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India SMART UTILITY Week 2024

Technical Paper Presentation

Evaluating the Performance of Maximum Power Point Tracking Methods for Photovoltaic Systems: Perturb & Observe, Incremental Conductance, and Fuzzy Logic-Based Approaches

Presented By: Lead Author

Nasreen N. Mansoori

Assistant Professor, Department of Electrical Engineering, Silver Oak University, Ahmedabad, Gujarat.

Co-Author

Dr.Rittal J. Gajjar

Associate Professor, Department of Electrical Engineering, Parul University, Vadodara, Gujarat.

OUTLINE OF PRESENTATION

- Introduction
- Significance of MPPT
- Grid Connected PV System
- Maximum Power Point Tracking Methods
- Result & Discussion
  - Variable Load Demand Under Constant Irradiance and Temperature – S1
  - Variable Irradiance Under Constant Temperature and Load Demand – S2
  - Variable Temperature Under Constant Irradiance and Load Demand – S3
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INTRODUCTION

- **India** is among the **greatest renewable energy producers** in the world. Renewable energy sources, such **as photovoltaic (PV) power**, play a substantial role in the production of electricity.[1-2]
- **PV systems** make use of a technology known as **MPPT** in order **to maximize the amount of power generated** by solar panels. [3]
- It is necessary to use Maximum Power Point Tracking, or MPPT, in order **to alter the characteristics of the load in such a way that they intersect with the Maximum Power Points (MPPs)** of the PV module. [4]
- **Efficiency, tracking accuracy, response time, and voltage ripples** are some of the metrics that may be used to assess the effectiveness of MPPT approaches [5]

- This article focus on the performance of three different methods:

1. **Perturb & Observe (P&O) MPPT,**
2. **Incremental Conductance (Inc.Cond.) MPPT**
3. **Fuzzy Logic Control (FLC)-based**

SIGNIFICANCE OF MPPT

- Figure 1 shows the **non-linear current-voltage (IV) characteristics** of a photovoltaic (PV) source alongside **various load characteristics.**
- The **intersection point** between the PV and load characteristics determines the **operating point for the source-load system**.
- As shown in the Fig.1, **to operate PV source at maximum power point (MPP), load impedance should remain at a particular value.**
- **Varying load demand** tends to **shift the operating point of PV source from MPP point to non-MPP point** resulting in reduction in power generation.

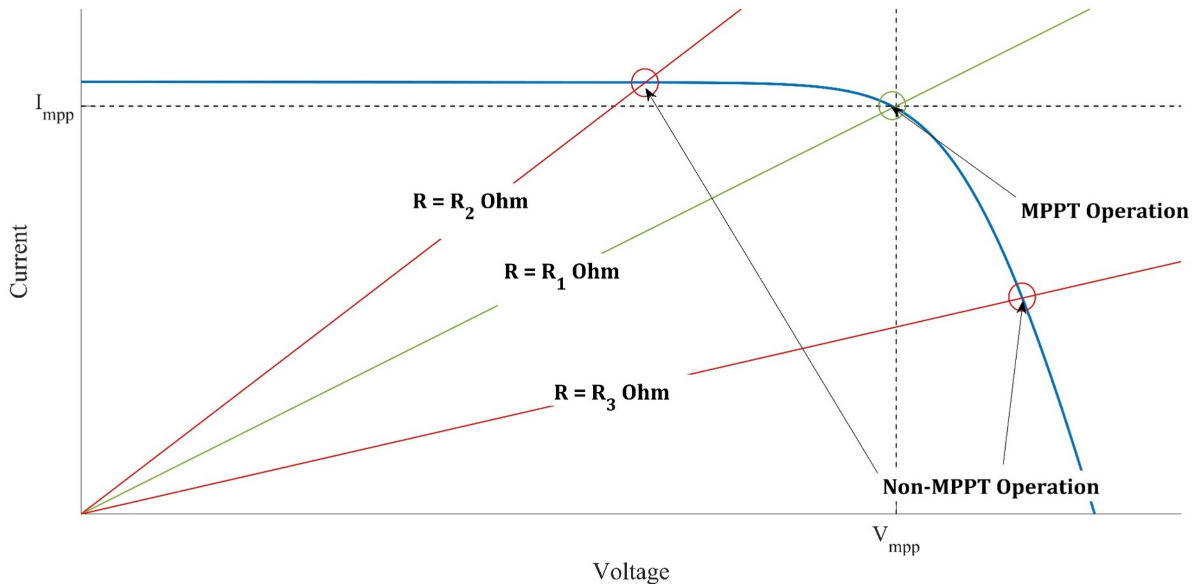

Figure 1
Current-Voltage (IV) Characteristic of PV Source

GRID CONNECTED PV SYSTEM

- Figure 2 shows the block diagram of a grid-connected photovoltaic (PV) system.
- The system consists of essential elements including the **PV array, a DC/DC converter (Boost converter) for maximum power point tracking (MPPT), and a DC to AC converter for grid integration.**
- **Table.1** shows different **parameters** of grid connected PV system.

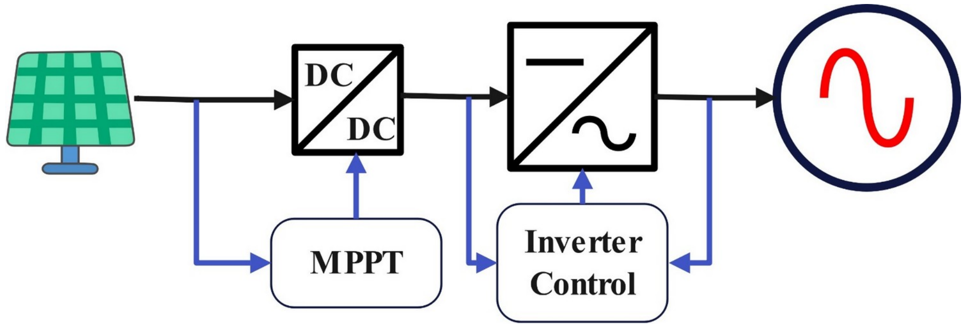

Figure 2
Grid connected PV System

Component	Parameter	Value
PV Array	Array Maximum Power	10.5 kW
	Array Maximum Power Point Voltage	104 V
	Array Maximum Power Point Current	101. 4 A
DC-DC Converter	Input Voltage	104 V
	Power Rating	11.5 kW
	Output Voltage	400 V
	Inductor	760
	Capacitor	1000
	Switching Frequency	5 kHz
DC-AC Converter	Rated Power	5 kW
	Maximum Power	11.5 kW
	DC Link Voltage	400 V
Grid	Voltage	110 V
	Frequency	50 Hz

Table 1 System Parameters

❖ **Note: Detailed design is available in paper.**

MPPT ALGORITHMS

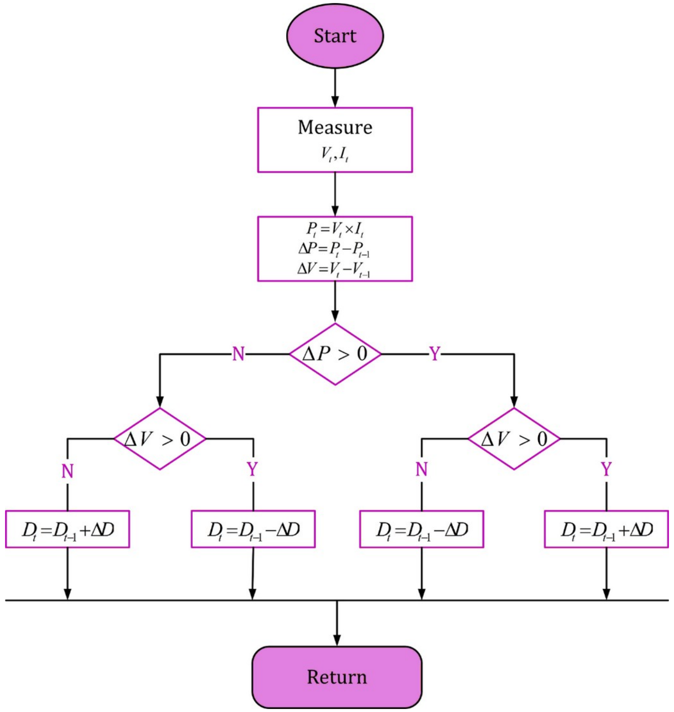

Figure 3
Perturb & Observe (P&O)

- Perturb & Observe MPPT method involves **applying a small perturbation to the operating point** of the system and observing the response in power output [6].
- This information is then used to **adjust the operating point to maximize power production.**

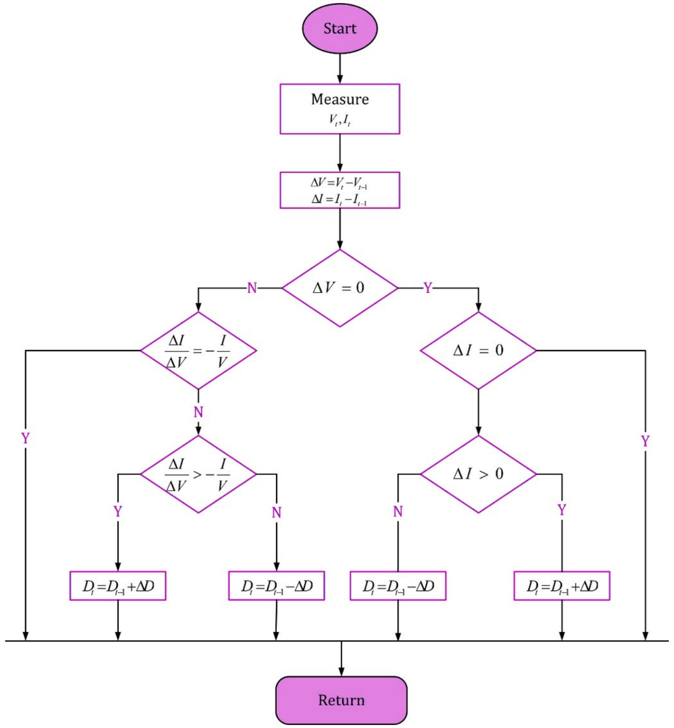

Figure 4
Incremental Conductance (Inc.Cond)

- The Incremental Conductance algorithm determines the MPP using **the slope of the output power versus voltage curve of the PV array** [7].
- If the slopes are unequal, the algorithm changes the PV system's operating point towards the direction of the **steeper slope** in order to attain the MPP.

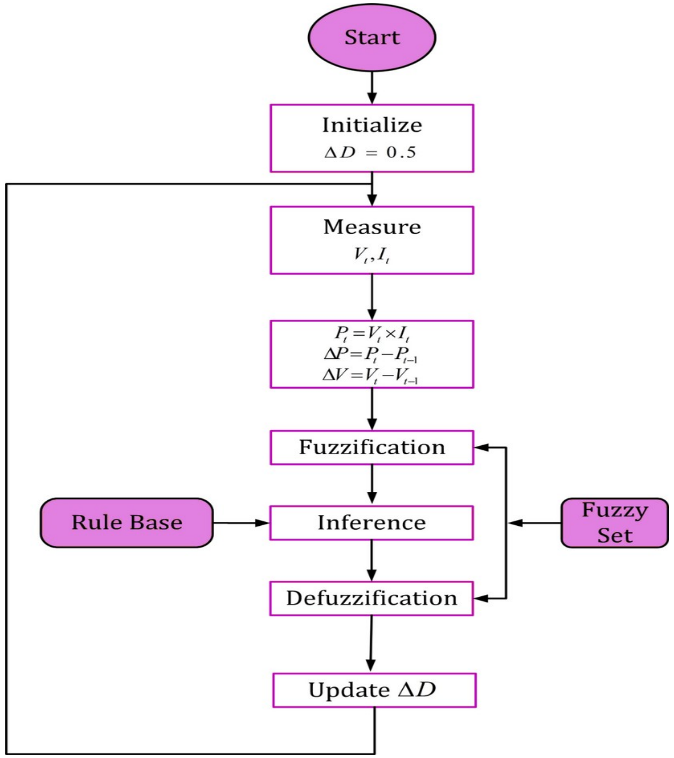

Figure 5
Fuzzy Logic Control (FLC)

- Fuzzy Logic is a popular method for MPPT due to its **ability to handle uncertainty and imprecise inputs** [8].
- Fuzzy Logic uses **linguistic variables to represent the input and output parameters, allowing for more intuitive and human-like control of the MPPT process.**

RESULT & DISCUSSION

- For the purpose of conducting a performance evaluation of the P&O, Inc.Cond. and FLC based MPPT techniques, a 10.5 kW PV energy conversion system is considered.
- A grid connected **PV system of 10.5 kW with a boost converter feeding DC to AC converter** is simulated under **3 scenarios.**

1. Variable Load Demand Under Constant Irradiance and Temperature – **S1**

Time					
Load Resistance(Ω)					

2. Variable Irradiance Under Constant Temperature and Load Demand – **S2**

Time					
Irradiance(					

3. Variable Temperature Under Constant Irradiance and Load Demand – **S3**

Time					
Temperature (					

VARIABLE LOAD DEMAND UNDER CONSTANT IRRADIANCE AND TEMPERATURE – S1

	Rise Time (mS)				PV Power (kW)				Output Voltage Ripple (V)			
MPPTs												
P&O	270	39	61	113	10.36	10.36	10.36	10.36	1.89	2.02	2.23	2.59
Inc.Cond.	269	36	71	139	10.39	10.47	10.39	10.50	1.79	1.99	2.29	2.59
FLC	49	29	32	47	10.39	10.39	10.45	10.45	1.79	3.40	2.30	2.59

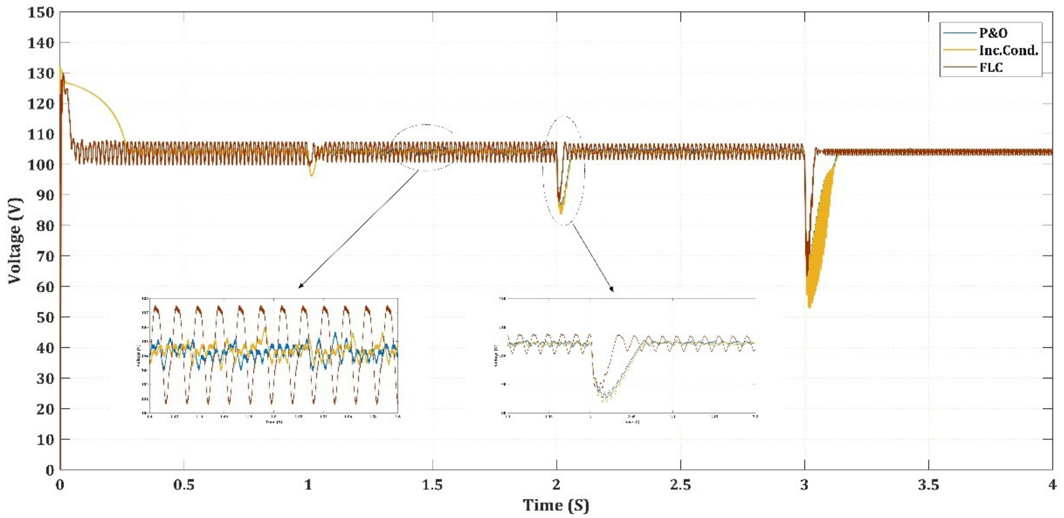

Figure 6
DC Link Voltage

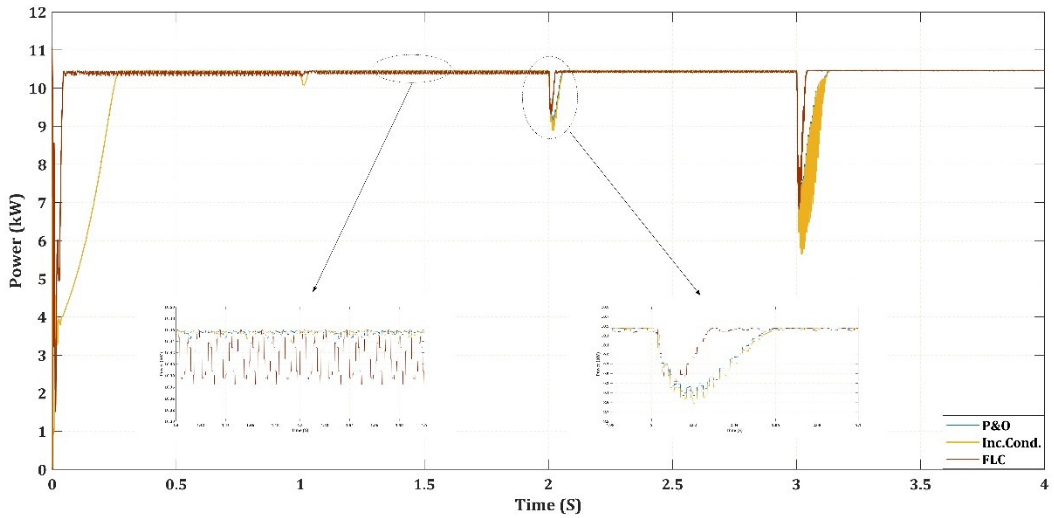

Figure 7
PV Power

- P&O, Inc.Cond. and FLC MPPTs are **tracking maximum power successfully**, irrespective of the load change.
- **P&O and Inc.Cond methods exhibit similar power ripples**, while **FLC method has larger power ripples**, as shown in Fig.6.

VARIABLE LOAD DEMAND UNDER CONSTANT IRRADIANCE AND TEMPERATURE – S1

	Rise Time (mS)				PV Power (kW)				Output Voltage Ripple (V)			
MPPTs												
P&O	270	39	61	113	10.36	10.36	10.36	10.36	1.89	2.02	2.23	2.59
Inc.Cond.	269	36	71	139	10.39	10.47	10.39	10.50	1.79	1.99	2.29	2.59
FLC	49	29	32	47	10.39	10.39	10.45	10.45	1.79	3.40	2.30	2.59

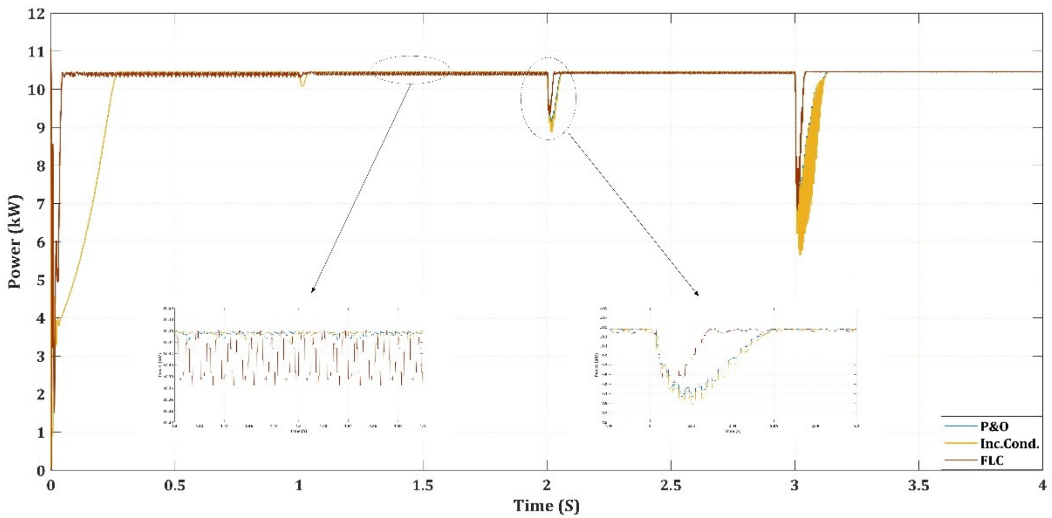

Figure 7
PV Power

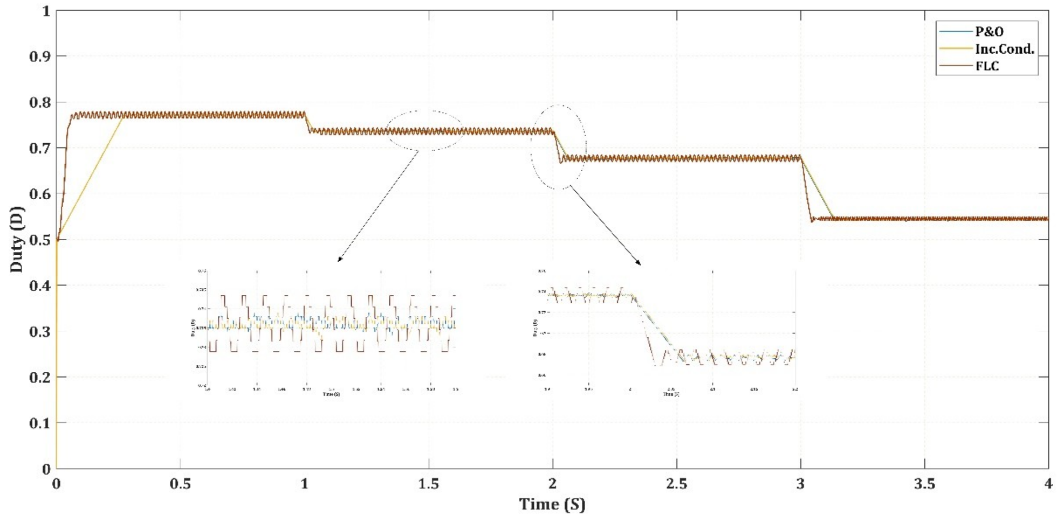

Figure 8
Duty Cycle

- **FLC** shows the **lowest Rise Time among the three**.
- This is because **FLC is flexible in updating the duty cycle (shown in Figure-8)** at each iteration, whereas **P&O and Inc.Cond. have the same and constant change in duty cycle**.

VARIABLE IRRADIANCE UNDER CONSTANT TEMPERATURE AND LOAD DEMAND – S2

	Rise Time (mS)				PV Power (kW)				Output Voltage Ripple (V)			
MPPTs												
P&O	270	49	75	120	10.39	8.00	5.32	10.45	2.00	1.67	1.19	2.00
Inc.Cond.	240	39	59	99	10.47	7.89	5.29	10.48	1.99	1.59	1.27	1.99
FLC	40	25	29	40	10.39	7.89	5.31	10.39	2.00	1.68	1.19	2.00

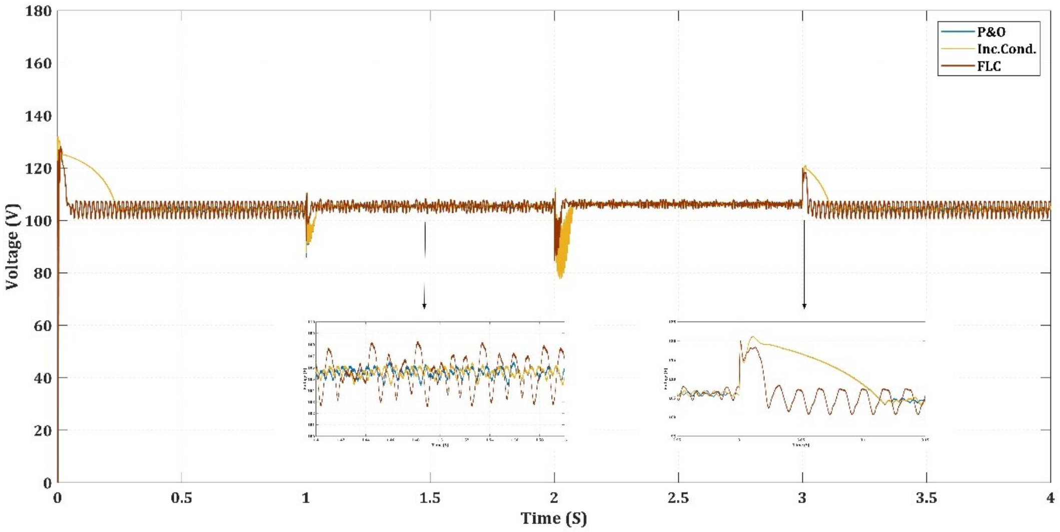

Figure 9
DC Link Voltage

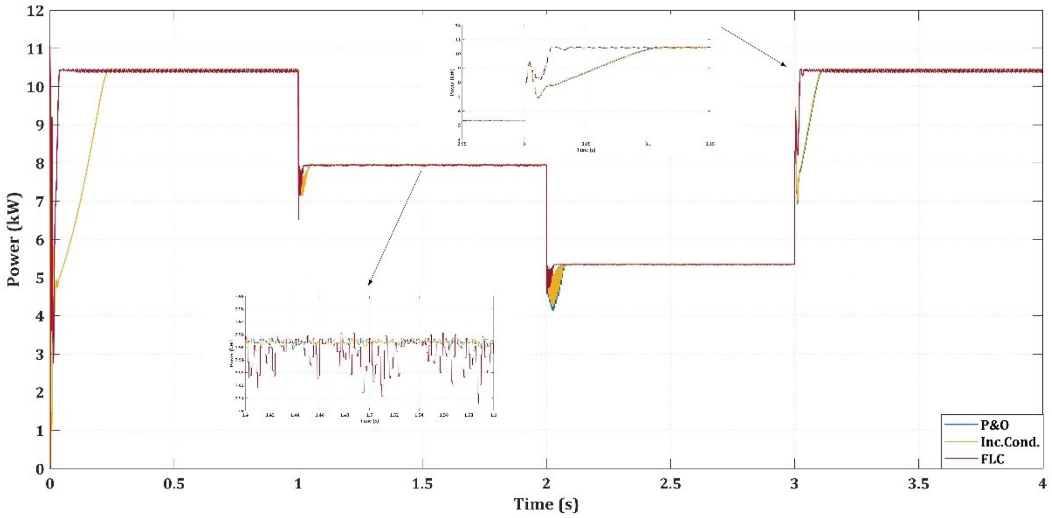

Figure 10
PV Power

- During this scenario, **FLC** shows the **smallest rise time** but **power ripples and voltage ripples are larger** compared to other two methods which can be observed in **Figure.9** and **Figure.10** respectively.

VARIABLE IRRADIANCE UNDER CONSTANT TEMPERATURE AND LOAD DEMAND – S2

	Rise Time (mS)				PV Power (kW)				Output Voltage Ripple (V)			
MPPTs												
P&O	270	49	75	120	10.39	8.00	5.32	10.45	2.00	1.67	1.19	2.00
Inc.Cond.	240	39	59	99	10.47	7.89	5.29	10.48	1.99	1.59	1.27	1.99
FLC	40	25	29	40	10.39	7.89	5.31	10.39	2.00	1.68	1.19	2.00

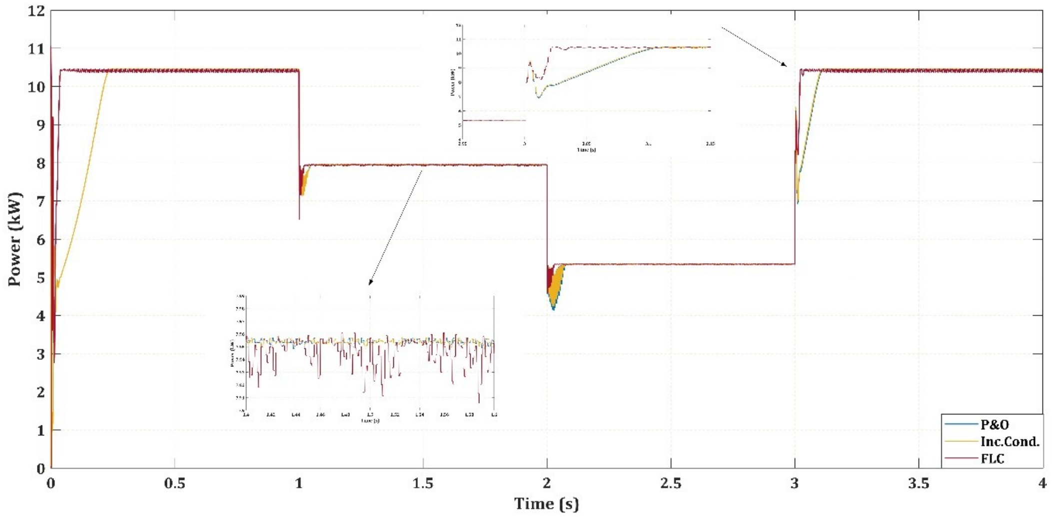

Figure 10
PV Power

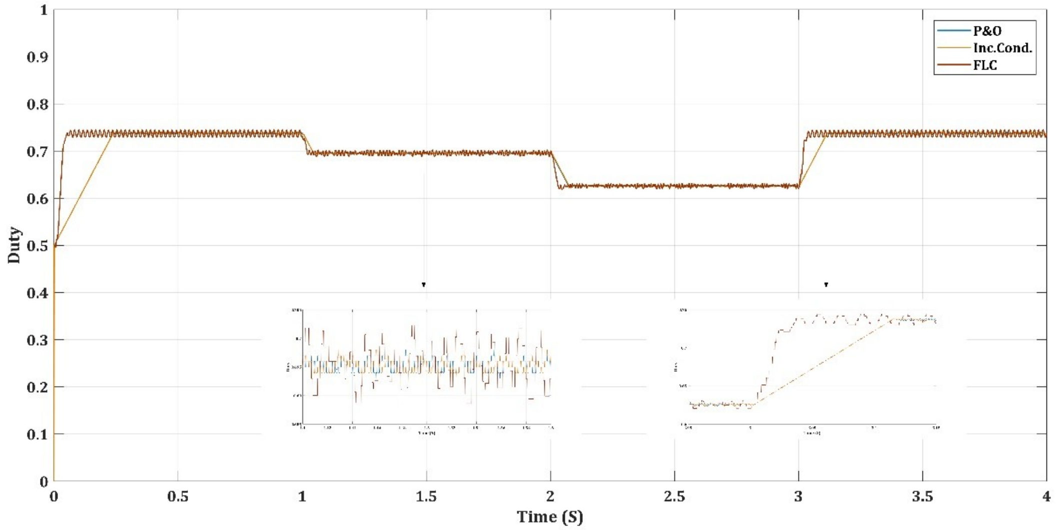

Figure 11
Duty Cycle

- As the **irradiance decreases**, generated **PV power also decreases**, as shown in **Figure.10.**
- To **hold the PV voltage at MPP** as shown in **Figure.9**, the **duty cycle of boost converter also needs to be decreased** as shown in **Figure.11**.

VARIABLE TEMPERATURE UNDER CONSTANT IRRADIANCE AND LOAD DEMAND – S3

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	Rise Time (mS)				PV Power (kW)				Output Voltage Ripple (V)			
MPPTs												
P&O	229	19	23	10	10.69	9.20	10.19	9.69	1.99	1.89	2.00	1.96
Inc.Cond.	240	19	20	09	10.69	9.20	10.19	9.69	1.99	1.89	2.00	1.93
FLC	39	15	05	10	10.59	9.09	10.10	9.59	1.98	1.90	2.00	1.89

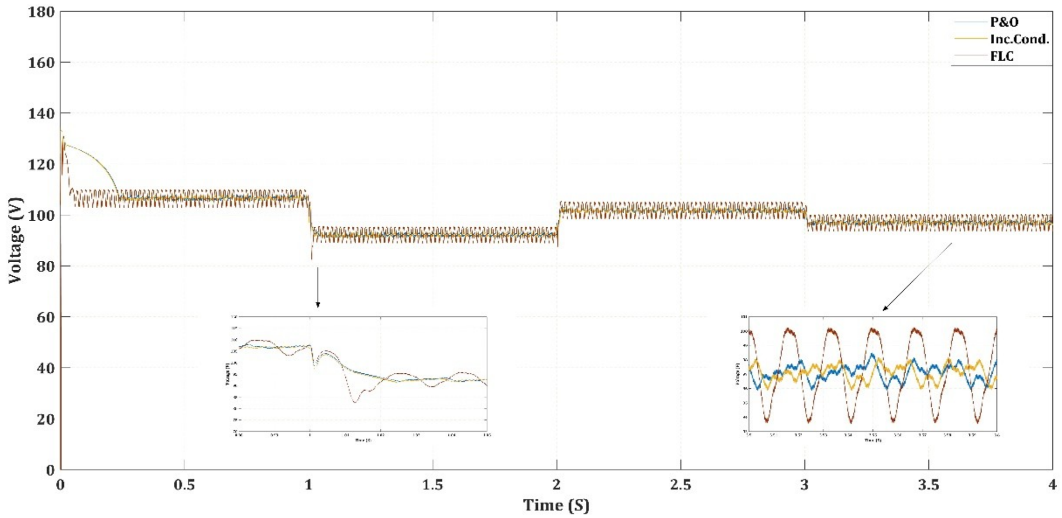

Figure 12
PV Voltage

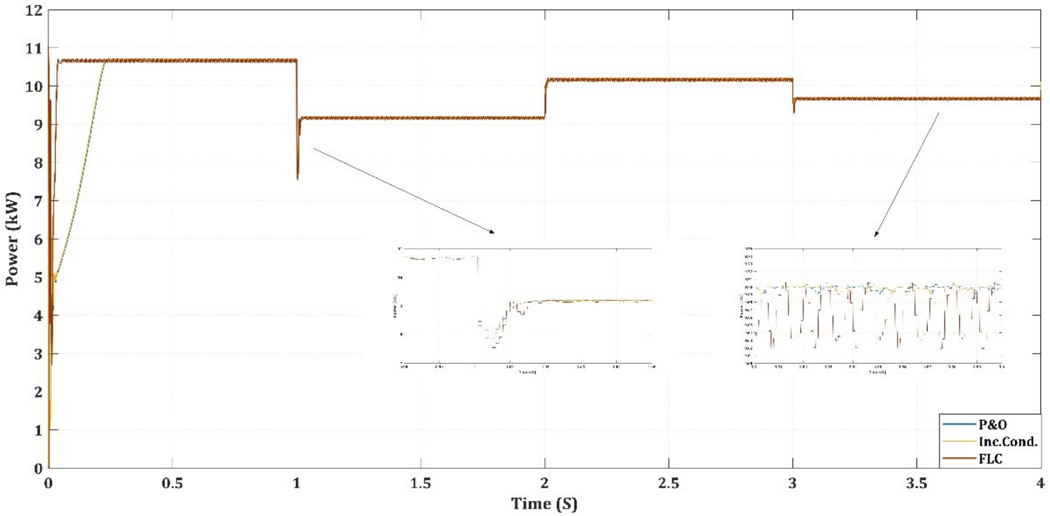

Figure 13
PV Power

- **Increment** in the ambient **temperature**, **reduce PV generated current** significantly. Hence, the **PV power also gets reduced** as shown in **Figure.12**.
- If the **temperature increases**, **maximum power point voltage decreases**. Change in maximum power point voltage with respect to temperature can be observed in **Figure.13.**

TOTAL HARMONIC DISTORTION

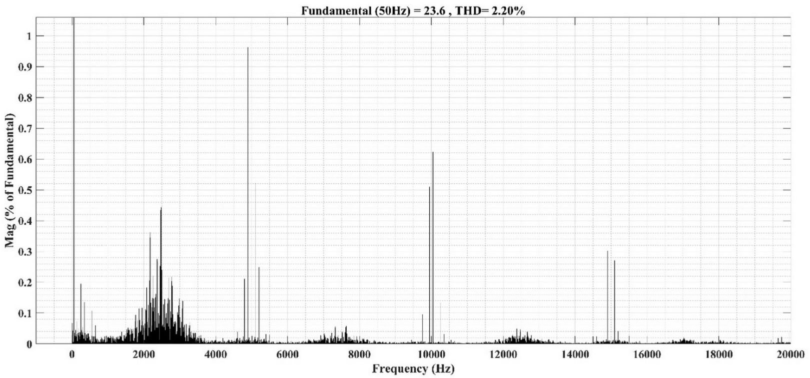

Figure 14
%THD with P&O MPPT

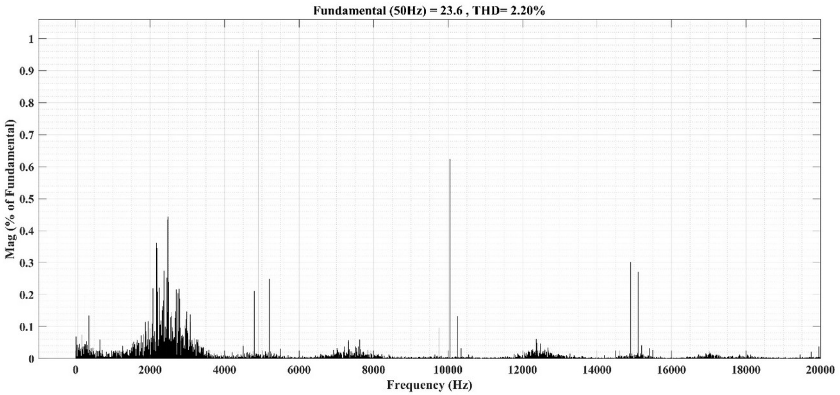

Figure 15
%THD with Inc.Cond. MPPT

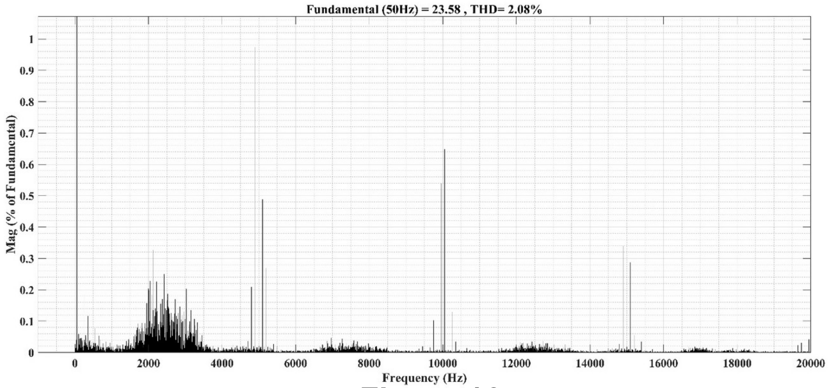

Figure 16
%THD with FLC MPPT

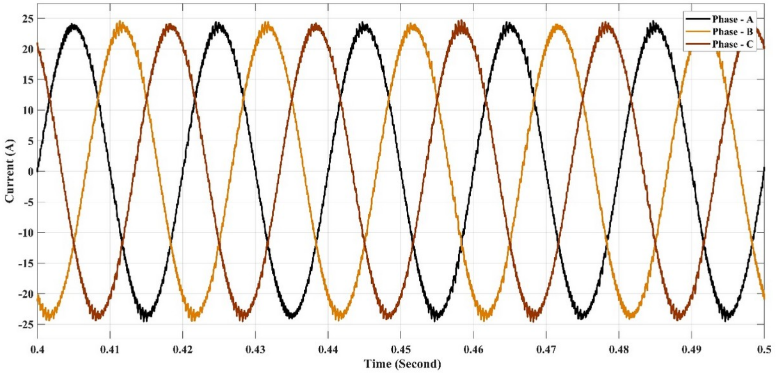

Figure 17
PCC Current with P&O MPPT

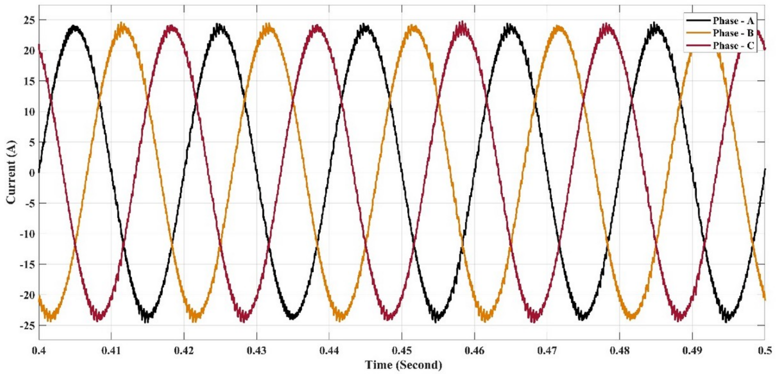

Figure 18
PCC Current with Inc.Cond. MPPT

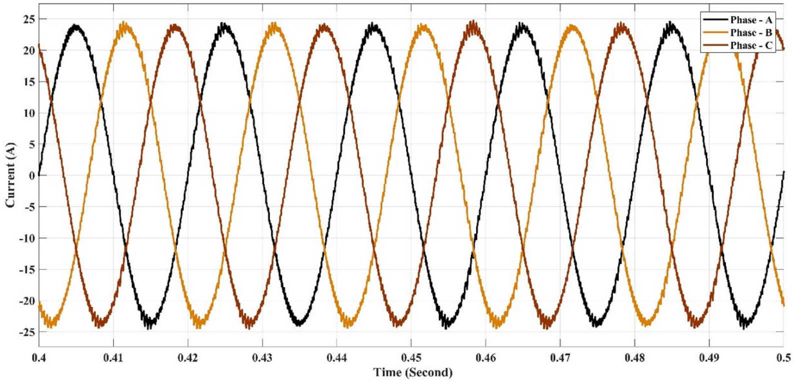

Figure 19
PCC Current with FLC MPPT

- **%THD** with **Perturb & Observe (P&O)** and **Incremental Conductance (Inc.Cond.)** MPPT are same of **2.20 %**. Whereas **%THD** with **Fuzzy Logic Control (FLC)** Based MPPT is **2.08%**.
- **FLC** stands out in terms of the **least THD** on the AC side, showcasing its potential for **improving power quality and efficiency** in the PV energy conversion system.

CONCLUSION

- **P&O and Inc.Cond.** demonstrated **robust performance** under dynamic load conditions, while **FLC** exhibited superior power quality with the **smallest Total Harmonic Distortion (THD) on the AC side**.
- FLC's **adaptability to changing environmental conditions**, though **accompanied by larger power** ripples, positions it as a promising choice for enhancing power quality in grid-connected PV systems.
- The selection of the **most suitable MPPT technique** should be tailored to specific system requirements, considering factors such as **rise time and adaptability to environmental changes**.

THANK YOU

For discussions/suggestions/queries email: ***isuw@isuw.in***

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