EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 5 No. 1 (2024) 348-357
https://publisher.uthm.edu.my/periodicals/index.php/eeee

Reduction of Hot-Spot on Solar PV Array Due to Partial Shading Condition

Nur Iman[1], Jabbar Al-Fattah[1]*, Zarafi Ahmad[1]

[1] *Department of Electrtical Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia*

*Corresponding Author: jabbar@uthm.edu.my
DOI: https://doi.org/10.30880/eeee.2024.05.01.044

Article Info

Received: 16 January 2024
Accepted: 14 March 2024
Available online: 30 April 2024

Keywords

Hotspot, Partial-shading,Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Boost converter, MATLAB Simulink

Abstract

Photovoltaic (PV) solar technology encounters issues with partial shading, resulting in hotspots. Conventional solutions, such as cooling systems, prove inadequate. Maximum Power Point Tracking (MPPT) systems offer a superior solution by dynamically adjusting solar panels to alleviate shade-induced inefficiencies. This advanced technology enhances overall efficiency and prolongs the life of solar panels, presenting a promising solution for sustainable energy. While understanding MPPT's complexities is imperative for integration, its adaptability positions it as a creative and effective tool in the quest for robust renewable energy solutions, addressing challenges associated with partial shading in PV solar systems.

1. Introduction

Photovoltaic (PV) solar technology harnesses sunlight to generate electricity, offering a sustainable alternative to traditional energy sources. This renewable energy solution aids in combating climate change and reducing carbon footprints across residential, commercial, and industrial sectors. Despite its advantages, PV solar systems face challenges, notably the hotspot problem (1). Hotspots occur due to shade, module mismatch, cell degradation, or electrical connection issues, leading to increased resistance and heat production. The extreme heat can decrease cell efficiency, cause breakdowns, and result in structural damage over time. Long-term partial shading leads to hotspots, causing overheating, reduced efficiency, and shortened lifespan of PV cells. Conventional solutions like bypass diodes and cooling systems face limitations in large-scale PV systems (3). The objective is to address hotspots in PV systems, ensuring optimal performance, longevity, and maximum energy output. Research and development efforts focus on techniques that not only reduce system temperature but also minimize power loss, striking a balance between temperature reduction and power optimization.

MPPT, or Maximum Power Point Tracking, is a method employed in power electronic circuits to optimize the extraction of energy from Photovoltaic (PV) Systems (5). Ensuring that PV systems consistently operate at their maximum power point is crucial for enhancing the overall energy efficiency of the system. A study in the Indonesian Journal of Electrical Engineering and Computer Science identifies commonly employed MPPT techniques, namely Perturb and Observe (P&O), Incremental Conductance (INC), and Hill Climbing.

This project aims three main objectives which are : 1) To determine the I-V characteristic of a Solar PV on multiple shading (different irradiance to declare partial shading), 2) To investigate the severity of hotspot based on prolonged exposure to partial shading, 3) To design and apply the MPPT controller that can help PV system in reducing the hotspot problem effect..

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2. Material and Method

This project will design 2 different PV system, the first one will be normal system that do not have MPPT controller and the other system will use the MPPT controller. For the first phase of this project, both of the systems will be design in MATLAB software. This phase aims to check the validity of hotspot on Solar PV panel when the partial shading occurs. Each of the system will have same parameter and specification on PV panel to make sure there will be accurate comparison.

For the second phase of the project, the boost converter and the MPPT controller hardware will be design. This hardware will be implements to the real PV panel for the real time experiment.

The block diagram depicted in Fig. 1 illustrates the comprehensive process of the Maximum Power Point (MPP) controller for the Photovoltaic (PV) system. The sequence begins with the solar panel receiving input from irradiance and temperature. From this input, the power input is determined by measuring voltage and current. Given that this system is designed to assess the variations in voltage and current input handling between Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms, these algorithms utilize Arduino Mega 2560 coding to calculate the duty cycle whenever there is a change in voltage and current. Subsequently, the voltage and current input values pass through the boost converter to elevate the voltage output. Finally, the recorded power, voltage, and current output values undergo analysis to facilitate a comparison between the P&O and INC algorithms.

For the case study scenario, this project will use 3 value of irradiance to create the partial shading with 3 condition: Case 1 (1000W/m2), Case 2 230% irradiance (700W/m2) and Case 3 50% irradiance (500W/m2).

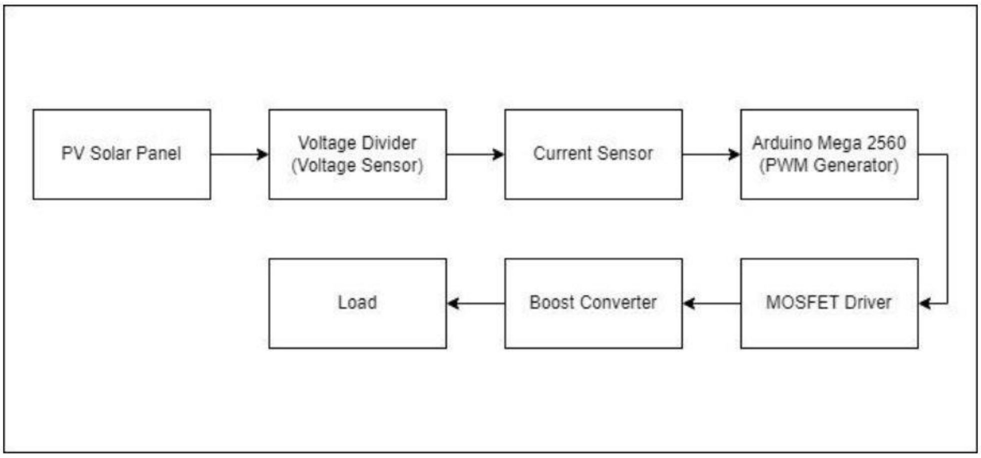


Fig. 1 *PV system with MPPT controller block diagram*

2.1 PV panel specification

Table 1 show the specification of PV panels to the both systems.

Table 1 *Parameter for each PV panel*

Description	Parameter value
Number of cells	36
Maximum power	20W
Maximum Voltage	17V
Maximum current	1.18A
Voltage open-circuit	22V
Current short-circuit	1.32A

Each system will use 6 panels. Based on the calculation, each panel will produce 120W, 102V and 1.18A.

2.2 Maximum Power Point Tracking algorithm

The incremental conductance MPPT algorithm will be use for this project. Illustrated in Fig. 2a, the Incremental Conductance (INC) method involves computing the ratio of the Photovoltaic (PV) array's change in current (dI) to the change in voltage (dV). This method also assesses the current-voltage (I-V) changes at the current operating point to ascertain the incremental conductance. The slope of the tangent to the power-voltage (P-V) curve is indicative of the Incremental Conductance (INC). In Fig. 2b, the MATLAB Simulink presents the algorithm coding for this method.

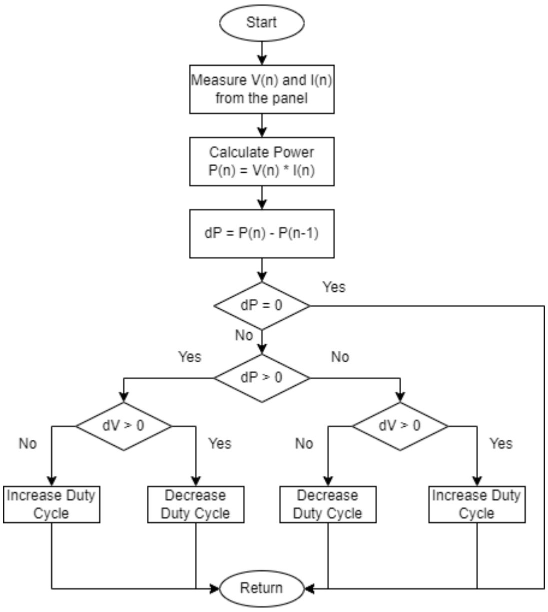
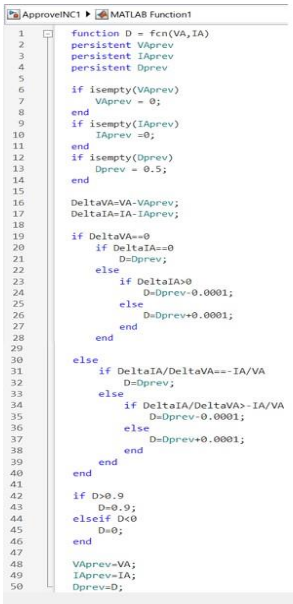


Fig. 2a *Incremental conductance algorithm*




```
function D = fcn(VA,IA)
persistent VAprev
persistent IAprev
persistent Dprev

if isempty(VAprev)
    VAprev = 0;
end
if isempty(IAprev)
    IAprev =0;
end
if isempty(Dprev)
    Dprev = 0.5;
end

DeltaVA=VA-VAprev;
DeltaIA=IA-IAprev;

if DeltaVA==0
    if DeltaIA==0
        D=Dprev;
    else
        if DeltaIA>0
            D=Dprev-0.0001;
        else
            D=Dprev+0.0001;
        end
    end

else
    if DeltaIA/DeltaVA==-IA/VA
        D=Dprev;
    else
        if DeltaIA/DeltaVA>-IA/VA
            D=Dprev-0.0001;
        else
            D=Dprev+0.0001;
        end
    end
end

if D>0.9
    D=0.9;
elseif D<0
    D=0;
end

VAprev=VA;
IAprev=IA;
Dprev=D;
```

Fig. 2b *Coding in MATLAB Simulink*

2.3 Boost converter design

This project employs a distinctive boost converter, featuring some variations from conventional designs. Described in equations (1) and (2), Cin and Cout are specialized capacitors integrated into this unique system. Cin plays a crucial role in maintaining the constancy of voltage and current, ensuring they do not experience excessive fluctuations. It serves as a supportive companion to the solar power system, contributing to its seamless and stable operation. Effectively, Cin plays a key role in maintaining the smooth functioning of the solar power system by preventing undue variations in electricity.

Cout, the second capacitor, serves as an electrical storage reservoir in the system. Its role is to maintain a stable power output, preventing fluctuations by storing surplus energy generated during the process and releasing it as needed. The collaborative action of these two capacitors—Cin and Cout—optimizes the performance of the boost converter for solar panels. This synergy guarantees users a dependable and uniform supply of solar power, effectively meeting their energy requirements with reliability and consistency.

Capacitor input (Cin):

$$Cin = \frac{4\,x\,Vmp\,(normal\ condition)\,x\,Dmp\,(normal\ condition)}{\Delta Vin\,x\,Rin\,x\,Frequency} \tag{1}$$

Capacitor output (Cout):

$$Cout = \frac{2\,x\,Vout\,(worst\ condition)\,x\,Dmp\,(normal\ condition)}{\Delta Vin\,x\,Rin\,x\,Frequency} \tag{2}$$

Inductor (L):

$$L = \frac{Vmp\,(worst\ condition)\,x\,Dmp\,(worst\ condition)}{2\,x\,\Delta Iout\,x\,Frequency} \tag{3}$$

The boost converter parameter are shown in the Table 2, it consist 5 components: capacitor input, capacitor output, inductor, fuse and MOSFET.

Table 2 *Boost converter parameter*

Component	Value
Capacitor Input	78μF
Capacitor Output	36.5μF
Fuses	3A
Inductor	0.287mH
MOSFET	-

2.4 Hardware Setup

This section will show the process of hardware setup starting from testing the component, design and layout until installation.

2.4.1 PV panel layout

For the hardware experiment, the system consists 3 panel for each system. This design aims to make sure the experiment for both systems will be run simultaneously to obtained the accurate result and comparison.

The initial section of the solar panel setup consists of the first three panels connected in series, directly linked to the load. In contrast, the second section comprises three panels also connected in series (in the red frame), but with an additional connection to both the MPPT controller and the boost converter. To optimize the reception of irradiance, the entire arrangement is mounted on an adjustable iron frame, allowing for variable angle positions. The system is vertically divided, with the upper three PV solar panels integrated with the MPPT system, while the lower three PV solar panels operate without the MPPT system. This panel configuration is visually represented in Fig. 3.

Fig. 3 *PV panel design and configuration*

2.4.2 Boost converter layout

The ARDUINO microcontroller assumes a dual role in the boost converter and MPPT controller setup. Serving as an MPPT, the ARDUINO MEGA board controller is equipped with programmed Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms for MPPT coding. Its primary function is to compute the voltage and current, determining the power generated by the photovoltaic panel. Subsequently, it calculates the duty cycle value required by the boost converter. The lab-tested configuration of the MPPT controller and boost converter setup is illustrated in Fig. 4. This setup incorporates components such as the voltage divider, ACS712 current sensor module, and L298N dc motor driver, which facilitates the control of pulse width modulation supplied to the MOSFET.

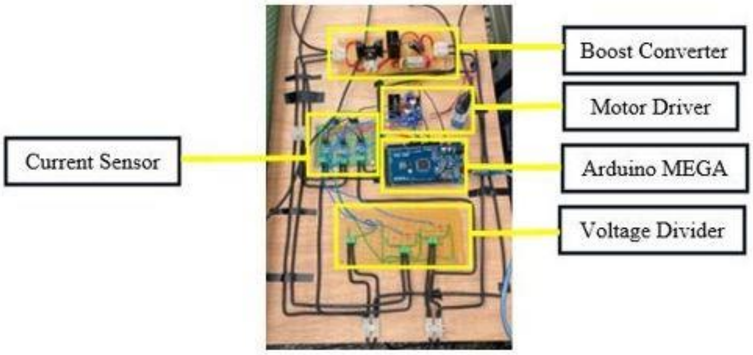


Fig. 4 *Boost converter and MPPT controller layout*

2.4.3 Boost converter and MPPT testing

Calibrating the MPPT controller and boost converter is a crucial step before their installation on the PV panel. This calibration is necessary because accurate voltage and current readings are pivotal for calculating the duty cycle value. Ensuring precise readings is essential for the reliable performance of the system.

During the testing phase, the primary objective is to assess the durability of the boost converter. The focus is on verifying whether the boost converter can withstand the voltage and current generated by the PV solar panel. Fig. 5 illustrates the use of an oscilloscope to visualize the PWM signal during testing. Additionally, a DC power supply is employed to provide voltage and current in accordance with the specifications of the PV solar panel. This meticulous testing process is designed to guarantee the robustness and resilience of the boost converter under real operational conditions.

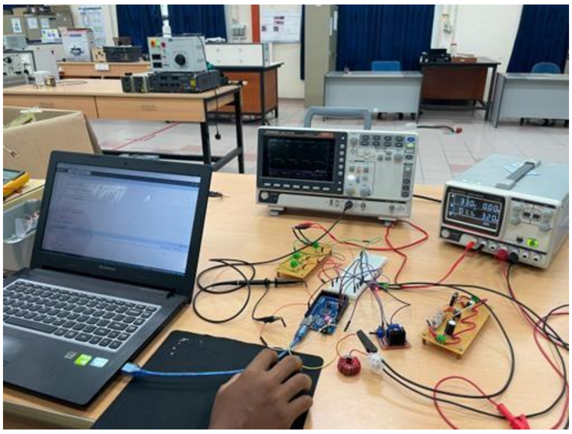


Fig. 5 *Boost converter and MPPT controller testing*

3. Result and discussion

This section will show the result between 2 PV system which with MPPT controller and without MPPT controller. The result also shows the effect of hotspot which are overheating on the panels because of hotspot and power degraded. Fig. 6a and 6b show the circuit that has been designed in MATLAB software.

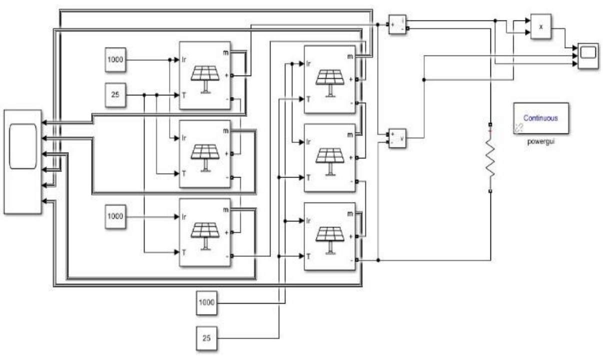


Fig. 6a *PV system without MPPT controller*

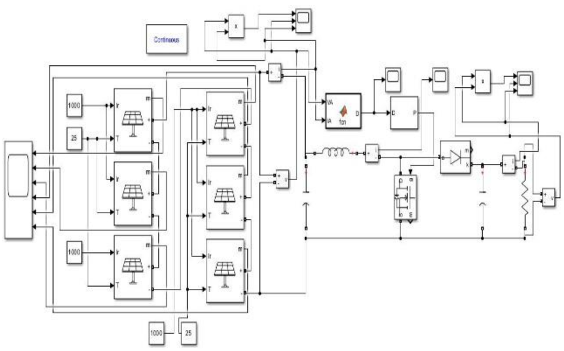


Fig. 6b *PV system with MPPT controller*

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3.1 Case Study 1 : 1000W/m2

In case study 1, every panel will get maximum irradiance value which is 1000W/m2. This case study indicates that there are no partial shading occurs on the PV system. Fig. 7a shows the result for PV system without MPPT and Fig. 7b shows the result PV system with MPPT.

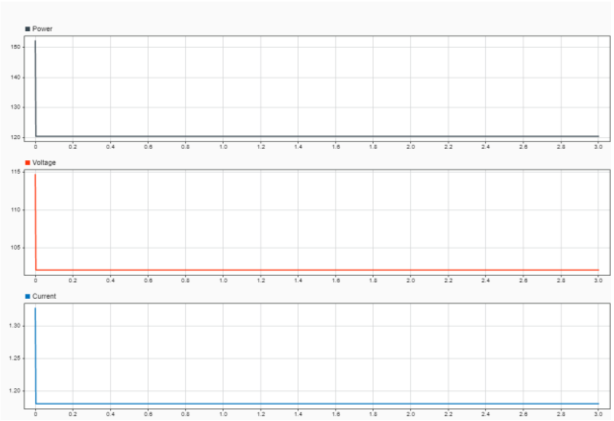

Fig. 7a *PV system without MPPT*

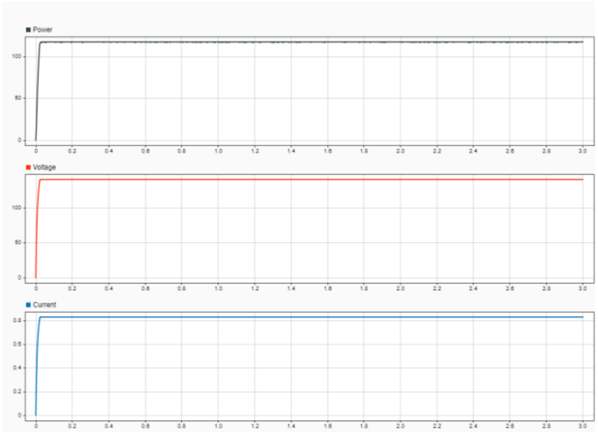

Fig. 7b *PV system with MPPT*

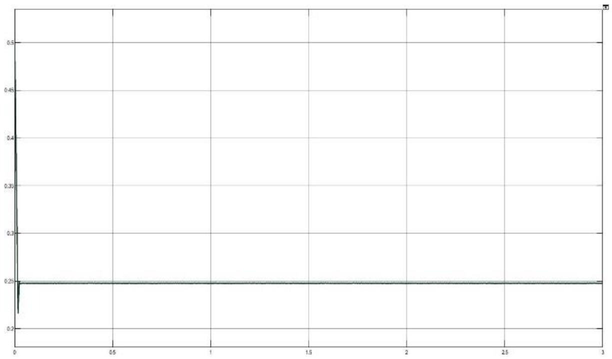

Fig. 7c Duty cycle for normal condition

Based on the Fig. 7a and 7b of the system will obtain the maximum value that same with the calculation. This result also indicates that the connection in the simulation is correct. The duty cycle that produce by MPPT controllers reaches the maximum value based on the calculation of boost converter design. The duty cycle value in the graph in Fig. 7c is the initial value for this PV system.

3.2 Case Study 2: 700W/m2

For the Case Study 2, panel number 3 will get 700W/m2 to declare as partial shading scenario. As the partial shading theory, one of the panels will have lower irradiance value compared to other panels. Fig. 8a and 8b shows the result between 2 PV systems.

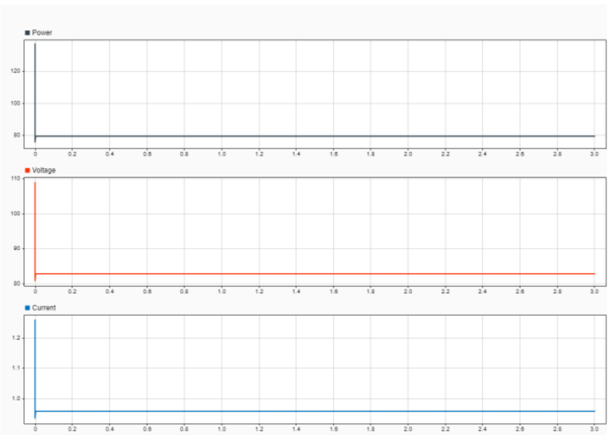

Fig. 8a *PV system without MPPT controller*

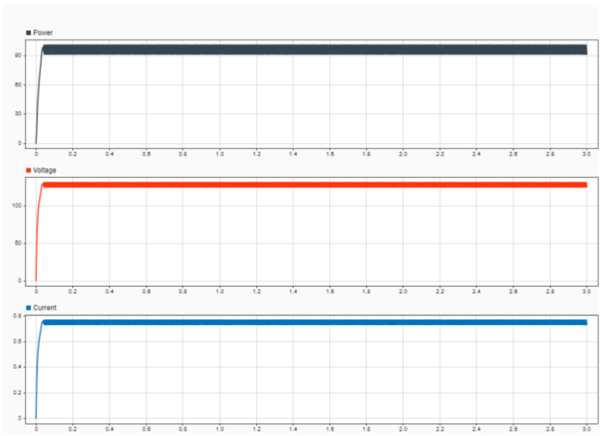

Fig. 8b *PV system with MPPT*

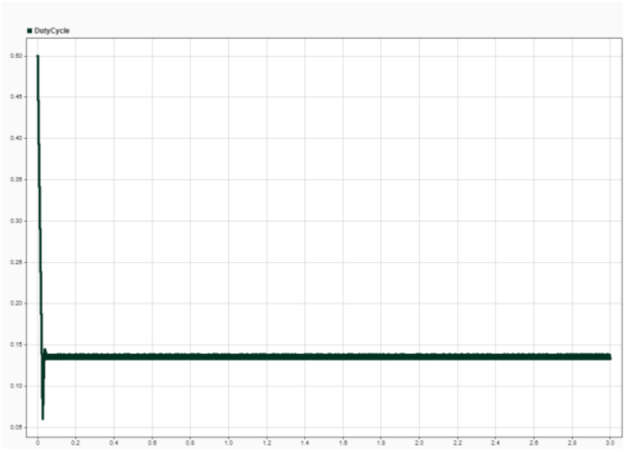

Fig. 8c *Duty cycle for 700 W/m2*

Analyzing the results derived from the simulation mentioned above, it was noted that the PV system still encounters a decline in power output. Nevertheless, the decrease in power is not as substantial when compared to the PV system lacking an MPPT controller. The graph in Fig. 8c shows the result of duty cycle that is produced by the MPPT controller when the partial shading occurs on solar PV panels. The duty cycle value will be decreasing to make sure the boost converter will operate based on irradiance value.

3.5 Case Study 3: 500W/m2

In Case Study 3, creating intensified the hotspot scenario by reducing the irradiance value on panel 2 from 1000W/m2 to 500W/m2 as shown in the Fig. 9a and 9b. Based on the calculations, the PV system is expected to undergo a more substantial decrease compared to the previous configuration.

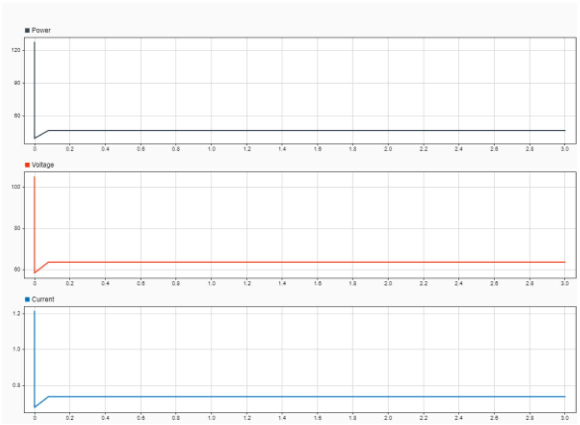

Fig. 9a *PV system without MPPT controller*

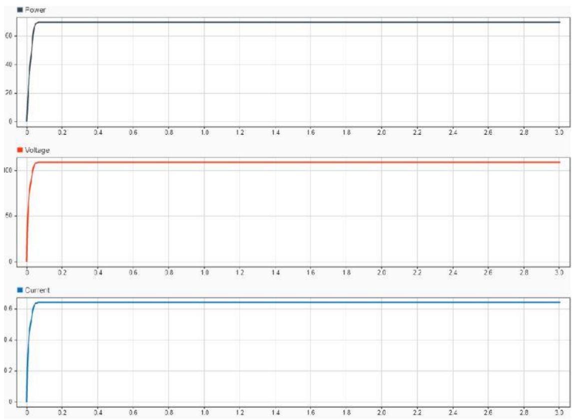

Fig. 9b *PV system with MPPT*

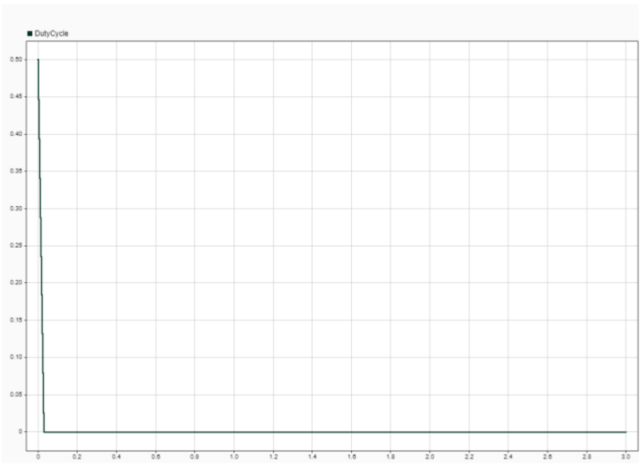

Fig. 9c *Duty cycle for 500 W/m2*

Based on the graph Fig. 9a and 9b, the power, current and voltage that produce by the PV system will keep decreasing. But for PV system with MPPT will try to minimize the hotspot effect. This can be proved that MPPT controller can mitigate the hotspot problem on solar PV panels by minimizing the hotspot effect that will cause the decreasing of the power, current and voltage generate. point even though there are hotspot occurs.

For the duty cycle value in Fig. 9c, Case 3 which is 500W/m2 irradiance will cause the decreasing of duty cycle value. Based on the graph above, the duty cycle is approaching zero value because of the hotspot effect. The MPPT controller decreases the duty cycle to make sure the power that generate by the PV panel can have maximum.

3.6 Hardware result

In the hardware experiment, two systems are run concurrently to observe and analyze the distinctions between the system incorporating the MPPT controller and the one functioning without it. This simultaneous experiment is designed to guarantee that both systems are subjected to an identical irradiance value, facilitating accurate and fair comparisons. The results obtained from this experiment are presented in Table 3.

Table 3 *Data obtained by hardware experiment*

INC	Irradiance	Voltage input	Voltage output
Case 1	861W/m2	45V	57V
Case 2	830W/m2	46V	56V
Case 3	698W/m2	41V	45V

In addition to investigating variations in power production as show in Fig. 10a, b and c, an analysis was conducted on the heat generated by the PV solar panel, with a specific emphasis on addressing the hot-spot issue.

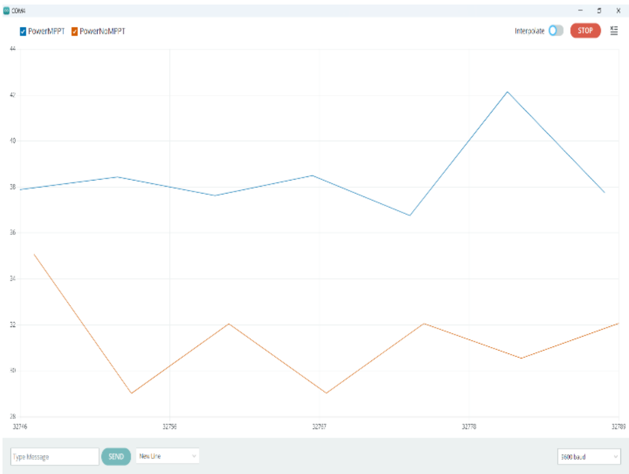

Fig. 10a *Case study 1*

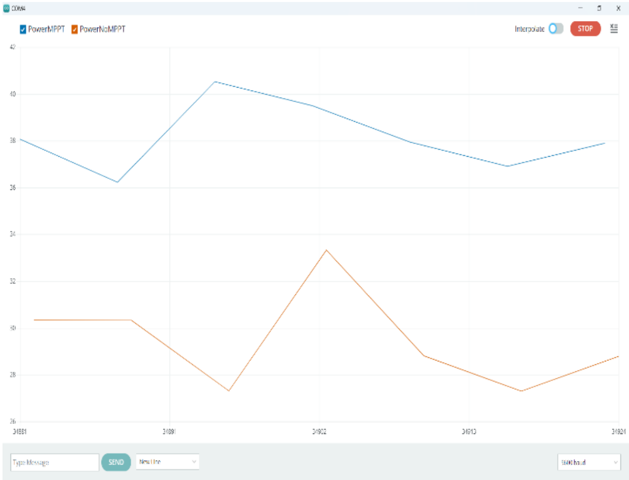

Fig. 10b *Case study 2*

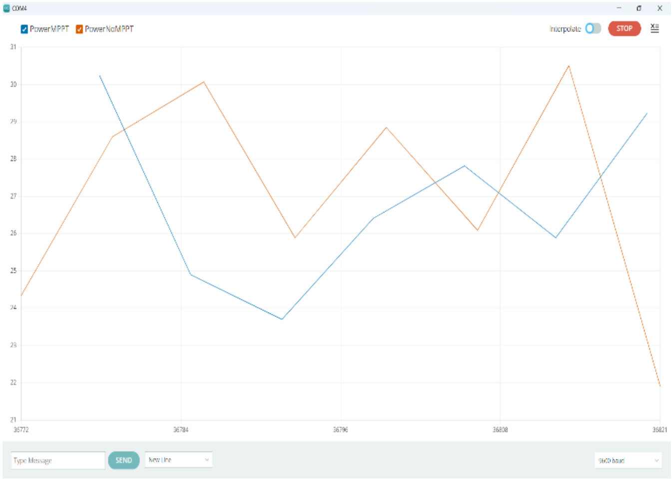

Fig. 10c *Case study 3*

Based on theoretical considerations and simulations, PV solar panels experiencing hot-spots demonstrate elevated temperatures in regions affected by partial shading. Fig.11a and 11b shows the result for temperature analysis on PV panel.

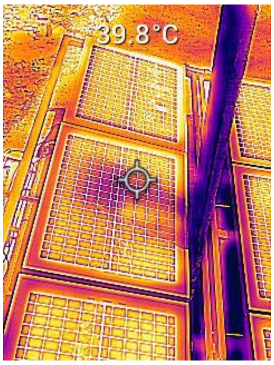

Fig.11a *PV system without MPPT*

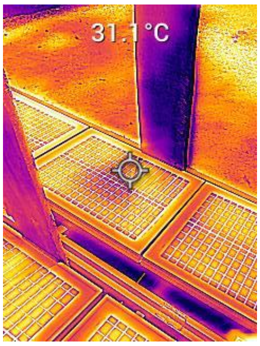

Fig.11b *PV system with MPPT*

4 Conclusion

In summary, a new solution was found to address the reduction in power output caused by partial shading in a PV array. The use of a Maximum Power Point Tracking (MPPT) controller minimized heat generation and prevented negative voltage readings. Simulations confirmed the effectiveness of this approach in preventing both reduced panel lifespan and diminished power quality.

For the first goal, a MATLAB-based PV system was designed, accurately determining key parameters with a remarkable 97% consistency between calculated and simulated values. Comprehensive analyses of P-V and I-V curves demonstrated a thorough understanding of the PV system's performance.

The second objective showcased how the MPPT controller mitigates degradation in power, voltage, and current levels, surpassing traditional methods. The third goal introduced an MPPT algorithm, Incremental Conductance, which continuously adjusts the duty cycle to ensure optimal voltage and power levels. The successful integration of theory and simulation highlights the proficiency in designing a robust PV system.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its great deal of support.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Nur Iman;* ***data collection:*** *Nur Iman;* ***analysis and interpretation of results:*** *Nur Iman;* ***draft manuscript preparation:*** *Nur Iman, Jabbar, Zarafi. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Rehman, S. U., Rehman, S., Shoaib, M., & Siddiqui, I. A. (2018). Feasibility Study of a Grid-Tied Photovoltaic System for Household in Pakistan: Considering an Unreliable Electric Grid. Environmental Progress & Sustainable Energy, 38(3), e13031. https://doi.org/10.1002/ep.13031

[2] Waqar Akram, M., Li, G., Jin, Y., Zhu, C., Javaid, A., Zuhaib Akram, M., & Usman Khan, M. (2020). Study of manufacturing and hotspot formation in cut cell and full cell PV modules. Solar Energy, 203, 247–259. https://doi.org/10.1016/j.solener.2020.04.052

[3] Rossi, D., Omana, M., Giaffreda, D., & Metra, C. (2015). Modeling and Detection of Hotspot in Shaded Photovoltaic Cells. 23(6), 1031–1039. https://doi.org/10.1109/tvlsi.2014.2333064

[4] Priya Ranjan Satpathy, Sharma, R., Suraj Kumar Panigrahi, & Panda, S. (2020). Bypass Diodes Configurations for Mismatch and Hotspot Reduction in PV Modules https://doi.org/10.1109/cispsse49931.2020.9212235

[5] Aman, R., & Rizwan, M. (2022). Power Enhancement and Hotspot Reduction of a Rooftop Solar PV Array Using MOSFETs [Review of Power Enhancement and Hotspot Reduction of a Rooftop Solar PV Array Using MOSFETs]. Electrical, Computer, Communications and Mechatronics Engineering. IEEE. https://doi.org/10.1109/ICECCME55909.2022.9988575

[6] Nasir, U., Rehman, S.-U., & Waqas, Dr. A. (2020). Improving Photovoltaic Module Efficiency Using Back Side Water-Cooling Technique. IEEE. https://doi.org/10.1109/INMIC50486.2020.9318093
[7] Kim, H., & Choi, K. (2020). Advanced Materials for High-Efficiency Photovoltaics. Advanced Materials, 32(43), 2001766
[8] Esram, T., & Chapman, P. L. (2007, July). Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques. IEEE Transactions on Energy Conversion, 22(2), 439-449. doi:10.1109/TEC.2006.874230
[9] Abdullah, M., Yatim, A., Tan, C., & Saidur, R. (2012). A review of maximum power point tracking algorithms for wind energy systems. Renewable and Sustainable Energy Reviews, 16(5), 3220-3227.doi: https://doi.org/10.1016/j.rser.2012.02.016
[10] Masoum, M. A., Dehbonei, H., & Fuchs, E. F. (2003, January). Theoretical and Experimental Analyses of Photovoltaic Systems With Voltage- and CurrentBased Maximum Power-Point Tracking. IEEE Transactions on Energy Conversion, 17(4), 514-522. doi: 10.1109/TEC.2002.805205