STUDY THE PERFORMANCE OF VARIOUS MPPT TECHNIQUES FOR PV SYSTEM

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ABSTRACT:

Optimizing the performance of photovoltaic (PV) systems to maximize power generation across varying environmental conditions is a critical objective. One effective strategy to achieve this is through the utilization of Maximum Power Point Tracking (MPPT) algorithms. This study presents a comprehensive analysis comparing two widely-utilized MPPT techniques, namely the Perturb and Observe (P&O) and Incremental Conductance (IC) algorithms, along with the introduction of an innovative Sliding Mode algorithm designed to enhance performance. The P&O algorithm adjusts the operating point of the PV system and monitors changes in power. However, it encounters challenges, such as oscillations around the maximum power point (MPP) during rapid variations in irradiance. Conversely, the IC algorithm overcomes these challenges by continuously evaluating incremental conductance and adapting the operating point accordingly. Nevertheless, the IC algorithm exhibits limitations in certain scenarios, including slow tracking speed and vulnerability to noise disturbances. To address these limitations, this study proposes a modified Sliding Mode algorithm that incorporates a robust control approach to achieve accurate and rapid tracking of the MPP. By leveraging sliding mode control techniques and employing a sliding surface, the proposed algorithm surpasses the performance of both the P&O and IC approaches.

Keywords – Photovoltaic; solar panels; MPPT techniques; MATLAB & Simulink; IC Model

1. INTRODUCTION

Solar energy harvesting systems have gained significant importance due to various compelling reasons. One crucial factor is the global energy crisis resulting from the depletion of traditional fossil fuel reserves and the environmental impact associated with their use. In contrast, solar energy provides a clean and renewable alternative that can be harnessed indefinitely.

Developing efficient solar energy harvesting systems allows us to tap into this abundant energy source more effectively, reducing our dependence on fossil fuels and mitigating the environmental consequences associated with their extraction and combustion.

Additionally, optimizing the capture and conversion of solar energy can make a significant contribution to reducing greenhouse gas emissions. The burning of fuels releases large quantities of CO_2 and pollutants, which contribute to climate change and air pollution. By maximizing the efficiency of solar energy systems, we can minimize the need for carbon-intensive energy production methods and decrease our overall carbon footprint.

Moreover, efficient solar energy harvesting systems have the potential to enhance energy accessibility and independence, particularly in remote or underdeveloped areas with limited access to reliable electricity grids. Implementing efficient solar energy solutions provides decentralized and sustainable power sources, empowering communities to meet their energy needs independently. This has a transformative impact on various aspects such as education, healthcare, and economic development, improving the quality of life and creating new opportunities.

1.2 Need for Solar Energy Harvesting

1. Renewable and Sustainable Energy Source: Solar energy is clean, renewable and virtually unlimited source of energy. Solar energy provides a sustainable way to satisfy our energy demands without using natural resources or producing damaging greenhouse gases, in contrast to fossil fuels, which are limited and contribute to environmental damage and climate change.

2. Mitigating Climate Change: We may produce energy without using fossil fuels by utilizing the power of the sun, which will reduce the amount of carbon dioxide and other harmful pollutants that contribute to global warming and air pollution.

3. Energy Independence and Security: Solar energy provides an opportunity for greater energy independence and security. By diversifying our energy sources and relying more on solar power, countries can reduce their dependence on imported fossil fuels, which are subject to price volatility and geopolitical risks. Solar energy can be harnessed locally, making it a decentralized and reliable energy option.

1.3 Different Ways of Solar Energy Harvesting

1. Photovoltaic (PV) Systems: PV systems, also known as solar panels, directly convert sunlight into electricity by utilizing semiconductor materials. These panels can be installed on rooftops, solar farms, enabling widespread solar energy generation.
2. Solar Thermal Systems: Solar thermal systems utilize solar energy to heat water or other fluids directly. These systems absorb sunlight through solar collectors and transfer the heat to a fluid. Solar thermal systems find applications in water heating, space heating, and industrial processes requiring heat.
3. Solar Chimneys: Solar chimneys, or solar updraft towers, generate electricity by combining solar heating and air flow. These structures capture sunlight and heat the air beneath them, creating an updraft that drives turbines at the base of the chimney, generating electricity.
4. Solar-Powered Water Pumping Systems: These systems utilize solar energy to power pumps that extract water from wells, rivers, or other sources. They are widely used in agriculture, irrigation, livestock watering, and remote areas without access to grid electricity.

2. *The flow of electricity in a solar cell*

When electrons, carrying negative charges, migrate towards the front surface of a solar photovoltaic cell, an electrical charge disparity emerges between the cell's front and back surfaces. This discrepancy generates a voltage potential akin to the positive and negative terminals of a battery. The presence of electrical conductors on the cell allows for the collection of these electrons. By establishing connections between these conductors and an external load, such as a battery, within an electrical circuit, electricity is able to circulate through the circuit, facilitating the transmission of electrical energy.

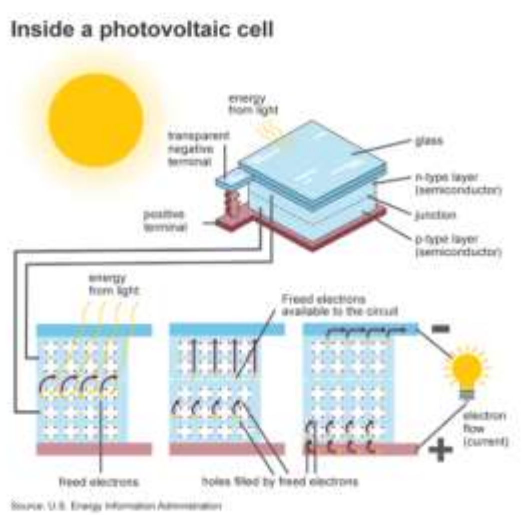


Figure 4-1-Electron Flow inside PV Cell

2.1 Photovoltaic System Modeling

PV modeling encompasses the mathematical depiction and simulation of the functionality and effectiveness of photovoltaic (PV) systems. It entails constructing models that portray the correlation between different factors, including solar irradiance, temperature, electrical properties, and environmental circumstances, to anticipate the performance of a PV system.

2.2 Equivalent model of a PV cell

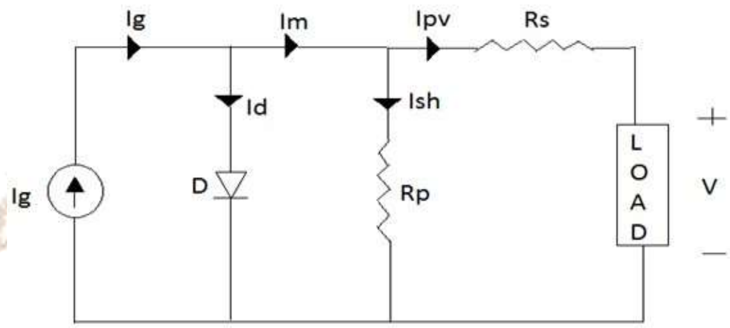


Figure 2.2: Equivalent model of PV Cell

The PV array's current output is directly inversely proportional to solar insolation. The following equations regulate the PV-generated current in the following equations:

$$I_{pv} = I_m - I_{sh}$$

Where I_{sh} is the shunt resistor's current provided by:

$$I_{sh} = \left(\frac{V + I_{pv} R_s}{R_p} \right)$$

$$I_m = I_g - I_d$$

Where I_g is the generated PV current proportional to solar insolation given by

$$I_g = \left(I_{g,n} + K_1 \Delta T \right) \frac{G}{G_n}$$

$$I_d = I_0 \left(\exp\left(\frac{(V + I_{pv} R_s)}{v_t n} \right) - 1 \right)$$

Where I_0 is the reverse saturation current of the diode given by

$$I_0 = \frac{I_{sc,n} + K_I \Delta T}{\exp\left(\left(\frac{V_{oc,n} + K_v \Delta T}{a V_t} \right) \right) - 1}$$

Where v_t is temperature equivalent voltage given by

$$v_t = \frac{N_s k T}{q}$$

Final expression for PV cell output current is given by:

$$I_{pv} = I_g - I_0 \left(\exp\left(\frac{(V + I_{pv} R_s)}{v_t n} \right) - 1 \right) - \left(\frac{V + I_{pv} R_s}{R_p} \right)$$

Where I_d is the diode current given by

Parameter	Description	Value	Parameter	Description	Value
V_{oc}	Open circuit voltage	32.9V	T	Ambient Temperature	301°K
$I_{sc,n}$	Short circuit current	8.21A	T_n	Nominal temperature	300°K
k	Boltzman's Constant	$1.38*10^{-23}$	q	Electron Charge	$1.6*10^{-19}$
N_s	Number of cells in series	54	n	Diode Ideality factor	2
N_p	Number of cells in parallel	1	I_0	Diode saturation current	
G	Solar Insolation	800	$I_{0,n}$	Diode nominal saturation current	$9.85*10^{-8}$
G_n	Nominal Solar insolation	1000	E_g	Bandgap Energy	1.12eV
K_V	Voltage coefficient	-0.1230	$I_{g,n}$	Nominal current at STC	8.214
K_I	Current coefficient	0.0032	R_s & R_p	Series and parallel resistance, respectively	0.221Ω, 414.5Ω

Table 2.1: Parameters of PV Cell

2.2.1 Simulink-based PV Cell Modelling

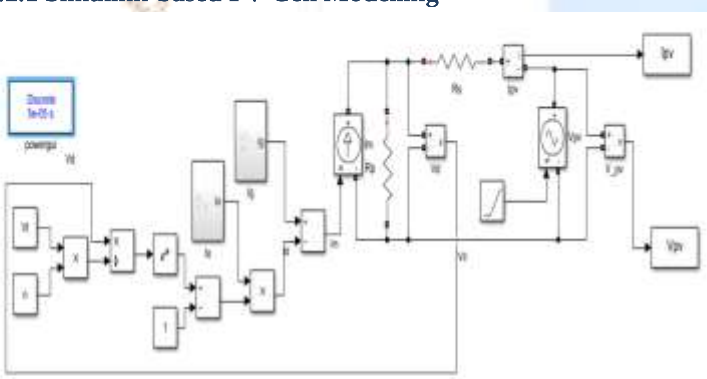


Figure 2.2.1: PV Cell Simulink Model

2.2.2 MATLAB Simulink Model

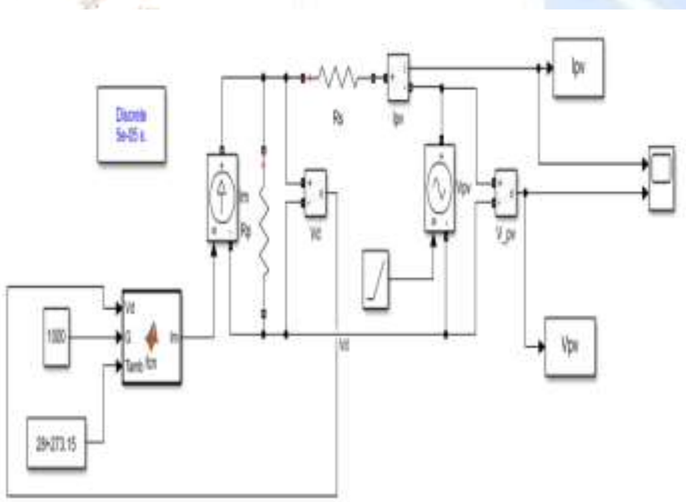


Figure 2.2.2: MATLAB Function-based PV Cell Model

2.3 Boost Converter

The boost converter functions by harnessing the concept of energy storage in an inductor. The voltage across the inductor is directly related to the rate of change of electric current passing through it. Through this circuit configuration, the boost converter ensures a stable and amplified DC output at the load.

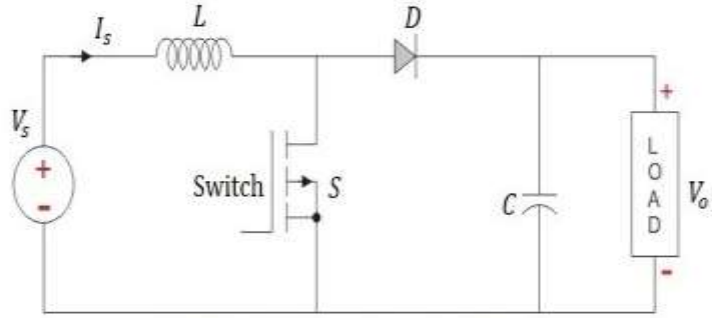


Figure 2.3: -Boost Converter Circuit Diagram

3. Presentation of the MPPT Algorithms

MPPT (Maximum Power Point Tracking) algorithms play a crucial role in solar charge controllers as they aim to optimize the power generation from PV panels by effectively tracking and operating at the PV cell's maximum power point (MPP).

The MPP represents the specific voltage and current combination at which the panel delivers its highest power output. MPPT algorithms are employed in solar charge controllers to optimize the power output of PV panels by tracking and operating at the maximum power point (MPP).

3.1 Flow Chart

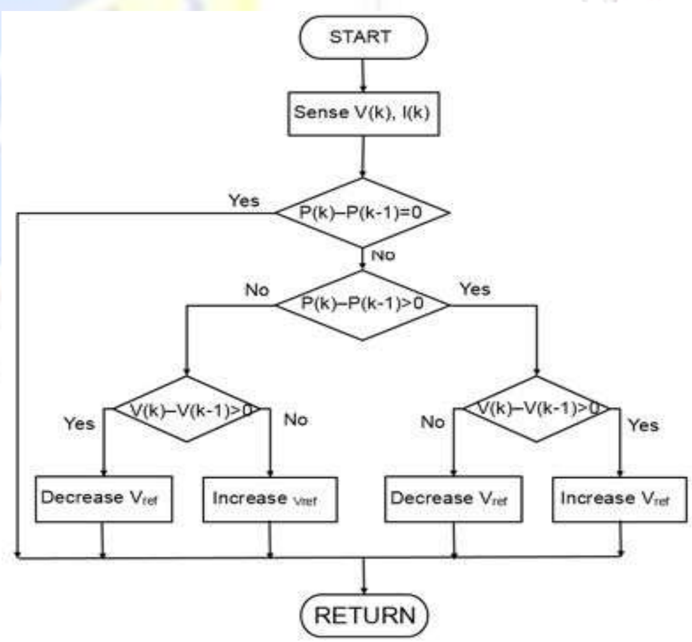


Figure 3.1: P&O Flow Chart

P&O is an extensively utilized MPPT algorithm renowned for its effectiveness. It functions by continuously perturbing the operating voltage of the PV panel and simultaneously monitoring the resulting power output.

3.2 IC Flow Chart

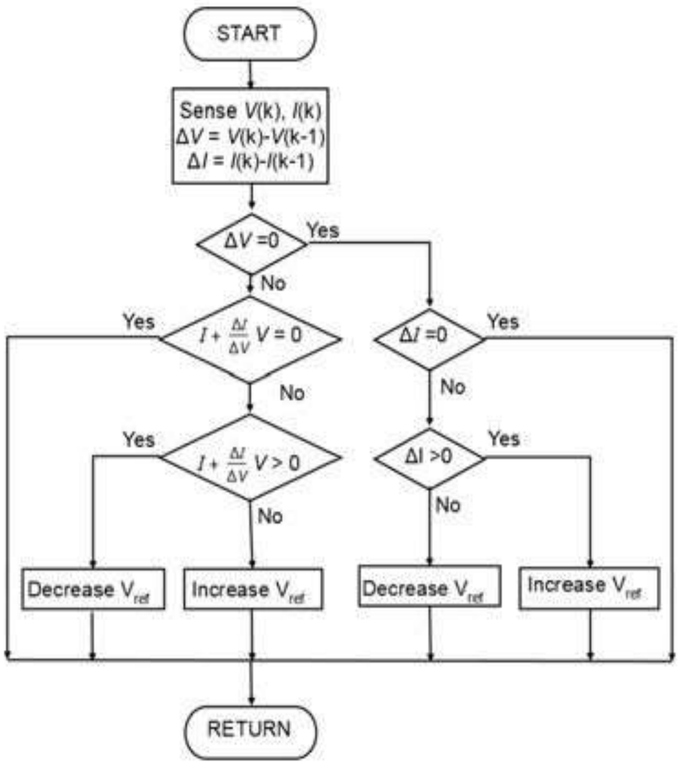


Figure 3.2: IC Flow Chart

The Incremental Conductance algorithm improves P&O approach by incorporating additional factors for tracking the MPP of a PV panel. In addition to considering the power output, it also takes into consideration the rate of change of power concerning voltage.

By analyzing the sign of the incremental conductance, this algorithm provides a more precise means of tracking the MPP. It proves to be particularly effective in environments where light conditions change rapidly.

3.3 Sliding Mode Controller

The Sliding Mode Controller block implements hysteresis-based sliding mode control (SMC).

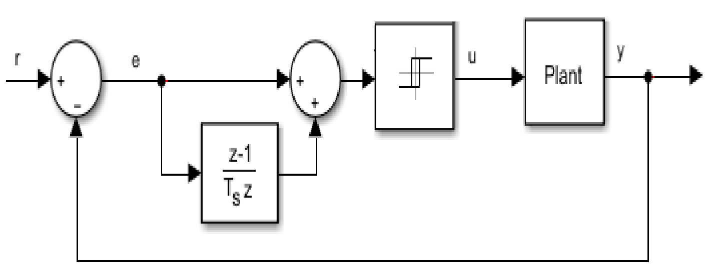


Figure 3.3: SMC Model Block

4. MPPT P&O and IC Model Combined Simulation

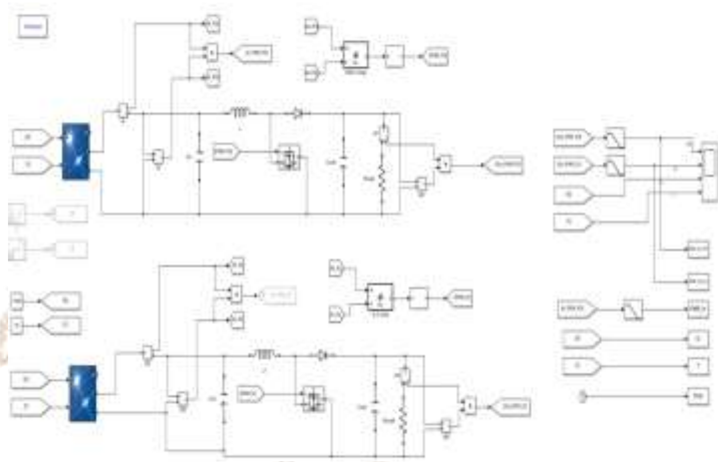


Figure 4 : P&O and IC Combined 4 MATLAB SIMULINK Model

4.1 SMC Simulink Modelling

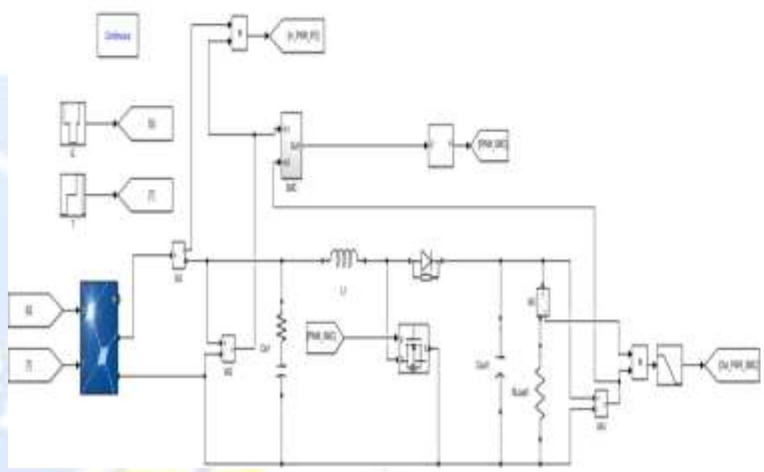


Figure 4.1: SMC MATLAB SIMULINK Model

4.2 MPPT SMC and IC Model Combined Simulation

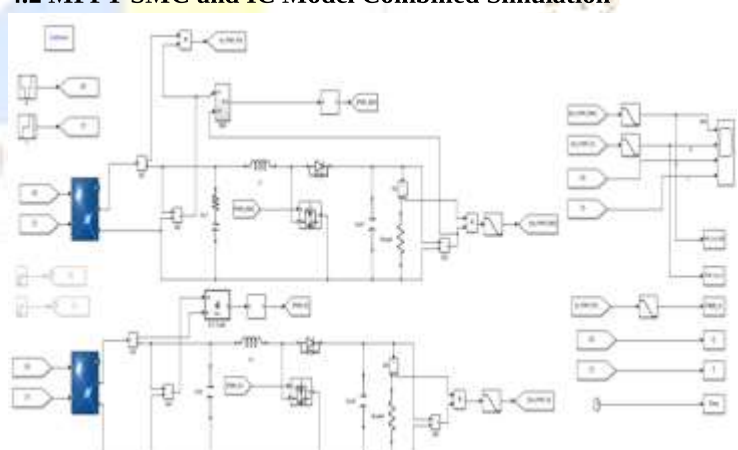


Figure 4.2: SMC and IC Combined MATLAB SIMULINK Model

5. Results and Discussion

Irradiation Constant and Temperature Constant

5.1 Fixed Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Solar Module	1Soltech 1STH-215-P	qty
2	Maximum Power (W)	213	W
3	Open circuit voltage Voc (V)	36.3	V
4	Voltage at maximum power point Vmp (V)	29	V
5	Cells per module (Ncell)	60	qty
6	Short-circuit current Isc (A)	7.84	A
7	Current at maximum power point Imp (A)	7.35	A
8	Temperature coefficient of Isc (%/deg.C)	0.102	%/deg.C
9	Temperature coefficient of Voc (%/deg.C)	-0.36099	%/deg.C
10	Cin	5mF	mF
11	L	2.5mH	mH
12	Cout	1000uF	uF
13	RLoad	200	ohm

Table 5.1: Fixed Simulation Parameters

5.2 MPPT Algorithm P&O and IC Comparison

Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	1000	W/m2
3	Temperature	25	Degree Celsius

Table 5.2: P&O and IC Input Parameter with Constant T and G

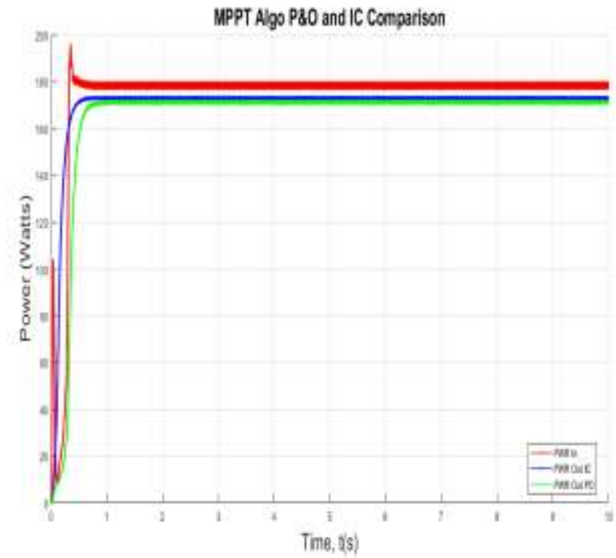


Figure 5.2: P&O and IC Output Comparison Graph with Constant T and G

5.3 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	1000	W/m2
3	Temperature	[25, 25,25, 30, 30, 30, 35, 35,25, 25]	Degree Celsius

Table 5.3: P&O and IC Input Parameter with Constant G

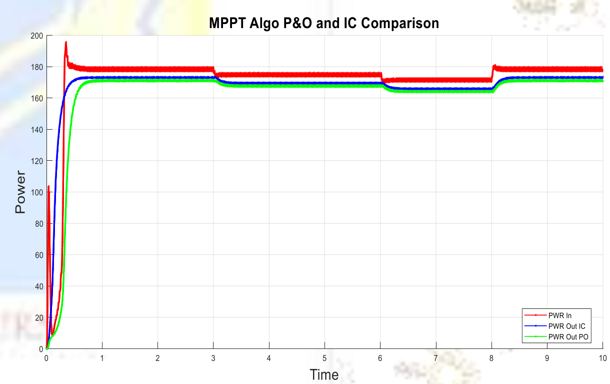


Figure 5.3:P&O and IC Output Comparison Graph with Constant G

5.4 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	[1000, 1000, 800, 800, 600,600, 800, 1000,1000,1000]	W/m2
3	Temperature	25	Degree Celsius

Table 5.4:P&O and IC Input Parameter with Constant T

Table 5.4:P&O and IC Input Parameter with Constant T

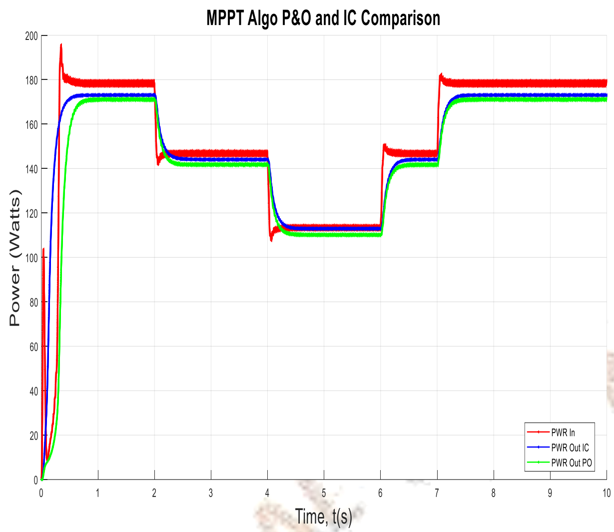


Figure 5.4:P&O and IC Output Comparison Graph with Constant T

5.5 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	[1000, 1000, 800, 800, 600,600, 800, 1000,1000,1000]	W/m2
3	Temperature	[25, 25,25, 30, 30, 30, 35, 35,25, 25]	Degree Celsius

Table 5.5: P&O and IC Input Parameter with Variable T and G

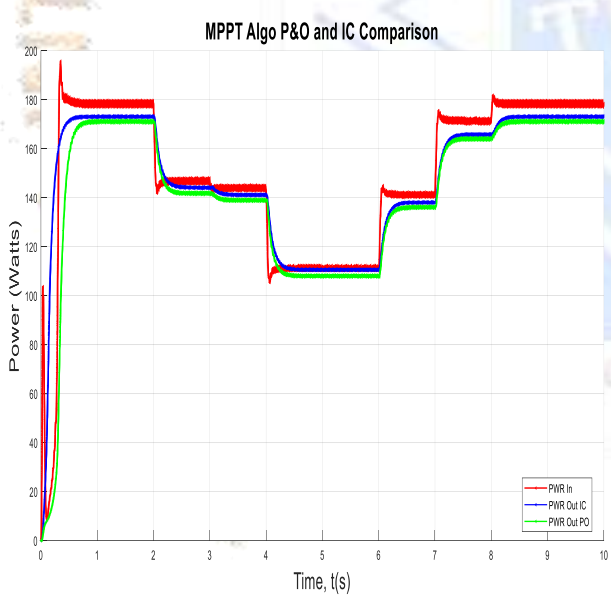


Figure 5.5:P&O and IC Output Comparison Graph with Variable T and G

6. MPPT Algorithm SMC and IC Comparison

Irradiation Constant and Temperature Constant

6.1 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	1000	W/m2
3	Temperature	25	Degree Celsius

Table 6.1: SMC and IC Input Parameter with Constant T and G

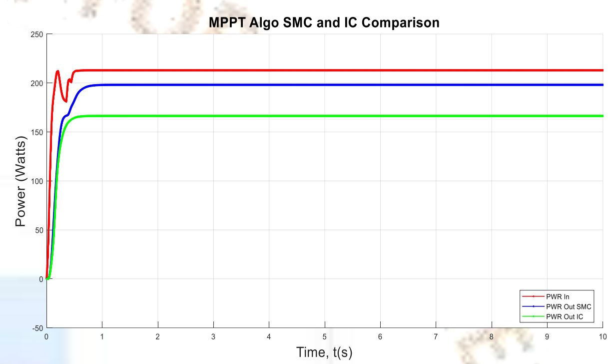


Figure 6.1 : SMC and IC Output Comparison Graph with Constant T and G

6.2: Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	1000	W/m2
3	Temperature	[25, 25,25, 30, 30, 30, 35, 35,25, 25]	Degree Celsius

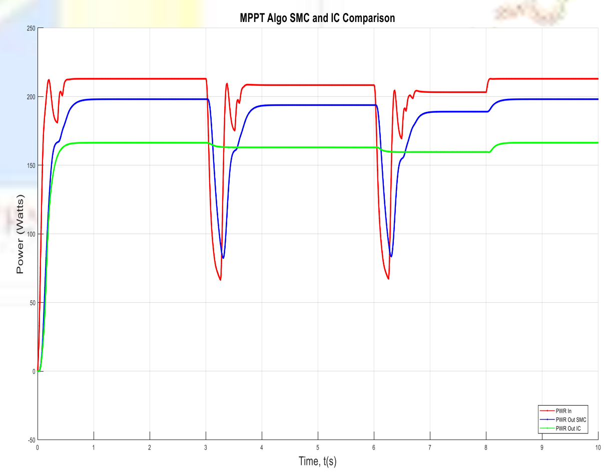


Figure 6.2: SMC and IC Output Comparison Graph with Constant G

6.3 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	[1000, 1000, 800, 800, 600,600, 800, 1000,1000,1000]	W/m2
3	Temperature	25	Degree Celsius

Table 0.3: and IC Input Parameter with Constant T

Figure 6.3: SMC and IC Output Comparison Graph with Constant T

6.4 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	[1000, 1000, 800, 800, 600,600, 800, 1000,1000,1000]	W/m2
3	Temperature	25	Degree Celsius

Table 6.4: SMC and IC Input Parameter with Constant T

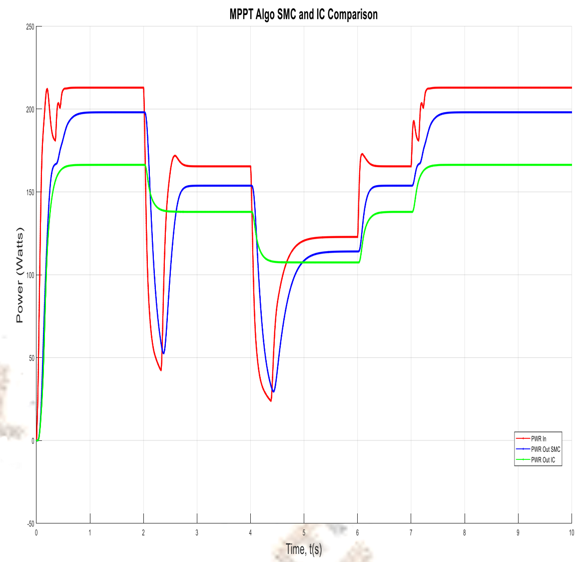


Figure 6.4 : SMC and IC Output Comparison Graph with Constant T

6.5 Dynamic Simulation Parameters

S.No.	Parameter Name	Parameter Value	Unit
1	Time	[0, 1, 2, 3,4,5,6,7,8,9]	Second
2	Irradiation	[1000, 1000, 800, 800, 600,600, 800, 1000,1000,1000]	W/m2
3	Temperature	[25, 25,25, 30, 30, 30, 35, 35,25, 25]	Degree Celsius

Table 0.5: SMC and IC Input Parameter with Variable G and T

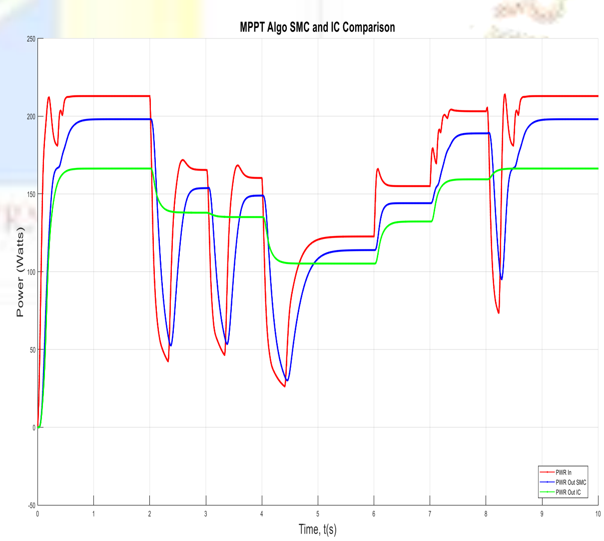
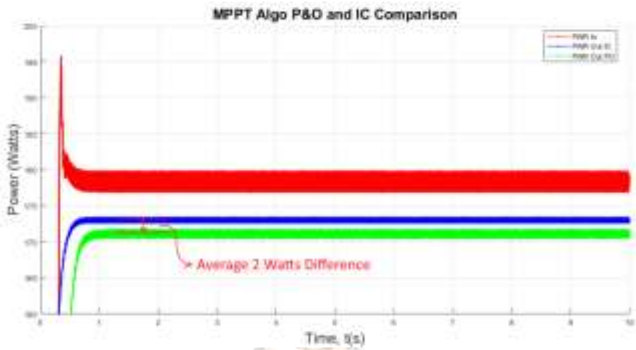


Figure 6.5: SMC and IC Output Comparison Graph with Variable T and G

7. Conclusion

1. MPPT IC algorithm is on average better by 2 watts than the P&O MPPT algorithm for a given common PV system, Temperature, and Irradiation.
So we can say IC is (2/180) *100 = 1.111%
Better than P&O.



2. SMC algorithm is on average better by 32 watts than IC MPPT algorithm for a given common PV system, Temperature, and Irradiation.
So we can say SMC is (32/214) *100 = **14.9%**

9. Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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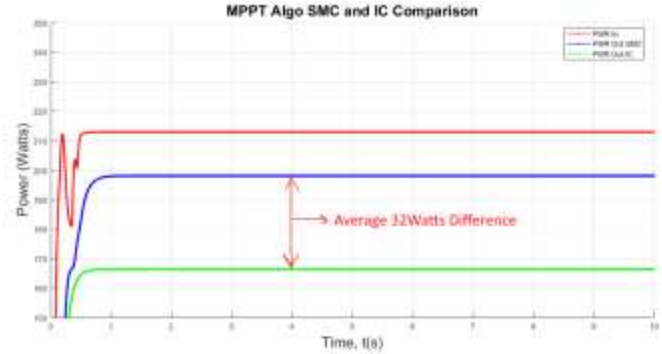

8. Future Work

1. We can see SMC algorithm output is steep at sudden Temperature change whereas P&O and IC results gradually changes. We can improvise the circuit and algorithm to improve the SMC performance in these conditions.

2. We can use the SMC algorithm to create microcontroller-based real-world hardware with the same circuit used for simulation to get real-world results.

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