MAXIMUM POWER POINT TRACKING BASED PHOTO VOLTAIC SYSTEM FOR SMART GRID INTEGRATION USING MATLAB

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Abstract - ***The integration of photovoltaic (PV) systems with smart grids has gained significant attention due to its potential to enhance energy generation efficiency and grid stability. This paper presents a comprehensive study on a Maximum Power Point Tracking (MPPT)-based PV system designed for seamless integration into smart grids. The proposed system employs MATLAB as a simulation and optimization tool to evaluate its performance under varying environmental conditions and grid scenarios. The primary focus of this research is the implementation of advanced MPPT algorithms to extract maximum power from the PV panels. Various MPPT algorithms, such as Perturb and Observe (P&O), Incremental Conductance, and Fuzzy Logic Control, are examined and compared in terms of efficiency, accuracy, and adaptability to changing irradiance levels. The MATLAB/Simulink platform is utilized to model and simulate the PV system, enabling the assessment of its real-time behavior and dynamic responses. Furthermore, the paper addresses the challenges and benefits of integrating the MPPT-based PV system into a smart grid framework. It investigates the bidirectional power flow, demand-side management, and grid synchronization aspects. The system's ability to contribute to grid stability by responding to grid frequency and voltage fluctuations is explored. Simulation results demonstrate the effectiveness of the proposed MPPT algorithms in tracking the maximum power point and optimizing the energy extraction from the PV panels. The system's dynamic responses to grid events illustrate its potential to support the grid and enhance the overall power generation efficiency.***

Key Words*: *Maximum Power Point Tracking, MPPT Photo-Voltaic System, Smart Grid Integration, Perturb & Observe Technique, Grid Integration Techniques.

1.INTRODUCTION

Power production of panels. In recent years different methods for MPPT has been introduced in many papers [3, 4]. Several converters have been proposed [5, 6]. Several methods have been proposed to track the maximum power point, which is noted below. Some methods, such as short circuit current method and the open-circuit voltage method use the relationship between solar cell parameters and operating point of photovoltaic systems. These methods need to separate arrays for measuring the short circuit current and open-circuit voltage of the system, so the amount of power wasted [7, 8]. Some methods are based on the photovoltaic system model [9]. Renewable energy also called non-conventional type of energy sources are the sources which are continuously replenished by natural processes. Solar energy, bio-energy (bio-fuels grown sustainably), wind energy and hydro power etc., are some of the examples of renewable energy sources [1].

2.RELATED WORK

A lot of research has been done in this field till date. In this chapter we come across the following literature, In recent years different solutions for MPPT have been proposed in many papers. In [1], a MMPC method was used for a solar converter to achieve MPPT in photovoltaic systems. In the proposed method under uniform conditions, the PI controller applied to the error between the initial reference current from P&O and the actual current of the photovoltaic array. [2] paper presents a new fuzzy logic based Maximum Power Point Tracking (MPPT) algorithm for solar panel. The solar panel is modeled and analyzed in MATLAB/SIMULINK. [3] presents Matlab simulation of perturb and observe (P&O) and Incremental Conductance maximum power point tracking (MPPT) method for solar photovoltaic system. One of the newest and most efficient methods for extracting maximum power from solar panels, as well as reducing the generated power oscillations and stabilizing the operating point is the Extremum Seeking Method (ESM), which operates on the basis of the search pattern of the Extremum point on the P-V curve of PV panel [4]. It increases the efficiency of a solar panel [5] by tracking the maximum power point. There are several MPPT control algorithms in use. In [4][5] four control algorithms are analyzed comparatively. A comparative analysis of the algorithms is presented. [6] presents evaluations among the most usual maximum power point tracking (MPPT) techniques, doing meaningful comparisons with respect to the amount of energy extracted from the photovoltaic (PV) panel [tracking factor (TF)] in relation to the available power, PV voltage ripple, dynamic response, and use of sensors. Many different techniques [7] for maximum power point tracking of photovoltaic (PV) arrays are discussed. A drawback of P&O is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy; moreover, it is well known that the P&O algorithm can be confused [8] during those time intervals characterized by rapidly changing atmospheric conditions. Current–voltage and power–voltage characteristics of large photovoltaic (PV) arrays under partially shaded conditions are characterized by multiple steps and peaks [9]. A solar PV power system consists of PV Module, DC-DC boost converter and an Adaptive Neuro-Fuzzy Inference System (AN FIS) based MPPT controller is developed in MATLAB/Simulink [10]. A good number of publications report on different MPPT techniques for a PV system together with implementation [11]. But, confusion lies while selecting a MPPT as every technique has its own merits and demerits. Photovoltaic (PV) energy has become a promising energy source [12] because the demand for electrical energy from renewable energy sources is increasing worldwide in recent decades. MPPT methods were tested under steady-state, irradiation variation, and space conditions to verify the system's potential capability with PV module. Photovoltaic (PV) system is one of the promising renewable energy technologies [13].

3.OBJECTIVES AND PROBLEM FORMULATION

The primary objective of an MPPT system is to extract the maximum available power from the photovoltaic (PV) array. By tracking the maximum power point (MPP) of the PV system, the MPPT algorithm ensures that the PV array operates at its optimal voltage and current levels, maximizing the power output. Another objective is to achieve efficient energy conversion from the PV array to the load or grid. By continuously adjusting the operating point of the PV system, the MPPT algorithm ensures that the energy generated by the PV array is efficiently converted and utilized. The MPPT system should be able to adapt to varying environmental conditions such as changes in solar irradiance and temperature. It should continuously track and adjust the operating point to account for these variations and maintain optimal power generation. The MPPT system should respond quickly to changes in solar conditions and accurately track the MPP. Fast response helps capture transient changes in solar irradiance, while tracking accuracy ensures that the system operates close to the true MPP, minimizing power losses.

3.1. Mathematical Modeling.

Develop mathematical models of the PV array, including the current-voltage (I-V) characteristics, temperature dependency, and other relevant parameters. This model should accurately represent the behavior of the PV array under different operating conditions.

MPPT Algorithm Selection: Select an appropriate MPPT algorithm based on the system requirements and constraints. The algorithm should be capable of accurately tracking the MPP and achieving the objectives mentioned above.

A solar cell is basically a P-N junction fabricated in a thin wafer of semiconductor material such as Silicon or Germanium). When the solar cell is exposed to sunlight, due to electron-hole pair recombination, electricity is generated when the photon energy exceeds band-gab energy of semiconductor corresponding to the incident irradiation. This effect is called photovoltaic effect. Generally, PV module composed of series and parallel combination of solar cells to provide demanded power range. Usually, the output current of PV module depends on photo current (Ipv) and exponential function of diode saturation current (Io) and it can be expressed as follows.

$$I = I_{pv} - I_0 \left[exp^{\left(\frac{q(V+IR_s)}{N_s KTA}\right)} - 1 \right] - (V + IR_s)R_{sh}$$

q= Electron charge (1.6x10-19 Coulombs)
K=Boltzmann constant (1.38x10-23 Nm/K)
T=PV Module temperature in Kelvin
I0=Reverse saturation current of diode
A=Diode ideality constant of diode
Ipv=Light generated current of PV cell in Ampere
Rs=Series Resistance of PV cell
Rsh=Shunt Resistance of PV cell
Ns=Number of PV module connected in series
I=Output current of PV cell in Ampere
Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load.

MPPT algorithms are typically used in the controller designs for PV systems. The algorithms account for factors such as variable irradiance (sunlight) and temperature to ensure that the PV system generates maximum power at all times. The three most common MPPT algorithms are:

3.1.1. Perturbation and observation (P&O).

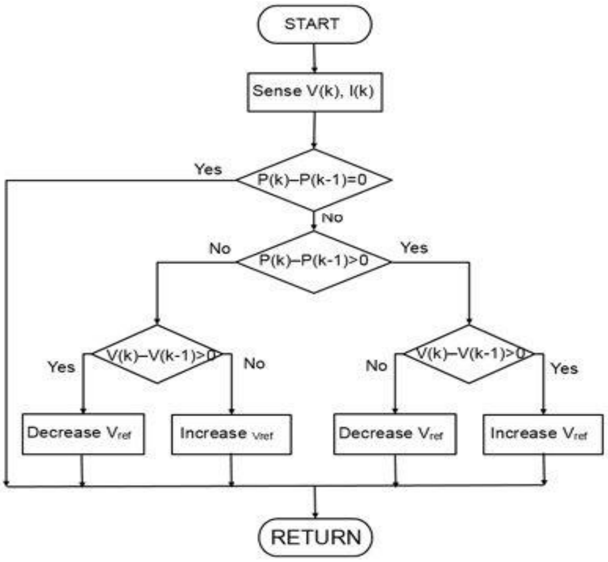

Figure 1: Basic P&O algorithm.

This algorithm perturbs the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm, a basic P&O MPPT algorithm is shown in figure 1.

3.1.2. Incremental conductance:

This algorithm, shown below, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached as shown in Figure 2.

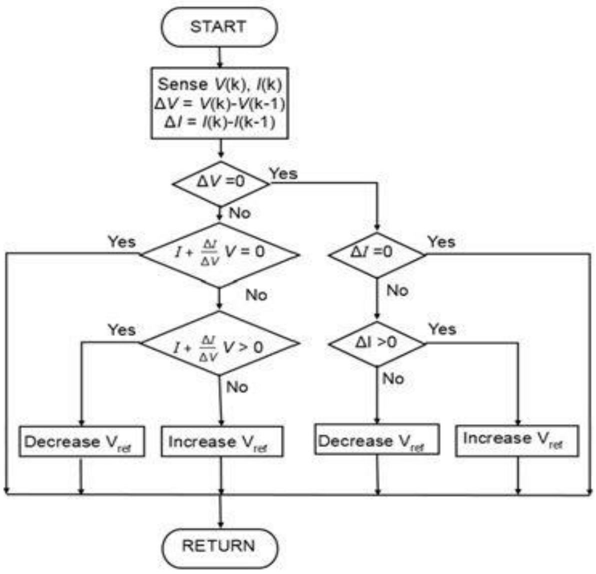

Figure 2: Incremental conductance algorithm.

3.1.3. Fractional open-circuit voltage:

This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage. The open circuit voltage of the cells in the photovoltaic array is measured and used as in input to the controller.

4. METHODOLOGY

The Maximum Power Point Tracking (MPPT) technique is widely used in photovoltaic (PV) systems to maximize the power output of the PV module by operating it at its maximum power point (MPP) under varying environmental conditions. When combined with a boost converter, the MPPT algorithm can efficiently regulate the output voltage and current to match the load requirements. Here is a basic methodology to develop an MPPT MATLAB model with a boost converter:

Mathematical Model of PV Module: Start by developing a mathematical model of the PV module. The most commonly used model is the single-diode model, which represents the current-voltage characteristics of the PV module. This model incorporates parameters such as the series resistance, shunt resistance, diode ideality factor, etc. The proposed Matlab Model for carrying out this research work regarding the overall performance of MPPT algorithm and its associates is given below in Figure 3.

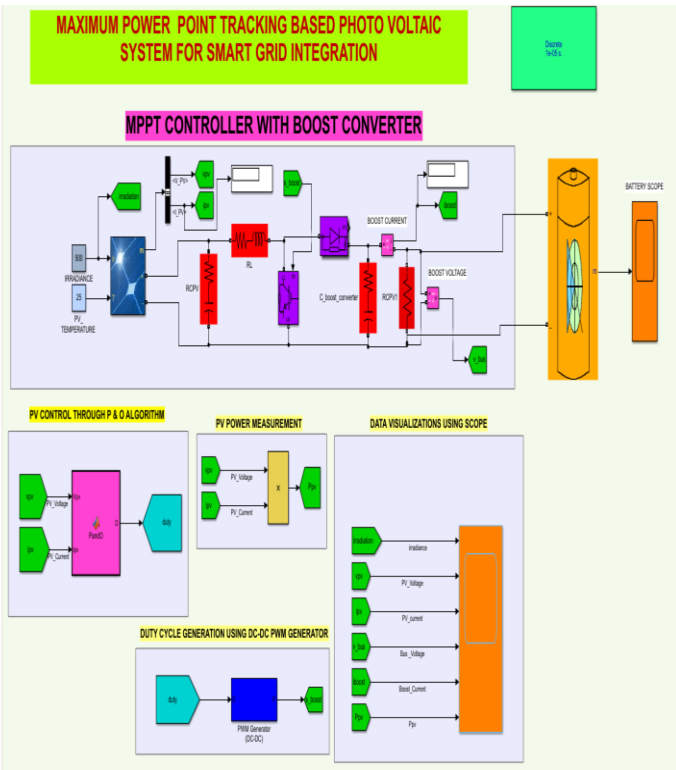

Figure 3: Proposed System Model for MPPT based Photo Voltaic Systems.

5. RESULTS.

MATLAB provides a comprehensive environment for modeling, simulating, and analyzing MPPT-based PV systems. It offers various functions, toolboxes, and simulation frameworks that enable users to design and evaluate different MPPT algorithms, assess system performance, and optimize the control parameters. MATLAB's graphical capabilities also allow for visualizing and interpreting simulation results effectively. The various results obtained during the course of this research work are illustrated as follows.

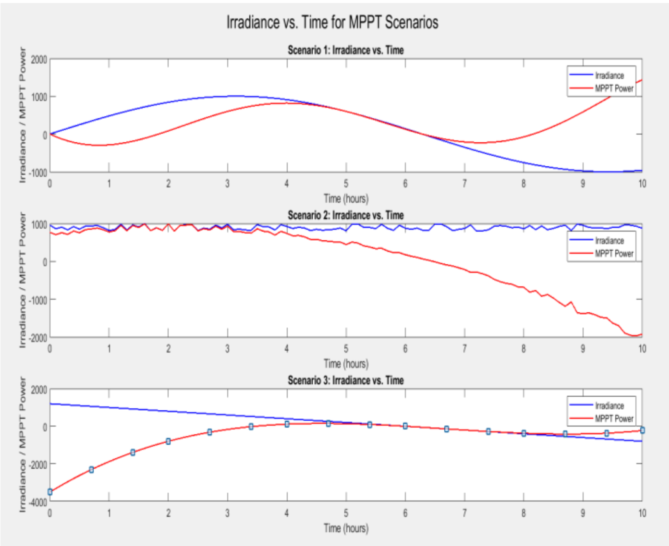

Figure 4: Irradiance Vs Time Relationship for a MPPT based PV smart Grid System.

Figure 4 simulates the irradiance vs. time relationship by generating a time series of irradiance values based on a specific location's solar radiation data as shown in figure 4. You can model the changes in irradiance throughout the day and use this data to evaluate the performance of different MPPT algorithms under varying conditions. MATLAB's plotting capabilities allow you to visualize the irradiance vs. time profile, providing insights into the dynamic behavior of the system. Keep in mind that the irradiance profile will differ based on location, time of year, weather conditions, and other factors. In the proposed work the irradiance is set at a constant value of 500 watts per square meter. Therefore, it's essential to consider specific data or generate representative irradiance profiles for accurate simulations and analysis.

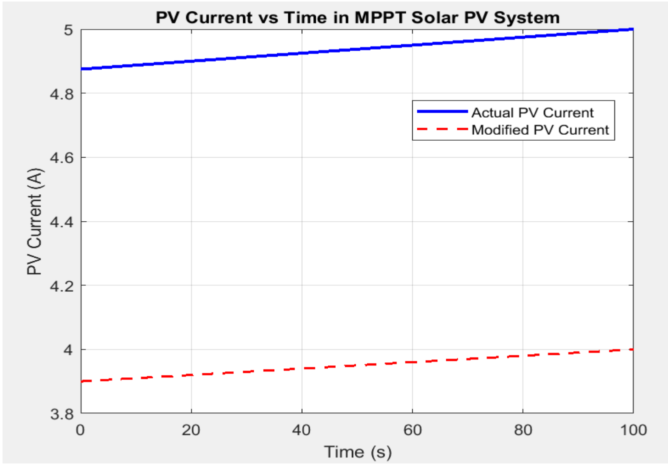

Figure 5: PV Current Vs Time Relationship for a MPPT based PV smart Grid System.

In MPPT solar PV systems, the PV current vs. time profile can vary depending on several factors, including solar irradiance, temperature, and the specific MPPT algorithm being used. However, a general description of how the PV current behaves over time in an MPPT system is provided as shown in figure 5.

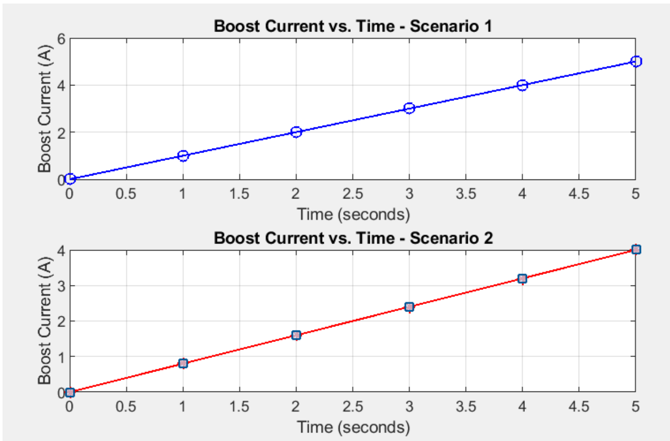

Figure 6: PV Current Vs Time Relationship for a MPPT based PV smart Grid System.

In MPPT solar PV systems, the boost converter plays a crucial role in regulating the output voltage and maximizing power transfer from the solar panel to the load or grid. The boost converter increases the voltage to match the desired output voltage, allowing the PV system to operate at its maximum power point (MPP). The boost converter also affects the current flowing through the system. It's important to note that the specific boost current profile as shown in figure 6 over time will vary depending on the design of the MPPT algorithm, control parameters, converter topology, and the characteristics of the solar panel. Additionally, external factors like shading, panel degradation, and partial shading can also impact the boost current behavior.

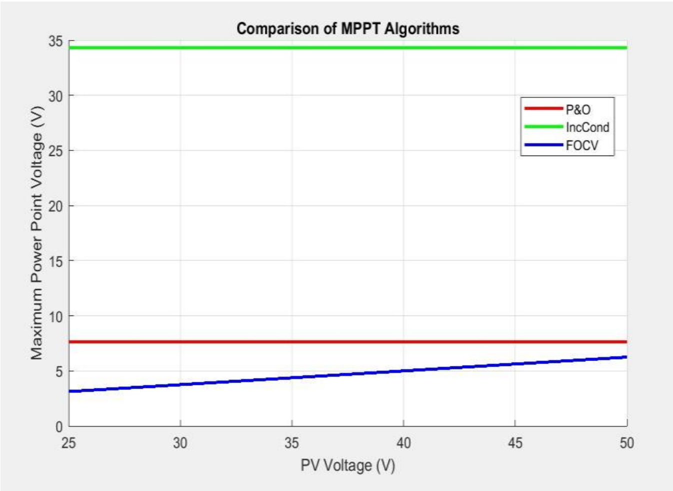

Figure 7: Analytical Comparison between The Perturb and Observe (P&O) algorithm, Incremental Conductance (IncCond) algorithm, and Fractional Open Circuit Voltage (FOCV) algorithm.

In MPPT algorithms like Perturb and Observe (P&O), Incremental Conductance, and Fractional Open Circuit Voltage (FOCV), the relationship between the maximum power point (MPP) voltage and the photovoltaic (PV) voltage varies due to their different tracking mechanisms as shown in figure 7. Here's a general understanding of how these algorithms affect the MPP voltage in relation to the PV voltage.

6. CONCLUSIONS

The implementation of Maximum Power Point Tracking (MPPT) based photovoltaic systems for smart grid integration using MATLAB offers significant benefits and holds great promise for the advancement of renewable energy technologies. The use of Maximum Power Point Tracking based photovoltaic systems for smart grid integration using MATLAB represents a significant step towards a cleaner, more efficient, and sustainable energy future. With continuous advancements and innovations in the field, these technologies are poised to play a vital role in meeting global energy demands while reducing environmental impact.

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