1016/j.egypro.2017.11.016.

[15]. V. Sharma and S. S. Chandel, "Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review," Renewable and Sustainable Energy Reviews, vol. 27. Pergamon, pp. 753–767, Nov. 01, 2013, doi: 10.1016/j.rser.2013.07.046.

[16]. S. Ahsan, K. A. K. Niazi, H. A. Khan, and Y. Yang, "Hotspots and performance evaluation of crystalline-silicon and thin-film photovoltaic modules," Microelectron. Reliab., vol. 88–90, no. June, pp. 1014–1018, 2018, doi: 10.1016/j.microrel.2018.06.097.

[17]. D. A. Quansah and M. S. Adaramola, "Ageing and degradation in solar photovoltaic modules installed in northern Ghana," Sol. Energy, vol. 173, pp. 834–847, 2018, doi: 10.1016/j.solener.2018.08.021.