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Design and Simulation of Fuzzy Logic-Based Maximum Power Point Tracking for Solar Pv Arrays

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Abstract- This paper presents a Fuzzy Logic-based Maximum Power Point Tracking (MPPT) algorithm for Solar Photovoltaic (PV) systems to enhance energy efficiency. The proposed approach adapts to fluctuating solar irradiance and temperature by utilizing rule-based logic, eliminating the need for precise mathematical models. Unlike traditional methods, the fuzzy logic controller provides fast and accurate responses, minimizing power loss and improving performance. It continuously adjusts the duty cycle of a DC-DC converter to maintain operation at the peak power point. MATLAB/Simulink simulations show faster tracking, reduced oscillations, and higher energy harvest compared to Perturb and Observe (P&O) and Incremental Conductance (IncCond) methods. This robust solution maximizes PV output, advancing the feasibility of solar energy as a renewable source.

Index Terms- Fuzzy Logic, Maximum Power Point Tracking (MPPT), Solar Photovoltaic (PV) Arrays, Energy Efficiency, DC-DC Converter.

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.

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 lossesFor 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).

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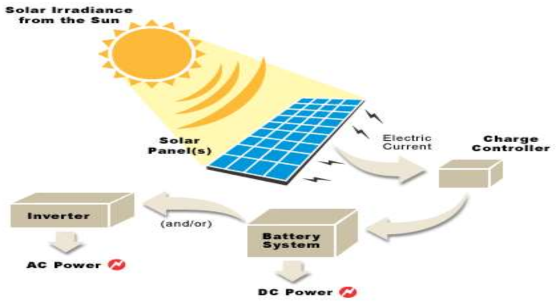

Fig. 1. Solar power.

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. [1].

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.

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.

Different MPPT techniques

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

1) Perturb and Observe (hill climbing method)
2) Incremental Conductance method
3) Fractional short circuit current
4) Fractional open circuit voltage
5) Neural networks
6) 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. [1].

Flow Chart of Perturb & Observe Algorithm:

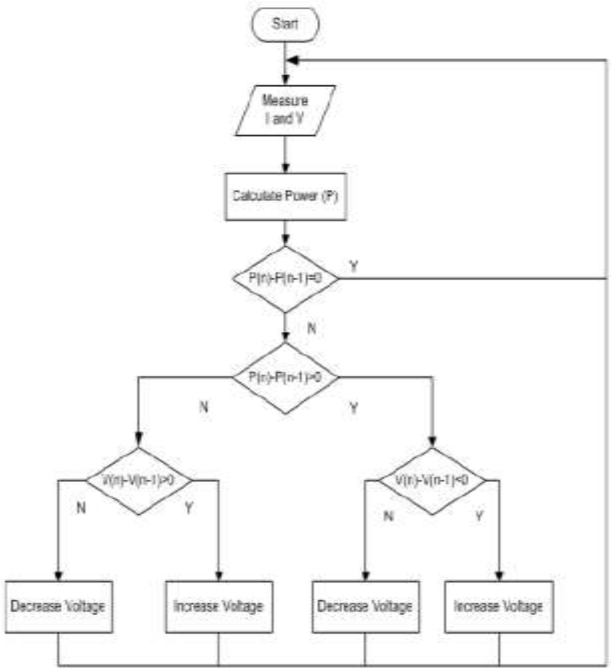

Fig. 2 Perturb & observe algorithm.

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.

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

$0=I+VdI/dV_{MPP}$

$dI/dV_{MPP} = - I/V$

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. [2].

Fuzzy Logic Control

Microcontrollers have made using fuzzy logic control popular for MPPT over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity.

Fuzzy Rule

ΔVpv*[o/p]	ΔVpv[i/p]					
		NB	NS	ZE	PS	PB
ΔPpv[i/p]	NB	PS	PB	NB	NB	NS
	NS	PS	PS	NS	NS	NS
	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	NS	PS	PS	PS
	PB	NS	NB	PB	PB	PS

Figure 2 Fuzzy rules.

A **fuzzy rule** is a core component of a fuzzy logic system, typically used in the inference process to make decisions based on fuzzy inputs. In a Fuzzy Logic-based MPPT (Maximum Power Point Tracking) system for solar PV arrays, fuzzy rules are used to adjust the duty cycle of the DC-DC converter in responses.

Fuzzy Rule Example for MPPT

Here's an example of how fuzzy rules might look for a fuzzy logic-based MPPT system:

Rule 1

IF (E is Positive) AND (ΔE is Positive) THEN (D is Increase)

Meaning: If the power is increasing and the rate of increase is also positive, then increase the duty cycle to keep the system moving toward the maximum power point.

Rule 2

IF (E is Negative) AND (ΔE is Negative) THEN (D is Decrease)

Meaning: If the power is decreasing and the rate of decrease is negative, then decrease the duty cycle to reverse the trend and attempt to reach the maximum power point.

Rule 3

IF (E is Zero) AND (ΔE is Zero) THEN (D is Maintain)

Meaning: If the power is at the maximum (no error) and the power is not changing (rate of change is zero), maintain the current duty cycle.

Rule 4

IF (E is Positive) AND (ΔE is Negative) THEN (D is Decrease)

Meaning: If the power is increasing, but the rate of increase is slowing down (negative change in error), reduce the duty cycle slightly to fine-tune the tracking towards the maximum power point.

Rule 5

IF (E is Negative) AND (ΔE is Positive) THEN (D is Increase)

Meaning: If the power is decreasing, but the rate of decrease is slowing down (positive change in error), increase the duty cycle to attempt to track the maximum power point again.

Defuzzification

The process of defuzzification converts the fuzzy output (which could be a fuzzy set) into a single crisp value. Common defuzzification methods include:

Centroid Method: Calculating the center of mass of the output fuzzy set to get the crisp value.

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Mean of Maxima: Taking the average of the maximum values of the output fuzzy set.

Example of Rule Base for MPPT:

Error (E)	Change in Error (ΔE)	Duty Cycle (D)
Positive	Positive	Increase
Positive	Negative	Decrease
Zero	Zero	Maintain
Negative	Positive	Increase
Negative	Negative	Decrease

This rule base helps the system decide how to adjustt the duty cycle to ensure that the solar PV system operates at its Maximum Power Point (MPP).

Summary of Fuzzy Rule Design in MPPT

1. **Inputs**: Error in power (E), Change in error (ΔE).
2. **Outputs**: Duty cycle adjustment (D).
3. **Fuzzy Rules**: Define the relationship between inputs and output using linguistic terms such as Positive, Negative, Zero.
4. **Membership Functions**: Represent the fuzzy sets for inputs and outputs.
5. **Fuzzy Inference**: Apply fuzzy rules to determine the fuzzy output.
6. **Defuzzification**: Convert the fuzzy output to a crisp value (duty cycle adjustment).

Applications of Fuzzy Logic

1. **Solar Energy Systems**: As mentioned, fuzzy logic is used in MPPT controllers for solar PV arrays to adjust operating points based on fluctuating environmental conditions, ensuring the system operates at its maximum power output.
2. **Automotive Industry**: Fuzzy logic is used in automatic transmission systems, braking systems, and adaptive cruise control to simulate human-like decision-making processes.
3. **Consumer Electronics**: Fuzzy logic is found in air conditioners, washing machines, and refrigerators to improve efficiency and user comfort by adjusting settings based on user preferences or environmental conditions.
4. **Robotics**: Fuzzy logic is used to control robotic movements and processes, particularly in situations that require a degree of flexibility and adaptation, such as robot navigation in dynamic environments.
5. **Healthcare**: Fuzzy logic has applications in medical diagnosis, treatment planning, and personalized healthcare systems, where decisions must be based on a combination of factors that may be uncertain or imprecise.[3].

Flow chat of Fuzzy logic MPPT

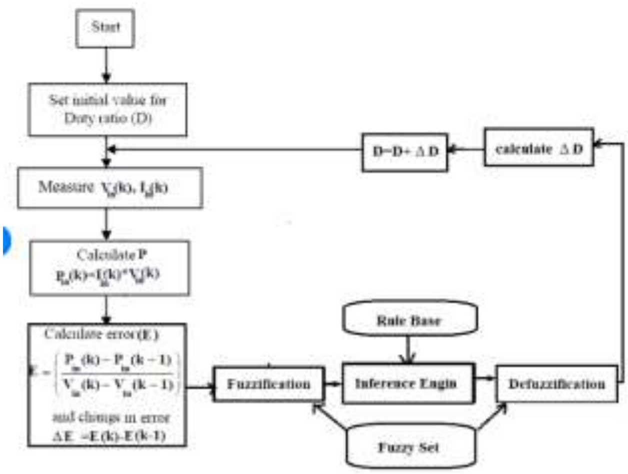

Fig. 3 Fuzzy logic MPPT.

Solar photovoltaic (PV) arrays have gained prominence as a renewable energy source due to their abundance, environmental benefits, and sustainability. However, one of the major challenges of solar power generation is the variability in solar irradiance and temperature, which causes the power output of PV arrays to fluctuate. To maximize the efficiency of energy conversion from solar energy to electrical power, Maximum Power Point Tracking (MPPT) techniques are used to continuously adjust the operating point of the PV array.

Objectives of the Study

The primary objectives of the study are:

To design a Fuzzy Logic Controller (FLC) for efficient MPPT of a solar PV system.

To develop a simulation model of the FLC-based MPPT in a solar PV system using tools like MATLAB/Simulink or similar platforms.

To compare the performance of the fuzzy logic-based MPPT with traditional MPPT methods (e.g., P&O and IncCond) in terms of tracking accuracy, stability, and dynamic response.

To analyse the effectiveness of the fuzzy logic-based MPPT under varying environmental conditions (solar irradiance and temperature).[3]

III. METHODOLOGY

Fuzzy Logic Control (FLC)

Fuzzy Logic is a form of many-valued logic that deals with reasoning that is approximate rather than fixed and exact. Fuzzy controllers are widely used in systems where there are uncertainties and where traditional methods fail. The use of fuzzy logic in MPPT is based on the idea that human reasoning can be used to develop rules to adjust the duty cycle of the converter to track the maximum power point.

In this study, the fuzzy logic controller will consist of:

Input Variables: The error (difference between the previous and current power or voltage) and the rate of change of error (change in error).

Output Variable: The change in the duty cycle of the PWM (Pulse Width Modulation) signal that controls the DC-DC converter (usually a buck or boost converter).

Membership Functions: The error and change in error are divided into categories, such as Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB).

Fuzzy Rules: Based on empirical data or expert knowledge, fuzzy rules are defined to determine how the duty cycle should be adjusted to maximize power extraction from the PV system.

System Modeling and Simulation

PV Module Model: The PV array is modeled based on its electrical characteristics (I-V and P-V curves), considering factors such as solar irradiance, temperature, and the voltage-current relationship.

MPPT Controller: The fuzzy logic controller is implemented to regulate the operating point of the PV system by controlling the duty cycle of the DC-DC converter.

DC-DC Converter: The DC-DC converter (buck or boost) is used to step up or step down the voltage, while maintaining maximum power extraction through the MPPT controller.

Working of Fuzzy Logic-Based MPPT for Solar PV Arrays

A Fuzzy Logic-Based Maximum Power Point Tracking (MPPT**)** system for solar photovoltaic (PV) arrays aims to optimize the power extraction by continuously adjusting the operating point of the PV system. Fuzzy logic is used to overcome the limitations of traditional MPPT algorithms, providing better performance in terms of accuracy, stability, and response time under dynamic environmental conditions.

Here’s a detailed breakdown of how a Fuzzy Logic-Based MPPT works for solar PV arrays:

Basic Concept of MPPT for Solar PV Systems

Solar PV systems generate electricity by converting sunlight into electrical power. The amount of power generated by a PV system varies with solar irradiance (the amount of sunlight) and temperature. The Maximum Power Point (MPP) is the point on the power-voltage (P-V) or power-current (P-I) characteristic curve of the PV array where the output power is maximum. The goal of MPPT is to operate the PV system at this point to maximize power extraction.

A **Fuzzy Logic Controller (FLC)** typically has three main components:

Fuzzification: Converts real-valued inputs into fuzzy values (linguistic terms like "small", "medium", "large").

Rule Base: Contains a set of rules in the form of "IF-THEN" statements that define how the system should behave.

Defuzzification: Converts the fuzzy output back into a crisp value (specific action or decision)

Steps Involved in Fuzzy Logic-Based MPPT

Step 1: Identify the Input Variables

The main inputs to the fuzzy logic controller are derived from the **Power (P)** and **Voltage (V)** of the PV array. These inputs are:

Error (e): This is the difference between the current power and the previous power, i.e., the rate of change of power.

e(k)=P(k)−P(k−1)e(k) = P(k) - P(k-1)e(k)=P(k)−P(k−1)

where P(k)P(k)P(k) is the current power and P(k−1)P(k-1)P(k−1) is the previous power.

Change in Error (Δe): This is the rate of change of the error.

Δe(k)=e(k)−e(k−1)\Delta e(k) = e(k) - e(k-1)Δe(k)=e(k)−e(k−1)

It represents how fast the power is changing over time and helps in identifying if the system is approaching or moving away from the MPP.

Step 2: Fuzzification of Input Variables

The error (e) and the change in error (Δe) are converted from their real values (crisp values) into **fuzzy values**. The fuzzy values are represented by linguistic terms like:

Negative Big (NB), **Negative Small (NS)**, **Zero (Z)**, **Positive Small (PS)**, **Positive Big (PB)**.

For example:

Error (e): If the power is increasing, the error will be positive, and the fuzzy set for error might be **PB** (Positive Big).

Change in Error (Δe): If the power is changing rapidly, the change in error could be categorized as **NB** (Negative Big) or **PB** (Positive Big) depending on whether the power is increasing or decreasing.

Membership functions (typically **triangular** or **trapezoidal**) are used to represent these fuzzy sets.

Step 3: Rule Base Definition

The fuzzy logic controller uses a set of predefined rules to determine the control action based on the fuzzy inputs. These rules dictate how the duty cycle of the DC-DC converter should be adjusted. A typical rule base might look like this:

IF error is **PB** AND change in error is **PB**, **THEN** increase the duty cycle significantly (move right on the P-V curve).

IF error is **NS** AND change in error is **Z**, **THEN** keep the duty cycle unchanged (stay near the MPP).

IF error is **Z** AND change in error is **Z**, **THEN** adjust the duty cycle slightly (fine-tuning to maintain the MPP).

IF error is **NB** AND change in error is **NB**, **THEN** decrease the duty cycle significantly (move left on the P-V curve).

The fuzzy logic rule base allows the controller to adjust the duty cycle based on the relative position of the operating point to the maximum power point.

Step 4: Fuzzy Inference

Once the fuzzy inputs are processed through the rules, the system uses **fuzzy inference** to combine the output of all the rules and generate a fuzzy output. This output is an intermediate value that still needs to be converted into a crisp value.

Step 5: Defuzzification

The fuzzy output is converted into a **crisp value** using **defuzzification**. One common method of defuzzification is the **centroid method**, which calculates the "center of mass" of the fuzzy output set. This produces a specific value for the duty cycle that controls the converter.[3].

Graphs and Characteristics

Power-Voltage (P-V) Characteristics of the Solar PV Array

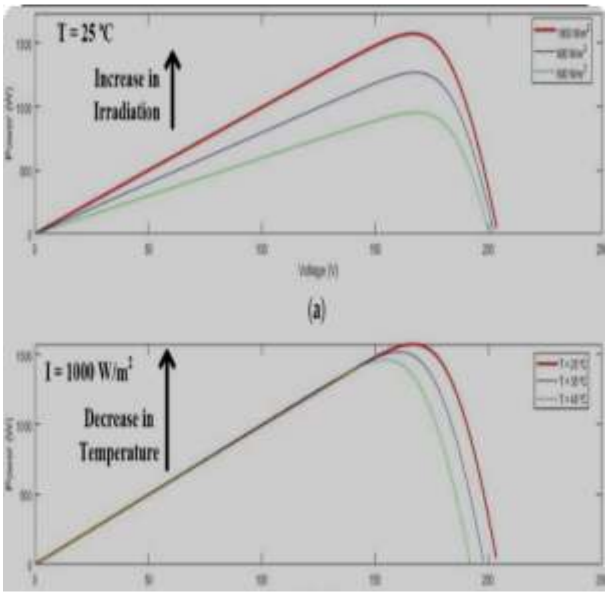

Fig. 4 Power voltage graph.

Description

The **P-V curve** shows the relationship between the output power and the output voltage of the solar PV array. This curve is nonlinear, and it features a point where the power output is maximized — the Maximum Power Point (MPP).

Graph Behavior in the Context of Fuzzy Logic MPPT

The system's goal is to adjust the voltage and current through the DC-DC converter (controlled by the Fuzzy Logic Controller) to operate at or near the MPP, ensuring maximum power extraction.

Fuzzy Logic MPPT adjusts the duty cycle of the DC-DC converter, which shifts the operating point of the PV array closer to the MPP, especially under changing environmental conditions.

Voltage vs. Time (V-t) and Current vs. Time (I-t) Graphs

Description:

Voltage vs. Time (V-t): This graph tracks how the output voltage of the solar PV array changes with time.

Graph Features

The output voltage (V) of the solar array fluctuates with changing environmental conditions, such as solar irradiance or temperature.

Current (I) is similarly affected, but it may vary more sharply in response to changes in irradiance.

The **fuzzy MPPT controller** continuously adjusts the output voltage and current to keep the system operating at or near the maximum power point.

IV. IMPLEMENTATION OF SIMULINK MODEL

Simulink Model Components The Simulink model for the Fuzzy Logic-Based MPPT system consists of the following key components:

Solar PV Array The solar PV array is the source of electrical power, which varies depending on solar irradiance and temperature. In Simulink, this can be modeled using the PV Array block available in the Simscape Electrical library.

The output from the solar array (voltage and current) is fed into the **Power Calculation** block to compute the instantaneous power.

Power Calculation The **Power Calculation Block** computes the instantaneous power P=V×IP = V \times IP=V×I using the voltage and current supplied by the PV array. This power is then used to determine the error in the next step.

Fuzzy Logic Controller The FLC is the heart of the fuzzy logic-based MPPT. It receives the error (e) and the change in error (Δe) as inputs, and produces a control signal that determines how much to adjust the duty cycle of the DC-DC converter.

DC-DC Converter The DC-DC Converter (buck or boost) adjusts the voltage and current of the PV array to ensure that the system operates at or near the maximum power point. The Simulink model uses the DC-DC Converter block to implement either a buck converter (for step-down conversion) or a boost converter (for step-up conversion).

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The duty cycle is adjusted by the fuzzy logic controller to maintain maximum power extraction. The output from the converter is then supplied to the load or a battery storage system.

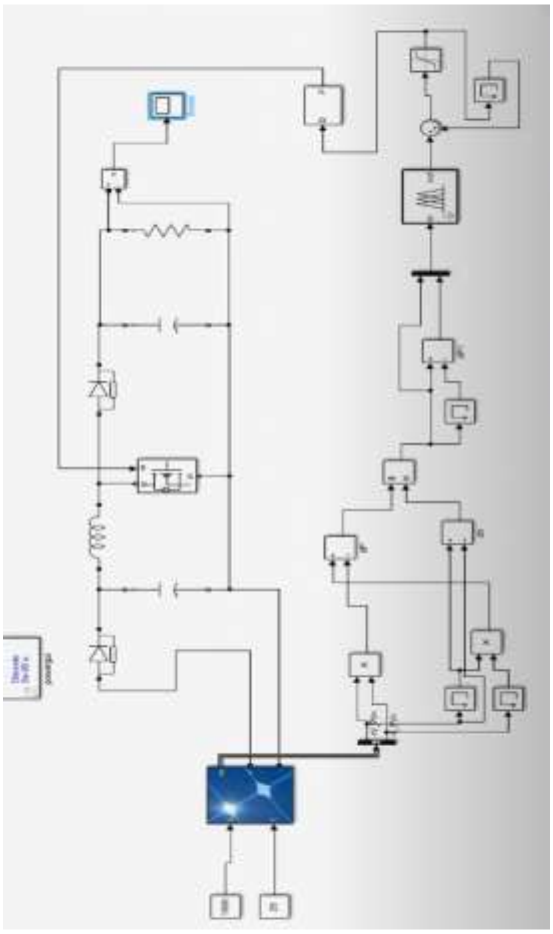


Fig. 5 Simulation work.

Simulink Model Overview

A typical Simulink model structure would look like:

PV Array Model (representing the solar panel)

Fuzzy Logic Controller Block (to adjust the duty cycle of the converter)

DC-DC Converter Block (to regulate the power delivered to the load)

Power Meter Block (to monitor the output power)

Irradiance and Temperature Simulation Blocks (to simulate environmental changes)

Example Simulink Implementation

Here is a step-by-step process for setting up the Simulink model:

Add PV Array:

Drag the **PV Array** block from Simscape Electrical and set up its parameters like the number of series and parallel cells, temperature, and irradiance.

Design Fuzzy Logic Controller:

Open the Fuzzy Logic Designer, define the fuzzy rules and membership functions based on your MPPT algorithm, and export the FIS to Simulink.

DC-DC Converter:

Drag and drop a **DC-DC Converter** block (buck or boost converter) and connect it to the output of the fuzzy logic controller.

Simulate and Analyze:

Use a **Scope** or **Power Meter** to observe the output of the PV array and evaluate the MPPT tracking performance.

THEORETICAL CALCULATIONS

Power Calculation of Solar PV Array

The basic equation to calculate the **instantaneous power** generated by a **solar PV array** is:

P=V×IP = V \times IP=V×I

Where:

- PPP is the instantaneous power (in watts),
- VVV is the voltage across the PV array (in volts),
- III is the current from the PV array (in amperes).

The voltage and current are influenced by environmental conditions such as solar irradiance (sunlight intensity) and temperature.

For simplicity, consider the following parameters for a solar PV array:

- **Voltage at MPP (V_mpp)**: 18 V

- **Current at MPP (I_mpp)**: 5 A
- **Solar Irradiance**: 1000 W/m²
- **Temperature**: 25°C

Then, the **instantaneous power** at the **maximum power point (MPP)** can be calculated as:

Pmpp=Vmpp×Impp=18×5=90 wattsP_{mpp} = V_{mpp} \times I_{mpp} = 18 \times 5 = 90 \text{ watts}Pmpp=Vmpp ×Impp=18×5=90 watts

Example:

Let's assume the following:

- At time t0t_0t0, the previous power is Pprevious=85P_{\text{previous}} = 85Pprevious=85 W, and the current power at t1t_1t1 is Pcurrent=90P_{\text{current}} = 90Pcurrent=90 W.
- The error eee at time t1t_1t1 is:

e=90−85=5 We = 90 - 85 = 5 \text{ W}e=90−85=5 W

Now, let's assume that at the previous time step t0t_0t0, the error was eprevious=3e_{\text{previous}} = 3eprevious=3 W.

The change in error Δe\Delta eΔe at time t1t_1t1 would be:

Δe=5−3=2 W\Delta e = 5 - 3 = 2 \text{ W}Δe=5−3=2 W

Thus, at time t1t_1t1, we have:

- **Error (e)** = 5 W
- **Change in error (Δe)** = 2 W

These values are fed into the Fuzzy Logic Controller.

Example Simulation Process

Let's assume that the following parameters are set for the simulation:

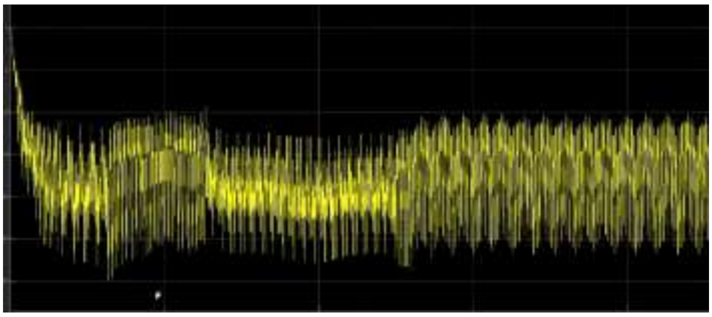
- **Initial Voltage (V)** = 18 V
- **Initial Current (I)** = 5 A
- **Solar Irradiance** = 1000 W/m²
- **Temperature** = 25°C
- **Maximum Power Point (MPP)**: Pmpp=90P_{mpp} = 90Pmpp=90 W

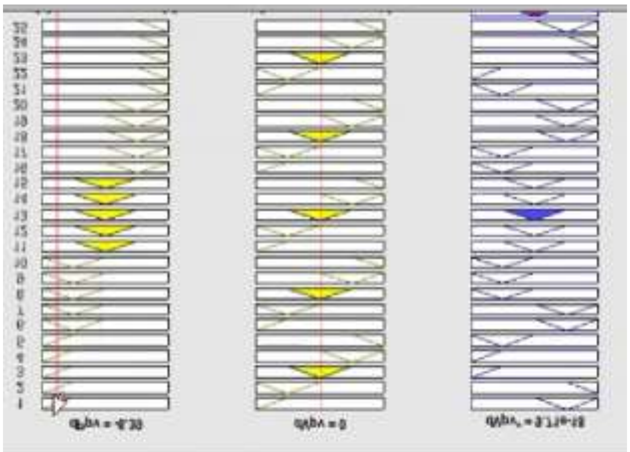
For the simulation, we calculate the **power** at the current time step, calculate the error and change in error, then use the Fuzzy Logic Controller to adjust the duty cycle of the DC-DC converter.

At time t0t_0t0, the system operates at Pprevious=85P_{\text{previous}} = 85Pprevious=**85 W.**

Simulation Results

Output Voltage:





ADVANTAGES

The Fuzzy Logic-Based Maximum Power Point Tracking (MPPT) is an advanced method for optimizing the power output from solar photovoltaic (PV) arrays.

1. Robust Performance Under Rapid Irradiance and Temperature Changes

Fuzzy logic controllers (FLCs) excel in environments where rapid fluctuations in solar irradiance and temperature occur, which are common in real-world settings (e.g., cloud cover, shading).

2. No Need for Precise Mathematical Models

Fuzzy logic-based MPPT does not require an explicit mathematical model of the PV array or its operating conditions.

3. High Adaptability to Nonlinear and Complex Systems

Fuzzy logic is particularly effective in handling the nonlinear and complex relationship between power, voltage, and current in solar PV systems.

DISADVANTAGES

1. Complexity in Designing the Fuzzy Rule Base

The design of the fuzzy rule base can be complex and time-consuming.

2. Requires Computational Resources

Fuzzy logic-based MPPT can require more computational resources than traditional methods.

3. Lack of Precision in Control Outputs

Fuzzy logic controllers can sometimes result in less precise control compared to other algorithms.

4. Dependency on Rule Base and Membership Functions

The performance of the fuzzy logic controller is highly dependent on the quality of the rule base and membership functions.

IV. CONCLUSION

In conclusion, Fuzzy Logic-Based MPPT presents a promising and highly adaptable solution for optimizing the performance of solar photovoltaic (PV) arrays. By using a set of linguistic rules and approximate reasoning, fuzzy logic controllers (FLCs) offer the ability to efficiently track the maximum power point (MPP) under varying environmental conditions such as fluctuating irradiance and temperature. This adaptability makes fuzzy logic-based MPPT particularly effective in real-world scenarios where traditional methods like Perturb and Observe (P&O) or Incremental Conductance (IncCond) may struggle, especially under rapid changes or partial shading.

One of the major strengths of fuzzy logic-based MPPT is its robustness, particularly in dynamic and unpredictable environments, where it can maintain stable and efficient power tracking. Additionally, the system does not require a precise mathematical model of the solar PV array, which simplifies its implementation and enhances flexibility. Moreover, fuzzy logic controllers can provide smooth, real-time adjustments to the duty cycle of the DC-DC converter, reducing oscillations and ensuring efficient energy extraction

FUTURE SCOPE

Integration with Machine Learning and AI: Fuzzy logic-based MPPT can benefit from machine learning algorithms, such as reinforcement learning, to automatically optimize fuzzy rule bases.

Real-Time Adaptation and Self-Optimization: By incorporating adaptive fuzzy logic, future MPPT systems can continuously update their rules and membership functions based on real-time data.

Improved Computational Efficiency: Future developments in fuzzy logic-based MPPT will focus on reducing computational overhead, enabling faster processing and response times.

Hybrid MPPT Algorithms: Combining fuzzy logic with other MPPT methods, such as Perturb and Observe (P&O) or Incremental Conductance (IncCond), could improve tracking speed and accuracy.

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