

Implementation of NN Based MPPT Technic for Solar PV Module

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Abstract- Efficient power extraction from photovoltaic (PV) systems is critical in optimizing energy utilization for renewable applications. This project explores a Neural Network (NN)-based MPPT technique implemented in MATLAB/Simulink, designed to dynamically predict and track the maximum power point (MPP) of a solar PV system with battery storage. The NN-based MPPT is trained on a dataset encompassing various environmental conditions (irradiance, temperature, PV voltage, and current) to accurately predict the optimal duty cycle for the DC-DC converter, thereby maximizing power transfer from the PV system to the battery. A Simulink model incorporating a PV array, DC-DC converter, and the NN-based MPPT controller was developed, allowing for simulation and performance assessment under diverse scenarios. This work underscores the viability of intelligent MPPT solutions for advancing solar energy efficiency and sustainability.

Index Terms-Solar panel, Neural Network, Boost Converter, IGBT

I. INTRODUCTION

Overview of Solar Energy

The sun is an incredible and renewable resource that has the power to fuel life on earth and provide clean, sustainable energy to all of its inhabitants. In fact, more energy from the sun reaches our planet in one hour than is used by the entire population of the world in one year. The sun's energy can be converted into electricity through solar photovoltaic (PV) modules (photo = light, voltaic = electricity).

How does solar energy work?

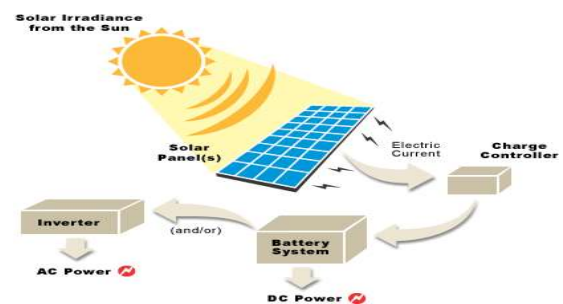
PV modules absorb sunlight and convert the energy into a usable form of electrical current. The sun shines all over the world, making solar electricity viable anywhere. Because solar can be paired with batteries for energy storage, solar electric systems can be independent of the utility grid, making them cost-effective for remote locations.

Solar modules have no moving parts making maintenance costs low, and they are highly reliable with a long service life of 25+ years of guaranteed electricity. Solar electricity relies on the sun as its fuel source, so there is no need to drill for petroleum-based fuels, refine them, or deliver them to the site. As you can see, there are a lot of advantages of solar energy.

The design and installation of PV systems on a large scale enable us to move away from other polluting and unsustainable energy sources. Since the solar industry is growing, that means that the need for skilled workers is also growing!

Impact of Environmental Conditions on PV Performance Shading

Shading is one of the most critical factors affecting PV performance. Even partial shading on a few cells in a module can lead to substantial drops in output, as shaded cells produce less current than unshaded cells. This imbalance can cause hotspots and reduce the efficiency of the entire panel or array. To mitigate these effects, systems often incorporate bypass diodes that allow current to bypass shaded cells.



Temperature: Temperature also plays a critical role in the performance of PV systems. Although PV cells generate more power under intense sunlight, higher temperatures can lead to efficiency losses. For instance, silicon-based PV cells experience a 0.4-0.5% decrease in efficiency for every 1°C increase above the optimal temperature (usually around 25°C).

Irradiance: Solar irradiance, or the amount of sunlight reaching a PV array, is the primary driver of energy generation. The variability of irradiance due to seasonal

changes, geographic location, and atmospheric conditions (e.g., dust, clouds, and pollution) can significantly impact the energy yield of a PV system.

II. MAXIMUM POWER POINT TRACKING

Introduction to Maximum Power Point Tracking (MPPT)

Solar photovoltaic (PV) systems are highly dependent on environmental factors like sunlight intensity and temperature, which directly affect their ability to generate power. Due to these dynamic conditions, solar PV modules often do not operate at their maximum efficiency. Maximum Power Point Tracking (MPPT) is a technique that addresses this issue by continuously adjusting the operating point of the PV system to ensure it produces the maximum possible power under given conditions. MPPT is critical in optimizing the energy output of PV arrays, making it a fundamental component in modern solar energy systems.

Overview of Maximum Power Point Tracking (MPPT)

The output of a solar PV array depends on both voltage and current, with the relationship between these parameters creating a unique power curve for each PV module. This curve has a single "maximum power point" (MPP) at which the product of current and voltage is highest, providing the maximum possible power from the module. However, the MPP is not static; it changes throughout the day with variations in sunlight intensity and temperature. The purpose of MPPT is to locate this point and adjust the operating parameters of the PV array to stay at the MPP, thus maximizing energy capture.

An MPPT controller accomplishes this by controlling a DC-DC converter connected between the PV array and the load (or inverter, in grid-tied systems). The MPPT controller adjusts the converter's output by varying the duty cycle, effectively modifying the PV array's operating voltage and current to match the MPP. This enables the system to continuously track the optimal point, even as external conditions change, ensuring maximum power transfer from the PV array to the load or grid. MPPT controllers are especially valuable in regions where irradiance levels frequently vary, as they significantly improve the energy yield of solar installations.

Different MPPT techniques

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

- Perturb and Observe (hill climbing method)
- Incremental Conductance method
- Fractional short circuit current
- Fractional open circuit voltage
- Neural networks
- Fuzzy logic

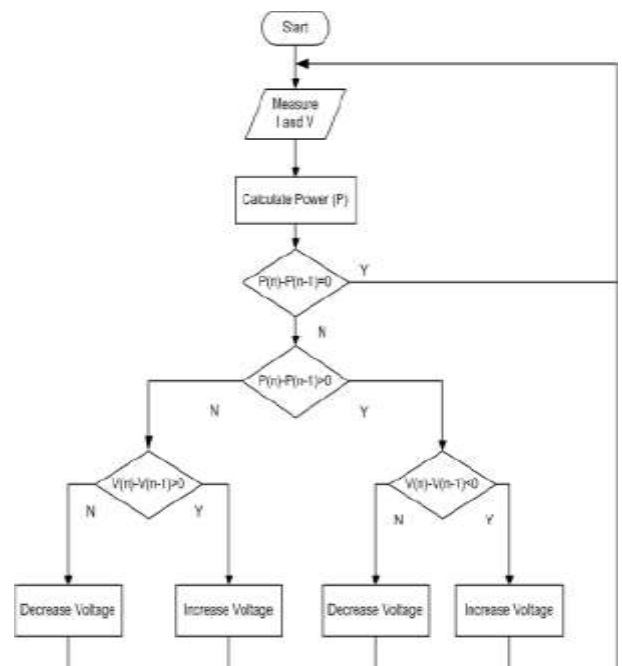
The choice of the algorithm depends on the time complexity the algorithm takes to track the MPP, implementation cost and the ease of implementation.

Perturb & Observe

Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

Flow Chart of Perturb & Observe Algorithm



Incremental Conductance

Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array. At MPP the slope of the PV curve is 0.

$$(dP/dV)_{MPP} = d(VI)/dV$$

$$0 = I + VdI/dVMPP$$

$$dI/dVMPP = - I/V$$

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increases. As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system.

This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms. Owing to its simplicity of implementation we have chosen the Perturb & Observe algorithm for our study among the two.

III. NEURAL NETWORK

Introduction

Another technique of implementing MPPT which are also well adapted for microcontrollers is neural networks. Neural networks commonly have three layers: input, hidden, and output layers. The number nodes in each layer vary and are user-dependent. The input variables can be PV array parameters like VOC and ISC, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the MPP.

Need of Neural Networks in MPPT

The need for neural networks in Maximum Power Point Tracking (MPPT) arises from several key challenges and opportunities in optimizing the performance of solar energy systems. Here are the main reasons why neural networks are increasingly applied in MPPT:

Dynamic Behavior

The relationship between solar irradiance, temperature, and the power output of photovoltaic (PV) systems is highly non-linear and can change rapidly. Neural networks are well-suited for modeling these complex interactions and can learn to predict optimal operating points effectively.

Real-Time Adaptation

Solar energy generation can be influenced by varying weather conditions (like clouds and shading). Neural networks can quickly adapt to these changes by continuously learning from new data, ensuring the system operates at maximum efficiency under different conditions.

Learning from Historical Data

Neural networks can analyze large amounts of historical data to identify patterns and trends, allowing them to predict future

performance and optimize the tracking process accordingly. This data-driven approach enhances the accuracy of MPPT.

Maximizing Energy Output

By effectively identifying the maximum power point under varying conditions, neural networks can improve the overall efficiency of solar systems, leading to increased energy yields and better return on investment.

Efficient Algorithms

Neural networks can be trained to simplify complex MPPT algorithms, making them computationally efficient. This is particularly useful in real-time applications where quick adjustments are necessary.

Implementation of Neural Network

Implementing a neural network for Maximum Power Point Tracking (MPPT) involves several steps, from defining the problem to training the model and deploying it in a real-time system. Here's a structured overview of the process:

Define the Problem

Objective: Clearly outline the goal of using neural networks in MPPT, such as maximizing the power output from solar panels under varying environmental conditions.

Data Collection

Gather Data: Collect historical data from the PV system, including:

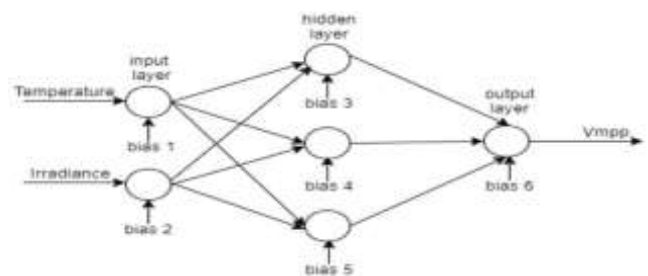
- Voltage (V)
- Current (I)
- Power (P)
- Environmental factors (solar irradiance, temperature)

Data Quality:

Ensure the data is clean, accurate, and representative of different operating conditions.

Preprocessing the Data

Normalization: Scale the input data to a standard range (e.g., 0 to 1) to facilitate training. **Feature Selection:** Identify relevant features that influence power output, potentially using domain knowledge or statistical techniques. **Splitting Data:** Divide the dataset into training, validation, and testing subsets to evaluate the model's performance.



Design the Neural Network

Architecture: Choose the appropriate neural network architecture (e.g., feedforward, recurrent, or convolutional) based on the complexity of the data and the problem.

Layers and Neurons: Define the number of hidden layers and neurons per layer, balancing complexity and computational efficiency.

Activation Functions: Select activation functions (e.g., ReLU, sigmoid) for each layer to introduce non-linearity.

Training the Neural Network

- **Loss Function:** Choose an appropriate loss function (e.g., mean squared error) to measure the difference between predicted and actual power outputs.
- **Optimizer:** Select an optimization algorithm (e.g., Adam, stochastic gradient descent) to update weights during training.
- **Training Process:** Feed the training data into the network, perform forward and backward propagation, and iteratively update weights until the model converges (i.e., minimizes the loss function).

Validation and Testing

- **Model Evaluation:** Use the validation set to tune hyperparameters and avoid overfitting. Assess the model's performance using metrics like accuracy, mean absolute error, or root mean square error.
- **Testing:** Evaluate the final model on the test dataset to ensure it generalizes well to unseen data.

Implementation in MPPT System

- **Real-Time Integration:** Deploy the trained neural network model in the MPPT controller. Ensure it can receive real-time inputs from the PV system (voltage, current, environmental data).
- **Control Logic:** Develop the control algorithm that uses the neural network's output to adjust the operating point of the inverter or DC-DC converter, maximizing power extraction.

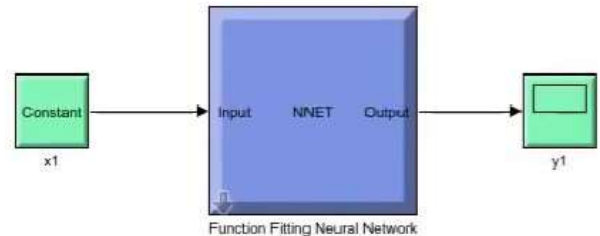
Monitoring and Optimization

- **Continuous Learning:** Implement a feedback loop to update the model periodically based on new data, allowing it to adapt to changing conditions.
- **Performance Monitoring:** Continuously monitor system performance and the accuracy of the neural network's predictions, making adjustments as necessary.

Testing and Validation in the Field

- **Field Trials:** Conduct tests in real-world conditions to validate the MPPT performance and the neural network's effectiveness.

- **Adjustments:** Make any necessary adjustments based on performance metrics and operational feedback.



IV. SOLAR PV MODULE

Introduction to PV Module in Simulink

Setting up a Photovoltaic (PV) module in Simulink is a fundamental step when modeling solar power systems for simulations. Simulink provides a range of blocks that can help you build a PV module model for evaluating performance, implementing MPPT algorithms, and testing different configurations. Below is a detailed guide on how to set up a basic PV module in Simulink, which can be used to feed data to a Neural Network (NN) or any other controller, such as an MPPT algorithm. A photovoltaic module is typically modeled using:

Solar Irradiance: The intensity of sunlight (W/m^2) falling on the solar panel.

Panel Temperature: The temperature of the PV panel ($^{\circ}C$).

PV Current and Voltage: The electrical output characteristics of the module, which depend on irradiance and temperature.

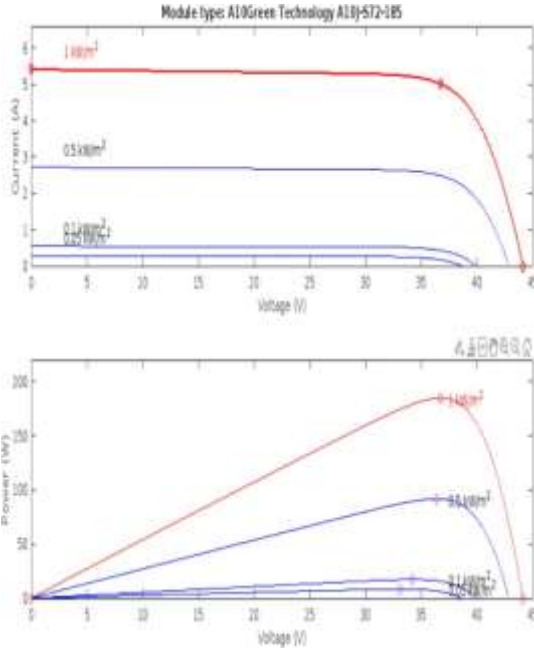


Solar PV Module

I-V characteristics of solar panel

The I-V (current-voltage) characteristics of a solar PV module describe the relationship between the current (III) and voltage (VVV) output of the module under specific environmental conditions such as solar irradiance and temperature. This

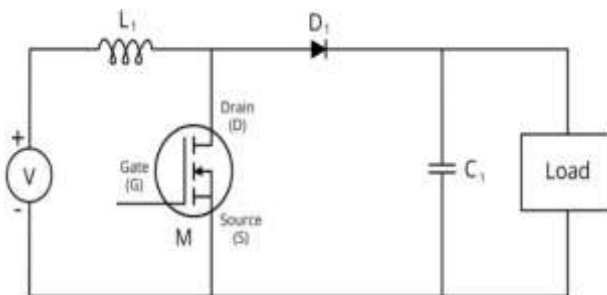
curve is fundamental for understanding the behavior of the PV module and optimizing its performance.



I-V characteristics of solar panel

Boost Converter

A boost converter is a type of DC-DC (Direct Current to Direct Current) converter that steps up (increases) the input voltage to a higher output voltage. It is a non-isolated power converter, meaning that the input and output share a common ground. The key feature of a boost converter is that it can provide a higher voltage than its input, making it useful in various applications where a higher voltage is required from a lower voltage source. A boost converter works based on the principle of energy storage and release using an inductor.



Boost Converter

Basic Operation of a Boost Converter:

A boost converter works based on the principle of energy storage and release using an inductor. Here’s how the boost converter works in general:

When the switch (typically a MOSFET) is ON

The inductor is connected directly to the input voltage source. Current flows through the inductor, and energy is stored in the magnetic field of the inductor.

During this time, the diode is reverse-biased (no current flows through it), and the output capacitor is not actively charged.

When the switch (MOSFET) is OFF

The inductor’s current continues to flow due to its stored magnetic energy, and the inductor’s voltage polarity reverses. This reversal of voltage causes the inductor to push current through the diode, which is now forward-biased.

The energy stored in the inductor is transferred to the output capacitor and load, increasing the output voltage.

The diode blocks the reverse current flow, and the output capacitor is charged.

This process of rapidly switching the MOSFET on and off (using PWM control) allows the boost converter to maintain a steady, regulated output voltage that is higher than the input.

Duty Cycle (D): The duty cycle is the fraction of time that the switch is on. It is related to the input and output voltages:

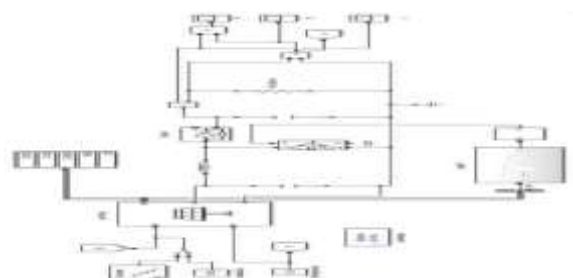
$$V_{out} = \frac{V_{in}}{1-D}$$

Where:

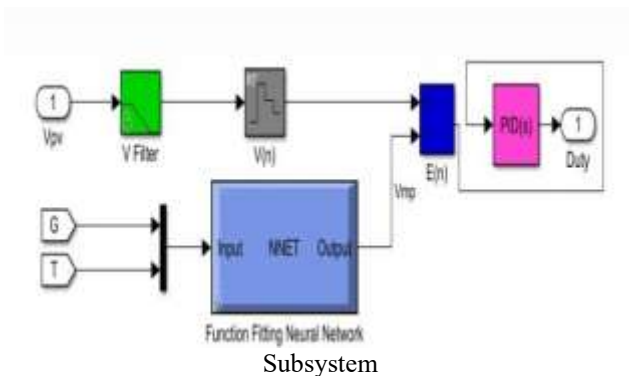
V_{in} is the input voltage. V_{out} is the output voltage. D is the duty cycle (the fraction of time the switch is on). As you can see, the output voltage is higher than the input voltage for $D > 0$ and $D < 1$.

Inductor Current Ripple: The inductor’s current ripple is an important factor in converter design, affecting efficiency and stability.

V. SIMULATION MODEL & RESULTS



Simulation Diagram



Maximum Power Point (MPP): The point on the I-V curve where the module generates the highest power.

Power at Maximum Power Point (MPP):

For the maximum power:

$$P_{max} = V_{mpp} * I_{mpp}$$

- V_{mpp} : Voltage at the maximum power point.
- I_{mpp} : Current at the maximum power point.

These values are typically obtained either experimentally (via an MPPT algorithm) or through a detailed simulation using the PV module's parameters.

The module's performance under non-STC conditions can be estimated using:

- $I \propto G$
- V adjusted using a temperature coefficient (β). Adjust the voltage and current as:

$$I = I_{sc} *$$

Gr e f

$$V = V_{oc} - \beta * (T - T_{ref})$$

$$V_{mpp} = 35.1V \quad I_{mpp} = 4.1A$$

$$P_{mpp} = V_{mpp} * I_{mpp} = 143.9W$$

V. CONCLUSION

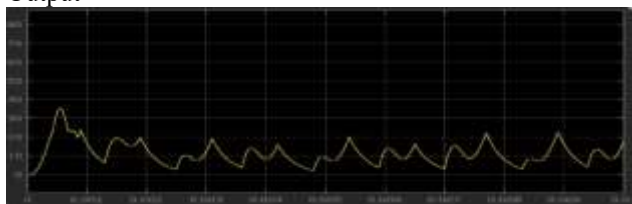
Neural network-based MPPT systems offer a powerful and efficient way to maximize the performance of solar PV modules. By leveraging the adaptability and learning capabilities of neural networks, these systems can handle complex and dynamic environmental conditions with greater accuracy than traditional methods. Although they require advanced design, training, and computational resources, their potential for higher energy efficiency, faster response, and scalability makes them a promising solution for modern solar energy systems. As technology advances, NN-based MPPT is expected to become more cost-effective and widely adopted, playing a crucial role in the transition to clean and sustainable energy.

The maximum output power by using Neural Network at a constant Temperature(25°C) under the irradiance((G=500 W/m²), is 143.9W

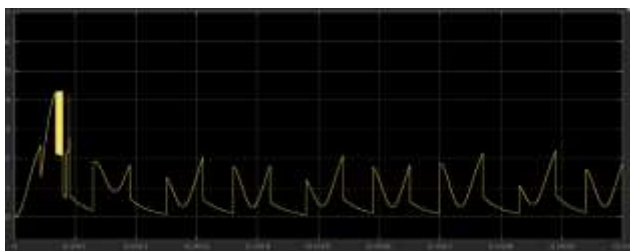
Future Scope

- **Smart Grid Integration:** Neural networks can help optimize solar energy usage in smart grids and balance electricity supply and demand.
- **Better Learning Models:** Advanced techniques like deep learning can improve accuracy and adaptability for tracking the maximum power point.

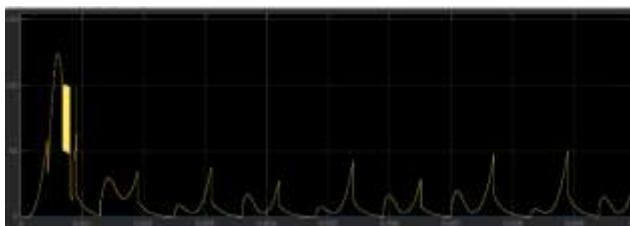
Output



Voltage



Current



Power

Theoretical Calculations

In the context of a solar PV system, the voltage and current depend on various factors, including the module's characteristics and environmental conditions such as solar irradiance and temperature.

$$\text{Power (P)} = \text{Voltage (V)} \times \text{Current (I)}$$

A solar PV module operates based on its current-voltage (I-V) curve, which is influenced by:

Open-circuit voltage (V_{oc}): The voltage across the module when no current flows (at zero load).

Short-circuit current (I_{sc}): The current through the module when the output terminals are shorted (at zero voltage).

- **IoT and Remote Monitoring:** Using IoT devices, NN-based MPPT can enable remote control, updates, and monitoring of solar systems.
- **Handling Partial Shading:** Future systems can handle shading problems more effectively, ensuring better performance in complex conditions.
- **Hybrid Systems:** Neural networks can be used to optimize power from solar panels combined with wind turbines and batteries.
- **Energy Prediction:** They can predict weather changes and adjust the solar system for better energy output.
- **Cost-Effective Solutions:** Advancements in technology can make NN-based MPPT affordable for homes and small-scale setups.
- **Self-Learning Systems:** Future systems may adapt and learn automatically over time, improving efficiency without manual updates.
- **Improved Efficiency:** Neural networks can optimize energy from multiple solar panels, increasing overall system performance.
- **Environmental Benefits:** By improving solar power efficiency, NN-based MPPT can promote renewable energy use and help reduce pollution.
- These advancements will make solar energy systems smarter, more efficient, and more reliable in the coming years

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