Evaluation of Maximum Power Point Tracking Techniques for Photovoltaic Systems.

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Abstract

This paper presents a comprehensive study to obtain the maximum power point tracking for a photovoltaic module connected to a resistive load. The MPPT methods and techniques used in this paper were presented (P&O, I.C, Hill Climb, AVOA-ANFIS and fuzzy logic MPPT methods). These techniques were compared to achieve MPPT, and the results showed that soft computing and artificial intelligence algorithms represented by AVO give the best performance among all the methods used to obtain MPP. It determines the MPP with high accuracy, great speed, and quick response, which improves the overall performance of the system and works to reduce losses, and thus the system's efficiency increases.

Keywords— *Photovoltaic, MPP tracking, MATLAB simulation.*

I. INTRODUCTION

The efficiency of the PV array is impacted by a variety of internal and external factors. Solar irradiation (*G*), ambient temperature (*T*), and wind are the main external elements that influence both the maximum power and the voltage at the maximum power point (MPP) of a PV array. These external factors also modify the placement of the maximum power point (MPP) on the current-voltage (I-V) curve. Additionally, the primary internal element that can force the PV panels to operate in direct coupled systems at a precise point on the I-V curve is load. The operational point on I-V curves is established by the intersection of diverse load lines and I-V curves across various environmental circumstances. Consequently, it is essential to regularly track the PV array's maximum power point (MPP) [1]. The MPP tracking control, however, is a challenging issue. To address this issue, a variety of tracking control techniques have been developed, including perturb and observe (P&O), incremental conductance (I.C), parasitic capacitance, constant voltage, and neural networks [2],[3]. These techniques' shortcomings include their high cost, intricacy, complexity, and instability [4]. The main approach utilized by these control mechanisms involves the modification of the duty cycle of the shunt metal oxide semiconductor field-effect transistor (MOSFET) in the maximum power point tracking (MPPT) converter. The operational point of the PV panel at the MPP is maintained using the MPPT converter. In order to accomplish this, the MPPT controller regulates the voltage or power of the PV array without regard to the load.

The bulk of MPPT control schemes, such duty cycle ratio control and employing a look-up table, rely on PV panel properties in real time [5]. Four main categories can be used to classify MPPT techniques:

(a) The perturbation and observation (P&O) algorithm is based on forcing the direction of tracking toward an MPP by perturbing a PV panel's operating points.
(b) The hill-climbing algorithm that directly affects a DC-DC power converter's duty cycle.

(c) Implementing the incremental conductance (INC) algorithm involves routinely assessing the PV panel's P-V curve's slope. The perturbation is halted, and the PV panel is made to operate at this operational point if the slope equals zero or a predetermined tiny value [6].

(d) The constant voltage algorithm is based on maintaining a constant value for the ratio of the PV voltage at maximum power (V_{mp}) to the open circuit voltage (V_{oc}) [7], and it also ignores the impact of fluctuations in solar irradiation.

II. PV POWER SYSTEM STRUCTURE

A photovoltaic power system usually consists of several basic ingredients; PV panels (PV modules), a DC-DC converter (buck-boost) with MPPT controller, and a stand-alone resistive load, as depicted in Figure 1. The operating characteristics of the PV array are the voltage and current (I-V) characteristics. The (I-V) characteristics of the PV array depend non-linearly on the changes occurring in the solar radiation. The performance of the photovoltaic power system is improved by using the DC-DC converter, which is also known as the MPPT. This MPPT is utilized to improve the characteristics of the PV panels.

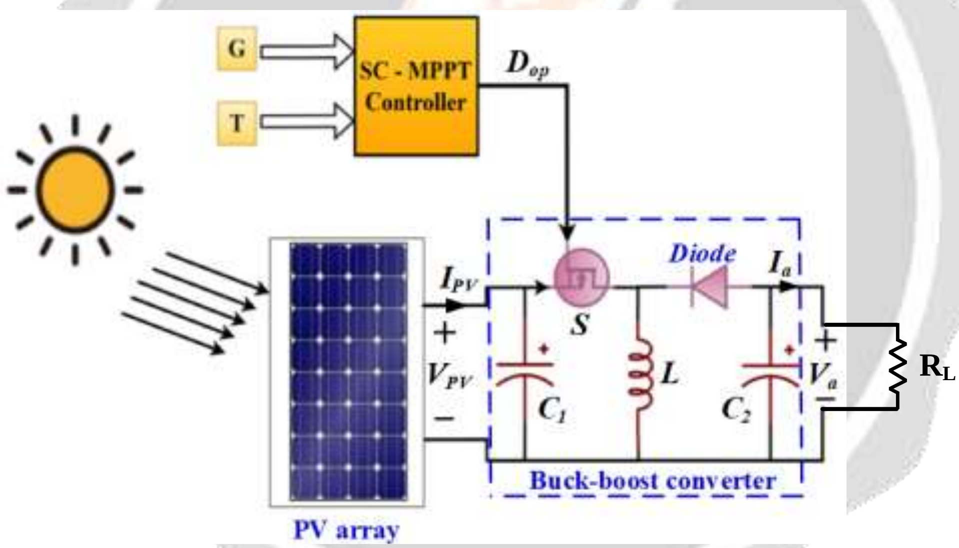

Figure1: Basic ingredients of the PV power control system.

III. MPPT Control Algorithms

3.1 P&O Method

One of the most often used strategies for MPPT in solar PV systems is the Perturb and Observe (P&O) method. Real-time data from sensors is utilized in this technique to compute PV power output, and voltage perturbations are systematically introduced to determine the direction in which the tracking should proceed [8]. The output power may grow or decrease continuously depending on the influence of these voltage disturbances. As a result, the algorithm constantly fine-tunes its parameters through voltage perturbations, leading to oscillations at the Maximum

Power Point (MPP) [9]. Despite the fact that it is simpler and has less computational complexity than other MPPT algorithms, the P&O approach is not the best solution for high-power applications.

3.2 I.C Method

This approach depends on the ratio of the incremental conductance to the instantaneous conductance value of the photovoltaic (PV) module to accomplish Maximum Power Point (MPP) tracking using the Incremental Conductance (I.C) technique. This ratio is used to change the slope of the P-V (Power-Voltage) characteristics curve, which defines the duty cycle (D) of the converter. MPP tracking using the I.C algorithm generally consists of two basic steps: zero error condition and leftward adjustment [10].

3.3 Hill climbing Technique

The Hill Climbing method is one of the most ancient and conventional ways of Maximum Power Point Tracking (MPPT) [11]. Its popularity can be ascribed to its ease of use and effectiveness. The system monitors both voltage and current levels in this technique, using these readings to determine power output. The duty cycle of the converter is then modified correspondingly. The duty cycle is changed incrementally or decrement ally in this modification. The converter progressively approaches the duty cycle that corresponds to the Maximum Power Point (MPP) after a given number of cycles. The Hill Climbing method is distinguished by its simplicity, making it simple to comprehend and apply [42].

3.4 Fuzzy logic Technique

Fuzzy logic is a computational method for dealing with imprecise or uncertain data. Unlike classical binary, it is capable of handling variables with degrees of truth. To make judgments, it employs language variables, membership functions, and fuzzy rules.

3.5 MPPT Neuro Fuzzy System Based AVOA

An Adaptive Neuro-Fuzzy Inference System (ANFIS) model trained using duty cycle data optimized by the Artificial Virus Optimization Algorithm (AVOA) is used in the proposed maximum power point tracking (MPPT) technique. This combination of optimization, AI, and MPPT results in an intelligent control solution.

IV. Results and Discussion

In this paper, the results of the model proposed in this paper will be presented. It contains the results of ANFIS and the performance of simulation models for MMPT with FLC. Besides assessing the MPPT system concerning a system directly linked to a resistive load. A comparison was made between traditional methods and methods that rely on soft computing for the performance of simulation models for MMPT. This comparison was made between the P&O, I.C, Hill Climb, AVOA-ANFIS and fuzzy logic MPPT methods to achieve the maximum power point tracking.

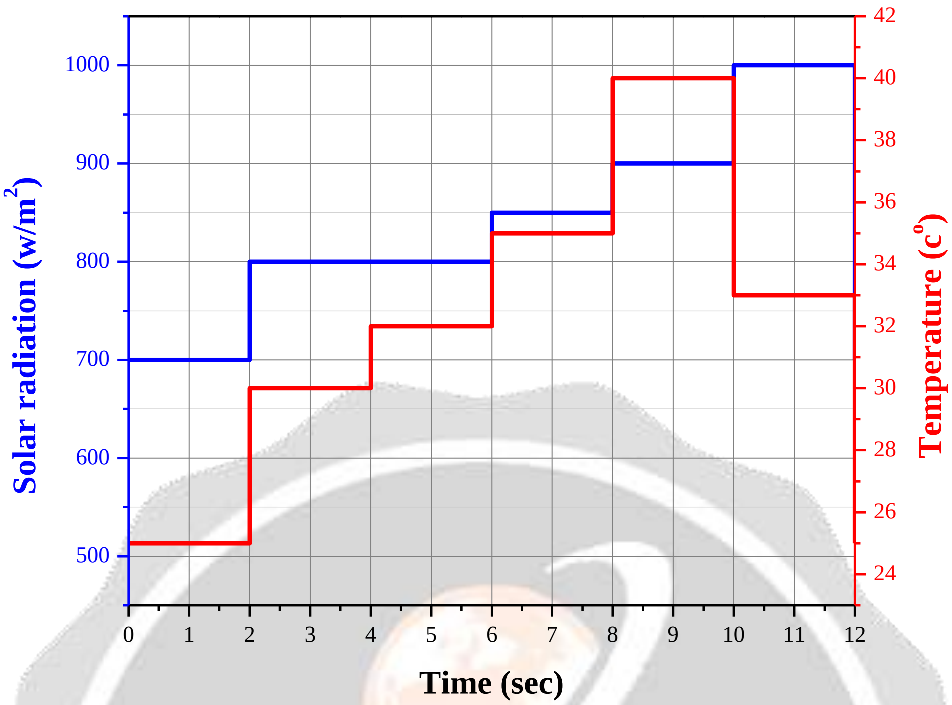

Figure 2: Graphical representation of solar radiation (G) and ambient temperature (T) of PV module.

First, a comprehensive explanation was provided of the dynamic changes in both parameters, solar radiation (*G*) and ambient temperature (*T*), which significantly affect the photovoltaic cell used throughout the simulation time period (12 Sec). These dynamic changes are presented as depicted in Figure 2. A comprehensive and detailed analysis of the response of the photovoltaic module to various environmental conditions can be performed by means of dynamic changes, as they do not occur gradually, but occur in distinct steps. What a solar irradiation (*G*) and ambient temperature (*T*) interact with the PV module can be seen in a stepwise manner by observing the graphical representation within Figure 2. This observation provides valuable and distinct insights into the performance of the PV module when affected by different and variable environmental factors.

Figure 3 serves as a compelling visual representation of the effectiveness of various control techniques in detecting and tracking the maximum power point (MPP) of a photovoltaic (PV) module throughout a simulation period. Notably, AVOA-ANFIS and fuzzy logic technique emerge as the most accurate and reliable methods for MPP tracking. The power load curve analysis reveals a distinct advantage in favor of the AVOA-ANFIS control technique, consistently demonstrating superior power transfer to the load across all simulated time periods as illustrated in Figure 4.

Throughout the subsequent simulation time, extending up to 12 seconds, the AVOA-ANFIS technique maintained its position as the pinnacle of precision and responsiveness among all the MPP tracking methods. It seamlessly adjusted to fluctuations in irradiance and temperature, consistently tracking the true MPP with unwavering accuracy. These findings underscore the AVOA-ANFIS method as the most dependable choice for optimizing PV module performance, particularly in dynamic environmental conditions, while highlighting the limitations of fuzzy logic and hill climb controllers in achieving accurate MPP tracking.

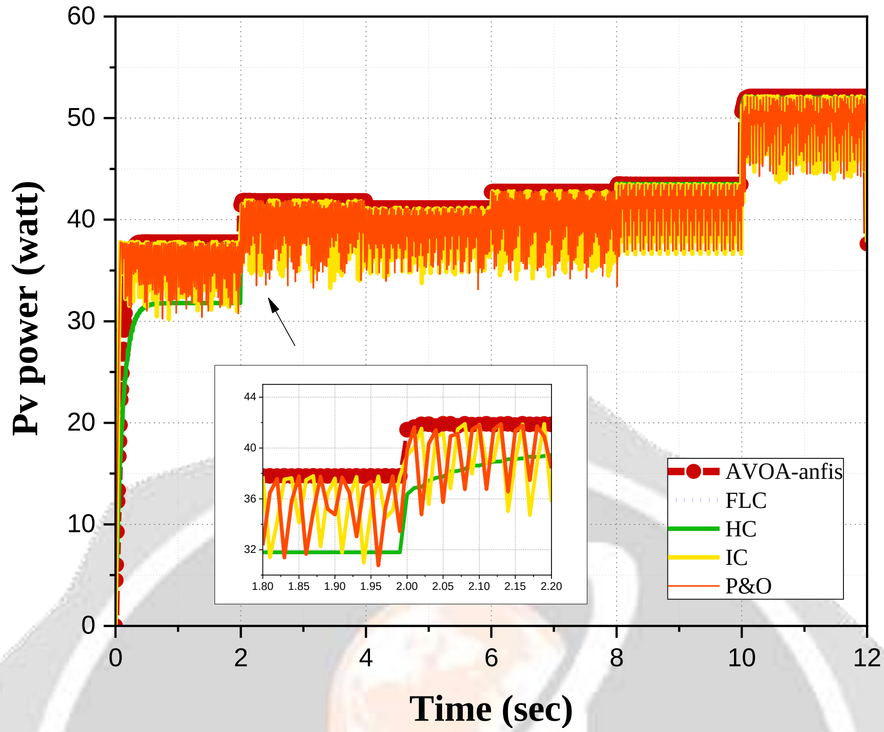

Figure 3 Performance characteristics of PV module, PV power vs. time.

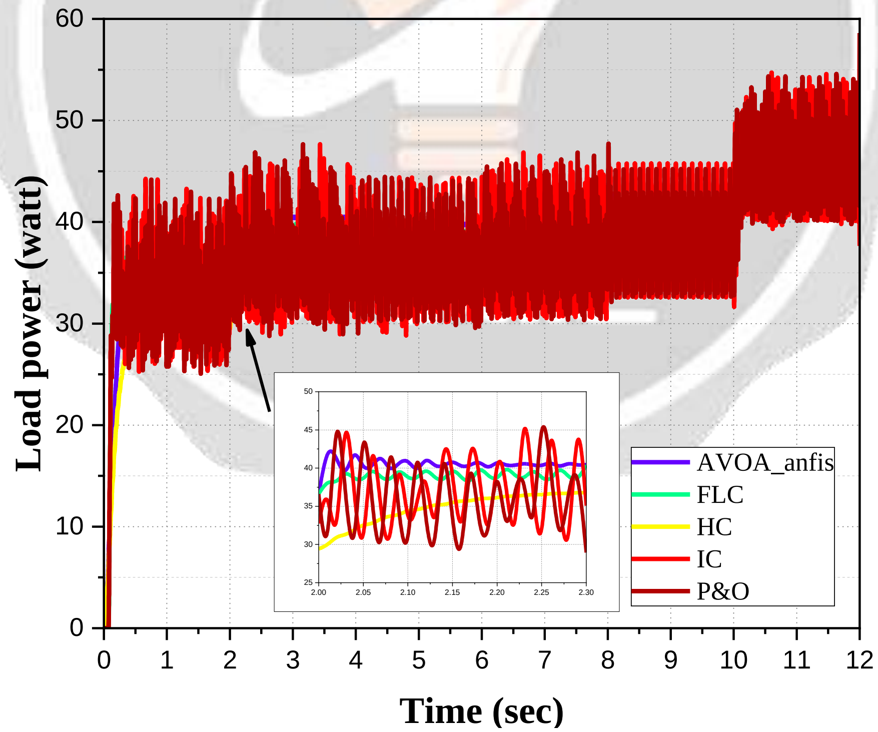

Figure 4: Performance characteristics of load, load power vs. time

Notably, during the crucial 2 to 4-second interval, the AVOA-ANFIS method excels by delivering 42 W to the load, clearly outperforming FLC control and HC strategies, which yield a comparatively lower 37 W and 35 W respectively. In contrast, P&O and IC control techniques lag further, with power fluctuating up and down and averaging only 34 W of power transfer over the same time frame.

V. Conclusion

This paper offers a thorough investigation to achieve maximum power point tracking for a photovoltaic module linked to a resistive load. The MPPT methods and techniques used in this paper were presented and analyzed. These techniques were compared to achieve MPPT, and the results showed that soft computing and artificial intelligence algorithms represented by AVO give the best performance among all the methods used to obtain MPP.

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