PERFORMANCE OF MAXIMUM POWER POINT TRACKING BY USING CONVENTIONAL AND SOFT COMPUTING TECHNIQUES DURING PARTIAL SHADING CONDITIONS

AMMAR SALAH MAHDI

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Universiti Tun Hussein Onn Malaysia

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DEDICATION

In the name of Allah, the most Merciful, the most Compassionate, I dedicate this project to Allah ALMIGHTY, my source of knowledge and understanding.

I also dedicate this work to my beloved parents for their encouragement and continued support. To my dear brothers and beloved wife. Thank you all.

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ABSTRACT

Characteristics curves of solar module represent the characteristic of particular photovoltaic (PV) module. These curves reveal the ability of a specific solar module conversion and efficiency to extract maximum available power. In this study, the MSX-64 PV module and boost DC/DC converter are used for simulation and modeling the maximum power point tracking system. Maximum power extraction from PV system can be achieved by using maximum power point tracking (MPPT) techniques that are classified into conventional and soft computing. This work demonstrates the performance of three types of MPPT techniques for the PV system during partial shading conditions (PSC), where 25% and 50% shaded weather profile applied to the system. The system also subjected to a non-shaded real weather profile to examine the proposed MPPTs performance under changing weather conditions. The techniques used are fuzzy logic (FL) and adaptive neuro-fuzzy inference system (ANFIS) as soft computing technique which are compared with the conventional perturb and observe technique. The performance has evaluated under the same conditions of irradiance and atmospheric temperature by using the same operating conditions. These MPPT techniques are compared in terms of power extracted, MPPT efficiency, rise time, steady-state oscillation, its ability to track global maximum power point and the response to a varied weather. Simulation results of soft computing MPPT techniques have shown the ability to track the maximum power point during partial shading conditions and the response to weather changes when non-shaded real weather profile applied to the system. The performance of the conventional perturb and observe based MPPT has depicted the failure of this controller to track the global maximum power point during partial shading and lack response to real weather changes. The proposed system has implemented by using MATLAB/SIMULINK environment.

ABSTRAK

Ciri-ciri lengkung modul solar mewakili sifat modul photovoltaic (PV) tertentu. Lengkung ini menjelaskan keupayaan penukaran dan kecekapan modul solar khusus untuk mengekstrak kuasa yang maksimum. Dalam kajian ini, modul PV MSX-64 dan penukar DC/DC peningkat digunakan untuk simulasi dan pemodelan sistem pengesanan titik kuasa maksimum. Pengekstrakan kuasa maksimum dari sistem PV boleh dicapai dengan menggunakan teknik pengesanan titik kuasa maksimum (MPPT) yang diklasifikasikan ke dalam pengkomputeran konvensional dan pengkomputeran lembut. Kerja-kerja ini menunjukkan hasil prestasi tiga jenis MPPT untuk sistem PV semasa keadaan teduhan separa (PSC), dengan 25% dan 50% profil cuaca yang teduh diterapkan pada sistem. Sistem ini juga tertakluk kepada profil cuaca sebenar untuk mengkaji prestasi MPPT yang dicadangkan di bawah perubahan keadaan cuaca. Teknik-teknik yang digunakan adalah logik kabur (FL) dan sistem inferensi neuro-fuzzy adaptif (ANFIS) sebagai teknik pengkomputeran lembut yang dibandingkan dengan teknik konvensional ganggu dan perhati. Prestasi telah dinilai di bawah keadaan yang sama dengan sinaran dan suhu atmosfera dengan menggunakan keadaan operasi yang sama. Teknik MPPT ini dibandingkan dari segi kuasa yang diekstrak, kecekapan MPPT, masa meningkat, ayunan stabil keadaan, keupayaannya untuk menjejaki titik kuasa maksimum global dan tindak balas kepada cuaca yang pelbagai. Keputusan simulasi teknik MPPT pengkomputeran lembut menunjukkan keupayaan sistem untuk pengesanan titik kuasa maksimum semasa separa teduhan dan bertindakbalas kepada perubahan cuaca apabila profile cuaca sebenar tanpa teduhan diaplikasi pada sistem. Prestasi MPPT konvensional ganggu dan perhati menunjukkan kegagalan pengawal untuk mengesan titik kuasa maksima global semasa separa teduh dan tindakbalas yang lemah kepada perubahan cuaca sebehar. Sistem yang dicadangkan ini diimplementasikan menggunakan perisian MATLAB / SIMULINK.

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LIST OF SYMBOLS AND ABBREVIATIONS

I_L	-	Temperature dependent photo generated current
K_i	-	Temperature coefficient of short-circuit current
q	-	Charge of electron
n	-	Diode Ideality factor
k	-	Boltzmann constant
E_g	-	bandgap energy of the PV cell (eV)
R_s	-	Series resistance(Ω)
R_p	-	parallel resistance(Ω)
T	-	module temperature in Kelvin
T_n	-	nominal temperature in Kelvin
G	-	Irradiance(W/m²)
G_n	-	Irradiance at STC= 1000 (W/m²)
I_{sn}	-	nominal saturation current(A)
I_{scn}	-	nominal short circuit current(A)
V_{ocn}	-	nominal open circuit voltage (V)
V	-	module output voltage
I	-	module output voltage
ZE	-	Zero
NS	-	Negative Small
NB	-	Negative Big
PS	-	Positive Small
PB	-	Positive Big
NB	-	Negative Big
$MPPT$	-	Maximum Power Pont Tracking
MPP	-	Maximum Power Point

PSC	-	Partial Shading Condition
P&O	-	Perturb and Observe
FLC	-	Fuzzy Logic Controller
ANFIS	-	Adaptive Neuro-Fuzzy Inference System
MF	-	Membership Function
PV	-	Photo Voltaic

LIST OF APPENDICES

LIST OF ACTIVITIES

(i) Submission of a research paper's abstract as partial requirement of publication in Malaysian Technical Universities Conference on Engineering and Technology (MUCET) at Universiti Malaysia Pahang (UMP).

(ii) Present a research methodology poster "Water purification system powered by photovoltaic supply" at university Tun Hussein Onn Malaysia.

(iii) Participation in a short course about Mendeley and Origin pro at university Tun Hussein Onn Malaysia.

(iv) Participation in a short course about systematic literature review at university Tun Hussein Onn Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, a brief background about the project followed by stating for the problem under study and the objectives as well as the project scope are discussed.

In section 1.2, a brief background of the topic has been introduced. Section 1.3 is stating for the problem under study. In section 1.4, the objectives of the project are presented and finally, section 1.5 is identifying for the scope of this project.

1.2 Project background

The increased worries over nature and growing request for energy as well as the world attention to global warming have induced thinking to find clean resources for energy, a renewable energy which varies as wind, geothermal, hydro, solar and bioenergy. Photovoltaic energy is one of such energy resources which its importance has increased due to its inexhaustible nature, cleanness, scalability in power and low maintenance required.

There is a diversity of reasons that impact the amount of power generated by the PV array like atmospheric temperature, solar irradiation, the dust accumulated at the surface of the panel and the configuration of the electrical connection of the panels in the array. Considerably, power extraction and the efficiency of the PV system are affected by changing weather and partial shading conditions (PSC). By applying various approaches, the effect of the factors above on maximum power generation can be reduced; these are maximum power point tracking techniques MPPT, PV array configuration, converter topologies, and the PV system architecture. For PV system architecture, it can be described as the different approaches of power electronics converters integrating into the PV system such as micro inverter, central inverter setup and cascaded DC-DC converters with central inverter configuration, while PV array configuration is depended on the techniques of electrical connection of the PV modules [1]. On the other hand, DC-DC converters or switch mode power converters have different topologies, these types of power electronics converters have been penetrated, and its use in PV system have been increased, some topologies have proved to track maximum power point and guaranteed convergence under partial shading conditions [2]. The fourth approach to get maximum power from the photovoltaic system is to employ maximum power point tracking algorithm to extract the peak power and enhance the efficiency of the photovoltaic system. MPPT techniques have been implemented in both of the uniform irradiations and partial shading conditions.

Varieties of MPPT algorithms have been used and tested; the most common are Fractional Short Circuit Current, Perturb and Observe (P&O), Fractional Open Circuit Voltage, Hill Climbing (HC) algorithm and Incremental Conductance (Inc.Cond.). Drawbacks of some algorithms such as the difficulty of implementation, overlook of the peak power point MPP during partial shading as well as low tracking speed have made the improvement of conventional techniques and rely on other methods that employ artificial intelligence is crucial for making the use of the photovoltaic system more effective.

Perturb and observe algorithm, is a vastly used conventional technique to track maximum power point that is installed in commercial PV controller due to its simplicity. However, it has two drawbacks, these involve the oscillation at the vicinity of maximum power point (MPP), and that result in unending oscillation in output power. Consequently, reduced energy and lower efficiency will yield. The second drawback is the divergence from MPP when a sudden change in weather conditions occur and will fail to track MPP which leads to a loss of energy [3]. Furthermore, to obtain an accurate MPPT algorithm, Soft computing innovations like Fuzzy Logic, Neural network (NN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) as an intelligent technique is chosen due to its capability to deal with the non-linear and non-exact mathematical model [4].

1.3 Problem statement

In spite of its widespread using, with a promising future for energy and the positive environmental impact, the photovoltaic system faces some drawbacks regarding the efficiency of power generation and the power transferred to the load. These drawbacks are a result of factors such as atmospheric temperature, solar radiation, failure of modules in the array and high ratio of PV modules shading, these factors and due to the presence of protection diodes connected in parallel with every module, power–voltage (P-V) characteristics of the PV system displays more than one peak, local peaks and one global. This multiplicity will prevent the maximum power point tracking algorithm from tracking the maximum power and may stick on the local peak. Consequently, reduced power will be extracted from the PV array.

Moreover, the maximum power point in the photovoltaic system will become more difficult to be tracked during changed climatic conditions.

To exploit the highest power produced by the photovoltaic system optimally and in all operating conditions, an efficient tracking method are needed. Some tracking algorithms are designed for this purpose, but they do not search and compare all peaks in the P-V curve. Other methods to tackle these problems are based on soft computing, but most of them increase the complexity and cost of implementation. In small and distributed PV systems simplicity and economy are a key factor, so that complexity in design is not preferred.

1.4 Objectives

This project objectives includes:

(i) Design a tracking controller that employs soft computing methods to track maximum power point (MPP) during partial shading conditions using Fuzzy Logic Controller (FLC) and Adaptive Neuro Fuzzy Inference System (ANFIS).

(ii) Design a conventional maximum power point tracker to examine its performance (MPP) during partial shading using perturb and observe (P & O) controller.

(iii) To compare the performance of both conventional and intelligent techniques in terms of steady-state oscillation, the efficiency of maximum power point controller and power extracted from the PV system as well as the response to varying weather conditions.

1.5 Project scope

The project scope includes achieving the objectives in 1.4, so there are few points to be verified: -

(i) Simulate the polycrystalline photovoltaic module type MSX-64 and analyse its power-voltage and current-voltage characteristics curves during uniform and partial shading conditions.

(ii) Using MATLAB/SIMULINK to design and simulate a Fuzzy logic controller (FLC) and Adaptive Neuro-Fuzzy Inference System controller (ANFIS).

(iii) Using MATLAB/SIMULINK to design and simulate a perturb and observe (P & O) controller.

CHAPTER 2

LITERATURE REVIEW

To make a connection and understand the relation between the project components (types of a PV power system, types of photovoltaic modules, partial shading, photovoltaic module, MPPT, DC-DC converter), this section of literature reviews has been presented.

2.1 Stand-alone and Grid-connected PV system

Photovoltaic power systems can be classified into two sorts, stand-alone and grid-connected, both of those are described briefly as below:

2.1.1 Stand-alone PV systems

Stand-alone (also known as off-grid) PV systems can be defined as the PV power generation plants that are not tied to the electrical power grid. For actual usage, it’s available in different forms [5]:

(i) Solar home systems: appropriate for private utilizations for example home lighting and PCs. Generally, it is designed to supply DC as well as AC electrical apparatuses.

(ii) Small AC local grid with coupled components: Due to the need to charge batteries and supply AC loads for a mini power, this form of PV technology has emerged.

(iii) Modular AC coupled systems: By combining all consumers and photovoltaic generator to the AC, a modularly structured components PV systems can be achieved, which is a more flexible photovoltaic system.

The stand-alone PV system consists generally of the PV generator, charge controller, batteries, inverter and loads.

2.1.2 Grid-connected PV systems

Depending on the power demand, size of the photovoltaic array that is connected to the utility grid may change, but they still have the same components. Figure 2.1 shows the block diagram for the grid-connected PV system; it involves the PV array, meter for measuring energy delivered to the grid and that drawn from the grid as well as the inverter. Electrical loads of the house are fed from both of PV system during the daytime, and during the night as well as extra demand for energy, the house loads will be supplied by the grid. To measure produced and consumed energy, house meter is used for this purpose [6].

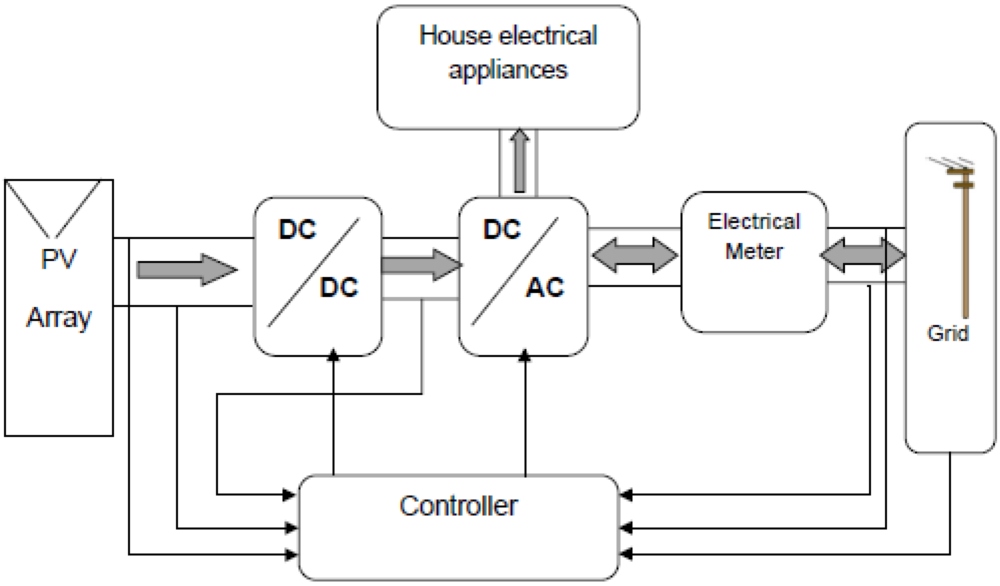

Figure 2.1: Block diagram of grid-connected photovoltaic system [6]

The most important part of the grid-connected photovoltaic systems is the inverter, where conversion of the direct current extracted from the PV system into the alternating current is done by inverter with the appropriate frequency and voltage and then fed to the domestic loads or exported to the utility grid [7].

Between these two forms of PV systems, grid-connected systems are more cost-effective, it requires less maintenance than stand-alone systems because storage batteries are not required which are needed in the stand-alone systems that increase the cost and the need for charging and discharging controllers. 99% of the whole installed capacity of PV systems are occupied by grid-connected systems compared with 1% of the standalone systems [6].

2.2 Photovoltaic modules types

By the photovoltaic effect, the solar cell or as known photovoltaic cell able to transform solar energy into electrical energy. A solar cell forms the fundamental component of a PV generator. A PV generator is the main component of a solar generator. PV generator is the whole system that contains every single photovoltaic module that are tied in parallel or series or blend of both configurations [8]. Lowering the cost and increasing the conversion efficiency of solar panels is the target of numerous research activities worldwide [8].

There are three generations of solar cells which are; crystalline PV modules, thin film PV modules, and Nano crystal-based solar cells. The third generation can be said to be within the research and development phase.

2.2.1 Crystalline PV modules

The first generation of solar cell technologies which are made of crystalline structure which employs silicon (Si) for solar cell production. This type of PV modules has high efficiency and reliability, but its costly [2]. There are two types of PV modules belongs to the silicon crystalline structures which are monocrystalline and polycrystalline [9].

2.2.1.1 Mono crystalline

Monocrystalline is the most commonly used type; about 80% of the market constitutes this type, until more efficient and cost-effective solar cell technology created, monocrystalline will continue to be the front-runner in this field. Under standard test condition (STC), the maximum efficiency of these solar cells has reached around 23%, and the highest was 24.7%. Self-losses are generated because of the blend of solar cell resistance, metal contacts available on the top side and solar radiation reflection [9].

2.2.1.2 Poly crystalline

To decrease the cost to improve solar cell, Polycrystalline cell is appropriate material. Nevertheless, it has lower efficiency comparing with monocrystalline [9].

2.2.2 Thin film PV panels

Thin film or a Thin-film photovoltaic cell (TFPV) or a thin-film solar cell (TFSC), is a second-generation solar cell which are fabricated by depositing one or more thin layers, or thin film of the PV material on a substrate, such as plastic, glass, or metal. Commercially, it is solar used in several technologies, for example, copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and amorphous. Its thickness changes from a few nanometers to tens of micrometers [10].

In the last two decades, thin-film market-share has never been reached more than 20 %, and in recent years it has been declined to about 9% of worldwide photovoltaic production [10].

The expense of the thin films production which is less than that of the conventional one and its low voltage temperature coefficients that diminish power losses versus hot temperature profiles is the main advantages of this type of PV modules [2].

2.2.3 Nano crystal Based Solar Cells

Belongs to the third generation. Generally, Nano crystal-based solar cells are called (QD) solar cells. These solar cells are made out of semiconductor material in the size of Nanocrystal range. Quantum dots are a name of the crystal size that ranging within the size of a few nanometers, porous Si or porous TiO2 is an example of materials used in QD. With the nanotechnology advancement, these Nanocrystals of semiconducting material are targeted to replace the semiconducting material in bulk state [11]. Table 2.1 demonstrates a comparison of different kinds of solar cells.

REFERENCES

1. S. R. Pendem and S. Mikkili, "Modeling, simulation, and performance analysis of PV array configurations (Series, Series-Parallel, Bridge-Linked, and Honey-Comb) to harvest maximum power under various Partial Shading Conditions," *Int. J. Green Energy*, vol. 15, no. 13, pp. 795–812, 2018.
2. E. Koutroulis and F. Blaabjerg, "A new technique for tracking the global maximum power point of PV arrays operating under partial-shading conditions," *IEEE J. Photovoltaics*, vol. 2, no. 2, pp. 184–190, 2012.
3. H. D. Liu, C. H. Lin, K. J. Pai, and Y. L. Lin, "A novel photovoltaic system control strategies for improving hill climbing algorithm efficiencies in consideration of radian and load effect," *Energy Convers. Manag.*, vol. 165, no. August 2017, pp. 815–826, 2018.
4. K. S. Tey and S. Mekhilef, "Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level," *Sol. Energy*, vol. 101, pp. 333–342, 2014.
5. L. Fara and D. Craciunescu, "Output Analysis of Stand-alone PV Systems: Modeling, Simulation and Control," *Energy Procedia*, vol. 112, no. October 2016, pp. 595–605, 2017.
6. I. Laib, A. Hamidat, M. Haddadi, N. Ramzan, and A. G. Olabi, "Study and simulation of the energy performances of a grid-connected PV system supplying a residential house in north of Algeria," *Energy*, vol. 152, pp. 445–454, 2018.
7. S. Rehman, M. A. Ahmed, M. H. Mohamed, and F. A. Al-Sulaiman, "Feasibility study of the grid connected 10 MW installed capacity PV power plants in Saudi Arabia," *Renew. Sustain. Energy Rev.*, vol. 80, no. December 2016, pp. 319–329, 2017.

8. G. N. Tiwari, R. K. Mishra, and S. C. Solanki, “Photovoltaic modules and their applications: A review on thermal modelling,” *Appl. Energy*, vol. 88, no. 7, pp. 2287–2304, 2011.

9. Z. Abdin *et al.*, “Solar energy harvesting with the application of nanotechnology,” *Renew. Sustain. Energy Rev.*, vol. 26, pp. 837–852, 2013.

10. A. Mohammad Bagher, “Types of Solar Cells and Application,” *Am. J. Opt. Photonics*, vol. 3, no. 5, p. 94, 2016.

11. S. Sharma, K. K. Jain, and A. Sharma, “Solar Cells: In Research and Applications—A Review,” *Mater. Sci. Appl.*, vol. 06, no. 12, pp. 1145–1155, 2015.

12. A. Al Nabulsi, R. Dhaouadi, and S. Member, “Nabulsi, Dhaouadi, Member - 2011 - Efficiency Optimization of a DSP-Based Standalone PV System using Fuzzy Logic and Dual-MPPT Control-annotated.pdf,” *IEEE Trans. Ind. Informatics*, vol. 8, no. 3, pp. 1–12, 2012.

13. A. Z. Hafez, A. M. Yousef, and N. M. Harag, “Solar tracking systems: Technologies and trackers drive types – A review,” *Renew. Sustain. Energy Rev.*, vol. 91, no. March, pp. 754–782, 2018.

14. M. H. Taghvaee, M. A. M. Radzi, S. M. Moosavain, H. Hizam, and M. Hamiruce Marhaban, “A current and future study on non-isolated DC-DC converters for photovoltaic applications,” *Renew. Sustain. Energy Rev.*, vol. 17, pp. 216–227, 2013.

15. 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.

16. R. Alik and A. Jusoh, “Modified Perturb and Observe (P&O) with checking algorithm under various solar irradiation,” *Sol. Energy*, vol. 148, pp. 128–139, 2017.

17. L. Liu, X. Meng, and C. Liu, “A review of maximum power point tracking methods of PV power system at uniform and partial shading,” *Renew. Sustain. Energy Rev.*, vol. 53, pp. 1500–1507, 2016.

18. K. S. Tey and S. Mekhilef, “Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation,” *IEEE Trans. Ind. Electron.*, vol. 61, no. 10, pp. 5384–5392, 2014.

19. N. K. S. Sujith, “COMPARISON OF FUZZY LOGIC BASED MPPT WITH P

& O FOR SOLAR PV PUMPING SYSTEM," *Int. Conf. Emerg. Technol. Trends [ICETT]*, 2016.

20. A. Padmaja, "Design of MPPT Controller using ANFIS and HOMER based sensitivity analysis for MXS 60 PV module," *Int. J. Innov. Res. Adv. Eng.*, vol. 2, no. 11, pp. 40–50, 2015.
21. A. Arora, "Comparison of f ANN and ANFIS bas ed MPPT controller fo or grid connected PV Sy ystems," *2015 Annu. IEEE India Conf.*, pp. 1–6, 2015.
22. M. Balamurugan, S. K. Sahoo, and S. Sukchai, "Application of soft computing methods for grid connected PV system: A technological and status review," *Renew. Sustain. Energy Rev.*, vol. 75, no. October, pp. 1493–1508, 2017.
23. K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 475–488, 2013.
24. A. Dolara, G. C. Lazaroiu, S. Leva, and G. Manzolini, "Experimental investigation of partial shading scenarios on PV (photovoltaic) modules," *Energy*, vol. 55, pp. 466–475, 2013.
25. M. Dhimish, V. Holmes, P. Mather, and M. Sibley, "Novel hot spot mitigation technique to enhance photovoltaic solar panels output power performance," *Sol. Energy Mater. Sol. Cells*, vol. 179, no. February, pp. 72–79, 2018.
26. A. Mohapatra, B. Nayak, P. Das, and K. B. Mohanty, "A review on MPPT techniques of PV system under partial shading condition," *Renew. Sustain. Energy Rev.*, vol. 80, no. May, pp. 854–867, 2017.
27. J. Bai, Y. Cao, Y. Hao, Z. Zhang, S. Liu, and F. Cao, "Characteristic output of PV systems under partial shading or mismatch conditions," *Sol. Energy*, vol. 112, pp. 41–54, 2015.
28. L. Bouselham, M. Hajji, B. Hajji, and H. Bouali, "A New MPPT-based ANN for Photovoltaic System under Partial Shading Conditions," *Energy Procedia*, vol. 111, no. September 2016, pp. 924–933, 2017.
29. N. H. Baharudin, T. M. N. T. Mansur, F. A. Hamid, R. Ali, and M. I. Misrun, "Topologies of DC-DC converter in solar PV applications," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 8, no. 2, pp. 368–374, 2017.
30. S. Li, H. Liao, H. Yuan, Q. Ai, and K. Chen, "A MPPT strategy with variable weather parameters through analyzing the effect of the DC/DC converter to the MPP of PV system," *Sol. Energy*, vol. 144, pp. 175–184, 2017.

31. P. System, “Fuzzy Logic Based Adaptive Perturbation & Observation MPPT for Photovoltaic System,” in *Renewable Energy and Sustainable Development*, 2015, no. June, p. 136119.

32. M. Mahdavi, L. Li, J. Zhu, and S. Mekhilef, “An adaptive Neuro-Fuzzy controller for maximum power point tracking of photovoltaic systems,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2016-January, no. November, 2016.

33 A. A. Aldair, A. A. Obed, and A. F. Halihal, “Design and implementation of ANFIS-reference model controller based MPPT using FPGA for photovoltaic system,” *Renew. Sustain. Energy Rev.*, vol. 82, no. August 2017, pp. 2202–2217, 2018.

34. J. Mroczka and M. Ostrowski, “A Hybrid Maximum Power Point Search Method Using Temperature Measurements in Partial Shading Conditions,” *Metrol. Meas. Syst.*, vol. 21, no. 4, pp. 733–740, 2014.

35. A. K. Mahammad, S. Saon, and W. S. Chee, “Development of optimum controller based on MPPT for photovoltaic system during shading condition,” *Procedia Eng.*, vol. 53, pp. 337–346, 2013.

36. K. Ishaque, Z. Salam, H. Taheri, and Syafaruddin, “Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model,” *Simul. Model. Pract. Theory*, vol. 19, no. 7, pp. 1613–1626, 2011.

37. K. Sundareswaran, V. Vignesh kumar, and S. Palani, “Application of a combined particle swarm optimization and perturb and observe method for MPPT in PV systems under partial shading conditions,” *Renew. Energy*, vol. 75, pp. 308–317, 2015.

38. M. Gradella Villalva, J. Rafael Gazoli, and E. Ruppert Filho, “Comprehensive {A}pproach to {M}odeling and {S}imulation of {P}hotovoltaic {A}rrays,” *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1198–1208, 2009.

39. N. Hashim, Z. Salam, D. Johari, and N. F. N. Ismail, “DC-DC boost converter design for fast and accurate MPPT algorithms in stand-alone photovoltaic system,” *Int. J. Power Electron. Drive Syst.*, vol. 9, no. 3, pp. 1038–1050, 2018.

40. R. Alik, A. Jusoh, and T. Sutikno, “A Review on Perturb and Observe Maximum Power Point Tracking in Photovoltaic System,” *TELKOMNIKA (Telecommunication Comput. Electron. Control.*, vol. 13, no. 3, p. 745, 2016.

41. M. Lasheen and M. Abdel-Salam, “Maximum power point tracking using Hill

Climbing and ANFIS techniques for PV applications: A review and a novel hybrid approach," *Energy Convers. Manag.*, vol. 171, no. March, pp. 1002–1019, 2018.

42. C. Paper, "Study of Different PV Systems Configurations Case Study : Aswan Utility Study of Different PV Systems Configurations Case Study : Aswan Utility Company," in *17th International Middle East Power Systems Conference*, 2015, no. December.

43. I. Idris, M. S. Robian, A. K. Mahamad, and S. Saon, "Arduino based maximum power point tracking for photovoltaic system," *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 14, pp. 8805–8809, 2016.

44. S. M. Sadek, F. H. Fahmy, A. E.-S. A. Nafeh, and M. A. El-Magd, "Fuzzy P & O Maximum Power Point Tracking Algorithm for a Stand-Alone Photovoltaic System Feeding Hybrid Loads," *Smart Grid Renew. Energy*, vol. 05, no. 02, pp. 19–30, 2014.

45. F. Belhachat and C. Larbes, "Global maximum power point tracking based on ANFIS approach for PV array configurations under partial shading conditions," *Renew. Sustain. Energy Rev.*, vol. 77, no. February, pp. 875–889, 2017.

46. H. Lund and B. V. Mathiesen, "Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources," *IET Renew. power Gener.*, vol. 3, no. August 2008, pp. 190–204, 2008.