INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 7 (2024) 176-187
https://publisher.uthm.edu.my/ojs/index.php/ijie

Simulation and Design of Modified Adaptive-based Maximum Power Point Tracking Methods for Photovoltaic Systems

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DOI: https://doi.org/10.30880/ijie.2024.16.07.016

Article Info

Received: 9 May 2024
Accepted: 11 November 2024
Available online: 3 December 2024

Keywords

Photo voltaic system, MPPT, adaptive fixed MPPT, adaptive variable MPPT

Abstract

The quality of the supplied electrical energy is becoming increasingly stringent as the use of energy grows. As traditional energy sources grow depleted and the cost of electricity rises, photovoltaic energy emerges as a possible option. A growing number of people are turning to photovoltaic (PV) generation as a renewable energy source due to its many benefits, including low maintenance and quiet operation. This research compares the most widely used MPPT algorithms which are the Adaptive fixed duty ratio method (AFDR) and the Adaptive variable duty ratio method (AVDR). In this paper the simulation and analytical analysis for the two MPPT techniques of AFDR and AVDR for the PV System under three methodologies such as irradiation, duty cycle variations of the converter, and load variations. From the results, it was found that AVDR increased the PV output power and the AVDR method has proved that it has fast transient convergence with a better steady-state tracking efficiency.

1. Introduction

Due to the massive usage and expiration of fossil fuels, renewable energy sources are becoming increasingly important. Solar energy is also the most widely accessible and premium source of energy. Among the applications of photovoltaic arrays are water pumping, rural lighting, and grid-connected systems [1]-[2]. With its numerous advantages, solar power generation is becoming more popular as a source of renewable energy, including cleanliness, low maintenance, and absence of noise. Power output from PV arrays varies depending on weather conditions, such as UV irradiance and temperature [3]-[6]. PV systems use MPPT to maximize the power output of photovoltaic arrays, regardless of weather conditions or load characteristics. PV array output power controls the electrical characteristics of the load directly. By directly controlling the dc/dc converter with PV array output power, system complexity is reduced. A maximum-power point tracking (MPPT) method is proposed in this paper, with high efficiency and a lower cost [6]-[9]. Perturb and observe (P&O) approaches still suffer from several drawbacks, including continuous oscillations about the MPP, tradeoffs between fast-tracking and oscillations, and the need to define constants for each experiment [10]-[15]. Adaptive fixed duty ratio (AFDR) and Adaptive variable duty ratio (AVDR) methods for PV systems are discussed in this research. The purpose of this research is to judge evaluate two main types of MPPT techniques. Simulation results are presented for the Adaptive fixed duty ratio method (AFDR) and Adaptive variable duty ratio method (AVDR) methods with changing radiation and temperature.

1.1 Mathematical Modeling of PV Array

Photovoltaic cell absorbs solar power and transforms it into DC power [16]-[22]. The Fig.1 depicts a simplified comparable circuit model 1.

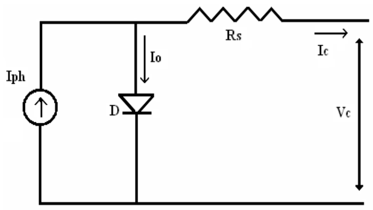

Fig. 1 *Equivalent circuit of photovoltaic cell*

Photovoltaic voltage is determined by the photocurrent equation, which is primarily dictated by load current during operation and is dependent on sun irradiation level. The primary eqn (1) is,

$$V_{cx} = \frac{AKT_c}{q} \ln\left[\frac{I_{ph} + I_0 - I_c}{I_0}\right] - R_s I_c \tag{1}$$

q: electron charge (1.602 × 10-19 C).
k: Boltzmann constant (1.38 × 10-23 J/^{0}K).
I_c: cell output current, A.
I_{ph}: photocurrent, the function of irradiation level and junction temperature (5 A).
I_o: reverse saturation current of a diode (0.0002 A).
R_s: series resistance of cell (0.001 Ω).
T_c: reference cell operating temperature (25 °C).
V_c: cell output voltage, V.

Kelvin or Celsius should be used as the temperature units for both k and TC. [4] describes a way for including these impacts in PV array modeling. As seen in eqn (2) and (3), the temperature coefficients are C_{TV} and C_{TI} for cell output voltage and cell photocurrent, respectively (3),

$$C_{TV} = 1 + \beta_T (T_a - T_x) \tag{2}$$

$$C_{T1} = 1 + \frac{\gamma_t}{sc}(T_x - T_a) \tag{3}$$

The cell temperature is T=0.004 and temperature T=0.06, the ambient temperature during cell testing is Ta=20°C. The operational temperature and photocurrent of the cell rise from T_{x1} to T_{x2} and I_{ph1} to I_{ph2}, respectively, when the solar irradiation level rises from S_{x1} to S_{x2}. In an equation, C_{SV} and C_{ST} are correction factors that are dependent on cell output voltage V_C and photocurrent I_{PH} (4). (5),

$$C_{SV} = 1 + \beta_T \alpha_S (S_x - S_C) \tag{4}$$

$$C_{ST} = 1 + \frac{1}{S_c}(S_X - S_C) \tag{5}$$

As illustrated in equations (7) and (8), the new values of the cell output voltage V_{CX} and photocurrent I_{PHX} are calculated using C_{TV}, C_{TI}, C_{SV}, and C_{SI} (correction factors) for the new temperature T_X and solar irradiation S_X (8).

$$V_{CX} = C_{TV} C_{SV} V_C \tag{6}$$

$$V_{CX} = C_{TV} C_{SV} V_C \quad (7)$$

V_C and I_{PH} are the photocurrent and output voltage benchmarks for reference cells, respectively. The I-V and P V curves that emerged for different temperatures and sun irradiation levels were described in results section. Using equations (8) and (9) get PV output power is computed (10). PV module power output is depicted in Fig.2.

$$P_c = V_c\left(I_{ph} - I_a * \exp(\frac{q}{AKT} V_c - 1)\right) \quad (8)$$

$$I_c = I_{ph} - I_0 * \exp\left(\frac{q}{AKT} V_c - 1\right) \quad (9)$$

1.2 MPPT Algorithm for Photovoltaic System

As illustrated in Fig.2, it is clearly observed that the new tracking technique is dependent on the derivative of the output power concerning the panel voltage being zero at the maximum power point [4]-[7]. The derivative of the output power is higher than zero to the left of the peak point and lower than zero to the right.

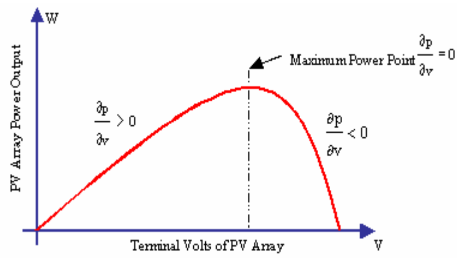

Fig. 2 *P-V characteristics of a module*

$$\frac{\partial P}{\partial V} = 0\, for V = V_{mp} \quad (10)$$

$$\frac{\partial P}{\partial V} > 0\, for V < V_{mp} \quad (11)$$

$$\frac{\partial P}{\partial V} < 0\, for V > V_{mp} \quad (12)$$

1.3 Adaptive Fixed Duty Ratio Method

To drag the utmost amount of power from the photovoltaic system to the grid (load), a proper optimized MPPT technique is very much required due to the low efficiency of the PV System as compared to other renewable energy sources. Based on power perturbations and duty cycle fluctuations, the adaptive fixed duty ratio method (AFDR) presents a novel control strategy that allows the system to function at utmost power. The AFDR control algorithms use the same inputs of derivative power and perturb voltage as shown in Fig. 3. In this method, the switching instants of the converter vary with the duty ratio of the control algorithm. Moreover, the duty ratio has an equal impact on voltage and current variations to achieve the optimal tracking power compared to the only voltage variations. The PV system output is sensed by using the voltage and current sensor which will act as an input to the control algorithm (AFDR). This control algorithm produces the necessary duty ratio to have a better tracking output power. As an input, the AFDC MPPT controller receives the PV output consisting of both voltage and current. The duty ratio is generated by the AFDC MPPT controller using a set step-size perturbation. By this method, the duty cycle is changed in response to the perturbation voltage, as well as the operating point oscillates around the MPPs. It can change the duty ratio to fit the PV array's characteristic impedance to the load impedance. As a result, the maximum power is supplied to the load

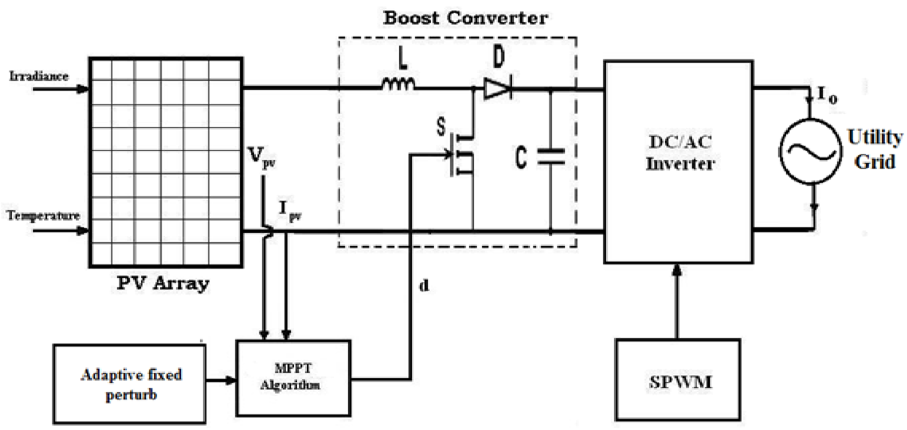

Fig. 3 *Block diagram of single phase grid connected PV system with AFDC MPPT technique*

1.4 AFDC MPPT Algorithm

In a solar system using a boost converter as a power conditioner, the relationship between the 'P' and 'D' curves is depicted in Fig 4. Where 'P' is for PV output power and 'D' stands for DC-DC boost converter duty cycle. The duty cycle is given in Eqn (13)-(15),

$$d(k) = d(k-1) \pm \frac{dP/dD}{P/D} \tag{13}$$

If *dP/dD*>0 be able to access maximum power point, then the expression (13) as modified as

$$d(k) = d(k-1) + \frac{dP/dD}{P/D} \tag{14}$$

Similarly, for *dP/dD*<0, then the equation is

$$d(k) = d(k-1) - \frac{dP/dD}{P/D} \tag{15}$$

If dP/dD>0, The P-D curve's operation starts on the left side. (MPP). The real operational point, however, is located on the right-hand side to maintain dP/dD0 at the maximum power supply. The power reaches its greatest point when the dP/dD tracking system is set to 0. It is clearly shown in Fig.4.

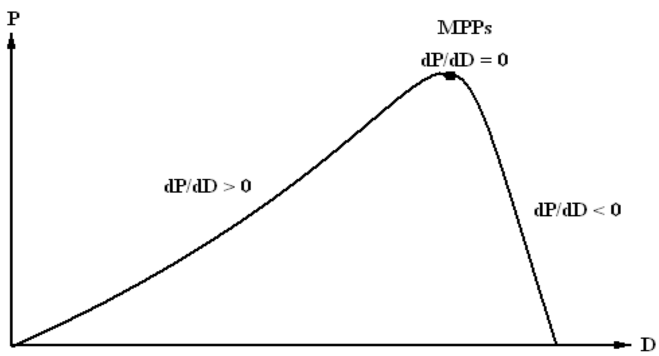

Fig. 4 *Relationship of P and D*

1.5 Flowchart of AFDC MPPT Algorithm

The algorithm compares the present power with the previous one and selects the best among them until the required MPPs are reached. The control algorithm flowchart is seen in Fig. 5

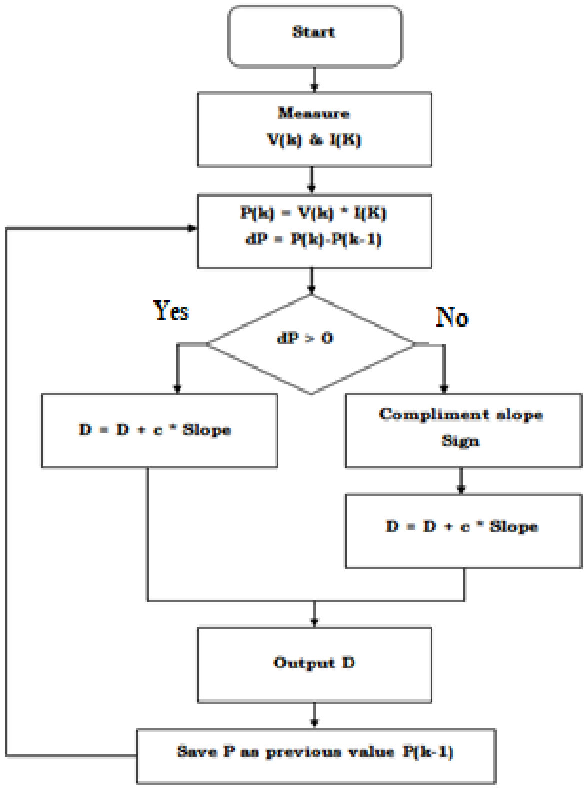

Fig. 5 *Flowchart of AFDC MPPT technique*

2. Adaptive Variable Duty Ratio Method

To make the performance better even for the smaller perturbs and to have a shorter settling time the adaptive variable duty ratio method is proposed to address the problem of faster tracking with lesser oscillations and to obtain the steady-state performance at a faster rate, the same isshown Fig.6. Since the evolution of digital controllers, the better control mechanism with lesser complexity to perform well has a larger advantage. The main issue of the AFDR technique, which is a trade-off between steady-state performance and dynamic response due to the selection of the incremental step of the switching duty cycle, is addressed in this proposed model. As a result, the performance is poor on both tracking and at the steady-state stage. In the proposed AVDR method, automatic tuning is done in incremental steps. The expressions for the AVDR method are given in the below eqn (16)-(18).

$$D(k) = c(k-1) \pm M \frac{|dP|}{c(k-1)} \tag{16}$$

Again the equation (16) is modified,

$$D(k) = c(k-1) \pm c(k) \tag{17}$$

$$c(k) = \pm M \frac{|dP|}{c(k-1)} \tag{18}$$

Where, *(k)*is a present incremental or decremented switching duty cycle. *c(k-1)*is a previous switching duty cycle from the above eqn (16)-(18) it is clear that the duty cycle purely depends upon the '*c(k)*' increment or decrement of the switching duty cycle. As result, the system is design-dependent and truly adaptive.

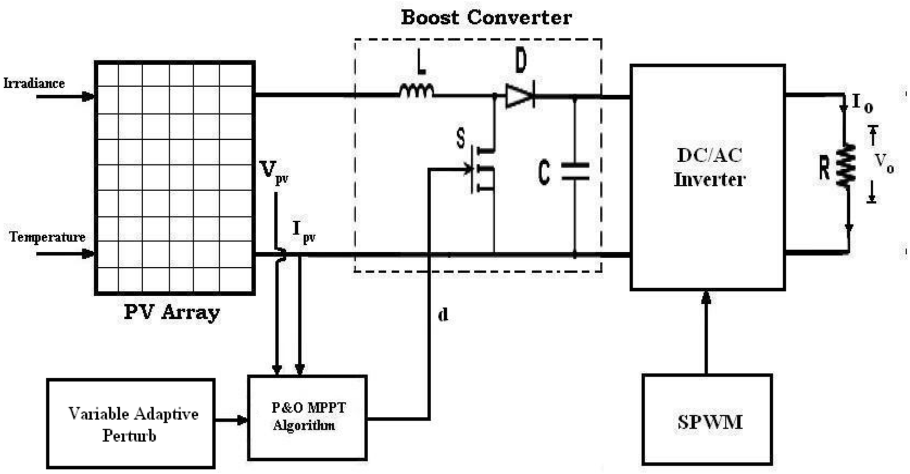

Fig. 6 *Block diagram of variable adaptive perturb and observe MPPT technique*

2.1 Flow Chart for AVDR MPPT Algorithm

The duty ratio is dependent upon the derivative Power and slope of the P & D curve which can be expressed as in the equation (19),

$$|dP|/c(k-1) \quad (19)$$

It is greater than the threshold, the controller recognizes that the power difference is primarily due to solar irradiation, thus the duty cycle aspect is increased in the same direction as d_P, and the power state shifts. The direction of perturbation is represented by slope in the flowchart as shown in Fig. 7. Similarly when the value $|dP|/c(k-1)$ is less, the controller supposes that the system control is limited by the steady-state.

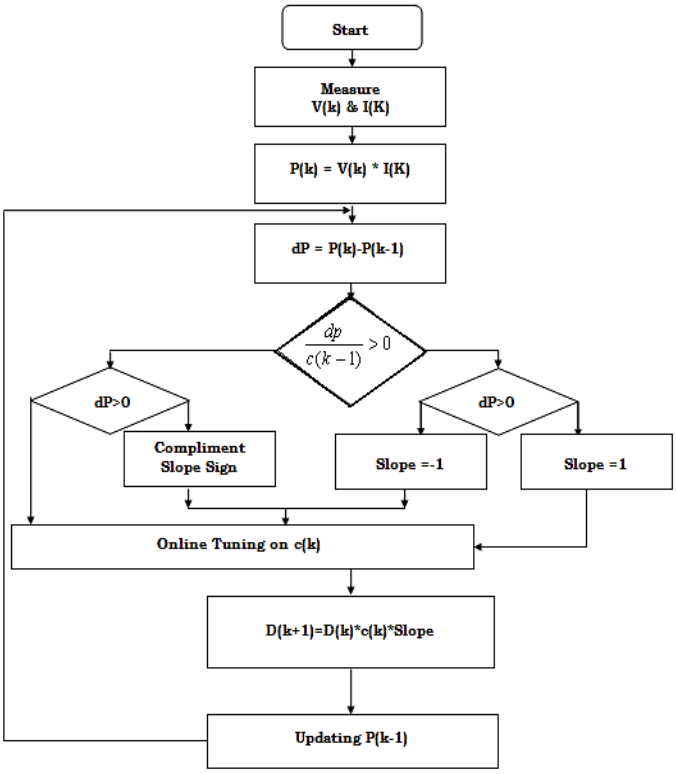

Fig. 7 *Flowchart for AVDR method*

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3. Results and Discussion

A voltage-controlled current source is precisely realized as a mathematical model of a 1000W photovoltaic array that is sensitive to two input parameters, temperature, and solar irradiation. Fig. 8 clearly shows I-V characteristics of various irradiation changes at 25^0C.

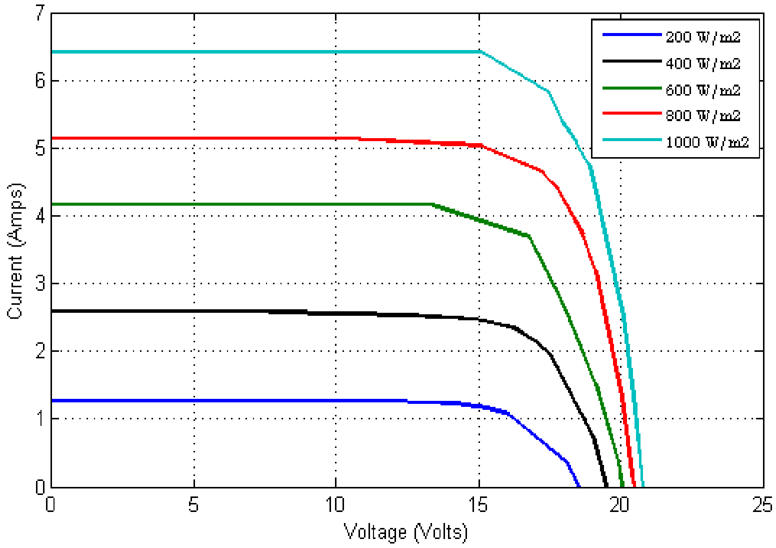

Fig. 8 *Simulated I-V characteristics with irradiance variations*

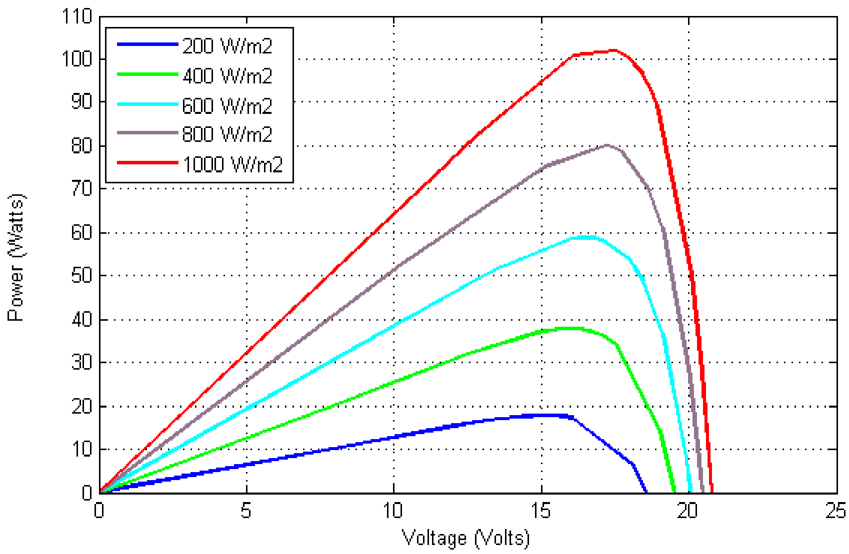

Fig. 9 *P-V curve with irradiance variations*

From fig. 8 & fig. 9, it can be observed that at constant temperature and varying irradiation the values of shout circuit current (I_{SC}), open circuit voltage(V_{OC}) and maximum power (P_{mp}) increases proportionally.

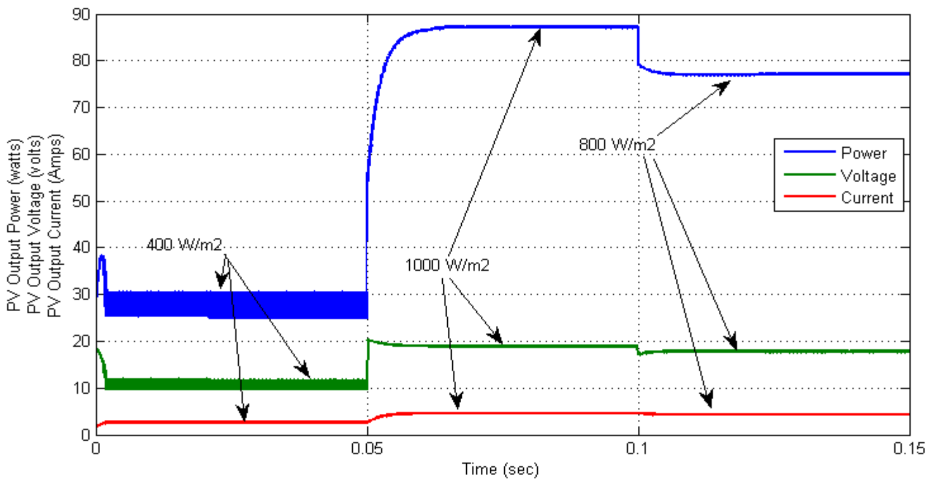

Fig. 10 *AFDC: simulated waveforms of PV output voltage, current, and power with various irradiances at a fixed temperature of 25°C*

Fig 10 shows that, particularly when the solar irradiances are operating at low values, the adaptive fixed duty cycle algorithm reaches oscillations more in PV power output of the PV system. But, when operating at moderate/high values of irradiances, the proposed AFDC control algorithm gives an optimal performance in PV output power. From the waveforms it is observed that as irradiance increases then the electrical parameters of the PV system also increases and vice versa.

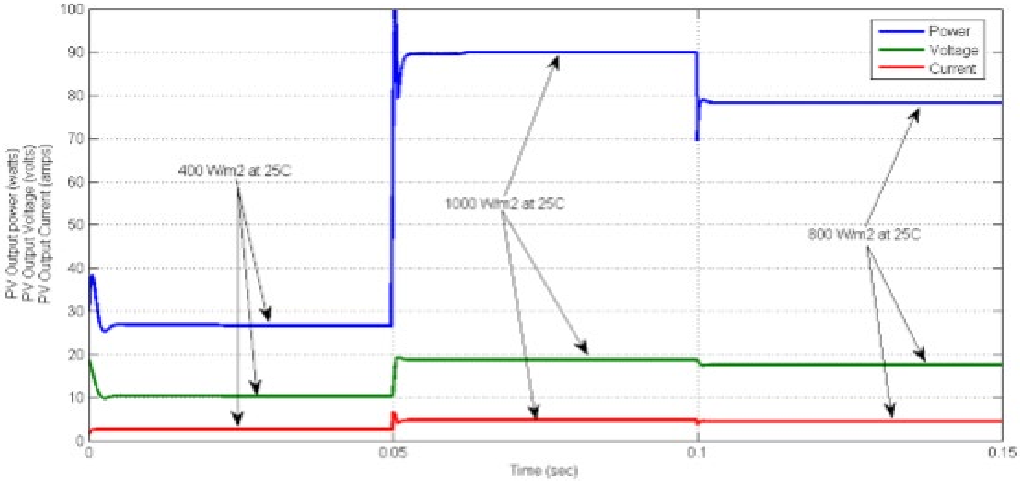

Fig. 11 *AVDR: Simulated waveforms of PV output voltage, current, and power with various irradiances at fixed temperature of 25°C*

A comparative analysis has been made between the two methods AFDR and AVDR for the change in irradiance from lowest value 200 W/m² to maximum value 1000 W/m² and at a constant temperature of 25°C.

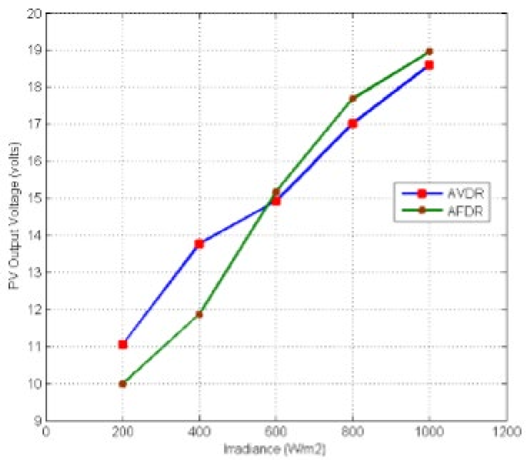

Fig. 12 *Comparative analytical evaluation of PV output voltage for different irradiances of AFDR and AVDR methods*

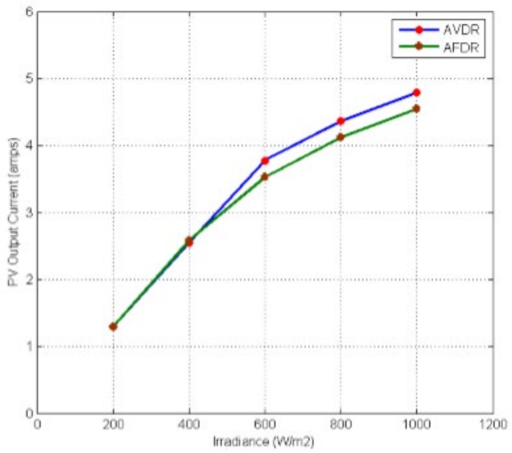

Fig. 13 *Comparative analytical evaluation of PV output current for different irradiances of AFDR method and AVDR method*

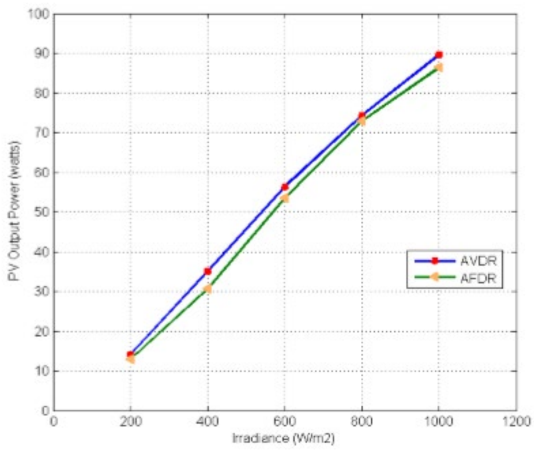

Fig. 14 *Comparative analytical evaluation of PV output power for different irradiances of AFDR method and AVDR method*

Fig. 11 depicts the comparative analysis of the PV System output voltage with two methods. The voltage sensing is better by AVDR even in the low irradiances as compared to the AFDR method. The current sensing is far better by the AVDR method rather than the AFDR method. The PV output current in both the methods is performing well up to 400 W/m² and sensing is better in the AVDR method for the higher irradiances. The important factor of PV output Power has been compared between the AFDR and AVDR methods and the later output power is better due to the fine variation in the duty cycle and this is depicted in Fig. 12-14.

Table 1 *Comparative analytical evaluation of PV output power for different irradiances of AFDR method and AVDR method*

Irradiance (w/m^2)	Temperature (^{0} C)	AFDR MPPT Technique			AVDR MPPT Technique		
		V_{mp}	I_{mp}	P_{mp}	V_{mp}	I_{mp}	P_{mp}
1000		18.97	4.548	86.29	18.61	4.786	89.60
800		17.70	4.120	72.92	17.02	4.366	74.32
600	25^{0}C	15.18	3.524	53.49	14.93	3.774	56.35
400		11.87	2.580	30.62	13.77	2.547	35.08
200		9.98	1.293	1.291	11.05	1.293	14.07

Table 1 shows that when the solar irradiation is 1000 W/m^2 and the cell temperature is 25^{o}C, the PV system's output power is 86.29 W. Table 1 shows that as the solar irradiance increases at constant temperature, the photovoltaic output power increases. From the above table it can be concluded that AVDR MPPT technique tracks more power when compared with AFDR MPPT technique. In the same way, as the temperature rises, the efficiency of photovoltaic output voltage decreases. Increases in temperature, on the other hand, enhance the photovoltaic system's output current. The tracking efficiency is better in the AVDR method as compared to AFDR under STC conditions by the simulation due to its better sensing and fast-tracking.

4. Conclusion

The conventional MPPT techniques are efficient but each and every MPPT MPPT suffers from the drawbacks which are produced due to the procedure followed for implementation. Keeping majority drawbacks in conisderation a modified and efficient MPPT technique is presented in this paper. Choosing an efficient MPPT algorithm is critical for obtaining the maximum power point of PV generator systems. One of the most well-known MPPTs is the adaptive fixed duty ratio approach, which is reasonably simple to simulate and apply. The AFDR approach has a spectacular rapid tracking capability, superior steady-state convergence, and tracking efficiency, but its performance is questionable for the transient period with slow response, and it performs poorly owing to non-flexible environmental variables and a fixed perturb step size. To address this issue, this paper proposes an adaptive variable duty ratio control technique that uses power as a control variable. The performance of an AVDR MPPT was observed at the DC-DC boost converter stage. As a result, increasing the execution speed allows the system to respond more quickly to rapid atmospheric changes as well as much higher efficiency of 89.60 percent compared to AFDR of 86.29 percent. Likewise, a closed-loop system is used to test the suggested adaptive variable duty ratio MPPT algorithm. As a result of the simulation results, the suggested MPPT control algorithm outperforms all other control strategies. As a result, MAP&O MPPT is well suited to increase tracking efficiency and reduce oscillation around MPPs in photovoltaic power output during different level temperature and solar irradiance areas.

Acknowledgement

We extend our heartfelt thanks to our co-authors, P.Sarala, D.Lenine, Ch.Sai Babu, J.Kanna Kumar for their significant support, particularly Lenine efforts in data collection and manuscript preparation. Special thanks to the Department of Electrical and Electronics Engineering at Rajeev Gandhi Memorial College of Engineering and Technology for providing the necessary resources. We also acknowledge the support of our colleagues and fellow researchers. Finally, we are grateful to our families for their unwavering support and understanding.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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Author Contribution

The authors confirm contribution to the paper is as follows: ***study conception and design:*** *P.Sarala, D.Lenine, Ch.Sai Babu;* ***data collection:*** *J.Surya Kumari, D.Lenine;* ***analysis and interpretation of results:*** *J.Surya Kumari, J.Kanna Kumar;* ***draft manuscript preparation:*** *J.Surya Kumari, P.Sarala, D.Lenine . All authors reviewed the results and approved the final version of the manuscript.*

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