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Research Paper

Analysis and Design of Modified Incremental Conductance-Based MPPT Algorithm for Photovoltaic System

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This study discusses the design of the Maximum Power Point Tracking (MPPT) technique for photovoltaic (PV) systems employing a modified incremental conductance (IncCond) algorithm to extract maximum power from a PV module. A PV module, a DC-DC converter, and a resistive load constitute the PV system. In the scientific literature, it is well-documented that typical MPPT algorithms have significant drawbacks, such as fluctuations around the MPP and poor tracking during a sudden change in atmospheric conditions. To solve the deficiencies of conventional methodology, a novel modified IncCond method is proposed in this study. The simulation results demonstrate that the updated IncCond algorithm presented allows for less oscillation around the maximum power point (MPP), a rapid dynamic response, and superior performance.

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1. Introduction

Currently, solar energy has a prominent position and plays a critical part in the global energy structure due to its benefits, which include abundant availability, low environmental pollution, and low carbon emission. Therefore, the prudent utilization of this clean energy will ultimately enable the fulfillment of all necessary needs. In this situation, PV modules offer a very competitive alternative, as they convert sunlight directly into electrical energy without the need for moving parts or noise pollution. However, its primary shortcoming is its nonlinear power-voltage (P-V) characteristics, which rely on climatic factors, especially temperature and sun irradiance [1, 2].

The PV generator's electrical properties (I-V) and (P-V) are nonlinear and have a particular point known as the maximum power point (MPP). This is the optimal operating point where the PV generator produces its greatest output. Because photovoltaic energy is dependent on climatic circumstances, the location of the MPP varies throughout time.

To address the problem of solar panel efficiency and achieve optimum efficiency. Incorporating a DC-DC converter between the PV panel and the load is required to find the maximum power point (MPP) under ideal climatic circumstances. DC-DC converters in a solar system transfer the maximum power to the load by tracking the maximum power point (MPPT). Numerous MPPT algorithms have been developed to maximize the energy of PV systems. MPPT's purpose is to establish a proper match between the PV generator and its load, as well as to identify the maximum power point (MPP).

Recent research has led to the development of numerous topologies and control strategies for MPPT algorithms, the majority of which are based on artificial intelligence techniques, such as artificial neural networks [3-6] and fuzzy Takagi-Sugeno control [7-10]. In contrast to the usual approaches of perturbation and observation (P&O) and incremental conductance (IncCond) [11-13], these methods suffer from numerous challenges during the actual implementation phase and a lack of labels in the sensor data.

The incremental conductance algorithm is extensively utilized because of its good tracking accuracy at a reasonable cost in a stable state, as well as its good performance and adaptability, respectively, when atmospheric conditions rapidly change [14].

On the one hand, the incremental conductance approach has some disadvantages, including a delayed reaction and significant variation around MPP. In this regard, a modified incremental conductance is proposed to solve the deficiencies of the standard one.

This essay is structured as follows: The technique of modeling the photovoltaic system, which involves both the PV panel and the DC-DC converter, is presented in Section 2. The proposed approach is then described in Section 3. Sections 4 and 5 provide and explain, respectively, the simulation results. A conclusion brings this paper to its conclusion.

2. Photovoltaic system modeling

The considered PV system is shown in Fig. 1, which mainly consists of a PV panel, a DC-DC boost converter controlled by an MPPT technique, and a load.

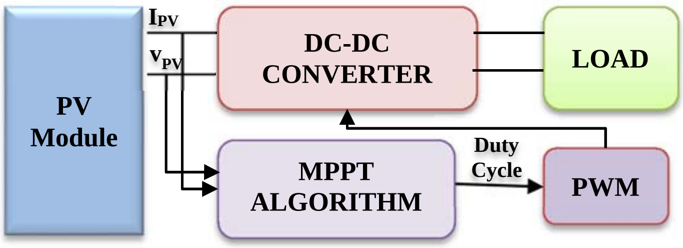


Fig.1 PV system control structure.

2.1 PV panel model description

Fig.2 depicts the equivalent circuit of a PV cell to represent the mathematical model for the current-voltage characteristic [15] and the output current of the PV system can be given by:

$$i_{pv} = n_p I_{ph} - n_p I_S \left(exp\left[\frac{q(V_{pv} + Rs i_{pv})}{KTA} \right] - 1 \right) - \left(\frac{V_{pv} + i_{pv} Rs}{R_{sh}} \right) \qquad (1)$$

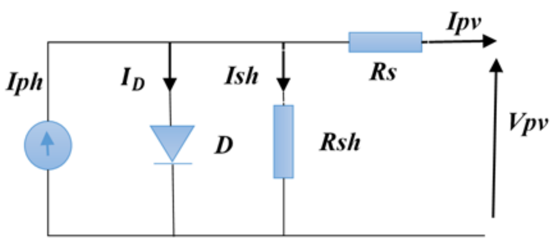


Fig.2. Electrical Equivalent scheme of a PV cell.

where I_{ph} denote the photocurrent generated by solar irradiation, I_S represent the saturation current, n_p is the number of parallel cells, T represents the cell temperature, A refers to the ideal factor, q is the electron charge equal to 1.062×10^{-19}, k stands for Boltzmann constant equal to $1.38 \times 10^{-23} J/K$, Rsh, and Rs denote both shunt and series resistances.

The photocurrent depends on the solar irradiation and the cell temperature according to (2):

$$Iph = G\left(Isc + K_{I(T - Tr)}\right) \qquad (2)$$

Where I_{sc} denote the nominal short-circuit current of the cell at 25°C and $1KW/\ m^2$, G solar irradiation inKW/m^2 , T the cell short-circuit current cell reference temperature and T_r temperature coefficient. Otherwise, the saturation current depends on the temperature of the cell according to (3):

$$I_s = I_{rs}(\frac{T}{T_r})^3 exp[(\frac{qE_g}{KA}(\frac{1}{T_r} - \frac{1}{T})] \qquad (3)$$

Where $E_g$is the band-gap energy of the semi-conductor and I_{rs} presents reverse saturation current, denoted by (4):

$$I_{rs} = \frac{I_{sc}}{exp\left[\frac{qV_{oc}}{n_{sKAT}}\right] - 1} \qquad (4)$$

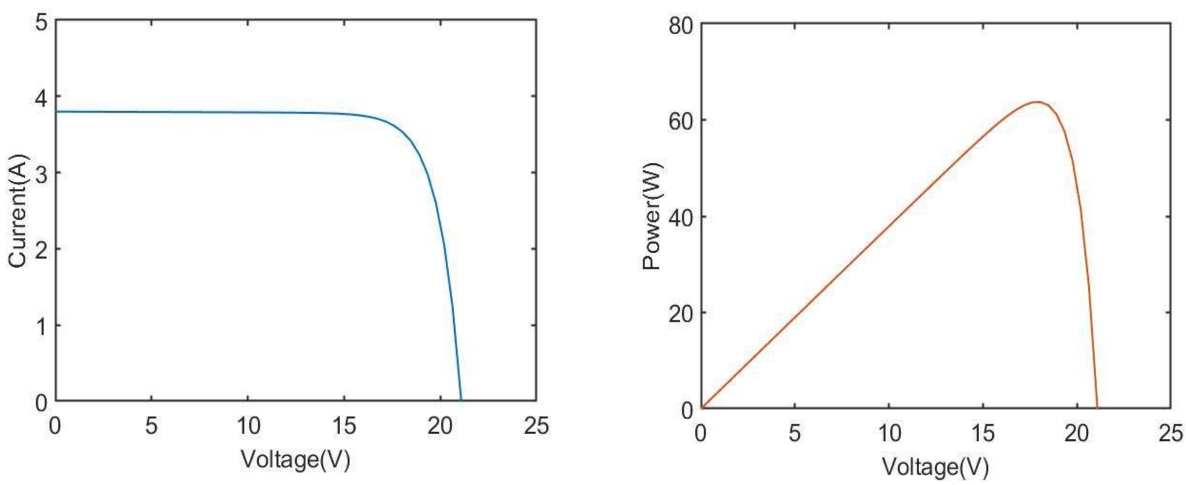
Where V_{oc} is the open circuit voltage.

The parameters of the PV panel used in this simulation study are given in table 1.

Table 1. PV conversion system parameters

Parameter	Value
N Numbers of cells connected in parallel (n_p)	1
Numbers of cells connected in series (n_s)	36
Rated power	80w
Open –circuits voltage (V_{oc})	22V
Short –circuits curent (I_{sc})	4.8V
Curent at MPP (Impp)	4.45V
Tension at Mpp (Vmpp)	18V

The following Fig. 3(a) and Fig. 3(b) described respectively P − V and $I – V$ of the PV panel.



(a) power-voltage characteristic (b) current-voltage characteristic

Fig. 3. Characteristics of PV panel

2.2 DC-DC Boost converter

In general, the job of the DC-DC converter in the PV chain is to optimize power transfer between the PV generator and the load. As shown in Fig. 4, a DC-DC boost converter is employed as the power stage interface between the PV system and the resistive load to achieve the requisite maximum voltage. The MPPT duty cycle-achieved Pulse Width Modulation (PWM) approach is used for the electrical switch of the converter [4].

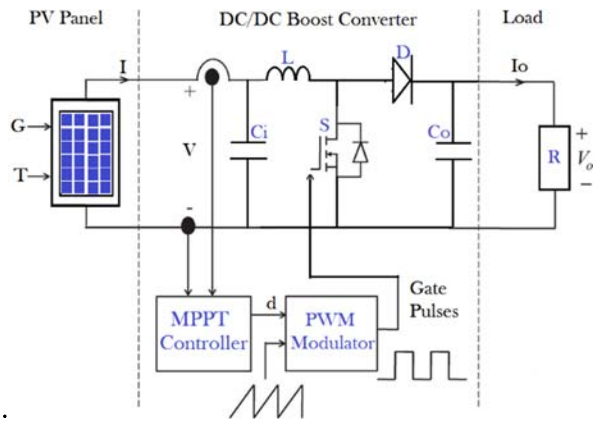


Fig. 4. DC-DC boost converter circuit.

The component values of the DC-DC boost converter characteristics are presented in Table 2

Table 2. DC-DC boost converter characteristics

Component	Spécification
N MOSFET	IRFZ44N
Diode (D)	BYT30P-1000
Inductor	180uH
Capacitor C0	1000uF
Capacitor Ci	100uF
Load	10 Ω
Switching frequency	31.4KHz

3. Proposed method

To determine the MPPT of the PV System, a novel modified incremental conductance approach is developed. It has been simulated under various air circumstances, and the results are compared to the traditional IncCond MPPT technique.

3.1 Conventional IncCond method

The IncCond is simple to imitate and commonly employed. It is based on the PV generator's power characteristic curve, which is zero at the PPM. Consequently, the voltage and current of this generator are the two quantities on which the MPPT controller depends to determine conductance and incremental conductance (increase or decrease the output duty cycle). Considering the following:

$$\frac{dP}{dV} = 0 \qquad \text{with } P = V.I \qquad (5)$$

Equation (5) can be rewritten as follows:

$$\frac{dP}{dV} = V\frac{dI}{dV} + I \qquad (6)$$

To use the IncCond algorithm is based on the fact that the slope of the PV array power versus voltage curve is zero at the MPP [12].

$$\frac{dI}{dV} = -\frac{1}{V} \qquad (7)$$

From the idea of IncCond which can be easily realized from the equation (7), the IncCond algorithm measures for each t instant, the PV voltage V (t), PV current I(t) and then measures the conductance value (I=V) and the IncCond value (dI=dV). Using these values, the algorithm finds the MPP of the PV panel in the P – V curve [1], and the flowchart is shown in Fig.5.

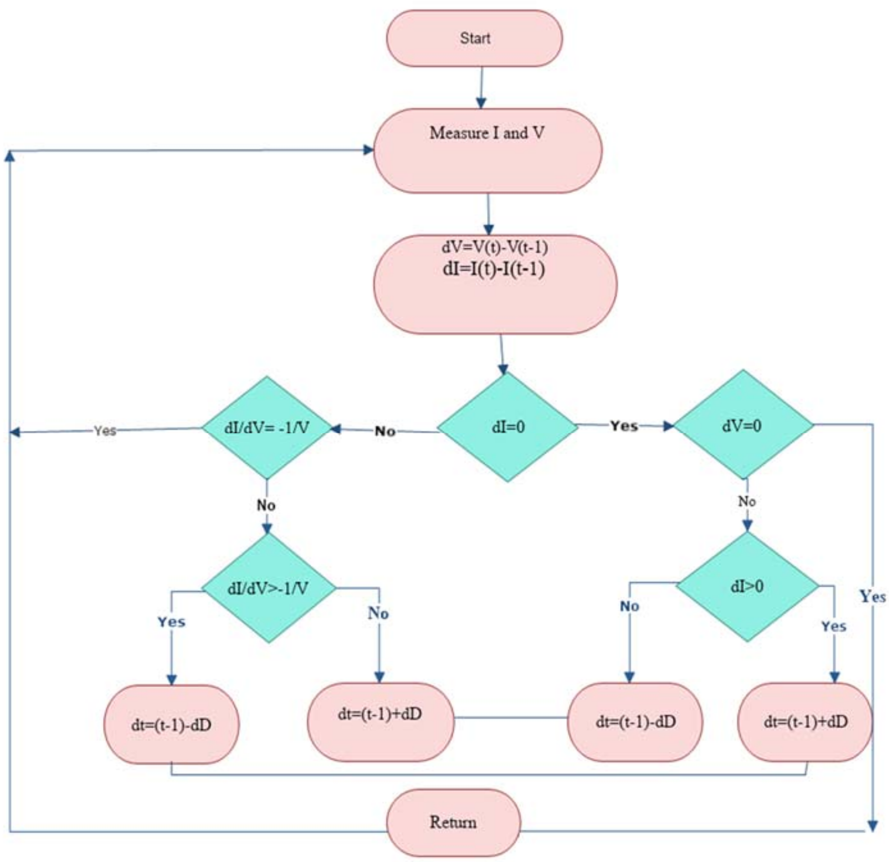


Fig.5. IncCond Conventional algorithm

3.2 Proposition IncCond modified

The new modified algorithm is proposed with a set of changes and the equations, presented in (8), (9) and (10) are added to accelerate the searching process for MPP.

$$P = I.V \tag{8}$$

$$dP = P(t) - P(t-1) \tag{9}$$

$$\mathrm{M} = \mathrm{V.abs(dP)} \tag{10}$$

The modified IncCond based on a comparison of the different parameter values such as; the voltage, power and current is presented in Fig. 6.

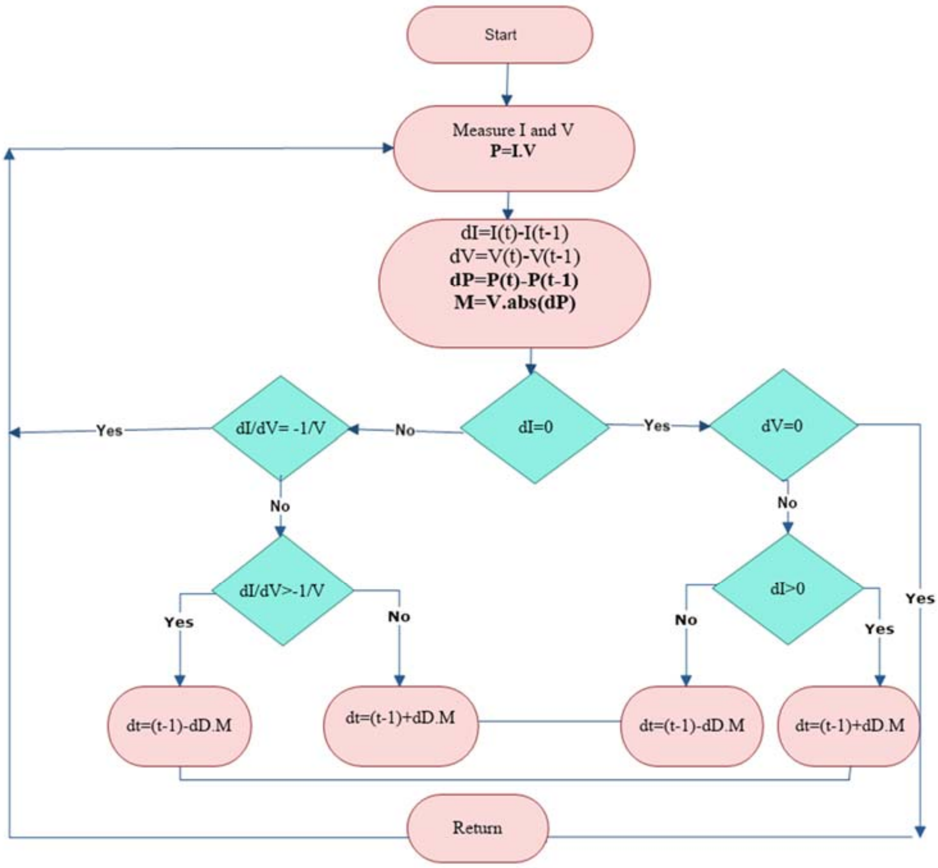


Fig.6. IncCond Modified algorithm

4. Simulation results

To demonstrate the performance of the updated IncCond algorithm and to validate its efficacy, we evaluate simulation tests with the settings listed in Tables 1 and 2. Various climatic conditions are tested using the Matlab/Simulink model in Figure 7.

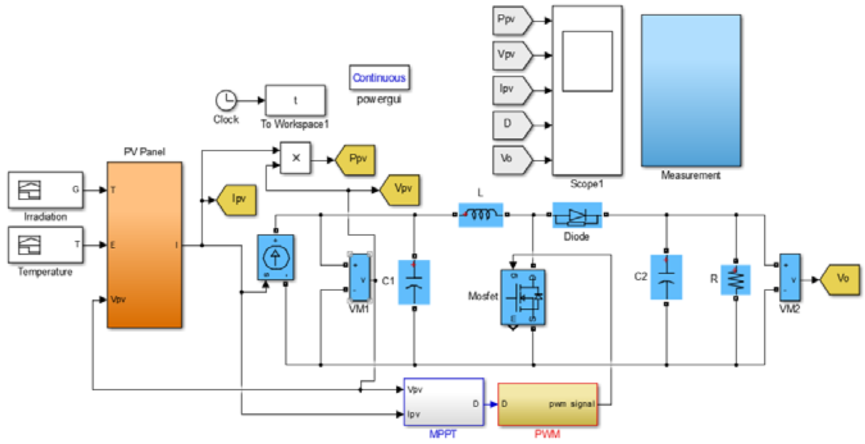
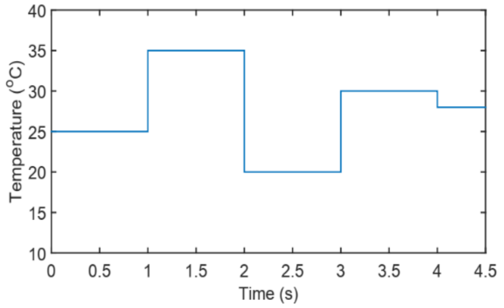
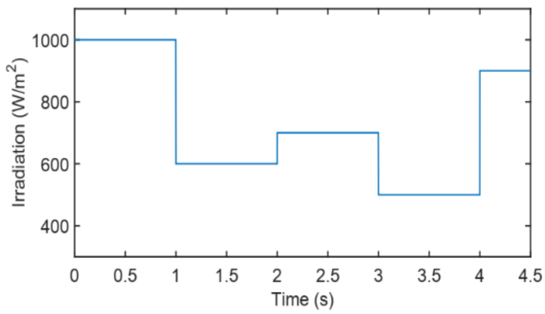


Fig.7. PV System Model

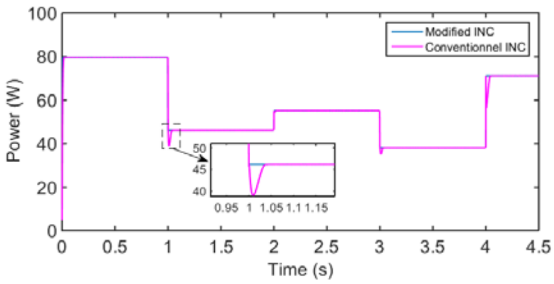
The profiles of solar irradiation and cell temperature are assumed to be as depicted in Figures 8(a) and (b), respectively. Using a fixed step size of 0.005 and a frequency of 31, 4 kHz, the proposed method is compared to the standard one.



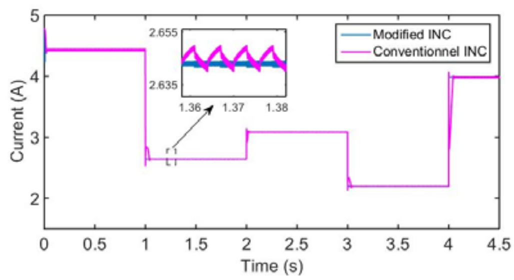
(a)Temperature profile



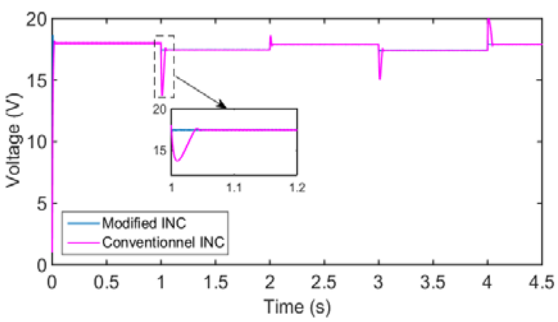
(b) Irradiation profile



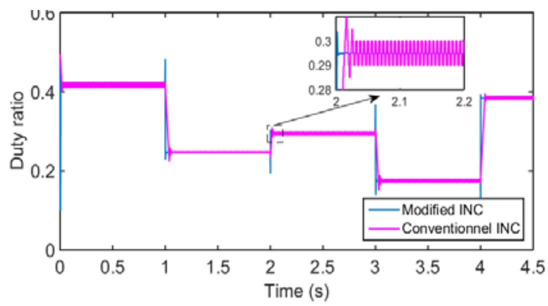
(c) Power responses



(d) Current response



(e)Voltage response



(f) Duty ratio

Fig. 8. Simulation results for PV system under varying environmental conditions

Figure 8(c) and 8(d) depict the responses of PV output power and PV output current, whereas figure 8(e) and 8(f) depict the reactions of PV output voltage and the control signal 8(f). At various temperatures and irradiance levels, it is evident that the modified incremental conductance has a faster tracking speed and more efficiency than the old technique. To emphasize the benefit of the proposed strategy more effectively. Table 3 also displays the performance of the newly proposed method in terms of efficiency and tracking.

Table 3. Comparative performances between IncCond and IncCond modified

Index	Conventional IncCond	modified IncCond
α_{MPPT}	98.4101	97.6449
n_{MPPT}	98.2547	97.1643
ε_{MPPT}	1.3937	2.9671
n_{MPPT}, E	98.4292	97.3918
ε_{MPPT}, E	1.4768	2.8768
Settling time t_s (s)	0.0515	0.0023

Where Accuracyα_{MPPT} is used to know how close is the tracking to the maximum point.
In our study, it was used to illustrate how close the PV current is during tracking to the current maximum power point, as given below:

$$\alpha_{MPPT} = \frac{I_{pv}}{I_{MPP}} \times 100 \qquad (12)$$

Static efficiency index n_{MPPT} shows the ratio of actual PV power to the maximum power. It is given by:

$$n_{MPPT} = \frac{P_{pv}}{P_{MPP}} \times 100 \qquad (13)$$

Relative tracking error (ε_{MPPT}) is expressed as follows:

$$\varepsilon_{MPPT} = \left|\frac{P_{pv}}{P_{MPP}} - 1\right| \times 100 \qquad (14)$$

The index $n_{MPPT,E}$ and $\varepsilon_{MPPT,E}$which represent, respectively the MPPT energetic efficiency and the MPPT energetic error are used to evaluate the tracking performance of the modified and conventional algorithms during dynamic changes in the MPP.

$$n_{MPPT,E} = \left(\frac{\int_0^{tf} P_{pv}\,dt}{\int_0^{tf} P_{MPP}dt}\right) \times 100 \qquad (15)$$

$$\varepsilon_{MPPT,E} = \left(\frac{\int_0^{tf} P_{pv}\,dt}{\int_0^{tf} P_{MPP}dt} - 1\right) \times 100 \qquad (16)$$

The simulation results confirm also that the responses of the steady states with the developed MPPT-based controller track perfectly the optimum operating points with much less oscillation, whereas the responses of the PV system with the conventional **I**ncCond -based controller show a considerable amount of fluctuation in the different states.

In addition, the performance of the proposed and compared methods are evaluated using root mean square error (RMSE) between the PV output power and its theoretical maximum power. The RMSE is defined as follows [7]:

$$\mathrm{RMSE} = \sqrt{\left(\frac{\sum_{i=1}^{N}\left(P_{PV,i}-P_{PVmax,i}\right)^{2}}{N}\right)} \times 100 \qquad (17)$$

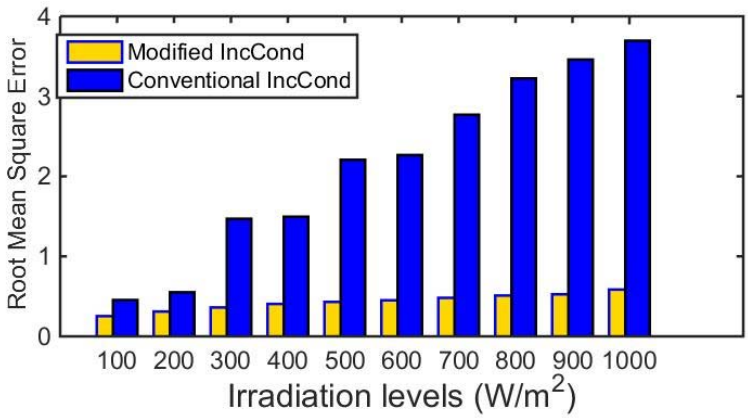


Fig. 9. RMS errors at different irradiations and constant temperature

Fig. 9(a) presents the RMS errors in the PV output power at different irradiation levels with a constant temperature of 25 ◦C. The RMS errors of the Conventional IncCond are greater than the proposed one for a wide range of operating conditions. This shows that the proposed controller can extract the maximum possible power with much less power loss settling time t_s.

5. Conclusion

This work presents a modified incremental conductance and compares it to a traditional one, allowing a high tracking speed to be demonstrated clearly. The simulation results demonstrate the efficacy of the suggested method, which can rapidly determine the Maximum Power Point (MPP) despite rapid changes in air conditions and has a higher power output efficiency than the standard method. Observe the correctness of the proposed strategy and its comparative performance in terms of convergence to the MPP with fewer oscillations. In the future, we plan to examine this strategy with PV panel flaws by rethinking the addition of artificial intelligence technology to reach maximum precision.

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