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POLYNOMIAL INTERPOLATION-BASED GLOBAL MPPT FOR PHOTOVOLTAIC SYSTEMS UNDER PARTIAL SHADING

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Abstract. *This paper presents a Global Maximum Power Point Tracking (GMPPT) method based on polynomial interpolation for photovoltaic systems under partial shading conditions. In the case of non-uniform irradiance, the photovoltaic power characteristic is nonlinear and may have multiple local maximum power points, increasing the risk of convergence to a non-optimal operating point. To this end, the proposed strategy exploits a limited number of selected duty-cycle and power measurements to build a low-order polynomial approximation of the power behavior around the most promising operating region. Then a bounded numerical optimization step is performed to estimate the duty cycle corresponding to the maximum interpolated power. A best power retention mechanism preserves the operating point corresponding to the highest extracted power. The efficiency of the method is tested by simulation in the case of a representative time-varying partial shading profile and then compared with P&O, INC, PSO and GWO algorithms. The obtained results show that the proposed method has a mean tracking efficiency of 99.11%, an energy-based efficiency of 99.15% and the lowest RMSE error of 1.0026 W. It presents the highest energy efficiency and the lowest mean tracking error in comparison with the other methods, confirming its capability to work close to the GMPP and to reduce unnecessary oscillations after convergence. The results indicate that polynomial interpolation can be used as a simple and effective numerical tool to improve MPPT performance in PV systems under partial shading conditions.*

Keywords: Photovoltaic systems; Global maximum power point tracking; Partial shading conditions; Polynomial interpolation; Numerical optimization; Duty-cycle optimization.

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1. Introduction

Photovoltaic (PV) energy is one of the most promising renewable energy sources due to its clean operation, modular nature and applicability for both distributed and large-scale generation [1]. However, the PV output is nonlinear and depends on the irradiance, temperature and the operating point imposed by the power converter [2], [14]. Therefore, an efficient maximum power point tracking (MPPT) controller is needed to harvest the maximum available power under varying operating conditions.

Classical MPPT methods like Perturb and Observe (P&O) and Incremental Conductance (INC) are popular because of their simplicity and easy implementation under uniform irradiance [3]. However, these local-search methods may lead to oscillations around maximum power point and may lead to inaccuracies for fast irradiance changes.

Partial shading makes MPPT more difficult because different PV modules can be under different irradiation due to clouds, buildings, trees or dust. This mismatch leads to several local maximum power points (LMPPs) and only one global maximum power point (GMPP). Hence, the traditional MPPT algorithms can reach a local maximum and extract less energy [3], [4].

To solve this problem, various GMPPT strategies have been proposed including metaheuristic, artificial-intelligence, hybrid and voltage-scanning methods [5]-[11]. Although these approaches can improve the global tracking ability, some of them require iterative search, parameter tuning, more computation or more time to converge. This motivates the design of simple numerical methods to compute the GMPP with low implementation complexity.

Polynomial interpolation is a useful numerical tool for approximating nonlinear behavior from a limited number of measured points. In PV applications, interpolation can represent the local shape of the power curve and help identify the most promising maximum-power region [12], [13]. When combined with a duty-cycle search, the GMPPT problem can be treated as a one-dimensional optimization problem over the admissible interval [11], [14].

This paper proposes a numerical optimization method for GMPPT under partial shading condition using polynomial interpolation. The proposed framework consists of duty-cycle exploration, local cubic polynomial interpolation, bounded numerical optimization and best-power retention. A local interpolated representation of the PV power behavior around the most promising operating region is constructed from selected duty-cycle and power measurements. Then the duty cycle for the highest interpolated power is estimated and the best detected operating point corresponding to the GMPP is kept. The proposed strategy is not limited to local perturbation methods such as P&O and INC methods and does not require population-based iterative search or heavy parameter tuning such as metaheuristic approaches. So the method improves the GMPP localization with only a few measured operating points and reduces oscillations with low computational complexity. The tracking performance of the proposed method is evaluated by comparison with P&O, INC, Particle Swarm Optimization (PSO), and Grey Wolf Optimizer (GWO) algorithms under the same partial shading profile.

The main contributions of this work are as follows:

- A polynomial interpolation-based numerical optimization method is proposed for GMPPT under partial shading conditions.
- The proposed method combines local duty-cycle exploration, cubic interpolation, and a best-power retention mechanism to improve GMPP localization with low computational complexity.
- Comparative simulation results demonstrate improved tracking efficiency and reduced tracking error compared with P&O, INC, PSO, and GWO algorithms.

The remainder of the paper is organized as follows. Section 2 formulates the PV system and GMPPT problem. Section 3 describes the proposed method. Section 4 presents and discusses the simulation results. Section 5 concludes the paper.

2. PV System and GMPPT Problem Formulation

A photovoltaic system converts solar irradiance into electrical energy through the nonlinear behavior of PV cells. The output voltage and current of the PV generator are mainly affected by irradiance and cell temperature [2]. In this work, the PV generator is connected to a DC-DC converter controlled by a duty cycle D, as illustrated in Figure 1. By adjusting this duty cycle, the operating point of the PV array can be modified in order to extract the maximum available power.

The instantaneous PV power is defined as

$$P_{PV} = V_{PV} \times I_{PV}$$

where V_{PV} and I_{PV} are the output voltage and current of the PV generator respectively. Since the duty cycle affects the PV voltage and current through the converter dynamics, the MPPT problem can be formulated as an optimization problem with respect to D [14]:

$$D^* = \arg\max_{D} P_{PV}(D)$$

$$D_{min} \leq D \leq D_{max}$$

where Dmin and Dmax are the admissible duty-cycle limits and D* is the optimal duty cycle corresponding to the maximum extracted power.

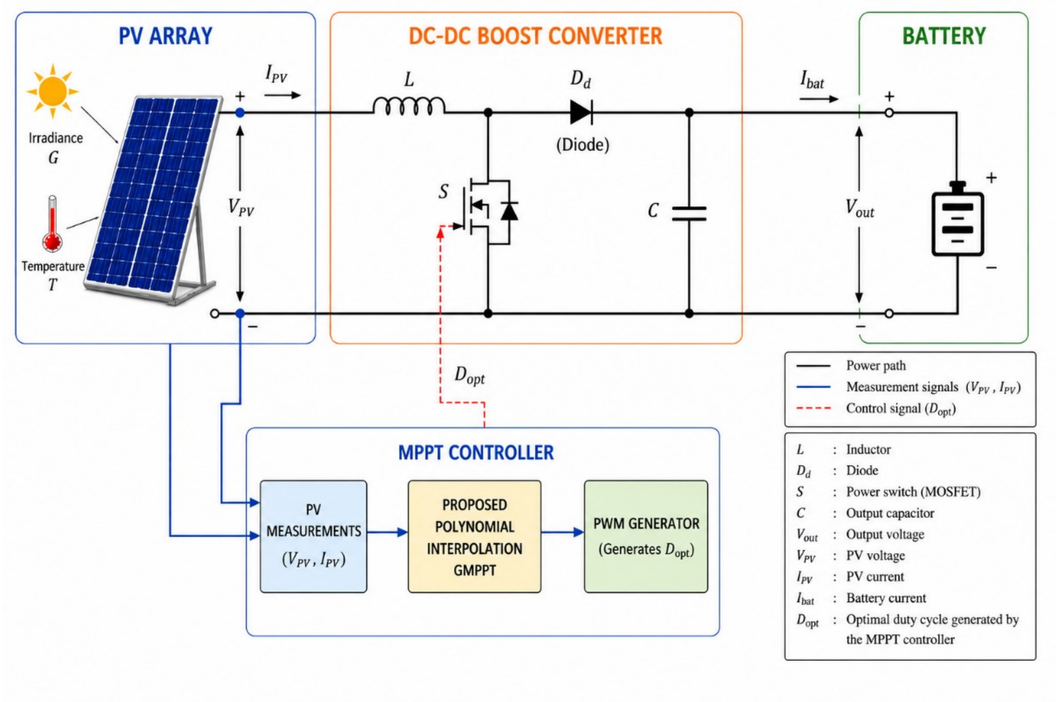

Figure 1. Configuration of the PV system with boost converter, battery load, and proposed GMPPT controller.

Under uniform irradiance conditions, the power-voltage characteristic of the PV generator generally contains a single maximum power point [3]. Under partial shading conditions, different modules may receive different irradiance levels. This mismatch results in a multimodal power-voltage curve with multiple local maximum power points and one Global Maximum Power Point (GMPP) [3], [4].

Define $P_{LMPP,i}$ as the i-th local maximum power point and P_{GMPP} as the global maximum power point. The objective under partial shading is to identify the highest power among all local maxima:

$$P_{GMPP} = \max_i P_{LMPP,i}$$

The corresponding optimal duty cycle is therefore

$$D_{GMPP} = \arg\max_D P_{PV}(D)$$

$$D_{min} \leq D \leq D_{max}$$

This formulation shows that GMPPT under partial shading is a nonlinear and multimodal optimization problem [4], [11]. The measured PV voltage and current are used to compute power values at selected duty-cycle points. These data points are then exploited by the proposed polynomial interpolation-based numerical approach to improve the estimation of the optimal operating region.

3. Proposed Polynomial Interpolation-Based Numerical Optimization Approach

The proposed approach is developed to enhance the localization of the Global Maximum Power Point (GMPP) under partial shading conditions, where several local maxima may appear and mislead conventional MPPT controllers [3], [4]. As formulated previously, the GMPPT problem can be treated as a bounded one-dimensional optimization problem with respect to the duty cycle (D) [11], [14]. Therefore, the proposed approach exploits a limited number of measured duty-cycle and power samples to construct an interpolated approximation of the PV power behavior around the most promising region.

For each tested duty cycle (D_i), the PV voltage ($V_{PV,i}$)and current ($I_{PV,i}$) are measured, and the corresponding power is calculated as

$$P_i = V_{PV,i} I_{PV,i}$$

The obtained pairs (D_i, P_i) are used as interpolation nodes within the admissible duty-cycle interval:

$$D_{min} \leq D \leq D_{max}$$

During each search event, the admissible interval [D_{min}, D_{max}] is explored using Ns duty-cycle samples, where Ns denotes the number of samples used during the scan stage. The sample giving the highest measured power is first identified as:

$$k = \arg\max_i P_\mathrm{i}$$

where k is the index of the best measured point during the exploration stage.

A cubic polynomial is used because it provides a good trade-off between local approximation accuracy, numerical stability, and computational simplicity. It can better approximate the local curvature and asymmetry of the PV power curve compared to linear or quadratic approximations, and at the same time avoid oscillations and higher computational cost of higher-order polynomials.

A cubic polynomial has 4 coefficients, so 4 interpolation points are necessary for it to be unique. The best measured duty-cycle point and the three closest valid neighboring samples are therefore selected. This allows the refinement to concentrate only on the high power region rather than fitting the whole multimodal curve. The interpolated power is expressed as:

$$P_{\mathrm{int}}(D) = a_0 + a_1 D + a_2 D^2 + a_3 D^3$$

where $P_{\text{int}}(D)$ is the estimated power and (a_0, a_1, a_2, a_3) are the polynomial coefficients. These coefficients are obtained by imposing the interpolation conditions on the four selected nodes:

$$P_{\text{int}}(D_i) = P_i \quad i = 1, 2, 3, 4$$

This means that the polynomial that is constructed will go through the selected measured points of duty-cycle and power. Thus the interpolation stage provides a direct analytical expression for the local power behavior without the need for empirical tuning parameters or fitting the whole multi-modal PV characteristic.

Once the polynomial approximation is obtained, the optimal duty cycle is estimated by maximizing the interpolated power over the admissible interval:

$$D_{\text{opt}} = \arg \max_{D \in [D_{min}, D_{max}]} P_{\text{int}}(D)$$

Since the interpolated function is cubic, the candidate optimal points can be obtained from the stationary condition:

$$\frac{dP_{\text{int}}(D)}{dD} = a_1 + 2a_2 D + 3a_3 D^2 = 0$$

The real roots located inside $[D_{min}, D_{max}]$ are evaluated together with the interval limits Dmin and Dmax. The duty cycle that gives the highest interpolated power among these candidates is selected as Dopt.

The estimated duty cycle D_{opt} is then applied to the DC-DC converter. The measured PV power is compared with the best power value stored previously. If the new measured power is greater than the stored best power, then update the best duty cycle and best power as follows:

$$D_{\text{best}} = D_{\text{opt}}$$

$$P_{\text{best}} = P(D_{\text{opt}})$$

Otherwise, the controller holds the previous value of (*D*best). This best-power retention mechanism prevents the operating point from drifting away from the highest detected power point and reduces unnecessary oscillations after convergence.

In summary, the proposed strategy involves three main stages: duty-cycle exploration, refinement via polynomial interpolation, and best power retention. Compared to classical perturbative MPPT techniques, the proposed method approximates the local power curve and estimates the GMPP more directly by using several measured operating points. The proposed MPPT method is suitable for digital implementation due to the low computational load of the interpolation stage based on only a few selected duty-cycle samples. This provides a good trade-off between tracking accuracy, oscillation reduction and implementation simplicity.

4. Simulation Results and Discussion

A simulation study is conducted to evaluate the proposed polynomial interpolation-based GMPPT method under a representative time-varying partial shading condition. The objective is to assess the ability of the proposed controller to track the global maximum power point under abrupt irradiance variations and to compare its performance with classical and metaheuristic MPPT methods.

The simulations were carried out using MATLAB/Simulink. The studied system consists of an STM6-40/36 photovoltaic module connected to a DC-DC boost converter supplying a 72 V battery. The same PV model, converter parameters, irradiance profile, and simulation conditions were used for all compared MPPT methods in order to ensure a fair comparison. The main simulation parameters are summarized in Table 1.

Table 1. Main simulation parameters of the PV system.

Category	Parameter	Symbol	Value
Simulation environment	Software	—	MATLAB/Simulink
PV generator	PV module	—	STM6-40/36
	Cell temperature	T	25 °C
Power converter	Converter topology	—	DC-DC boost converter
	Input capacitance	Cin	470 µF
	Inductance	L	1 mH
	Inductor resistance	RL	0.05 Ω
Output side	Battery voltage	Vbat	72 V
Control	Duty-cycle lower limit	Dmin	0.15
	Duty-cycle upper limit	Dmax	0.95

The duty cycle was constrained within the interval $0.15 \leq D \leq 0.95$ to ensure safe operation of the DC-DC boost converter.

The PV array is divided into three irradiance sections, G1, G2, and G3. The cell temperature was maintained at 25 °C, and the adopted time-varying irradiance profile is summarized in Table 2.

Table 2. Time varying irradiance and temperature profile used for the representative partial shading condition.

Step	Time interval (s)	Temperature (°C)	G(t) = [G1, G2, G3] (W/m²)
S1	0-500	25	[100, 60, 40]
S2	500-1000	25	[150, 120, 90]
S3	1000-1500	25	[300, 230, 150]
S4	1500-2000	25	[200, 150, 100]
S5	2000-2500	25	[500, 350, 250]

S6	2500-3000	25	[600, 430, 300]
S7	3000-3500	25	[400, 300, 180]
S8	3500-4000	25	[400, 270, 160]
S9	4000-4500	25	[650, 450, 280]
S10	4500-5000	25	[850, 700, 300]
S11	5000-5500	25	[500, 280, 150]
S12	5500-6000	25	[900, 560, 300]
S13	6000-6500	25	[1000, 700, 400]

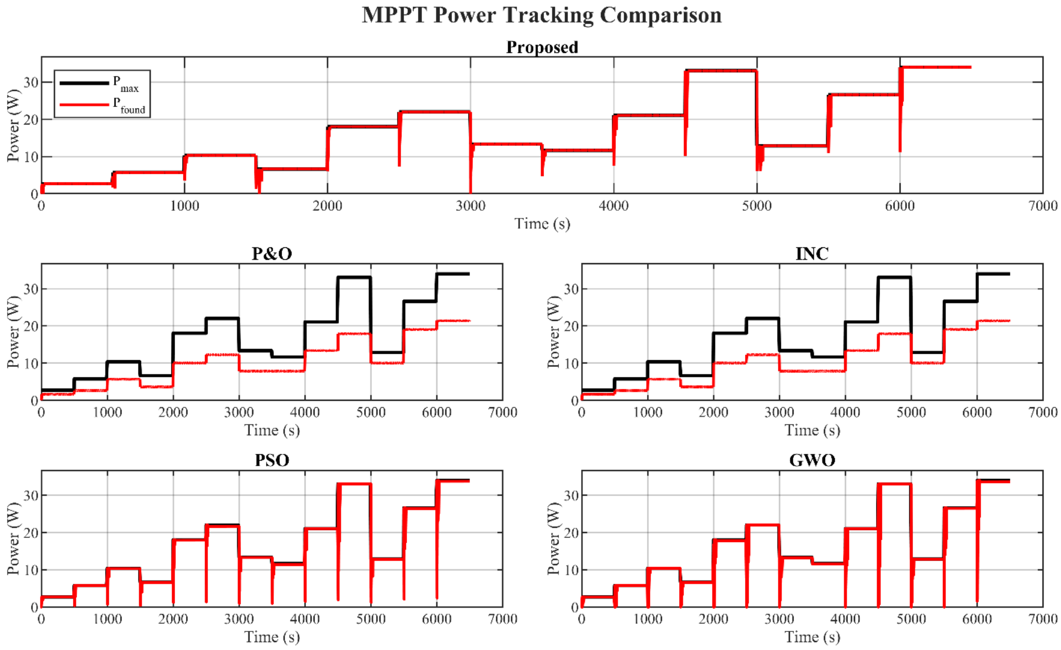

Figure 2. Dynamic power tracking comparison under time-varying partial shading conditions

The dynamic power tracking comparison of the proposed method with P&O, INC, PSO and GWO is shown in Figure 2. The extracted power P_{found} is compared with the reference maximum power P_{max} for each method. The proposed method tracks the reference maximum power closely after each irradiance transition and settles near the GMPP. P&O and INC, on the other hand, are far from the reference power in several intervals, which indicates convergence to local maxima. PSO and GWO have better global tracking capability than P&O and INC, but still show larger transient deviations than the proposed method in some irradiance changes.

The tracking efficiency is evaluated by comparing the power obtained by the controller with the reference maximum power:

$$\eta(\%) = \frac{P_{found}}{P_{max}} \times 100$$

where P_{max} is the reference maximum power and P_{found} is the power obtained by the controller. In addition, the energy-based efficiency is computed by comparing the total extracted energy with the total available maximum energy over the complete simulation time. The main performance indicators are summarized in Table 3.

Table 3. Comparative GMPPT performance under the representative partial shading profile.

Method	Mean efficiency (%)	Energy efficiency (%)	RMSE error (W)
Proposed	**99.110**	**99.153**	**1.0026**
P&O	**60.357**	**61.138**	**7.6331**
INC	**60.386**	**61.161**	**7.6296**
PSO	**98.238** ± 0.242	**98.277** ± 0.204	**1. 4635** ± 0.0285
GWO	**98.331** ± 0.213	**98.400** ± 0.198	**1. 0530** ± 0.0317

The reported values for PSO and GWO are the mean ± standard deviation over 10 independent runs. The proposed method, P&O and INC are deterministic, therefore the one reproducible simulation is presented.

Table 3 shows the comparison of the proposed method with P&O, INC, PSO and GWO under the same partial shading profile. The proposed method achieves the best overall performance with the highest mean efficiency of 99.110%, the highest energy efficiency of 99.153%, and the lowest RMSE error of 1.0026 W. This shows that it is able to track the GMPP correctly and keep the operating point near the maximum power region.

P&O and INC performed badly primarily due to their local-search behavior. The power curve under partial shading conditions has many local maxima and these methods may converge to a local maximum instead of the GMPP. This explains their reduced mean and energy efficiencies, which are close to 60%.

PSO and GWO have a much better performance due to their global search ability, reaching energy efficiencies higher than 98%. However the energies obtained by their method are still lower than the proposed method. The PSO gives a close RMSE value, but the energy efficiency is still lower, which indicates that the interpolation-based refinement improves the overall harvested energy.

To summarise, the proposed polynomial interpolation based strategy provides the best compromise between global tracking ability, energy extraction and tracking accuracy. It integrates duty-cycle exploration, interpolation-based refinement and best-power retention to escape local maximum trapping and obtain the highest harvested energy under the partial shading condition considered.

5. Conclusion

In this paper, a polynomial interpolation-based numerical optimisation approach for GMPPT in photovoltaic systems under partial shading conditions is proposed. The proposed method builds a local cubic approximation of the PV power curve based on selected duty-cycle and power samples, estimates the optimal duty cycle and preserves the best detected operating point to minimise unnecessary oscillations after convergence. The proposed method was evaluated under a time-varying partial shading profile and compared with P&O, INC, PSO and GWO algorithms. The obtained results showed that the proposed approach achieved the highest mean tracking efficiency of 99.110%, the highest energy efficiency of 99.153% and the lowest RMSE error of 1.0026 W, proving its capability to work close to the GMPP and improve the harvested energy.

The results are encouraging, but there are a few limitations to keep in mind. The validation was carried out through simulations and on a limited number of partial shading conditions. Moreover, the effect of measurement noise, variations in converter parameters, sampling time and real time implementation limitations were not completely discussed. Future work will therefore consist of extending the validation to other shading scenarios, analysing the convergence time and computational complexity, evaluating the robustness to noisy measurements and implementing the proposed method on an experimental PV setup.

R E F E R E N C E S

[1] M. Dada and P. Popoola, "Recent advances in solar photovoltaic materials and systems for energy storage applications: A review," Beni-Suef University Journal of Basic and Applied Sciences, vol. 12, Art. no. 66, 2023, doi: 10.1186/s43088-023-00405-5.

[2] M. K. Al-Ghezi, R. T. Ahmed, and M. T. Chaichan, "The influence of temperature and irradiance on performance of the photovoltaic panel in the middle of Iraq," International Journal of Renewable Energy Development, vol. 11, no. 2, pp. 501-513, 2022, doi: 10.14710/ijred.2022.43713.

[3] M. Y. Worku et al., "A comprehensive review of recent maximum power point tracking techniques for photovoltaic systems under partial shading," Sustainability, vol. 15, no. 14, Art. no. 11132, 2023, doi: 10.3390/su151411132.

[4] N. H. Alombah et al., "Multiple-to-single maximum power point tracking for empowering conventional MPPT algorithms under partial shading conditions," Scientific Reports, vol. 15, Art. no. 14540, 2025, doi: 10.1038/s41598-025-98619-3.

[5] N. Akram, L. Khan, S. Agha, and K. Hafeez, "Global maximum power point tracking of partially shaded PV system using advanced optimization techniques," Energies, vol. 15, no. 11, Art. no. 4055, 2022, doi: 10.3390/en15114055.

[6] A. Moghassemi, S. Ebrahimi, S. Padmanaban, M. Mitolo, and J. B. Holm-Nielsen, "Two fast metaheuristic-based MPPT techniques for partially shaded photovoltaic system," International Journal of Electrical Power & Energy Systems, vol. 137, Art. no. 107567, 2022, doi: 10.1016/j.ijepes.2021.107567.

[7] M. Z.-E. Masry, A. Mohammed, F. Amer, and R. Mubarak, "New hybrid MPPT technique including artificial intelligence and traditional techniques for extracting the global maximum power from partially shaded PV systems," Sustainability, vol. 15, no. 14, Art. no. 10884, 2023, doi: 10.3390/su151410884.

[8] M. A. Husain, S. B. Pingale, A. B. Khan, A. F. Minai, Y. Pandey, and R. S. Dwivedi, "Performance analysis of the global maximum power point tracking based on spider monkey optimization for PV system," Renewable Energy Focus, vol. 47, Art. no. 100503, 2023, doi: 10.1016/j.ref.2023.100503.

[9] F. Abdelmalek, H. Afghoul, F. Krim, et al., "Experimental validation of effective zebra optimization algorithm-based MPPT under partial shading conditions in photovoltaic systems," Scientific Reports, vol. 14, Art. no. 26047, 2024, doi: 10.1038/s41598-024-77488-2.

[10] O. Elbaksawi, N. A. S. Elminshawy, S. Diab, A. M. Eltamaly, A. Mahmoud, and H. Elhadidy, "Innovative metaheuristic algorithm with comparative analysis of MPPT for 5.5 kW floating photovoltaic system," Process Safety and Environmental Protection, vol. 185, pp. 1072-1088, 2024, doi: 10.1016/j.psep.2024.03.082.

[11] R. Celikel, M. Yilmaz, and A. Gundogdu, "A voltage scanning-based MPPT method for PV power systems under complex partial shading conditions," Renewable Energy, vol. 184, pp. 361-373, 2022, doi: 10.1016/j.renene.2021.11.098.

[12] A. Ostadrahimi and Y. Mahmoud, "Novel spline-MPPT technique for photovoltaic systems under uniform irradiance and partial shading conditions," IEEE Transactions on Sustainable Energy, vol. 12, no. 1, pp. 524-532, Jan. 2021, doi: 10.1109/TSTE.2020.3009054.

[13] L. Yu, H. Wu, F. Yang, J. Jiang, and B. Deng, "Maximum power point tracking techniques using cubic spline interpolation-perturb and observe for partial shading conditions," in Proc. 2024 International Symposium on Electrical, Electronics and Information Engineering, 2024, pp. 500-506, doi: 10.1109/ISEEIE62461.2024.00097.

[14] M. A. Jusoh, M. F. N. Tajuddin, and M. A. Roslan, "MPP tracking with a modified duty cycle sweeping algorithm for various environmental irradiance conditions," Journal of Physics: Conference Series, vol. 2550, no. 1, Art. no. 012007, 2023, doi: 10.1088/1742-6596/2550/1/012007.