Design and Implementation of Solar Maximum Power Point Tracker With Energy Monitoring Under Real-Time Conditions

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***Abstract*— The primary objective of this research is to develop a robust and cost-effective solar energy management system that maximizes energy extraction from photovoltaic (PV) panels by employing the MPPT technique. The performance evaluation is conducted across varying weather conditions and load scenarios to assess its effectiveness, reliability, and adaptability to dynamic operational conditions.**

***Keywords*— Renewable Energy, Solar Energy, MPPT, PV System, Synchronous Buck, Arduino NANO.**

I. Introduction

Electricity consumption has been increasing globally over the past several years. To meet the energy demand, fossil fuels cannot sustain as the primary fuel for energy production. Besides, the depletion of fossil fuels and their adverse effect on the environment enables the need for alternative fuel sources which are sustainable and environmentally friendly [1]. Solar Energy is one of the best alternatives which comes under renewable sources of energy. To efficiently reduce carbon dioxide emissions and avoid global warming, emphasize the need of integrating multiple sources of renewable energy, including concentrated solar power plants (CSPP) and other forms of CSP. The combined method not only addresses the energy demand and supply imbalance, but in addition drastically minimizes the environmental impact.

It has emerged as a promising alternative to conventional energy sources due to its abundance, sustainability, quiet operation, and inexhaustible nature. Solar photovoltaic (PV) systems have gained significant attention and adoption worldwide, with advancements in technology making them a viable option for meeting electricity demands[2]. However, the performance of Solar PV systems is heavily influenced by environmental factors such as solar irradiance and temperature. The P-V and V-I characteristics of a PV array are non-linear which depends on thermal gradients and irradiation from sunlight[3]. The electrical equivalent single-diode model is commonly used for modeling PV cells in literary works, as seen in Fig.1.

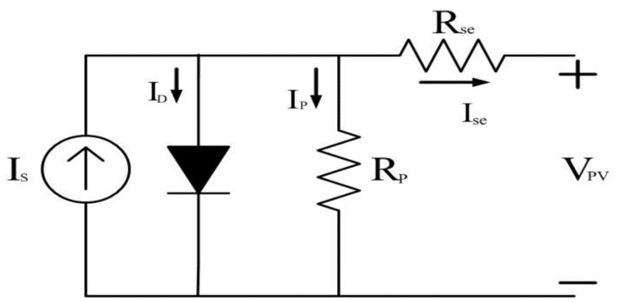

Fig. 1. Single-Diode model of a PV Cell

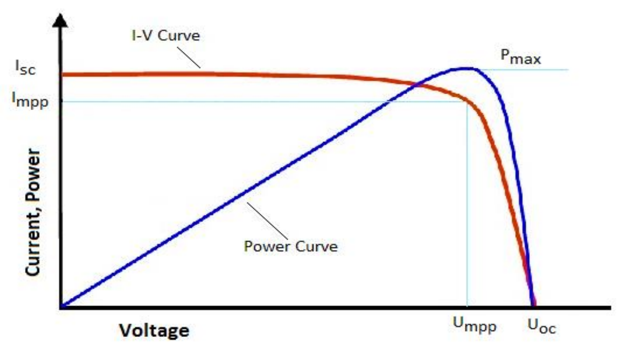

Fig. 2. I-V and P-V curve of a PV array

There is a point on the Power-Voltage (P-V) curve of the solar array called the Maximum power point (MPP). At this point, the PV system delivers its maximum output power with maximum efficiency. When the PV system is connected to a load, the intersection of the I-V curves of the PV array gives the operating point. But, under most conditions, this operating point is not at the Maximum power point. Hence, it is essential to ensure that the load line passes through the MPP to continuously deliver the maximum output power. To optimize the power output of solar panels, maximum power point tracking (MPPT) techniques are employed[4]. In this research, at first, the PV system is simulated by implementing the MPPT technique. Next, a low-cost Arduino-based hardware model is developed and tested in real-time conditions. Also, the solar panel parameters are monitored and updated on the server.

II. MPPT TECHNIQUES

MPPT algorithms play an essential role in PV system applications to optimize the power output from solar panels[5]. These techniques aim to find and maintain the maximum power point (MPP) of the solar panel, which is the operating point that maximizes power generation. These MPPT techniques try to maintain the PV array's operating point at its MPP (Maximum Power Point). There are different MPPT techniques that track operating points. A few of many are:

A. Perturb and Observe (P&O)

In this technique, continuous perturbation of the operating point of the solar panel is done by slightly increasing or decreasing the voltage and measuring the resulting power output[6]. The algorithm compares the power at the new operating point with the previous one to determine the direction to move toward the MPP. The process is iterated until the MPP is reached[7].

B. Incremental Conductance

In this technique, the MPP is found by using the incremental conductance of the solar panel. The comparison is made between the instantaneous conductance (dI/dV) of the panel and the reference conductance. The voltage is adjusted based on the comparison, such that dI/dV is zero.

C. Fractional Open-Circuit Voltage (FOCV)

The fraction of the open-circuit voltage is calculated to determine the desired voltage for maximum power. This technique utilizes the relationship between the open-circuit voltage (Voc) and the MPP voltage (Vmpp) of the solar panel[8]. the MPP is determined by adjusting the operating voltage based on the fraction.

D. Fractional Short-Circuit Current (FSCC)

Similar to FOCV, the fraction of the short-circuit current is calculated to determine the optimum current for maximum power. This technique utilizes the relationship between the short-circuit current (Isc) and the MPP current (Impp) of the solar panel[9]. Thus, the MPP is determined by adjusting the operating current based on the fraction.

E. Fuzzy Logic Control

This is a popular approach that utilizes fuzzy logic principles to track the MPP of a solar panel. This is a robust and adaptive method as it can handle uncertainties and work with imprecise inputs, not needing an accurate mathematical model and handling nonlinearities present in the solar energy system.

F. Neural Network

Neural network-based MPPT algorithms have been utilized to improve the accuracy and performance of solar energy systems and leverage the capabilities of artificial neural networks to learn the mapping between input parameters and the desired MPP. A dataset is used for training the neural network that includes input parameters like solar panel voltage, current, irradiance, and corresponding output values representing the MPP.

Each MPPT technique has its own advantages and limitations, and its effectiveness can vary depending on factors such as solar panel characteristics, environmental conditions, and system design.

TABLE I. Types of MPPT Techniques and their characteristics

MPPT Technique	Convergence speed	Implementation Complexity	Sensed Parameters
Perturb and Observe	Varies	Low	Voltage
Incremental Conductance	Varies	Medium	Voltage, Current
Fractional Open-Circuit Voltage	Medium	Low	Voltage
Fractional Short-Circuit Current	Medium	Medium	Current
Fuzzy Logic Control	Fast	High	Varies
Neural Network	Fast	High	Varies

III. PERTURB & OBSERVE ALGORITHM

The flowchart of the P&O method is shown in Fig. The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if power P is positive, then perturbation is done in the same direction as MPP[8]. If P is negative, moved away from the direction of MPP, and the sign of perturbation is changed. The algorithm follows these steps:

1) Initialization:

Start with an initial operating point, typically set to the open circuit voltage or maximum power point.

2) Perturbation:

Slightly increase or decrease the operating voltage or current of the system.

3) Power measurement:

Measure the power output of the system at the perturbed operating point.

4) Power comparison:

Compare the measured power with the power measured in the previous iteration.

5) Decision-making:

Based on the power comparison, make a decision on how to adjust the operating point in the next iteration. The adjustment is typically done in the direction that leads to an increase in power output.

6) Iteration:

Repeat steps 2-5 until the MPP.

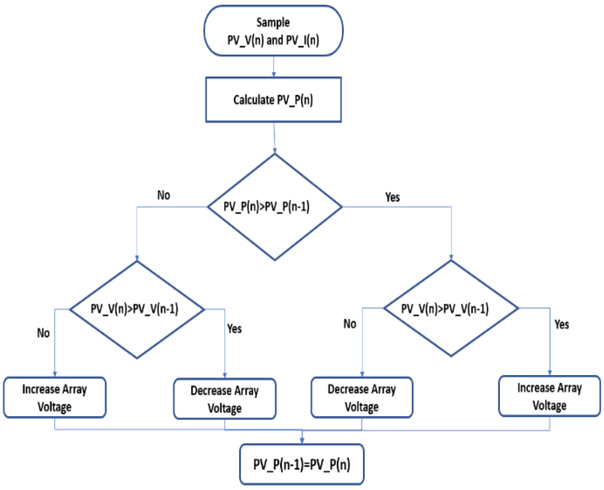

Fig. 3. Flowchart of P&O Algorithm

IV. Simulation

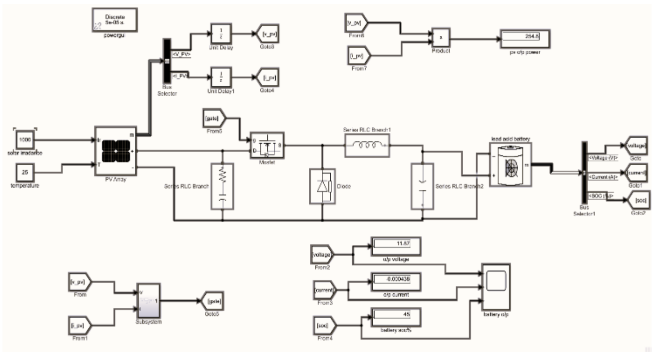

Fig. 4. Simulink model

This system includes a PV module, a buck converter with a battery block, and an MPPT block (subsystem). Solar irradiance and cell temperature profiles are given as input to the solar panel[10]. The output of the solar panel block is connected to the input of the buck converter. The 12V lead-acid battery is taken as load and connected across the buck converter. The MPPT block (subsystem) generates a duty cycle as the output which is given as gate pulses to the buck converter[11].

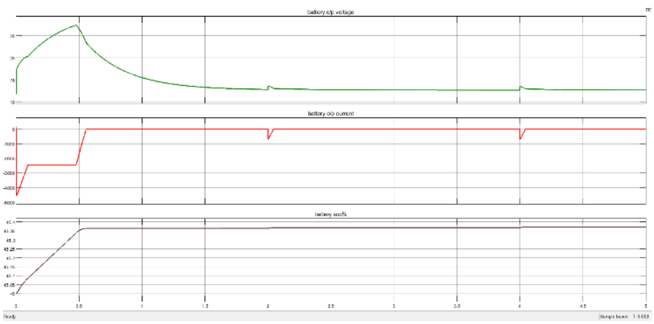

Fig. 5. Output voltage, current, and SOC of battery

Initially, the battery with 45% SOC is considered. At first, the battery voltage fluctuated but came to steady-state conditions and the corresponding output current is varied[12]. The battery's SOC started increasing indicating the charging of the battery. This shows that the MPPT algorithm is working and the expected results are obtained.

V. Hardware Implementation

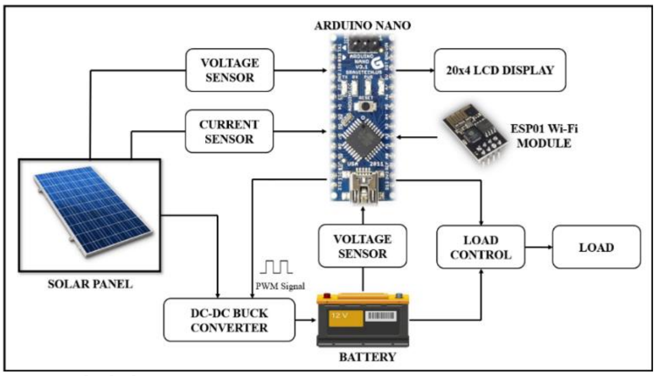

Fig. 6. Block diagram

The block diagram of the Solar MPPT system is given in Fig. It has a solar panel, voltage and current sensor, Arduino NANO microcontroller, DC-DC Buck Converter [13], Battery, ESP01 Wi-Fi module,20x4 LCD, and load. Solar Panel produces electrical energy from the light incident on it. Arduino NANO board is chosen to implement P&O Algorithm.ACS712 current sensor is used to sense the current from the solar panel[14]. The DC-DC Synchronous Buck converter is designed to reduce the panel voltage to the load voltage[15]. The voltage conversion is made by adjusting the duty cycle of the MOSFET switches of the Buck Converter[16]. The PWM signal is given to the gate of the Buck converter to vary the duty cycle, from the Arduino NANO depending on the input voltage received from the solar panel. A voltage divider circuit is used to measure panel voltage and battery voltage[17]. The voltage divider reduces the voltage range of the Arduino analog inputs for measuring. 20 × 4 Liquid crystal display (LCD) is used to display load condition, solar panel voltage, SOC of battery, and percentage of pulse width modulation (PWM). ESP01 Wi-Fi module is interfaced with Arduino to fetch the solar panel parameters and send them to the server through the internet to enable monitoring under real-time time conditions[18].

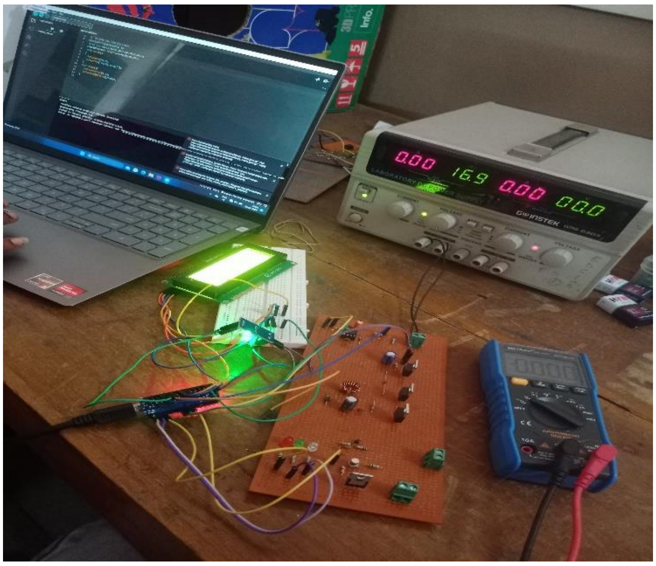

Fig.7: Experimental Set-up in Laboratory

VI. Conclusion

In this study, we embarked on a comprehensive exploration of solar maximum power point tracking (MPPT) and energy monitoring systems under real-time conditions. The primary objective was to design and implement an efficient solar MPPT system that not only optimizes energy harvesting but also provides accurate real-time monitoring. The response is more stable and relatively faster. Its increased energy harvesting efficiency contributes to higher energy yields, while real-time monitoring aids in system maintenance and fault detection.

References

[1] kumar Nath U, Sen R. A Comparative Review on Renewable Energy Application, Difficulties and Future Prospect. 2021 Innovations in Energy Management and Renewable Resources (52042). 2021 Feb 5:1-5.

[2] Parimi SR, Dawn S, Karri H, Polavarapu A, Yakasiri R. A Comparative Study of CSP to Produce Electricity Even at Night. In2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS) 2023 Mar 23 (pp. 1075-1080). IEEE.

[3] Guangul FM, Chala GT. Solar energy as renewable energy sources SWOT analysis. In2019 4th MEC international conference on big data and smart city (ICBDSC) 2019 Jan 15 (pp. 1-5). IEEE.

[4] Yu J, Tang YM, Chau KY, Nazar R, Ali S, Iqbal W. Role of solar-based renewable energy in mitigating CO2 emissions: evidence from quantile-on-quantile estimation. Renewable Energy. 2022 Jan 1;182:216-26.

[5] Bollipo RB, Mikkili S, Bonthagorla PK. Hybrid, optimal, intelligent and classical PV MPPT techniques: A review. CSEE Journal of Power and Energy Systems. 2020 Aug 19;7(1):9-33.

[6] Ahmed AS, Abdullah BA, Abdelaal WG. MPPT algorithms: Performance and evaluation. In2016 11th International Conference on Computer Engineering & Systems (ICCES) 2016 Dec 20 (pp. 461-467). IEEE.

[7] Beriber D, Talha A. MPPT techniques for PV systems. In4th International conference on power engineering, energy and electrical drives 2013 May 13 (pp. 1437-1442). IEEE.

[8] Sharma A, Gupta S, Kumar N. Modelling and Comparison of Different MPPT Algorithms for a Standalone PV System. In2020 International Conference on Electronics and Sustainable Communication Systems (ICESC) 2020 Jul 2 (pp. 989-995). IEEE.

[9] PK VK, Manjunath K. A comparitive analysis of MPPT algorithms for solar photovoltaic systems to improve the tracking accuracy. In2018 International Conference on Control, Power, Communication and Computing Technologies (ICCPCCT) 2018 Mar 23 (pp. 540-547). IEEE.

[10] Hamidon FZ, Aziz PA, Yunus NM. Photovoltaic array modelling with P&O MPPT algorithm in MATLAB. In2012 International Conference on Statistics in Science, Business and Engineering (ICSSBE) 2012 Sep 10 (pp. 1-5). IEEE.

[11] Villalva MG, Ruppert E. Analysis and simulation of the P&O MPPT algorithm using a linearized PV array model. In2009 35th Annual Conference of IEEE Industrial Electronics 2009 Nov 3 (pp. 231-236). IEEE.

[12] Saidi K, Maamoun M, Bounekhla MH. Simulation and analysis of variable step size P&O MPPT algorithm for photovoltaic power control. In2017 International Conference on Green Energy Conversion Systems (GECS) 2017 Mar 23 (pp. 1-4). IEEE.

[13] Wang Z, Chen Y. Design of a High Efficiency Buck Converter. In2020 IEEE 1st China International Youth Conference on Electrical Engineering (CIYCEE) 2020 Nov 1 (pp. 1-6). IEEE.

[14] Masri S, Mohamad N, Hariri MH. Design and development of DC-DC buck converter for photovoltaic application. In2012 International Conference on Power Engineering and Renewable Energy (ICPERE) 2012 Jul 3 (pp. 1-5). IEEE.

[15] Bernardo PC, Peixoto ZM, Neto LM. A high efficient micro-controlled buck converter with maximum power point tracking for photovoltaic systems. InInternational Conference on Renewable Energies and Power Quality (ICREPQ'09), Valencia (Spain), 15th to 17th April 2009 Apr.

[16] Deekshitha C, Shenoy KL. Design and simulation of synchronous buck converter for LED application. In2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT) 2017 May 19 (pp. 142-146). IEEE.

[17] Gopal M, Prakash TC, Ramakrishna NV, Yadav BP. IoT based solar power monitoring system. InIOP Conference Series: Materials Science and Engineering 2020 Dec 1 (Vol. 981, No. 3, p. 032037). IOP Publishing.

[18] Zeroual B, Moummi A. Design of parabolic trough collector solar field for future solar thermal power plants in Algeria. In2012 2nd International Symposium On Environment Friendly Energies And Applications 2012 Jun 25 (pp. 168-172). IEEE.