Dijlah Journal of Engineering Science (DJES) Vol. 3, No. 3, August, 2026, pp. 1-9
ISSN: Printed: **3078-9656, Online: 3078-9664**, paper ID: 181

Enhanced Incremental Conductance MPPT algorithm for Photovoltaic Systems by Adaptive Hysteresis Control

Mustafa F. Mohammed
[1]BIT Dept., Collage of Business Informatics, University of Information Technology and Communications, Baghdad, Iraq

Article Info

Article history:

Received Jan., 20, 2026
Revised May.,15, 2026
Accepted Jun.,10, 2026

Keywords:

DC/DC;
Incremental Conductance
Hysteresis
MPPT
Zeta

ABSTRACT

In recent decades, “renewable energy sources” (RES) such as photovoltaic (PV) have been developed and enhanced to generate more power at the same panel area. Also, many researchers have developed many techniques to extract the maximum power from these panels at different operating conditions. This research presents a design for an upgraded adaptive hysteresis incremental conductance AHIC “maximum power point tracking” MPPT algorithm for photovoltaic systems. This MPPT improves the traditional IC approach by adaptive hysteresis control and directed memory. This MPPT is engineered for photovoltaic PV systems functioning under variable environmental conditions. The suggested AHIC algorithm mitigates three significant drawbacks of the traditional IC method, namely persistent oscillations and sluggish responsiveness to variations in irradiance. The suggested enhancement involves the self-adjusting hysteresis band to attain the “maximum power point” MPP, fluctuating between 70% and 82% of the photovoltaic input power. The present study has devised a design for a 2kW photovoltaic system utilizing a "Zeta" converter to execute MPPT. The suggested MPPT algorithm and the complete system are implemented and simulated using MATLAB SIMULINK software.

Corresponding Author:

Mustafa F. Mohammed
Department of Business Information Technology, Collage of Business Informatics, University of Information Technology & Communications

Al-Nidhal street, Baghdad, Iraq
Email: Mustafa.fawzi@uoitc.edu.iq

1. INTRODUCTION

Renewable energy sources RES have emerged as a crucial complement to fossil fuels. RES such as wind, sun, and hydropower are the most prevalent and dependable forms of energy. Photovoltaic PV is a type of renewable energy source that converts solar radiation into electrical energy through PV panels. It is regarded as one of the most pristine energy sources because to its simplicity and operational efficacy. Given the intermittent availability of these renewable energy sources, optimizing photovoltaic system power has emerged as a critical priority for academics [4]. Various techniques have been employed for power optimization to enhance the electrical energy conversion from solar energy via a PV system, including the implementation of the "maximum power point tracking" MPPT concept [5-6].For enabling the system to operate at the “Maximum Power Point” MPP, an MPPT controller or algorithm is typically required. A multitude of strategies and techniques have been devised and implemented by numerous researchers in this domain [7-8] The most famous MPPT algorithms are “perturb and observe (P&O)”, “Incremental conductance (IC)” [9], and many techniques that mainly depend on those algorithms, like Fuzzy logic, sliding mode control, neural networks, etc. The IC algorithm is working on the aim that the instantaneous and incremental conductance ($dI/dV= -IV$) at MPP. This approach achieves the MPP more rapidly than the P&O algorithm [10]. Numerous researchers have contributed to the development and optimization of the MPPT algorithm. N. I. P. d. L. et al. [11] proposed a dynamic hysteretic P&O MPPT technique for a PV system utilizing a boost converter. The technique employed enhanced the efficacy of the P&O algorithm across various temperature fluctuations and solar radiation levels. Y. Goswami et al. [12] introduced a modified variable step size incremental conductance maximum power point tracking approach for photovoltaic systems. The predicted step size is determined by the fractional change in power relative to the current. In [13], a Fuzzy logic-based Perturb and Observe method is employed for a MPPT stand-alone transformer-less system utilized for irrigation applications. A cascade boost converter is used and linked to a T-type five-level inverter to provide power to a single-phase motor. The PV system developed by H. El Ouardi et al. [14] employs a combination of the IC algorithm and hysteresis control. The IC algorithm facilitates the reach to the MPP. The hysteresis control enhance the precision of tracking of the MPP under diverse environmental circumstances. R. Torres et al. [15] devised a fixed-step MPPT algorithm for low-power solar systems. The design employed a full-bridge DC-AC converter to establish a single-stage system. The design is both simulated and practically executed. The study published in [16] introduced a swift response tracking MPPT technique utilizing a "model reference adaptive controller" MRAC derived from the MIT formula to identify the MPP without oscillations. Their proposed regulator is improved by using 2 algorithms: the 1st algorithm is called "genetic algorithm" GA and the 2nd one is called whale optimization method. A Neuro-Fuzzy Inference System (NFIS) generates the reference voltage. A. Asnil et al. [17] examined modifications to the IC algorithm aimed at enhancing its performance and mitigating oscillations around the MPP. Their proposed alterations to the IC method are implemented in two ways, accompanied by a comparison of their replies. Each of the preceding researchers discussed in this literature has implemented adjustments to their suggested MPPT algorithms, which are based on either the P&O or IC methods. The IC algorithm is commonly acknowledged to exhibit a more rapid response than the P&O method. This study presents an improved MPPT algorithm for photovoltaic systems, which is founded on the IC method and incorporates an adaptive hysteresis controller and directed memory to operate under varying dynamic and environmental conditions. The optimized MPPT algorithm is linked to an appropriate DC/DC converter to increase the performance of the PV system. The present study work is structured as follows: an introduction, suggested system, upgraded IC MPPT algorithm, results and discussions, and conclusions.

2. System Architecture

The architecture of the proposed system consists of a PV solar panels and a "Zeta" converter. The details of each part are listed below:

2.1 PV solar panels:

The PV panels can be analyzed using semiconductor physics and electrical equations. The fundamentals of PV cells are modeled as a p-n junction diode that generates electrical energy when this junction is exposed to light. The total current that is generated by a solar cell is expressed by [18]:

$$I = I_L - I_0\left(e^{\frac{qV}{nkT}} - 1\right) - \frac{V + IR_s}{Rsh} \quad (1)$$

Where: I is the solar cell output current, I_L is a current is generated by the light (solar irradiance), I_0 represents the diode reverse saturation current, q represents the electron charge, V represents the cell voltage, k represents Boltzmann's constant, T represents the temperature in kelvin, and R_s and Rsh represents the series and shunt resistances in Ω. The electrical power is calculated by:

$$P = V \times I \quad (2)$$

and the **Maximum Power Point (MPP) is obtained when:**

$$\frac{dP}{dV} = 0 \quad (3)$$

And the efficiency (η) is measured by:

$$\eta = \frac{P_{max}}{P_i} = \frac{V_{oc} \times I_{sc} \times FF}{G \times A} \quad (4)$$

Where: G represents the solar radiation, A is the cell area, **I_{sc} and V_{oc} are short circuit current and open circuit voltage respectively, and FF is the form factor.**

2.2 Zeta DC/DC converter

The zeta converter is one kind of step up-step down DC/DC converters. It is considered non-inverting, continuous input current, and Fourth-order converter (2 capacitors and 2 inductors) [19-20]. The circuit of this converter is shown in Figure 1.

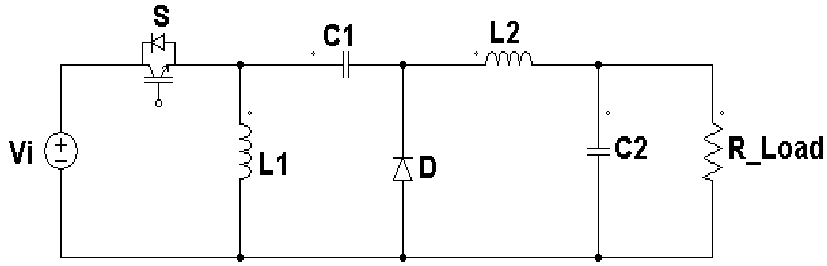


Figure 1. Circuit diagram of DC/DC Zeta converter

The voltage conversion ratio of this converter is:

$$\frac{V_{Load}}{V_i} = \frac{D}{1-D} \qquad (5)$$

Where D represents the duty cycle. The design equations are as stated below:
The inductor ripple ΔI_L is 20% of *the input current* I_i. Then the inductor L_1 can be determined by:

$$L_1 = \frac{V_i \times D}{fs \times \Delta I_{L1}} \qquad (6)$$

Where fs represents the switching frequency in Hertz, Then the equation for L_2 is:

$$L_2 = \frac{V_{Load} \times (1-D)}{fs \times \Delta I_{L2}} \qquad (7)$$

Also, C_1 (intermediate capacitor), and C_2 are expressed by:

$$C_1 \geq \frac{I_{load} \times D}{fs \times \Delta V_{C1}} \qquad (8)$$

$$C_2 \geq \frac{I_{load} \times (1-D)}{8 \times fs \times \Delta V_{laod}} \qquad (9)$$

The proposed system is shown in fig. (2) below.

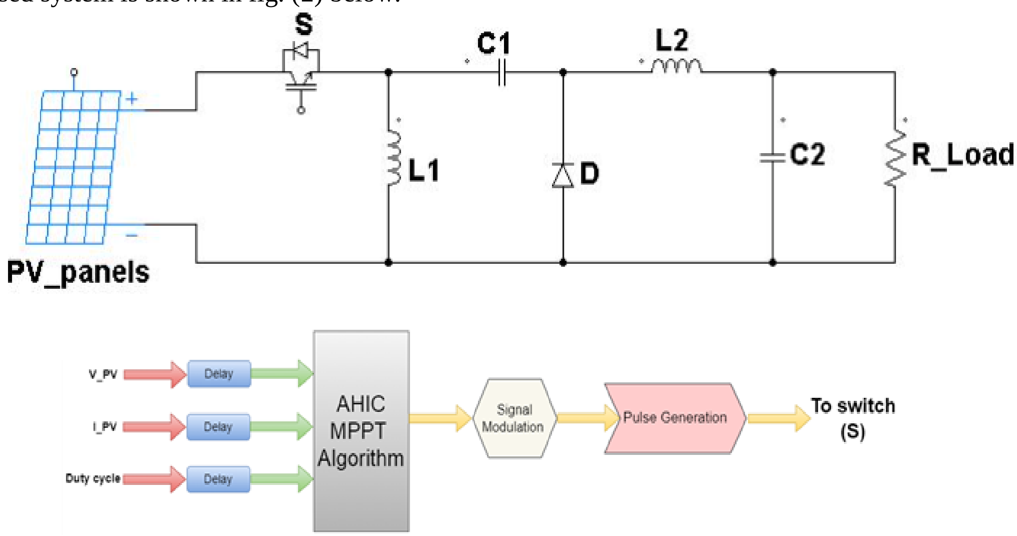


Figure 2. PV and Zeta converter with the Proposed AHIC MPPT algorithm

3. The enhanced IC MPPT algorithm

In this research, the proposed algorithm is known as an enhanced Adaptive Hysteresis Incremental Conductance (AHIC) MPPT algorithm. This algorithm is based on the normal Incremental Conductance (IC) algorithm. The mathematical foundation can be expressed as follows:
For the decision of the duty cycle selection for MPP reaching then

$$\frac{dI}{dV} + \frac{I}{V} = 0 \qquad (10)$$

at MPP with (stay at the current duty cycle)

$$\frac{dI}{dV} + \frac{I}{V} < 0 \qquad (11)$$

Which is on the left-side to the MPP (increase current duty cycle)

$$\frac{dI}{dV} + \frac{I}{V} > 0 \tag{12}$$

Which is on the right-side to the MPP (decrease current duty cycle)
For the changing in power calculations

$$\Delta P = P(n) - P(n-1) = \mathrm{V(n)} \times \mathrm{I(n)} - \mathrm{V(n-1)} \times \mathrm{I(n-1)} \tag{13}$$

then the normalized ratio of power is:

$$\boldsymbol{r_{dP}} = \frac{\boldsymbol{\Delta P}}{\mathbf{max}(\boldsymbol{P(n-1)}, \mathbf{0.1})} \tag{14}$$

also, the adaptive Hysteresis Band is expressed by

$$\boldsymbol{H_{band\,(n)}} = \mathbf{0.002} + \mathbf{0.018}\,(\mathbf{1} - \boldsymbol{e}^{-\mathbf{10}\times \boldsymbol{r_{dP}}}) \tag{15}$$

where the following constants such as which 10 represents sigmoid steepness factor, 0.018 is the adjustable range (up to 2% total), 0.002 is minimum band (0.2%), and 0.05 is the threshold for mid-band adjustment.

The step size adaptation is formulated as:

(r_{dP} > 0.1) For large changes then:

$$\text{step size} = \min(0.05, 0.01 + 0.04 \times r_{dP}) \tag{16}$$

but, for small changes:

$$\text{step size} = \max(0.001, 0.01 - 0.009 \times \frac{(0.1 - \boldsymbol{r_{dP}})}{0.1}) \tag{17}$$

the directional memory is found by:

If $\text{sign(conductance\_ratio)} = \text{last\_direction}$ for accelerate then

$$\text{step size} = \min(0.05, \text{step size} \times 1.2) \tag{18}$$

but for decelerate then

$$\text{step size} = \max(0.001, \text{step size} \times 0.8) \tag{19}$$

in the case of Anti-Windup Protection, so

If $(\mathbf{P} < \mathbf{0.4} \times \boldsymbol{P_{max}})$ **AND** $(\mathbf{D} < \mathbf{0.2}$ **OR** $\mathbf{D} > \mathbf{0.8})$ then:

D = 0.5, step size = 0.02, and last direction = 0

The algorithm tracking efficiency is:

$$\boldsymbol{\eta_{MPPT}} = \frac{\int \boldsymbol{P_{actual}\,at}}{\int \boldsymbol{P_{MPPT}\,dt}} \times \mathbf{100}\% \tag{20}$$

Fig. 3 shows the flow chart of the proposed AHIC algorithm. The hysteresis controller is utilized to rapidly improve the accuracy of the MPP tracking even at various fluctuations in weather conditions and very low oscillations around the MPP. The proposed AHIC algorithm overcomes three significant limitations in a MPPT which are steady-state oscillations, slow response to changes in irradiance, and divergence during partial shading. Its key innovation is a

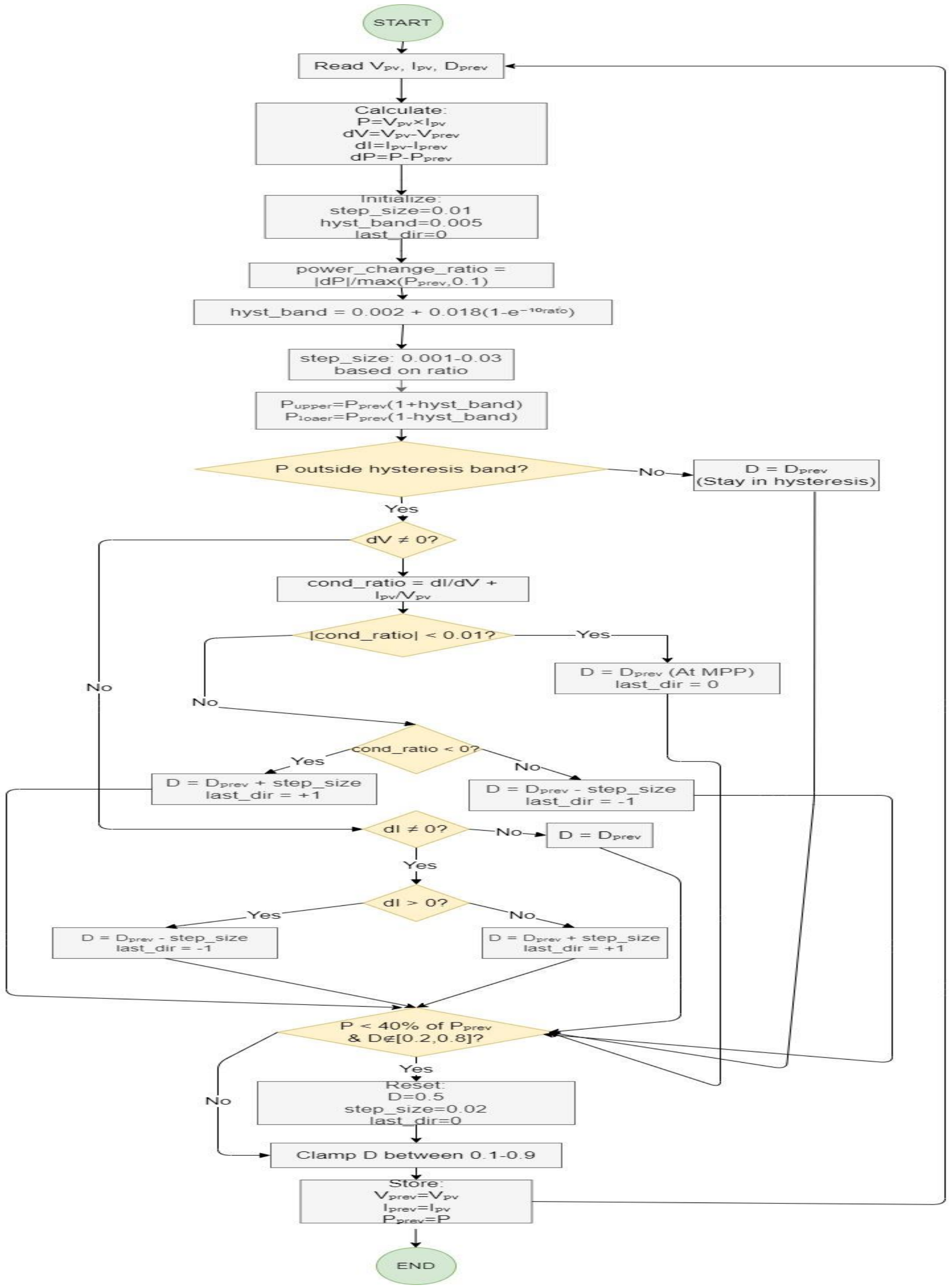


Figure. .3 The proposed AHIC algorithm flow chart self-tuning hysteresis band that varies between 0.2% and 2% of the operating power. This band is adjusted in real-time based on the rate of power change (dP/dt). The innovations of the AHIC algorithm are adaptive hysteresis, directional memory, and anti-windup protection while maintaining the core incremental conductance approach.

4. Results and Discussion

A simulation of the proposed system is made by MATLAB SIMULINK software. The capacity of the designed system is 2 kW. 4 PV panels are connected as two in series and two in parallel to make a role as source to the used Zeta converter. The specifications of the entire system are listed in table 1 below.

The system has been simulated in various operating conditions to examine the enhanced algorithm performance. Also, some of the results are compared with the traditional IC algorithm.

Table 1. The specifications of the proposed system

Item	Specifications	
PV panel (2 in series ×2 in parallel) The specification of a single panel [21]	Maximum Power	475 W
	Open Circuit Voltage	50.05 V
	Voltage at MPP	41.9 V
	Short Circuit Current	11.93 A
	Rated solar irradiation and Temperature	1000 W/m2 at 25 0C
Zeta converter	C1	100 μF
	L1	20 μH
	L2	20 μH
	C2	100 μF
	Fs	25 kHz

Fig. 4 presents the designed zeta converter's input power and output voltage. In this figure, it is clear to observe that the stability and superiority of the AHIC algorithm than the normal IC algorithm. In the case of the input voltage, the system works well near the MPP which is 1.9 kW whereas in IC the system suffers from high oscillations around the MPP. In the case of the system load voltage, the same performance can be obtained when the AHIC is used, the output voltage has fewer fluctuations as compared to when the normal IC algorithm is used. To test the AHIC algorithm at various solar radiation values, a simulation is made when the temperature is set at 25 0C, and the system input power is observed at different solar radiations like (500, 750, 1000, and 600) W/m2 respectively. The results are shown in Fig. (5). For each solar corresponding radiation change, the recorded input power is (950, 1428, 1895, and 1142) W respectively. The AHIC algorithm shows high stability and efficiency for the different changes in radiation. There is a fact that the temperature is not fixed all day long. So, to examine the AHIC algorithm performance for a dual change in temperature and solar radiation throughout the day. Another test is made which represents the different temperature and solar radiation changes that happened on the 20th of May/2024 in Iraq [22]. The test starts from 5:00 AM till 7:00 PM. Fig. (6) shows a bar chart of the input power concerning the temperature and solar radiation. In this figure, it can be seen that the highest input power occurs when the time is 12:00 PM where the solar radiation and the temperature conditions are 1050 W/m2 and 41 0C respectively where the input power is 1840 W. It is well known that the load can be varied as desired. The AHIC algorithm was tested under conditions of load switching. Specifically, the load resistance was switched from 100 Ω to 50 Ω when the simulation time exceeded 0.3 seconds, as illustrated in Figure (7). In this figure, it is evident that the AHIC response remains unaffected by any variations in input power, continuing to operate at the Maximum PowerPoint (MPP). However, the load voltage decreased from 420 V to 300 V. This reduction occurred because no adjustments were made to the load voltage; such control can be implemented later based on the system's requirements in the future.

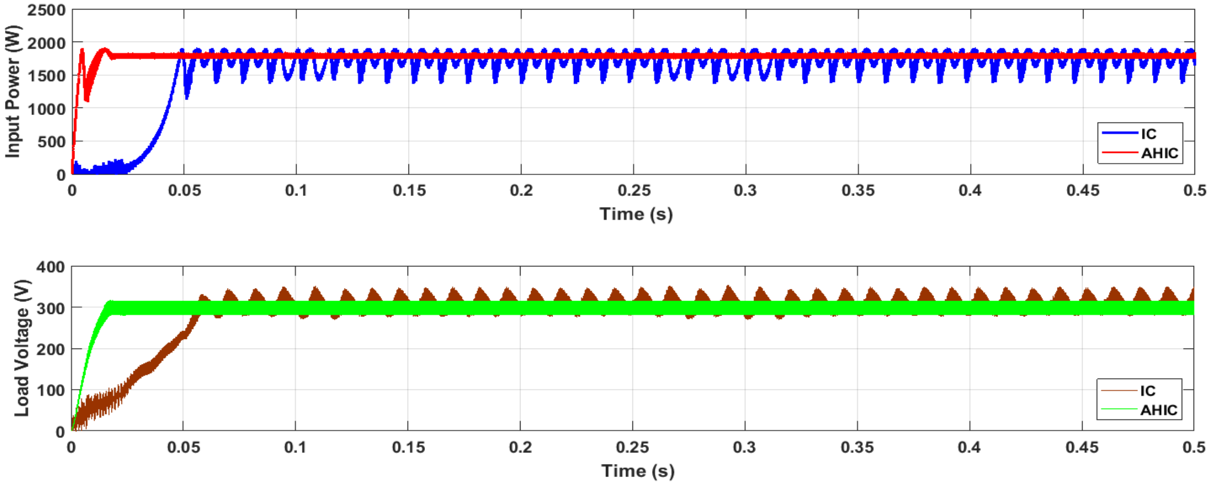


Figure 4. Input power and load voltage at both IC algorithm

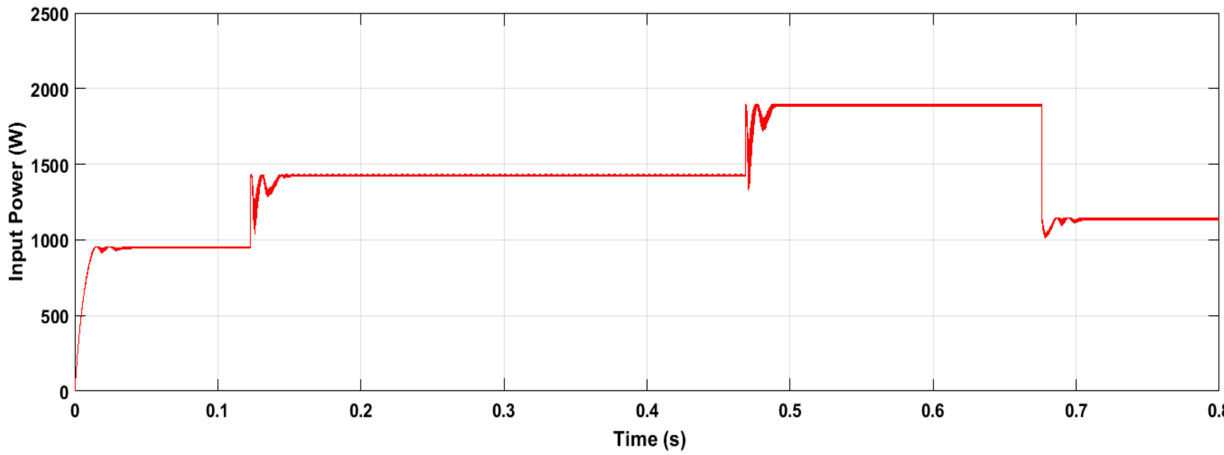
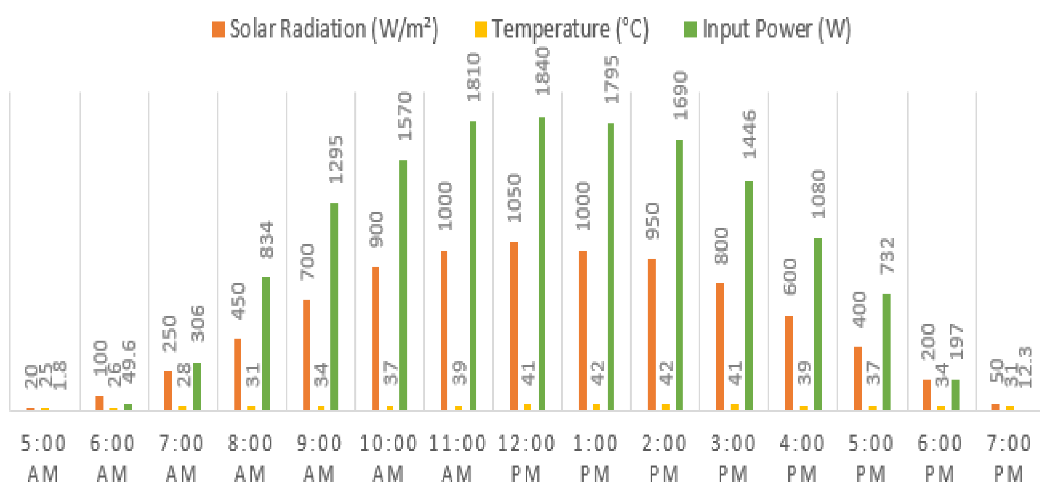


Figure 5. Input power at the proposed AHIC algorithm at different solar radiation



Figur. 6. Effect of solar radiation and temperature change during a day in Iraq

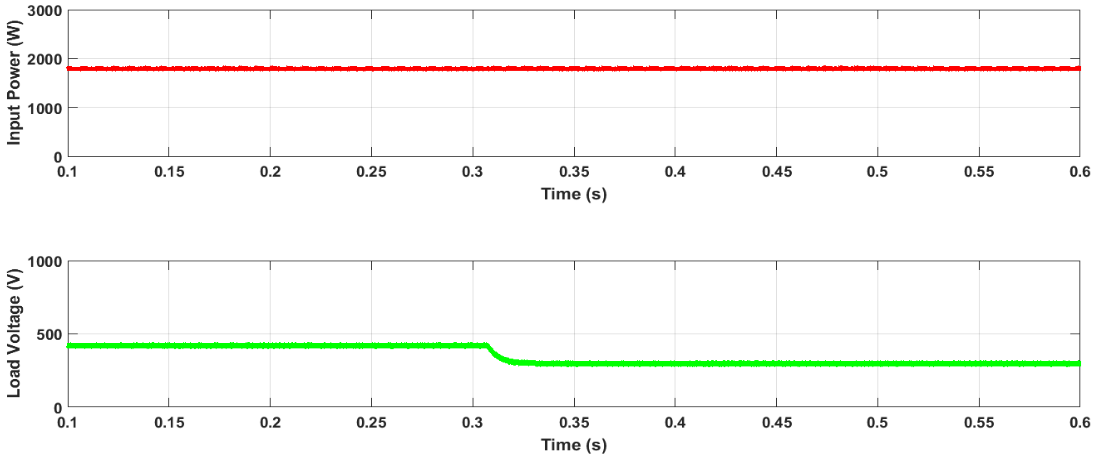


Figure 7. Effect of load change

5. Conclusions

In the present research, a design of an enhanced AHIC MPPT algorithm has been made. The performance of this algorithm is compared with a normal IC algorithm. Both algorithms are applied for solar PV systems to feed a zeta converter. The AHIC is applied at different environmental and operating circumstances like changes in solar radiation along with various temperature changes, and load switching. The proposed improvement lies in the self-tuning hysteresis band to reach the MPP, which is changing between 70 % and 82% of the PV input power. Also, the AHIC is faster by 60 % than the IC algorithm. It can be concluded that the AHIC algorithm gives more precise performance with high efficiency than the normal IC algorithm. Due to its rapid response and high performance with load power fluctuations, the AHIC algorithm can be adapted as an MPPT technique for solar PV systems.

References

[1] Z˙ ywiołek, J.; Rosak-Szyrocka, J.; Khan, M.A.; Sharif, A. (2022) "Trust in Renewable Energy as Part of Energy-Saving Knowledge". Energie, 15, 1566.

[2] Shoeibi, S.; Kargarsharifabad, H.; Sadi, M.; Arabkoohsar, A.; Mirjalily, S.A.A. (2022) "A review on using thermoelectric cooling, heating, and electricity generators in solar energy applications". Sustain. Energy Technol. Assess.,Vol. 52, p.102105.

[3] Motahhir, S., El Ghzizal, A., Sebti, S., Derouich, A. (2017). "MIL and SIL and PIL tests for MPPT algorithm". Cogent Engineering, Vol.4, issue p.1378475.

[4] Verma, R.; Chauhan, A.; Kalia, R.; Jasrotia, R.; Sharma, M.; Kumar, R. (2020) "A comprehensive study on piezo-phototronic effect for increasing efficiency of solar cells: A review", Opt. Laser Technol.,Vol. 149, 10777

[5] Bollipo, R.B., Mikkili, S., Bonthagorla, P.K.. "Critical review on PV MPPT techniques: Classical, intelligent and optimization", IET Renewable Power Generation, 14(9): 1433-1452.

[6] Asnil, A., Nazir, R., Krismadinata, K., Sonni, M.N. (2023), "A review of partial shading MPPT algorithm on speed, accuracy, and cost embedded", Diyala Journal of Engineering Sciences, Vol.16, No.1, 1-14.

[7] Khalf, D.; Hassan, K.; Shary, D. , (2021), "A PV generation system based on P&O MPPT algorithm and SVPWM inverter for standalone applications, "In Proceedings of the 2nd International Multi-Disciplinary Conference Theme: Integrated Sciences and Technologies", IMDC-IST, Sakarya, Turkey, 7–9 September.

[8] Rajamand, S. (2022) "A novel sliding mode control and modified PSO-modified P&O algorithms for peak power control of PV", ISA Trans., 130, 533–552.

[9] M. A. Qasim, V. I. Velkin, M. F. Mohammed , A. A. Sammour, Y. Du, S. A.Salih, B. Abdulkareem Aljashaami, S. P. Gulmurodovich (2023), "Design of a multi-level inverter for solar power systems with a variable number of levels technique", International Journal of Power Electronics and Drive Systems (IJPEDS),Vol. 14, No. 2, June, pp. 1218-1229

[10] Mohammed A Qasim, and Vladimir I Velkin, (2020), "Maximum power point tracking techniques for micro-grid hybrid wind and solar energy systems-A review", International Journal on Energy Conversion, Vol. 8, No. 6 , pp. 223-234

[11] N. I. P. d. L. Puig, L. A. and Jos´e Rodellar (2019), "Numerical Experimental Validation of a Proposed MPPT Algorithm with Dynamic Hysteresis for PV Systems", 17th International Conference on Renewable Energies

and Power Quality(ICREPQ'19) Tenerife, Spain, Renewable Energy and Power Quality Journal ,10th to 12th April, Volume No.17, July 2019, pp. 459-465

[12] Y. Goswami, K. P. S. Rana and V. Kumar, (2021)"Performance Analysis of an Improved Variable Step-Size IC MPPT Technique for SPV System," International Conference on Computing, Communication, and Intelligent Systems (ICCCIS), Greater Noida, India, 2021, pp. 822-827

[13] M. F. Mohammed, M. A. Qasim, V. I. Velkin (2023), "Stand-alone transformer-less multilevel inverter fed by solar energy for irrigation purposes", Materials Today: Proceedings, Vol. 80, Part 2, , pp. 1071-1078

[14] El Ouardi, H.; El Gadari, A.; Mokhlis, M.; Ounejjar, Y.; Bejjit, L.; Al-Haddad, K. (2023) "A Novel MPPT Technique Based on Combination between the Incremental Conductance and Hysteresis Control Applied in a Standalone PV System". Eng, 4, 964–976.

[15] Ramírez Torres, J.A.; Lastres Danguillecourt, O.; González Domínguez, R.A.; Ibánez Duharte,G.R.; Verea Valladares, L.E.; Pantoja Enríquez, J.; Enríquez Santiago, J.A.; López López, A.; Verde Anorve, A. (2025), "Development and Implementation of the MPPT Based on Incremental Conductance for Voltage and Frequency Control in Single-Stage DC-AC Converters". Energies, Vol.18, p.184.

[16] Deghfel, N., Badoud, A.E., Merahi, F. et al. (2024), " A new intelligently optimized model reference adaptive controller using GA and WOA-based MPPT techniques for photovoltaic systems",.Sci Rep 14, 6827 (2024).

[17] Asnil Asnil , K. Krimadinata , E. Astrid , I. Husnaini, (2024), "Enhanced Incremental Conductance Maximum Power Point Tracking Algorithm for Photovoltaic System in Variable Conditions", Journal Européen des Systèmes Automatisés Vol. 57, No. 1, February, 2024, pp. 33-43

[18] Chetan Singh Solanki, "Solar Photovoltaic Technology and SystemsA Manual for Technicians, Trainers and Engineers", Phi Learning Private limited, ISBN-978-81-203-4711-3, Delhi, 2013.

[19] Robert W. Erickson & Dragan Maksimović , "Fundamentals of Power Electronics" (2nd Ed.) – Springer, 2001.

[20] Ned Mohan, Tore Undeland, & William Robbins "Power Electronics: Converters, Applications, and Design", 3rd edition, Wiley, October 10, 2002)

[21] J Y solar, Trina Solar, https://solarbay.com.mx/FC/TRINA_495.pdf

[22] Solar radiation in Baghdad, https://en.tutiempo.net/solar-radiation/baghdad.html