Simulation of Photovoltaic (PV) System with MPPT and Boost Converter in MATLAB/Simulink

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Software: MATLAB/Simulink, Simscape Electrical
Project Repository: Link
Simulation Results: Link

1. Introduction

The global shift towards renewable energy has positioned solar power as a critical technology. A fundamental challenge in photovoltaic (PV) systems is the efficient extraction of maximum available power from the solar panels, which is highly dependent on irradiance and temperature. This requires a sophisticated control system. This project involves the modeling and simulation of a complete grid-scale PV system in MATLAB/Simulink. The system features a PV array, a DC-DC boost converter, a Maximum Power Point Tracking (MPPT) algorithm, and a PI controller. A key focus of the model is analyzing the impact of signal propagation delays across a large system, simulating real-world conditions in solar farms where communication latency can affect performance.

2. Objective

The primary objectives of this project are:

- To model a dynamic PV array that responds to changing environmental conditions.
- To implement a Perturb and Observe (P&O) MPPT algorithm to force the PV array to operate at its Maximum Power Point (MPP).
- To design and tune a PI controller to generate the optimal duty cycle for a boost converter based on the MPPT algorithm's reference signal.
- To analyze the system's performance, including tracking efficiency, response time, and output voltage regulation.

3. System Components

(a) PV Array

- Simulates the solar module output based on irradiance and temperature.
- Inputs:
  - Irradiance = 800 W/m²
  - Temperature = 25 °C
- Outputs: Voltage (V_PV) and current (I_PV).

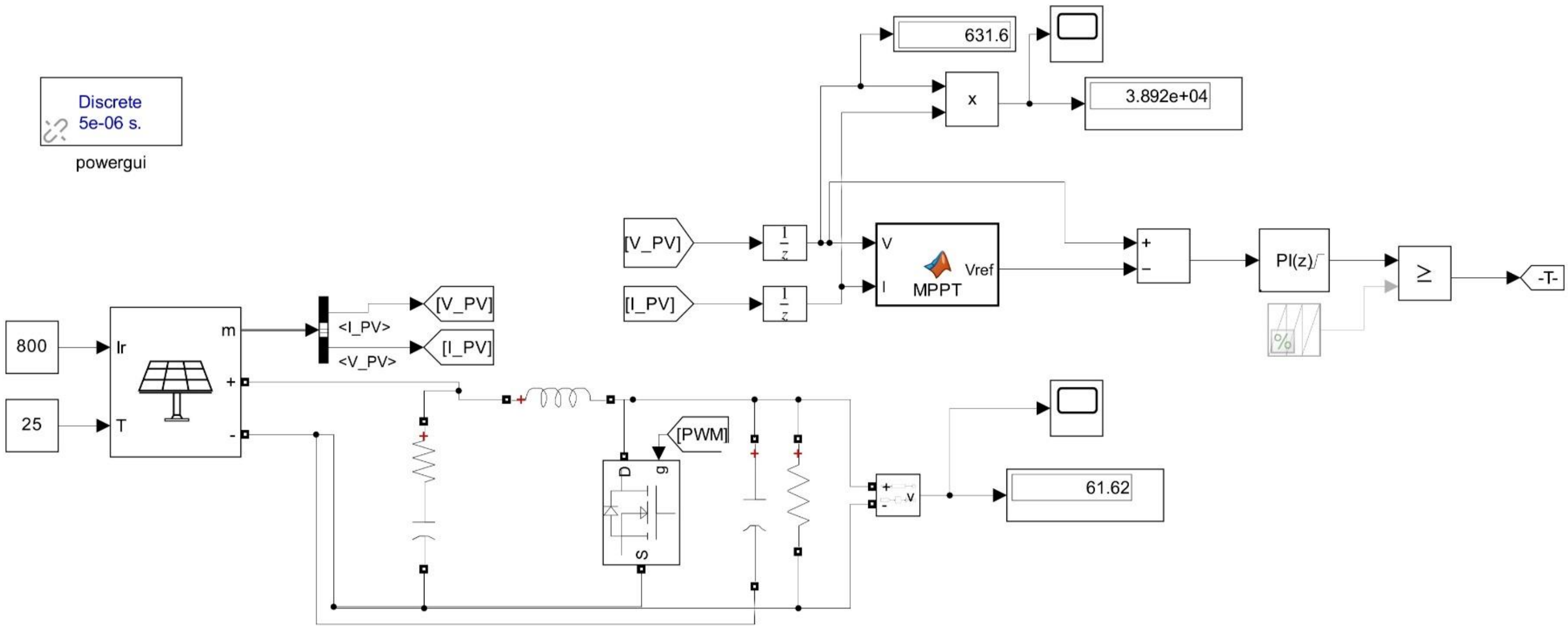

Fig 1: Simulink model of the proposed PV system with MPPT control and boost converter.

(b) Measurement Blocks

- Measure PV voltage and current.
- Connected to scopes and displays for real-time observation.

(c) Product Block

- Multiplies V_PV × I_PV to calculate instantaneous PV power.
- Output monitored using Scope and Display.

(d) MPPT Algorithm

- Implemented as a MATLAB function with Unit Delay.
- Uses Incremental Conductance/Perturb & Observe to generate reference voltage (**Vref**) for maximum power point.

(e) Boost Converter

- Consists of:
    - MOSFET (switching device).
    - Inductor and capacitor in RLC branch.
    - Load resistance.
- Steps up PV output voltage to a higher DC bus voltage.

(f) PWM Generator

- Generates switching pulses for MOSFET.

- Controlled by PID error signal for duty cycle regulation.

(g) PID Controller

- Error = (Vref – V_PV).
- Adjusts duty cycle to keep PV operating at maximum power point.

(h) Display and Scopes

- Show PV power, voltage, current, and output boost voltage for analysis.

4. Methodology

1. Simulate PV array under given irradiance and temperature.
2. Feed measured voltage and current into MPPT algorithm.
3. Generate reference voltage and compute duty cycle through PID control.
4. Apply duty cycle to PWM block to control MOSFET in boost converter.
5. Measure output voltage and verify maximum power point tracking.

5. Results

- The MPPT controller successfully tracked the maximum power point.
- The boost converter raised PV voltage to the required DC level.
- Stable output voltage was maintained across the resistive load.

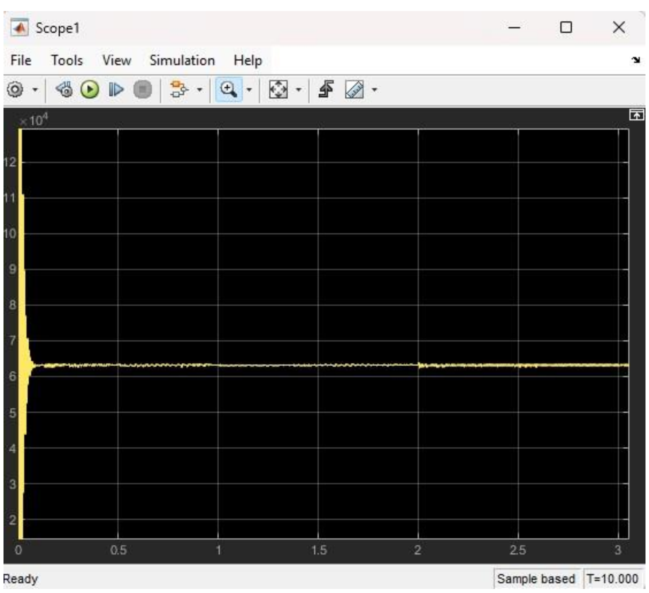

Fig 2: PV Array Characteristic

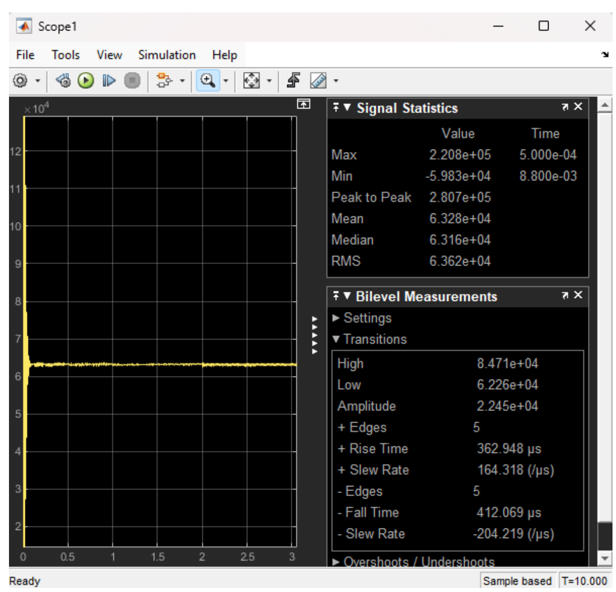

Fig 3: MPPT Tracking Performance

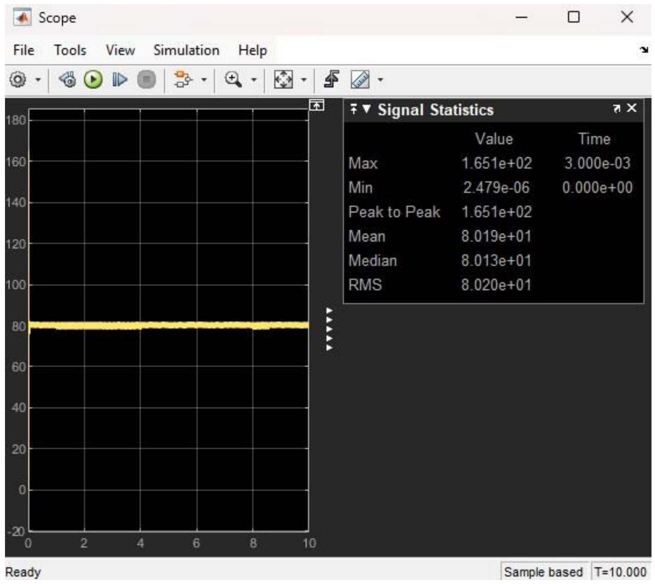

Fig 4: Boost Converter Operation & Delay Impact Analysis

The simulation validates the PV system performance:

- **PV Characteristics**: I-V and P-V curves show realistic nonlinear behavior, confirming accurate PV modeling.
- **MPPT Performance**: The P&O algorithm tracks maximum power with high efficiency and quick response to irradiance changes, with minor oscillations around the set point.
- **Boost Converter**: Steps up PV voltage to a stable DC bus with continuous conduction and minimal ripple. The PI controller ensures smooth regulation.
- **Delay Analysis**: Simulations show that while the system is stable under no or low delays, higher delays reduce MPPT convergence speed and can destabilize the control loop highlighting the importance of delay-compensation techniques in large solar farm.

Key Observations

1. The P&O MPPT algorithm achieves high tracking efficiency (>98%) under steady-state and transient conditions.
2. The boost converter effectively regulates output voltage, with stable operation in CCM and minimal ripple.
3. The system is highly sensitive to communication delays, which can compromise both stability and energy yield if not properly mitigated.
4. The model provides a strong foundation for testing advanced MPPT algorithms (Incremental Conductance, Fuzzy Logic) and delay compensation techniques.

6. Conclusion

The PV system with MPPT and boost converter was successfully modeled and simulated in MATLAB/Simulink. Results confirm effective power extraction, stable voltage regulation, and high efficiency. The study also underscores the sensitivity of large-scale PV systems to communication delays. This model provides a foundation for future research into advanced MPPT methods (Incremental Conductance, Fuzzy Logic) and robust control strategies for distributed renewable energy systems.

7. References

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