

Implementation of Incremental Conductance MPPT in Photovoltaic System with DC-DC Boost Converter

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ABSTRACT

This paper presents the implementation of Incremental Conductance (IC) Maximum Power Point Tracking (MPPT) for photovoltaic (PV) system integrated with a DC-DC boost converter to enhance energy harvesting efficiency. Output power varies with environmental conditions such as solar irradiance and temperature due to the nonlinear characteristics of PV modules. To address this challenge, The IC MPPT technique is employed to accurately track the maximum power point (MPP) under both steady-state and rapidly changing environmental conditions. Unlike conventional methods, the incremental conductance approach determines the MPP by comparing IC ($\frac{dI}{dV}$) with the instantaneous conductance ($\frac{I}{V}$), reduced oscillations and improved tracking speed.

The proposed system consists of a PV array, an IC based MPPT controller and a boost converter that steps up the output voltage to a required level for efficient load utilization. The boost converter is controller through pulse width modulation (PWM) signals generated by the MPPT algorithm, enabling optimal power extraction from the PV panel. MATLAB/Simulink is used to model and simulate the system, validating its performance under varying irradiance conditions.

Simulation outcome indicates that the IC MPPT technique achieves improved efficiency, quicker tracking of MPP and minimizes steady-state fluctuations when compared to conventional approaches like Perturb and Observe (P&O) method. The system ensures reliable and stable operation, making it suitable for renewable energy applications. Overall, the integration of the IC MPPT with a boost converter significantly improves the performance and efficiency of photovoltaic energy systems.

Keywords: Photovoltaic system, Incremental Conductance, DC-DC boost converter.

INTRODUCTION

The rapid expansion of renewable energy technologies has led to increased reliance on photovoltaic (PV) systems for clean power generation. However, the electrical characteristics of PV modules are inherently nonlinear and strongly influenced by environmental factors such as solar irradiance and temperature. As a result, the operating point of a PV system varies continuously, and maximum power can only be obtained at a specific point known as the maximum power point (MPP). If the system does not operate at this point, energy extraction becomes inefficient. To overcome this limitation, Maximum Power Point Tracking (MPPT) techniques are implemented to dynamically adjust the operating conditions of the PV system. Among the available methods, the Incremental Conductance (IC) algorithm is widely adopted due to its capability to accurately locate the MPP under both steady-state and rapidly changing conditions. This method relies on the relationship between incremental conductance and instantaneous conductance to determine the direction of operation, thereby reducing oscillations and improving tracking precision.

In practical PV applications, a DC–DC boost converter is used to interface the PV array with the load, enabling voltage regulation and efficient power transfer. The converter's duty cycle is continuously controlled by the MPPT algorithm to maintain operation at the optimal point. In this study, an enhanced IC-based MPPT strategy is developed by incorporating adaptive decision-making and a PI-assisted control mechanism to achieve faster convergence and improved stability. The proposed system is modeled and analyzed using MATLAB/Simulink, and its performance is evaluated under varying environmental conditions using key indicators such as tracking efficiency, response time, and system stability. A comparative evaluation with the conventional Perturb and Observe (P&O) method is also included to demonstrate the effectiveness of the proposed approach.

LITERATURE REVIEW

Several studies have focused on improving the performance of Incremental Conductance (IncCond) based MPPT techniques for photovoltaic (PV) systems operating under dynamic environmental conditions. In [1], The modified approach improves tracking precision by refining the decision-making mechanism under varying irradiance and temperature, resulting in better steady-state stability and reduced power loss. The work presented in [2] investigates the effectiveness of the IncCond method under rapidly changing atmospheric conditions. The study demonstrates that the algorithm can accurately estimate the MPP by utilizing the slope of the PV curve, thereby achieving improved dynamic response and reduced oscillations compared to traditional MPPT strategies. In [3], a performance evaluation of the IncCond algorithm is carried out under fast irradiance variations. The results indicate that while the method maintains acceptable tracking accuracy, minor steady-state oscillations and transient delays still exist, highlighting the need for further optimization.

To overcome these issues, a variable step-size IncCond technique is introduced in [4], where the step size is adaptively adjusted based on the operating region of the PV system. A system-level optimization is presented in [5], where a single-stage IncCond-based MPPT is integrated with a flyback inverter topology. This configuration reduces system complexity and improves energy conversion efficiency by eliminating intermediate conversion stages while maintaining effective MPP tracking. Furthermore, adaptive enhancements such as step-size control combined with holding mechanisms have been explored in [6] to suppress unnecessary perturbations near the MPP. This method significantly improves tracking stability and reduces power fluctuations under rapidly varying conditions. Hebchi et al. [7] proposed an improved version of the IC algorithm aimed at enhancing tracking accuracy and reducing steady-state oscillations. Their work demonstrates better performance compared to conventional IC, particularly during rapid changes in solar irradiance. Hemavathi et al. [8] focused on defect detection in polycrystalline solar cells using electroluminescence imaging. Their study highlights how identifying defects can significantly improve the reliability and efficiency of PV systems. Chawda et al. [9] introduced a hybrid approach combining Incremental Conductance with Particle Swarm Optimization (PSO) to address the issue of multiple power peaks under partial shading conditions. The proposed method effectively tracks the global maximum power point, overcoming the limitations of traditional IC algorithms.

Elgendy et al. [10] conducted a detailed performance analysis of the IC MPPT algorithm, emphasizing its advantages such as accuracy and stability. However, the study also points out challenges like complexity and slower response under certain dynamic conditions. Putri et al. [11] implemented the IC method for MPPT and demonstrated its effectiveness in achieving stable and accurate tracking of the maximum power point. Their results confirm that IC performs better than simpler methods like Perturb and Observe under steady-state conditions. In another study, Hemavathi et al. [12] explored the simulation of a SEPIC DC–DC converter using LabVIEW. Their work highlights the importance of efficient power converters in PV systems, as they play a key role in implementing MPPT algorithms effectively.

Overall, the reviewed literature indicates that although the conventional IncCond algorithm provides reliable MPP tracking, recent advancements primarily focus on adaptive control strategies to enhance dynamic response, minimize steady-state oscillations and improve overall system efficiency.

METHODOLOGY

The system consists of a photovoltaic (PV) array, an IC MPPT controller, a DC-DC boost converter, and a load

as shown in Figure 1. The PV voltage and current are continuously measured to determine the maximum power point using the condition $\frac{dI}{dV} = -\frac{I}{V}$. Based on this, the IC algorithm adjusts the duty cycle to ensure optimal power extraction with minimal oscillations. The PWM pulses control the boost converter to regulate and increase the output voltage (V_{out}) and current (I_{out}). The complete system is modeled in MATLAB/Simulink to analyze performance under varying environmental conditions.

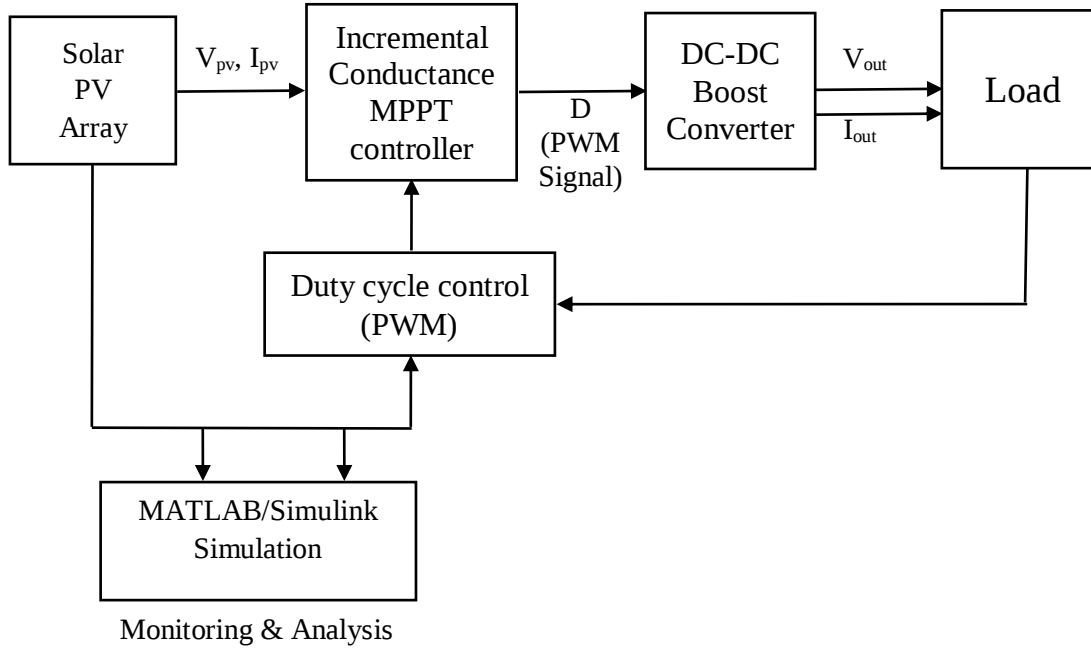


Figure 1: Block Diagram of Proposed PV SYSTEM

PV array modelling:

The photovoltaic (PV) array is represented using a single-diode equivalent circuit, which captures the nonlinear electrical characteristics of a solar cell. The model consists of a current source, a diode, and series (R_s) and shunt (R_p) resistances to account for internal losses. The output current of the PV cell is expressed as:

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + IR_s}{aV_t}\right) - 1 \right] - \frac{V + IR_s}{R_p}$$

where I_{ph} is the photo-generated current, I_o is the diode saturation current, a is the diode ideality factor and

$V_t = \frac{N_s KT}{q}$ represents the thermal voltage.

The photo-current depends on irradiance and temperature, given by:

$$I_{ph} = \frac{G}{G_n} [I_{ph,n} + K_i (T - T_n)]$$

Where G is the Actual irradiance, G_n is the Nominal irradiance, T is the Cell temperature, T_n is the Reference temperature and K_i is the Temperature coefficient. This equation helps to estimate the current generated by the PV cell under different environmental conditions.

The diode reverse saturation current varies with temperature and is modeled as

$$I = I_{o,n} \left(\frac{T}{T_n}\right)^3 \exp\left[q \frac{E_g}{ak} \left(\frac{1}{T_n} - \frac{1}{T}\right)\right]$$

Where: q = Electron charge, k = Boltzmann constant and E_g = Bandgap energy

The diode reverse saturation current varies with temperature, As temperature increases, rises due to increased charge carrier activity and changes in bandgap energy. This affects the performance of the PV cell, particularly reducing the output voltage at higher temperatures.

Nominal saturation current calculation:

$$I_{o,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right) - 1}$$

where, V_{oc} is the nominal open circuit voltage, V_t is the nominal thermal voltage of the cell and I_{sc} is the short-circuit current. This equation helps to determine the diode parameter required for accurate PV modeling.

PV array configuration:

For practical applications, PV cells are connected in series and parallel to form an array. The array output current is expressed as

$$I = N_p I_{pv} - N_p I_o \left[\exp\left(\frac{V + IR_s \left(\frac{N_s}{N_p}\right)}{aV_t N_s}\right) - 1 \right] - \frac{V + IR_s \left(\frac{N_s}{N_p}\right)}{R_p \left(\frac{N_s}{N_p}\right)}$$

where N_s and N_p represent the number of series and parallel connected modules, respectively. The total current is obtained by scaling the single-cell current, while the diode and resistive effects are adjusted based on the array configuration. This equation models the overall behavior of the PV array under different operating conditions.

Table 1: PV Array Specifications

PARAMETER	SYMBOL	VALUE
Irradiance	G	1000W/m ²
Temperature	T	25° C
Voltage at MPP	V_{mp}	24 V
Current at MPP	I_{mp}	9 A
Open circuit voltage	V_{oc}	32 V
Short circuit current	I_{sc}	9.5 A
Maximum Power	P_{max}	216 W
Series resistance	R_s	0.48 ohm
Shunt Resistance	R_{sh}	678 ohm
Diode ideality factor	a	0.86
Saturation Current	I_o	3.254×10^{-10} A
Photo current	I_{ph}	9.64 A

MPPT Control Using Incremental Conductance Method

Maximum Power Point Tracking (MPPT) is essential for maximizing energy extraction from photovoltaic (PV) systems under varying irradiance and temperature. The Incremental Conductance (IC) method determines the maximum power point (MPP) by evaluating the slope of the power–voltage characteristic, which becomes zero at the MPP:

$$\frac{dP}{dV} = 0 \Rightarrow \frac{dI}{dV} = -\frac{I}{V}$$

By comparing incremental conductance ($\frac{dI}{dV}$) with instantaneous conductance ($\frac{I}{V}$), the algorithm identifies the operating region. When $\frac{dI}{dV} = -\frac{I}{V}$, the system operates at MPP; if $\frac{dI}{dV} > -\frac{I}{V}$, the operating point is left of MPP, and if $\frac{dI}{dV} < -\frac{I}{V}$, it is right of MPP. The controller measures PV voltage and current, computes incremental changes and updates the duty cycle of the DC-DC converter accordingly. This adaptive adjustment enables fast convergence and reduces steady-state oscillations, improving overall tracking efficiency.

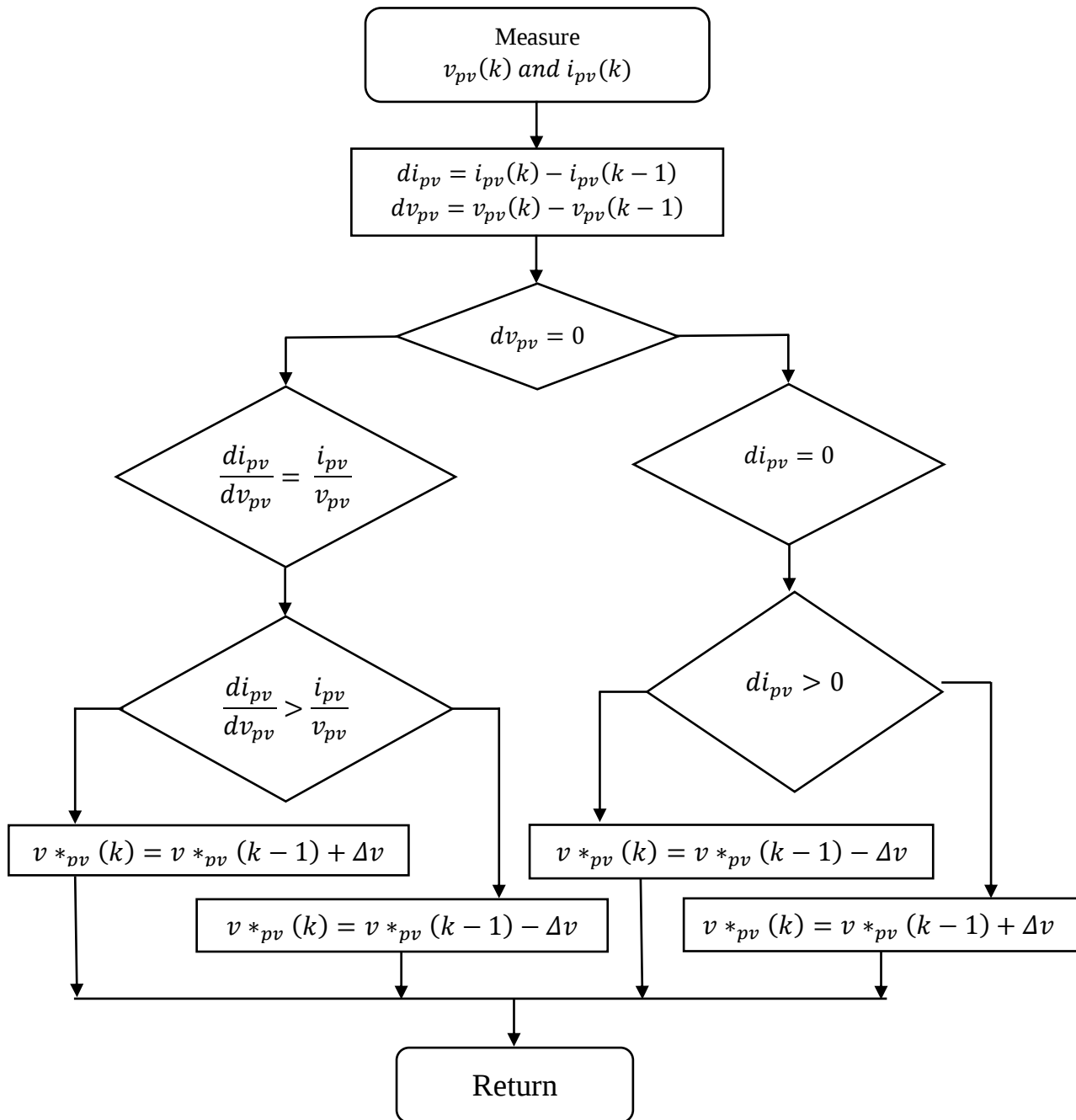


Figure 2: Flow Chart of Incremental Conductance Algorithm

Figure 2 presents the flowchart of the Incremental Conductance (IC) MPPT algorithm. The process begins with measuring the PV voltage and current, followed by calculating their incremental changes. The algorithm

compares the ratio of change in current to change in voltage with the instantaneous conductance to determine the position of the operating point relative to the maximum power point (MPP). Based on this comparison, the duty cycle of the converter is adjusted to move the system toward the MPP. This procedure is repeated continuously to ensure accurate tracking under varying environmental conditions

Algorithm steps

1. Acquire the instantaneous PV voltage $V(k)$ and current $I(k)$.

2. Determine incremental variations:

$$\Delta V = V(k) - V(k-1), \Delta I = I(k) - I(k-1)$$

3. If $\Delta V = 0$:

- $\Delta I = 0 \rightarrow$ system operates at MPP
- $\Delta I > 0 \rightarrow$ increase duty cycle
- $\Delta I < 0 \rightarrow$ decrease duty cycle

4. If $\Delta V \neq 0$:

- Evaluate $\Delta I / \Delta V$ and compare with $-I/V$
- Update duty cycle to shift operating point toward MPP

5. Repeat the process continuously for real-time tracking.

DC-DC Boost Converter

A DC-DC boost converter is utilized to elevate the output voltage of the photovoltaic (PV) array to a higher level suitable for load and battery requirements. It enables efficient power transfer by regulating the voltage through controlled switching action. The converter stores energy in the inductor during the ON state of the switch and transfers it to the load during the OFF state, resulting in an output voltage higher than the input.

Modes of operation:

The converter operates in two conduction modes:

Continuous Conduction Mode (CCM):

The inductor current remains non-zero throughout the switching cycle, ensuring lower ripple and stable operation.

Discontinuous Conduction Mode (DCM):

The inductor current drops to zero within a switching period, typically under light load conditions, leading to increased ripple.

Design relations:

The voltage gain of the boost converter is given by:

$$D = 1 - \frac{V_{in}}{V_{out}}$$

The output current is expressed as:

$$I_{out} = \frac{P}{V_{out}}$$

The inductor current ripple and output voltage ripple are approximated as:

$$\Delta I_L = 0.01 \times I_{out(max)} \times \left(\frac{V_{out}}{V_{in}} \right)$$

$$\Delta V_o = 0.01 \times V_{out}$$

The required inductance and capacitance values are:

$$L = \frac{V_{in}(V_{out} - V_{in})}{V_{out} \times f_s \times \Delta I_L}$$

$$C = \frac{I_{out(max)}(1 - \frac{V_{in}}{V_{out}})}{f_s \times \Delta V_o}$$

The load resistance is given by:

$$R = \frac{V_{out}}{I_{out(max)}}$$

Table 2: BOOST Converter Specifications

PARAMETER	SYMBOL	VALUE
Input Voltage	V_{in}	24 V
Output Voltage	V_{out}	48 V
Duty Cycle	D	0.5
Switching Frequency	f_s	20 KHz
Inductor	L	0.47 mH
Input Capacitor	C_{in}	220 μ F
Output Capacitor	C_{out}	470 μ F
Load Resistance	R	10.7 ohm

Matlab/Simulink Model

The proposed system is developed in MATLAB/Simulink by integrating key functional blocks, including the PV array subsystem, Incremental Conductance (IC) MPPT controller, PWM generator and DC-DC boost converter. The PV subsystem provides real-time voltage and current signals, which are processed by the MPPT controller to determine the optimal operating point. The IC algorithm computes the required duty cycle based on these inputs, which is then converted into PWM pulses to control the switching of the boost converter, ensuring efficient power transfer to the load

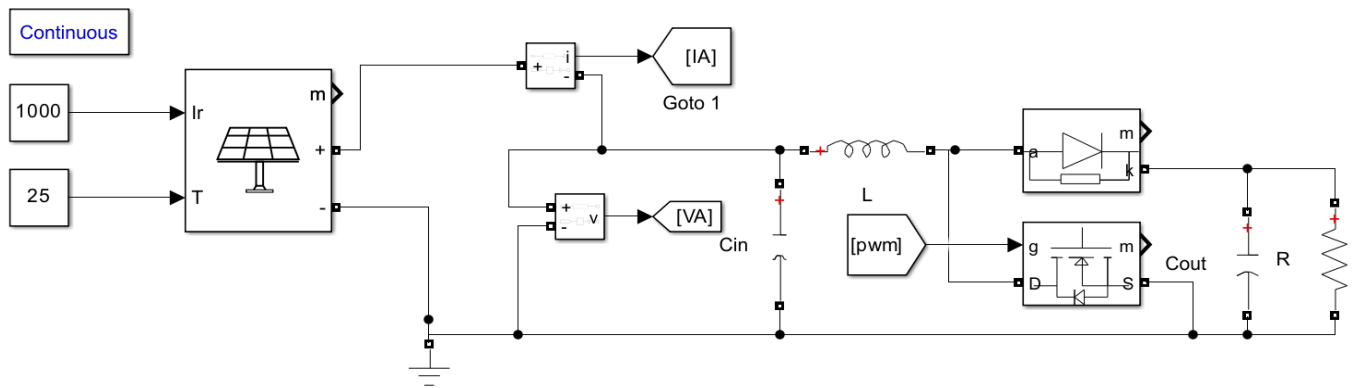


Figure 3: Boost Circuit

Figure 3 shows the simulation model of the DC–DC boost converter used in the photovoltaic system. The circuit consists of an inductor, switch (MOSFET), diode, and output capacitor. The inductor stores energy when the switch is ON and releases it when the switch is OFF, thereby increasing the output voltage. The diode ensures unidirectional current flow, while the capacitor smooths the output voltage and reduces ripple. The switching operation is controlled by a PWM signal generated from the MPPT controller, which adjusts the duty cycle to maintain maximum power extraction from the PV system

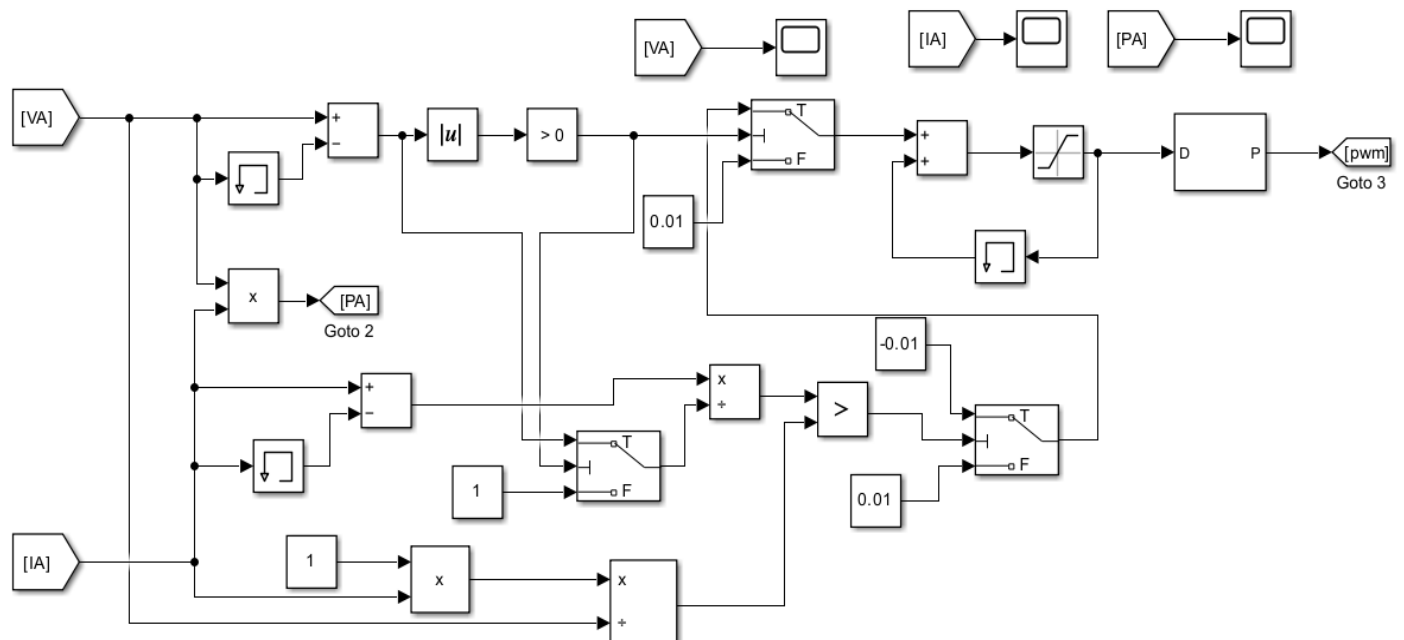


Figure 4: PWM Generator Block

Figure 4 represents the PWM generator block used in the Incremental Conductance (IC) MPPT system. This block converts the duty cycle signal obtained from the IC algorithm into a pulse-width modulated (PWM) switching signal. The duty cycle determines the ON and OFF duration of the switch in the boost converter. By varying this duty cycle, the PWM generator controls the switching operation of the converter, ensuring that the PV system operates at or near the maximum power point. This enables efficient regulation of output voltage and optimal power extraction.

Simulation Results Analysis

Figure 5 illustrates the dynamic response of the photovoltaic system employing the Incremental Conductance (IC) MPPT algorithm, showing the variation of output power, voltage and current.

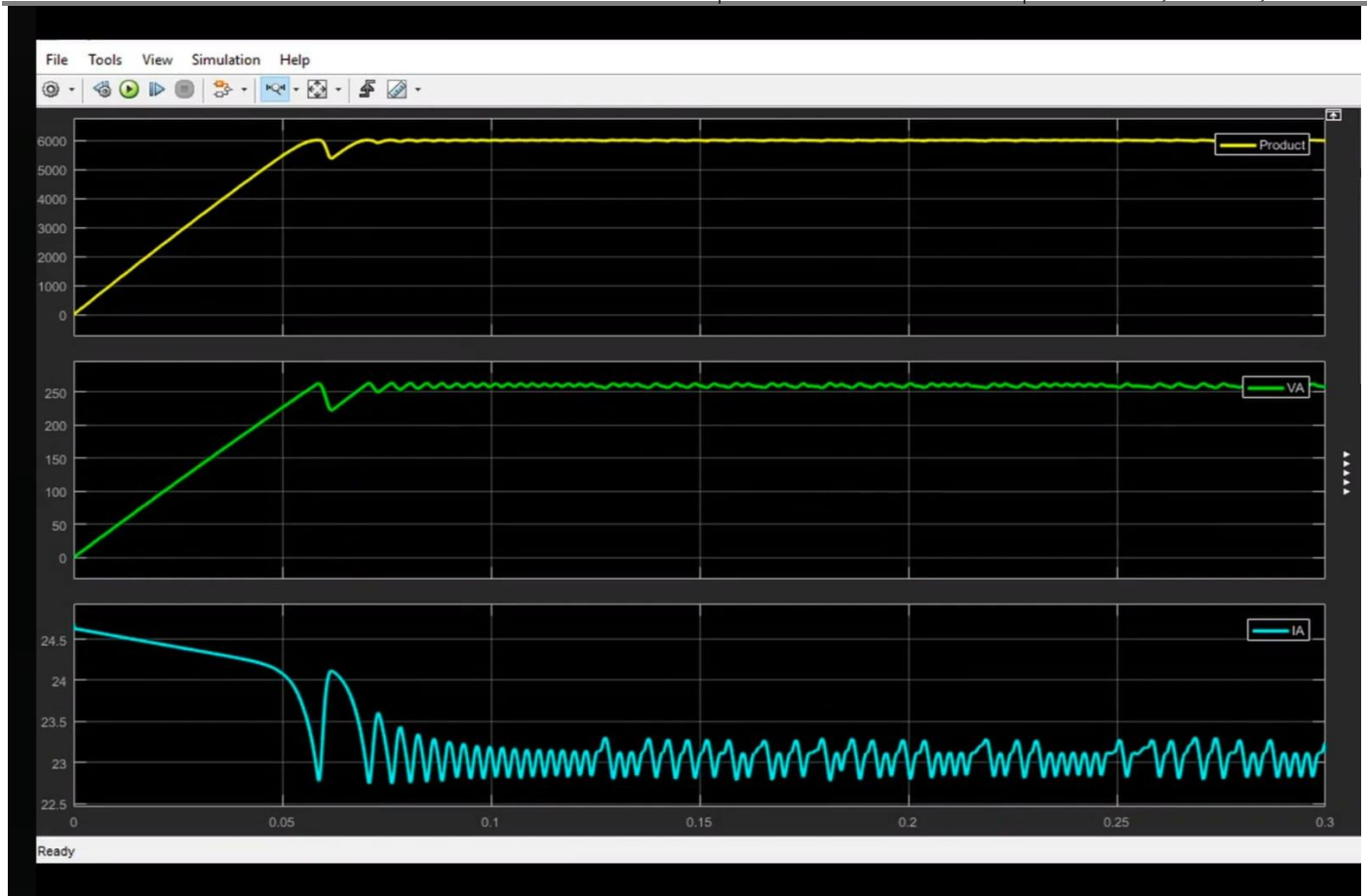


Figure 5: Incremental Conductance MPPT Controller Output Power, Output Voltage and Output Current

The system demonstrates fast convergence to the maximum power point (MPP) with high stability and minimal oscillations. Under varying irradiance conditions, the proposed method achieves a tracking efficiency of approximately 96–98%, indicating effective utilization of available solar energy. The convergence time is observed to be less than 0.05 seconds, reflecting a rapid dynamic response. Furthermore, steady-state oscillations around the MPP are significantly reduced compared to conventional methods such as Perturb and Observe (P&O). These results confirm that the proposed IC-based MPPT system provides reliable, accurate and efficient performance, making it suitable for practical photovoltaic applications.

To calculate MPPT Tracking Efficiency:

$$\eta = \frac{P_{out}}{P_{max}} \times 100$$

P_{out} = Output power obtained (from simulation graph)

P_{max} = Theoretical maximum power of PV panel

Table 3: Comparison Table

PARAMETER	P&O METHOD	IC PROPOSED METHOD
Tracking Efficiency	90-94%	96-98%
Convergence Time	High (0.1 to 0.2 sec)	Low (< 0.05sec)
Steady-state oscillation	High	Low
Accuracy	Moderate	High
Complexity	Low	Moderate

CONCLUSION

This paper presented an improved Incremental Conductance MPPT technique integrated with a DC–DC boost converter for photovoltaic systems. The proposed method enhances tracking performance by improving convergence speed and reducing oscillations. Simulation results confirm high efficiency and stable operation under varying environmental conditions. Although the study is limited to simulation, the results indicate strong potential for practical implementation. Future work will focus on hardware validation and comparison with intelligent MPPT techniques such as fuzzy logic and neural networks.

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