A report on “Grid-Tied Photovoltaic System with MPPT and Low THD Current Injection”

Abstract

This project presents the modeling and simulation of a **grid-connected solar photovoltaic (PV)** system with **Maximum Power Point Tracking (MPPT)** under variable irradiance conditions. The system consists of a PV array, DC–DC boost converter, DC-link capacitor, and grid-connected voltage source inverter (VSI). Irradiance levels of 500, 700, 800, 1000, and 1500 W/m^2 at constant temperature (25°C) were tested. A MATLAB Function block was used to generate time-varying irradiance profiles to evaluate dynamic system performance. The **Perturb and Observe (P&O)** MPPT algorithm was implemented to track maximum power. **Total Harmonic Distortion (THD)** analysis confirmed grid current quality within acceptable limits. Results demonstrate effective MPPT tracking and stable DC-link regulation under variable irradiance conditions.

I. Introduction

The integration of photovoltaic energy into power grids requires efficient MPPT and low harmonic injection. Grid-tied PV inverters must maintain:

- Maximum power extraction under variable irradiance
- Low current distortion (THD < 5%)
- Stable synchronization with the grid

This work presents a MATLAB/Simulink simulation study of a three-phase grid-connected PV system demonstrating high tracking efficiency and low THD.

II. System Description

The proposed system consists of:

- **PV Array**: Provides DC power from solar irradiance
- **DC-DC Boost Converter**: Controls voltage and enables MPPT
- **MPPT Controller**: Perturb & Observe algorithm used to track maximum power
- **DC-Link Capacitor**: Smooths voltage for inverter input

- **Grid-Tied Inverter**: Converts DC to AC for grid injection
- **LCL Filter**: Reduces switching harmonics
- **Phase-Locked Loop (PLL)**: Synchronizes inverter to grid voltage
- **Current Controller**: PI-based, regulates grid current to maintain unity power factor

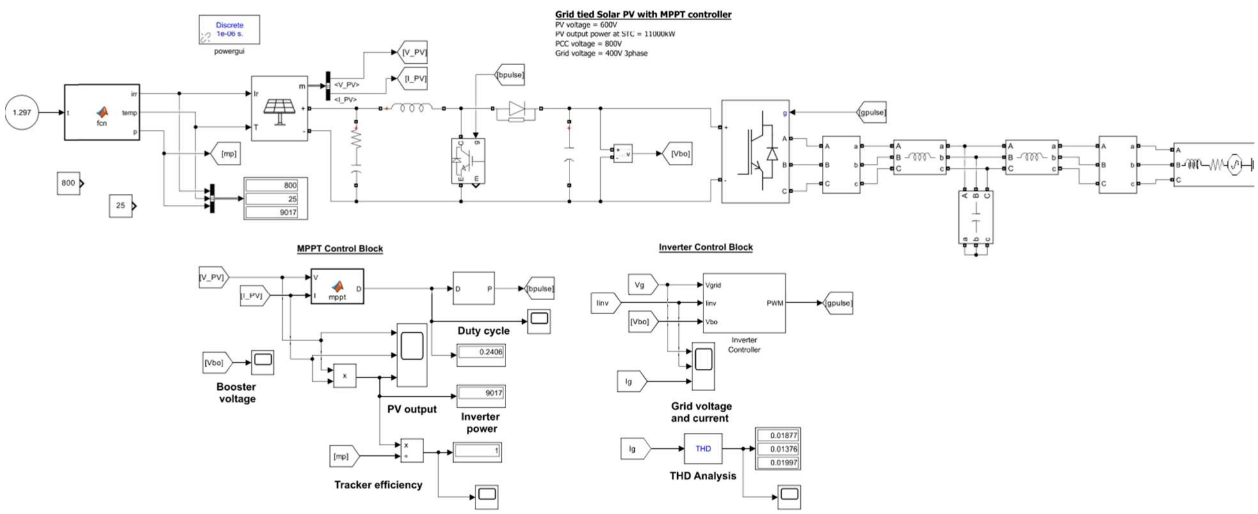

Figure 1: Grid-tied solar PV Simulink Model

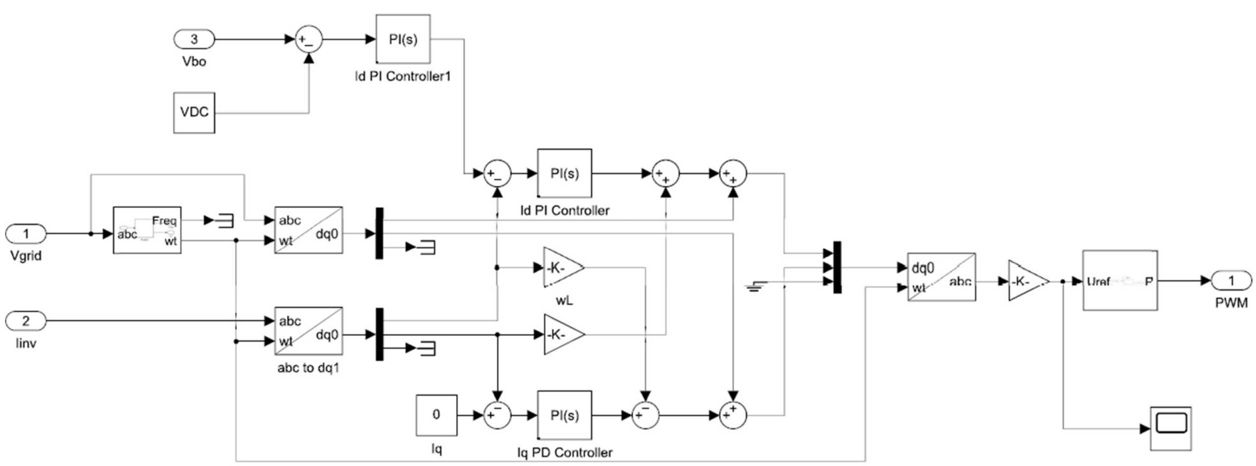

Figure 2: Inverter controller block diagram

Code block: MPPT Controller

```
function D = mppt(V,I)

persistent oldV oldP oldD;

if isempty(oldV)
    oldV = 0;
    oldP = 0;
    oldD = 0.5;
end

deltaD = 0.00005;
Dmax = 0.9;
Dmin = 0.1;

newD = oldD;
newP = V*I;
delP = newP - oldP;
delV = V - oldV;

if abs(delP) > 1
    if delP > 0
        if delV > 0
            newD = oldD - deltaD;
        else
            newD = oldD + deltaD;
        end
    elseif delP < 0
        if delV > 0
            newD = oldD + deltaD;
        else
            newD = oldD - deltaD;
        end
    end
end

newD = max(min(newD, Dmax), Dmin);

oldV = V;
oldP = newP;
oldD = newD;

D = newD;
```

Code block: Variable irradiance generator

```
function [irr,temp,p] = fcn(t)

temp = 25;
if t <= 1
    irr = 1000;
    p = 11210;
elseif t >1 && t <= 2
    irr = 800;
    p = 9017;
elseif t >2 && t <= 3
    irr = 500;
    p = 5644;
elseif t >3 && t <= 4
    irr = 700;
    p = 7903;
else
    irr = 1500;
    p = 16455;
end
```

III. Simulation Setup

Simulation parameters:

Parameter	Value
Grid Frequency	50 Hz
Switching Frequency	20 kHz
Filter Type	LCL
Filter Inductance /Capacitance	2 mH inverter side + 100 microFarad shunt capacitance + 0.5mH grid side
DC-Link Voltage	800 V
Grid Voltage	400V phase to phase
Sampling Time	1e-6 s
Irradiances	500, 700, 800, 1000, 1500 W/m^2
PV rated power	11kW

Simulation is performed in MATLAB/Simulink, with steady-state analysis after 0.2 s.

IV. PV array model

The PV array model that was used for this simulation is **Avid Solar ASMS-165P**.

Characteristics of this PV:

- Maximum power per module: 164.85W
- Vmp = 35V, Imp = 4.71A
- Series connected modules per string: 17
- Parallel strings: 4
- PV STC power: 11,210W
- PV STC voltage: 595V

V. Irradiance Generation Method

A MATLAB Function block was implemented to generate time-varying irradiance levels during simulation.

Example logic:

- 0–1 s → 1000 W/m²
- 1–2 s → 800 W/m²
- 2–3 s → 700 W/m²
- 3–4 s → 500 W/m²
- 4–5 s → 1500 W/m²

This approach enabled evaluation of system dynamic response to step changes in solar input.

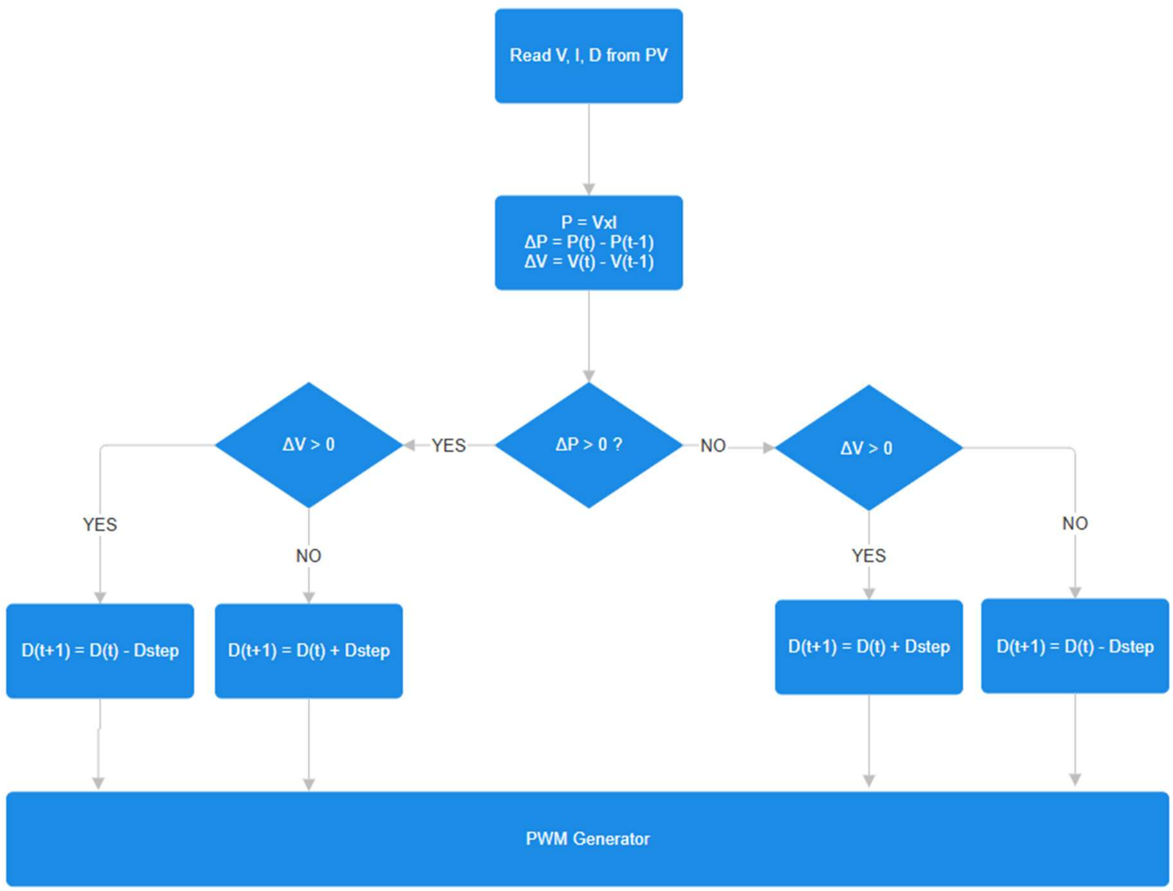

Figure 3: Flowchart of MPPT Algorithm

VI. MPPT Control Strategy

The **Perturb and Observe (P&O)** algorithm was used.

Algorithm steps:

1. Measure PV voltage and current
2. Compute power
3. Compare with previous sample
4. Adjust duty cycle accordingly

The MPPT controller regulates the boost converter duty cycle to ensure operation at maximum power point.

VII. DC-Link Voltage Control

The boost converter output forms the DC-link voltage, which is regulated to maintain stable inverter operation.

The DC-link reference voltage was maintained constant during simulation. Proper regulation ensures:

- Stable inverter switching
- Minimal voltage ripple
- Improved grid power quality

VIII. Control Strategy

A. MPPT Control

- **Perturb & Observe** algorithm adjusts boost converter duty cycle to maximize PV power.
- Steady-state tracking efficiency: 98–99%.

B. Current Control

- PI controller regulates inverter output current.
- Maintains unity power factor with grid.
- Reduces harmonics using LCL filter.

C. Grid Synchronization

- PLL generates phase angle reference for current injection.
- Ensures inverter is in phase with grid voltage.

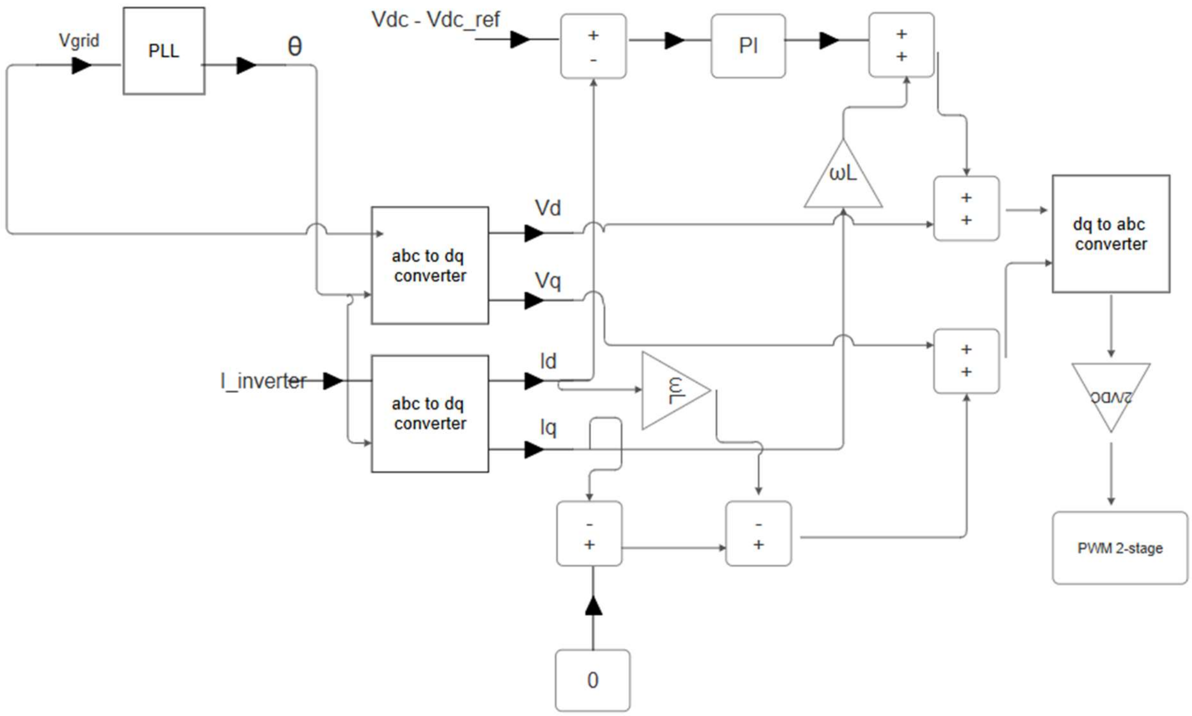

Figure 4: Block diagram of inverter controller

IX. Results

A. PV Power Response

- Output power increases proportionally with irradiance.
- MPPT successfully tracks new MPP after each irradiance step.
- Transient response is stable with minimal overshoot.

B. DC-Link Voltage

- DC-link voltage remains regulated during irradiance variation.
- Small transient deviation observed during rapid irradiance change.
- Voltage quickly stabilizes after disturbance.

C. Grid Current and THD

FFT analysis was performed on the grid current.

The measured THD was varying for different irradiance levels. THD was highest for the lowest irradiance (500 W/m^2) since the PV current was lowest at this stage. But, during the total simulation period, the THD did not exceed 3.96%.

This indicates:

- Good harmonic performance
- Compliance with standard grid interconnection requirements (IEEE < 5%)

Irradiation (W/m^2)	Temperature (degree C)	Pmax (PV curve)	Pmax (Simulation)	Tracker efficiency	MPPT duty cycle	THD %
1000	**25**	**11210**	**11201**	**0.99**	**0.2584**	**0.8% - 2.2%**
800	**25**	**9017**	**9007**	**0.99**	**0.2405**	**1% - 2.5%**
500	**25**	**5644**	**5626**	**0.99**	**0.2218**	**1.85% - 3.96%**
700	**25**	**7903**	**7896**	**0.99**	**0.2598**	**1.39% - 2.76%**
1500	**25**	**16455**	**16362**	**0.99**	**0.2678**	**0.7% - 2.3%**

Table 1: PV performance metrics for different irradiation

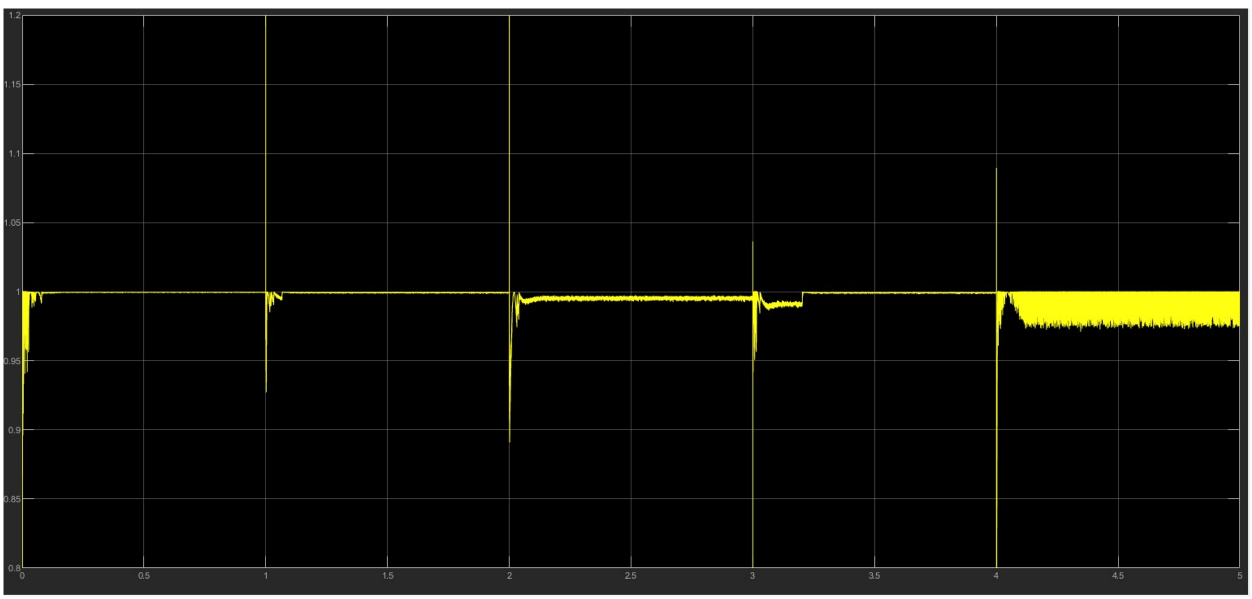

Figure 5: Tracker efficiency

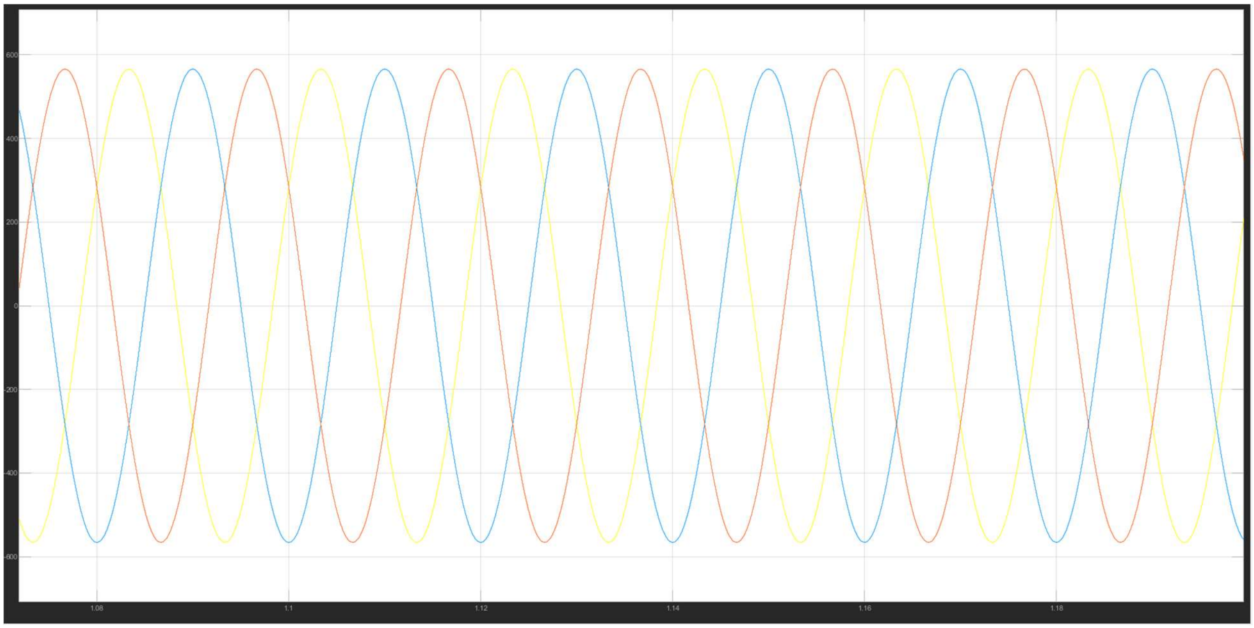

Figure 6: Grid voltage

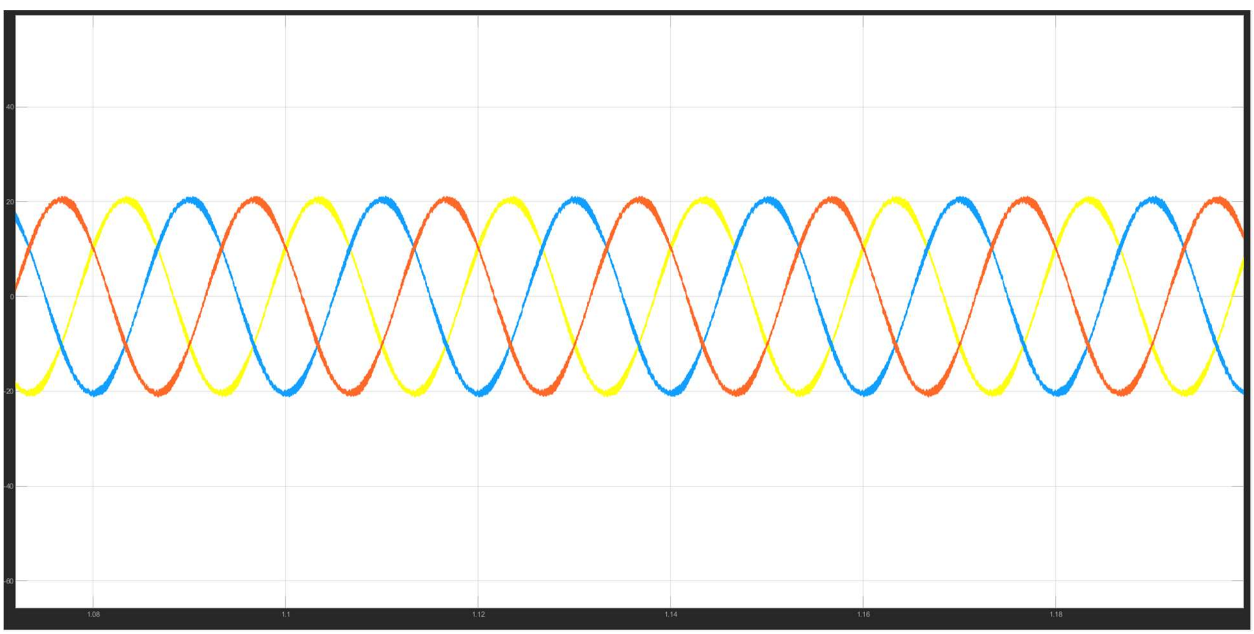

Figure 7: Inverter current

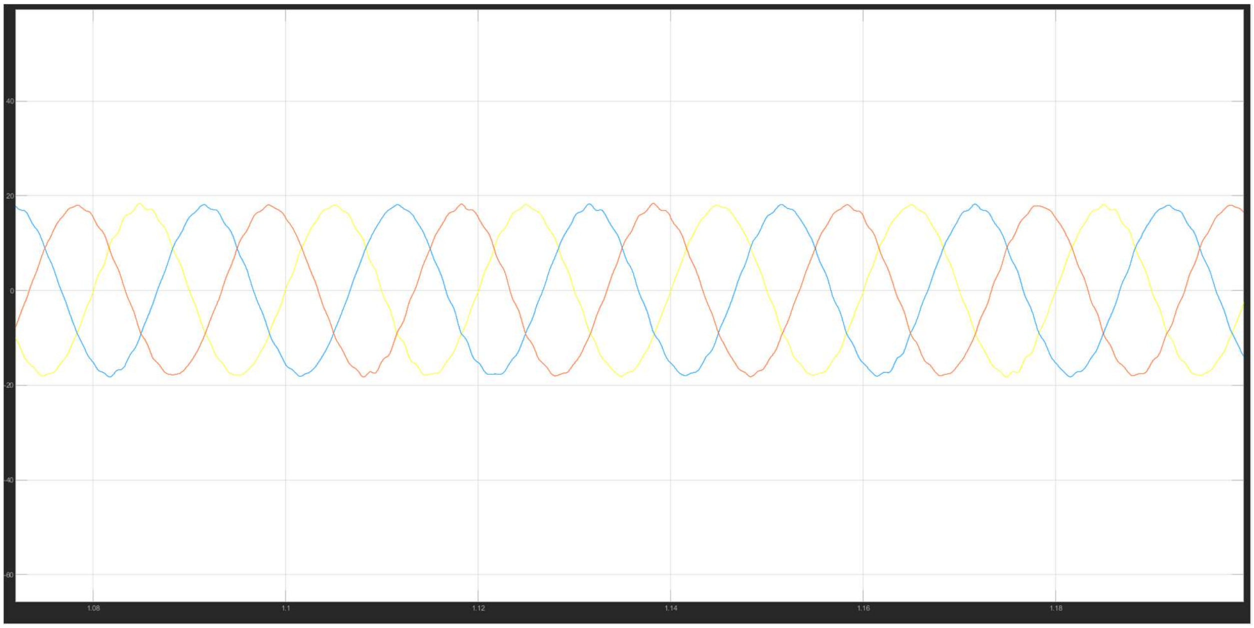

Figure 8: Grid Current

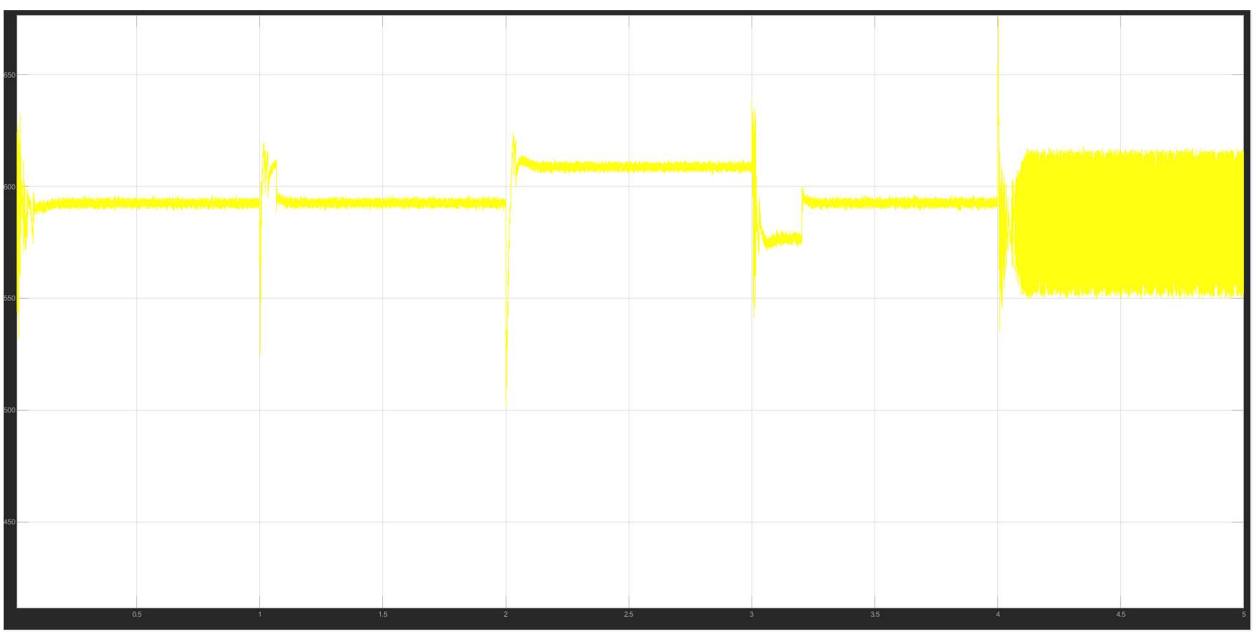

Figure 9: PV voltage

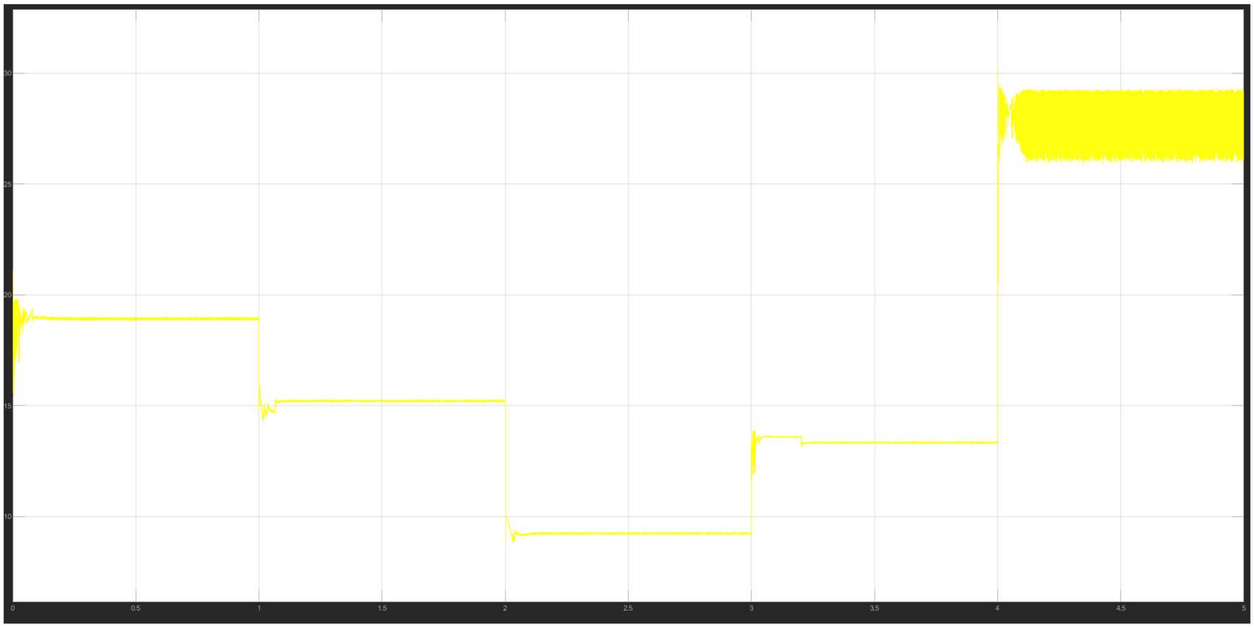

Figure 10: PV current

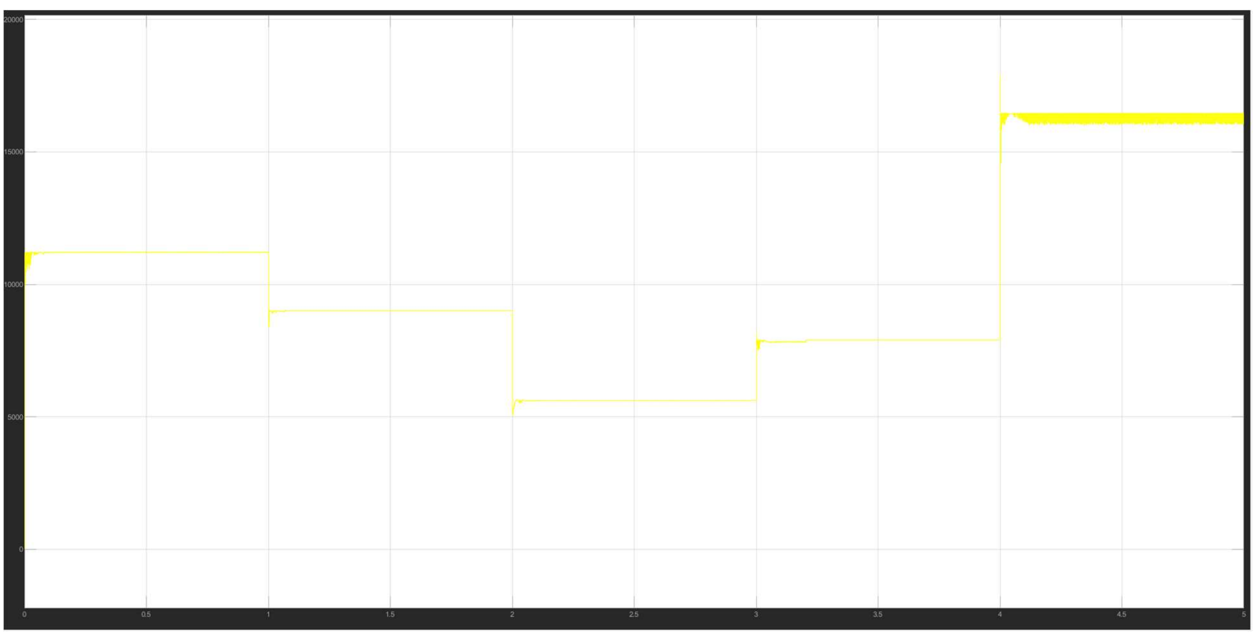

Figure 11: PV power

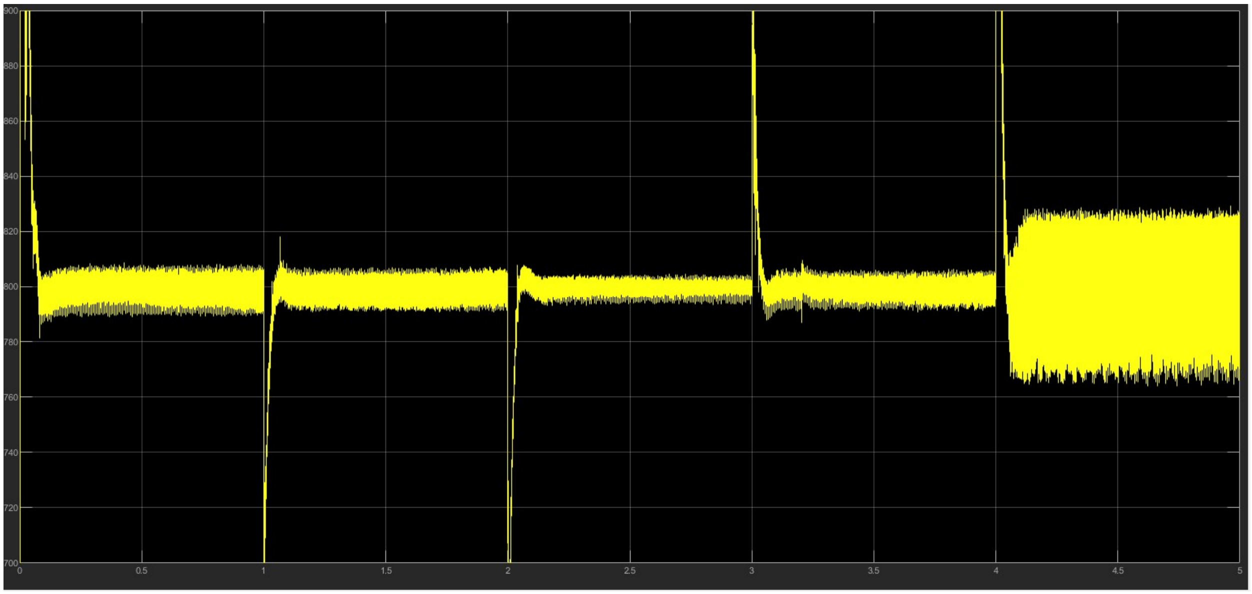

Figure 12: DC link voltage

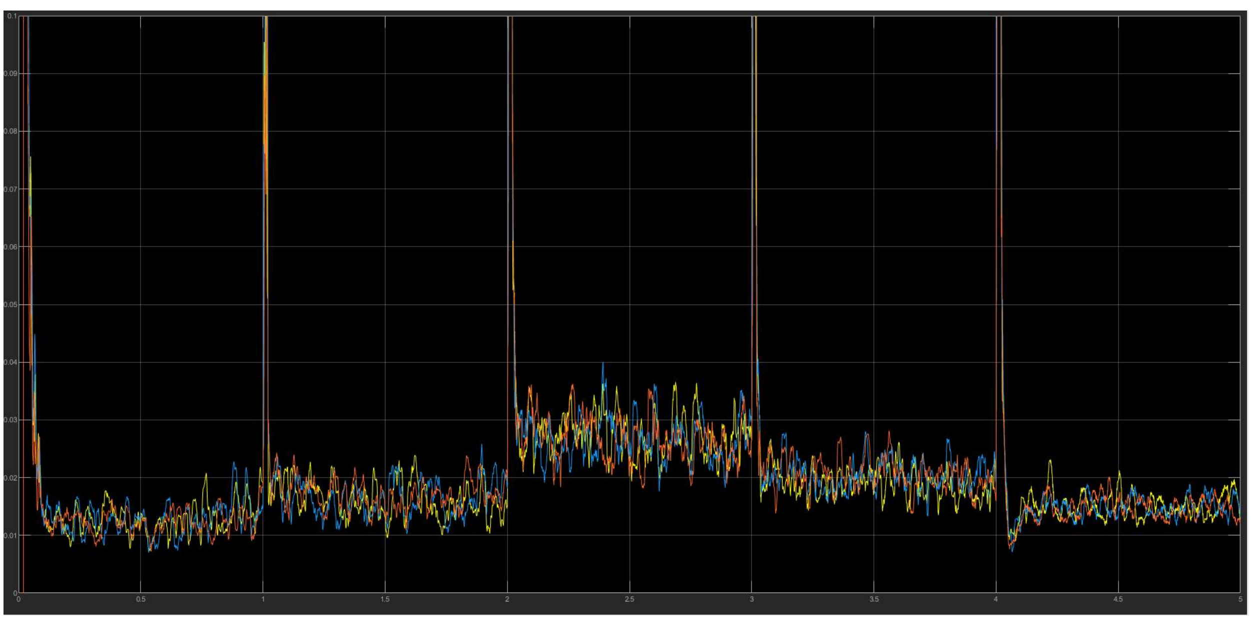

Figure 13: THD

X. Discussion

- The system achieves high power extraction and low harmonic injection.
- Proper filter sizing and PI controller tuning are critical to reduce THD.
- MPPT algorithm responds effectively to irradiance variations.
- Further improvement can be achieved using advanced MPPT techniques.

XI. Conclusion

This simulation demonstrates a **grid-tied PV system with efficient MPPT and low THD current injection**. The system shows:

- High MPPT efficiency (>99%)
- Grid current THD well within IEEE limits (<5%)
- Stable operation under steady and variable irradiance

XII. Future work

In future, a machine learning based MPPT controller can be implemented. Also, adaptive PI controller and performance under weak grid conditions can be evaluated.