Analysis of Photovoltaic & Grid Interfaced Power Converters for Electrolyser & Battery Charging Applications

1st Phase of Project report submitted to Visvesvaraya National Institute of Technology, Nagpur in partial fulfilment of the requirements for the award of the degree

Bachelor of Technology
In
Electrical and Electronics Engineering

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CHAPTER 1:
INTRODUCTION TO POWER ELECTRONICS AND INVERTERS

1.1 History and Overview:

The history of power electronics, with a focus on inverters, traces a significant evolution driven by technological advancements and the growing demand for efficient energy conversion. Here is an overview:

1. Early Developments (19th Century):
The roots of power electronics can be traced back to the late 19th century with the advent of electrical systems. Inventors like Nikola Tesla and Thomas Edison contributed to the understanding of electrical power.

2.Introduction of Semiconductor Devices (20th Century): The mid-20th century saw a transformative shift with the development of semiconductor devices. The invention of the transistor in the 1940s and the subsequent development of power diodes and thyristors (SCR) in the 1950s laid the foundation for modern power electronics.

3.Vienna Rectifier(1993): The Vienna Rectifier is a pulse width modulation rectifier, invented in 1993 by Johann W. Kolar at TU Wien, a public research university in Vienna, Austria.

4.Full Bridge DC-DC Converter: The introduction of power semiconductors and integrated circuits made it economically viable to make dc-dc converter.A DC-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter.

5.Interleaved Buck Converter: An interleaved buck converter (IBC) is a power electronics converter that connects multiple converter stages to a single voltage source and one or more outputs. The stages are connected in parallel and phase-shifted to eliminate current ripples.

6.Electrolyser: The principle of the electrochemical decomposition of water in an electrolysis cell has already been known for more than 230 years. The first generation of hydrogen by electricity was done as early as 1789 by van Troostwijk and Deiman using an electrostatic generator as the direct current source.

7. Digital Control and Microprocessors (2000s):
The integration of digital control and microprocessors in power electronics systems became prevalent in the 2000s. This allowed for advanced control algorithms, precise monitoring, and communication capabilities in inverters, enhancing their performance and adaptability

The history of power electronics, marked by the evolution of inverters, reflects a continuous quest for more efficient and reliable energy conversion technologies to meet the demands of various applications

NEED OF THIS POWER CONVERTER

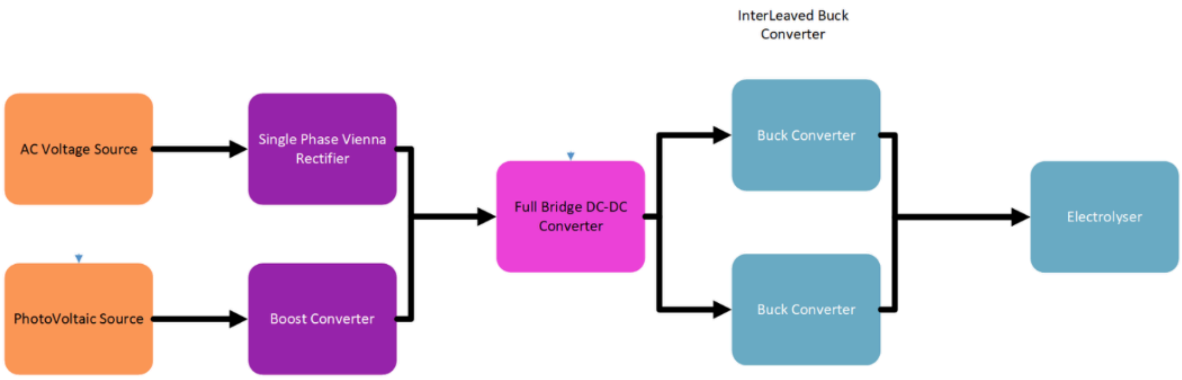
In case of the conventional Power converters the conversion is done using the Power devices which has Non-linear V-I characteristics .This Nonlinear characteristics causes harmonic distortion in the current drawn from the source (grid) Which is a Power Quality issue.

This Converter is designed such that the current waveform on the source side contains less ripple due to which the power Factor of the load (including converter) is improved, reducing losses and unnecessary heating.

The Vienna Rectifier acts as a Boost PFC where it converts the AC to DC ,the Full-Bridge on the other hand provides Galvanic Isolation , increasing efficiency .

The Interleaved Buck converter is connected to serve loads demanding Low Voltage High current . This converter also ensures the voltage regulation on the load side .

BLOCK DIAGRAM OF THE CONVERTER



The block diagram outlines a converter system designed for processing power from different sources (AC and DC) and delivering it to a load (electrolyzer).

1. AC Voltage Source: Provides alternating current (AC) as the input to the system.
2. Single-Phase Vienna Rectifier: A power factor correction (PFC) circuit that converts AC to DC while ensuring high efficiency and low harmonic distortion.
3. Photovoltaic Source: A solar power source providing DC input directly to the system.
4. Boost Converter: Steps up the DC voltage from the photovoltaic source to match the required input level for further processing.
5. Full-Bridge DC-DC Converter: Converts the rectified DC voltage into a regulated DC voltage, ensuring isolation and maintaining system efficiency.
6. Interleaved Buck Converter: Steps down the DC voltage to deliver low voltage and high current to the load while improving efficiency and reducing ripple.

7. Electrolyzer: The final load, which uses the regulated low-voltage, high-current power for its operation (e.g., splitting water into hydrogen and oxygen).

This setup combines multiple power sources and regulates them for efficient operation of the electrolyzer.

1.2 What is a Vienna Rectifier?

A single-phase Vienna rectifier is a unidirectional converter that converts AC to DC. It's a combination of a boost DC/DC converter series and a single-phase rectifier. It's a highly efficient method for converting single-phase AC to DC and is useful for achieving unity power factor correction.

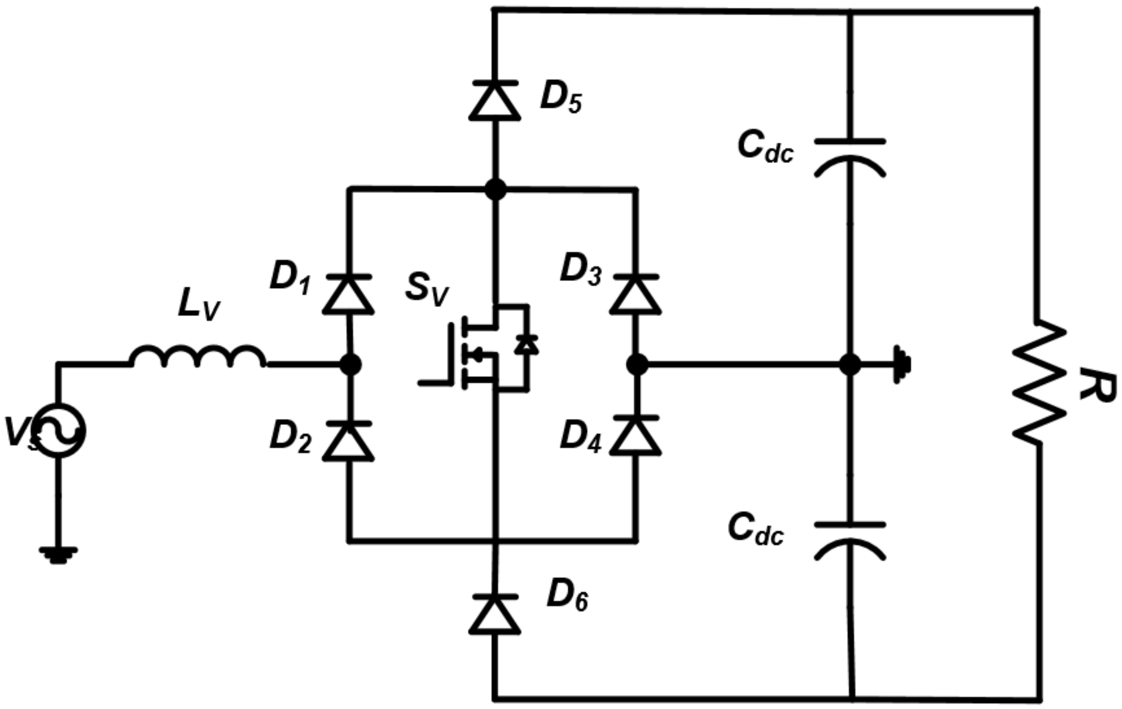


Fig 1.1 Vienna Rectifier

Key Features of a Single-Phase Vienna Rectifier:

1. **Three-Level Operation:**
    - The rectifier achieves a three-level DC output voltage, reducing voltage stress on the power devices and smoothing the output.
2. **Active Power Factor Correction (PFC):**
    - Ensures a high power factor by actively shaping the input current to be sinusoidal and in phase with the input voltage.
3. **Reduced Harmonic Distortion:**
    - With proper control, it minimizes input current harmonics, complying with stringent power quality standards such as IEEE 519.

4. **Bidirectional Power Flow:**
    - Vienna rectifiers support current flow from AC to DC but are unidirectional in energy flow unless modified.
5. **High Efficiency:**
    - Operates efficiently due to reduced switching losses and low conduction losses.

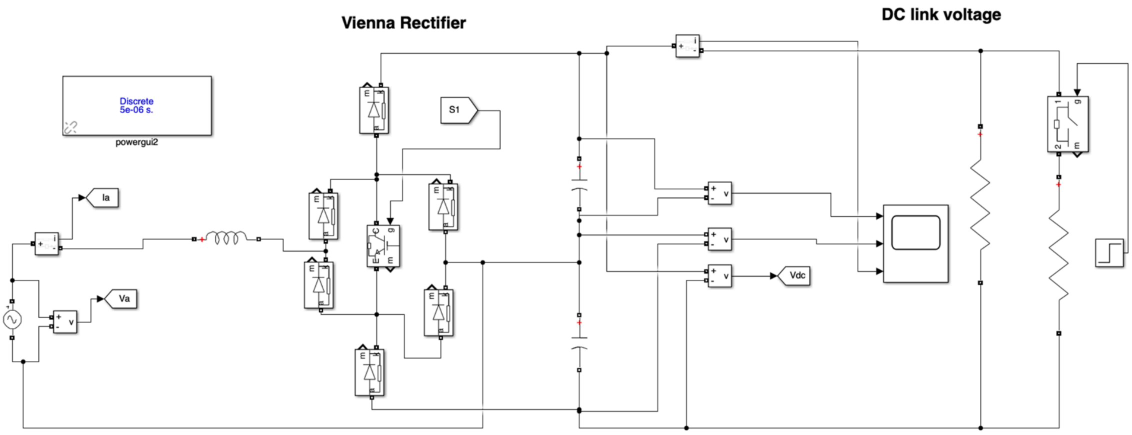


Fig 1.2 Simulink Model of Vienna Rectifier

1.3 Modes of Operation

Vienna Bridge operates in 4 different modes, characterized by voltage, current and conduction of power switches and their impact on output waveform.

Mode 1: Vs=+ve, Is>0, Sv is On

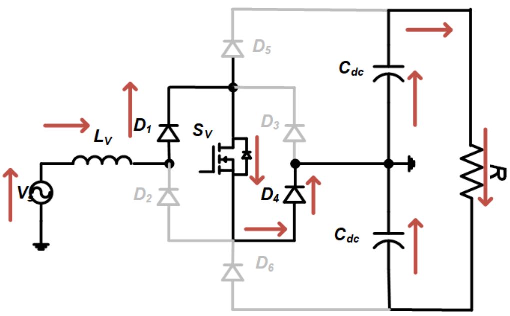


Fig 1.3

Mode 2: Vs=+ve, Is>0 , Sv is OFF

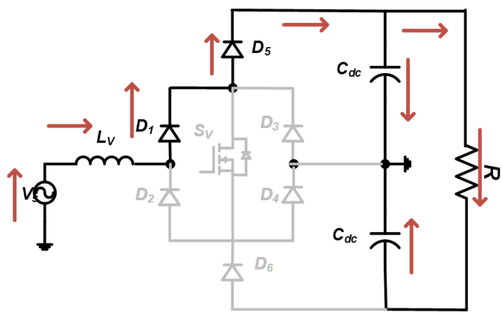
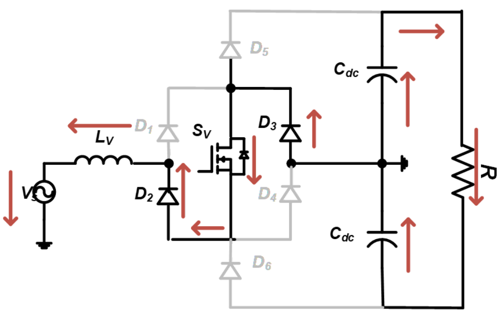
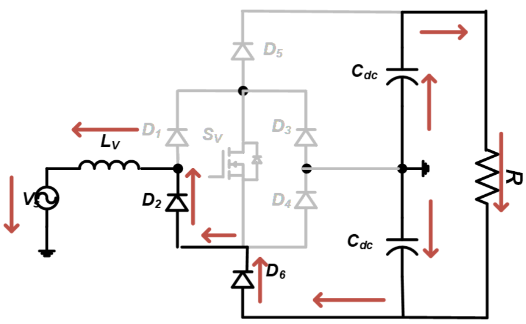


Fig 1.4

Mode 3: Vs=-ve , Is<0 , Sv is ON



Mode 4: Vs=-ve , Is<0, Sv is ON



1.4 Control Circuit for Vienna Rectifier

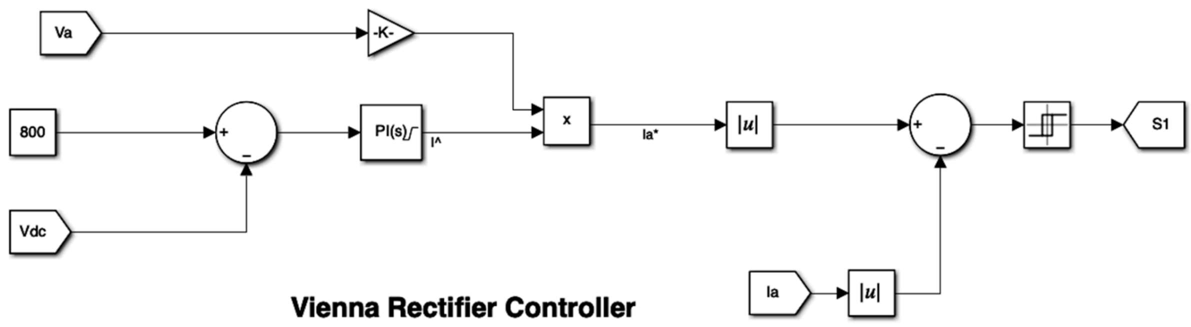


Fig 1.7 Control Circuit of Vienna Rectifier

- The control circuit is used to regulate output voltage of the rectifier.
- By comparing it with the reference (Vdc) produces an error signal which is fed to the PID controller which is followed by the current loop for current regulation.
- This control circuit helps the rectifier trace its output voltage even after switch load switching.

1.5 Simulation Results Obtained for Vienna Rectifier

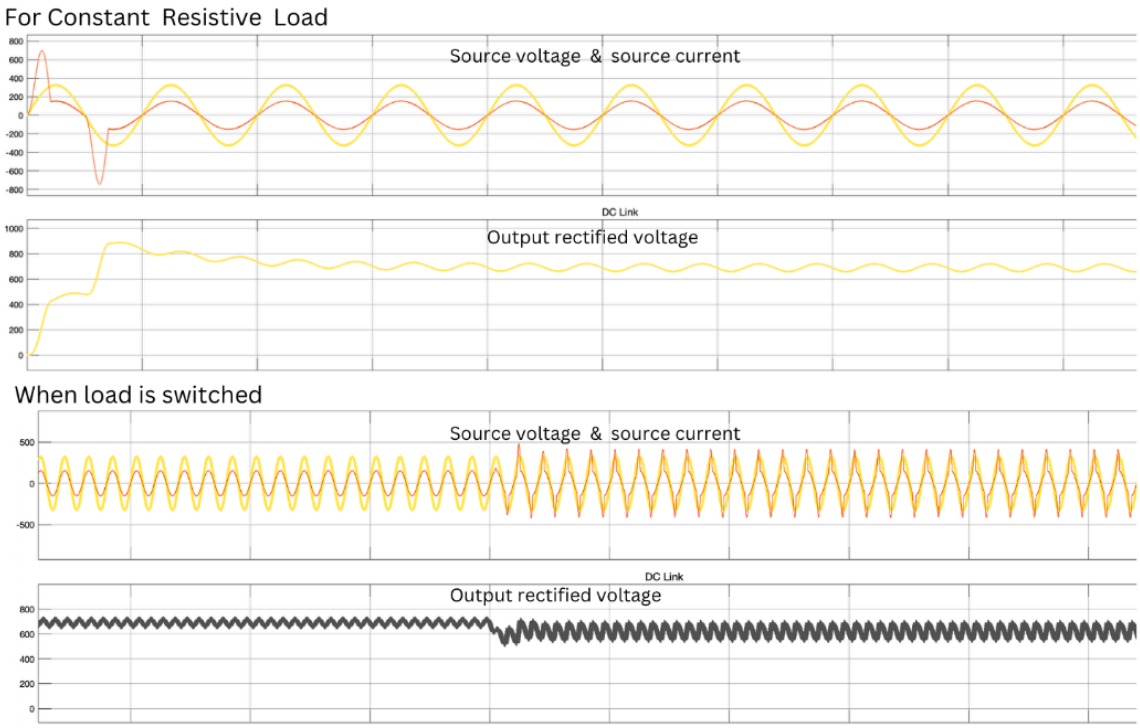


Fig 1.8 Simulation results for Vienna Rectifier.

The second set of results are obtained when there is change in load at 2.5 sec.

1.6 Full Bridge DC-DC Isolated Converter

A Full-Bridge DC-DC Isolated Converter is a type of power electronic converter used to transfer electrical energy between two DC sources or a DC source and a load, while providing galvanic isolation and high efficiency. Its design makes it ideal for medium- to high-power applications, where isolation and voltage scaling are required.

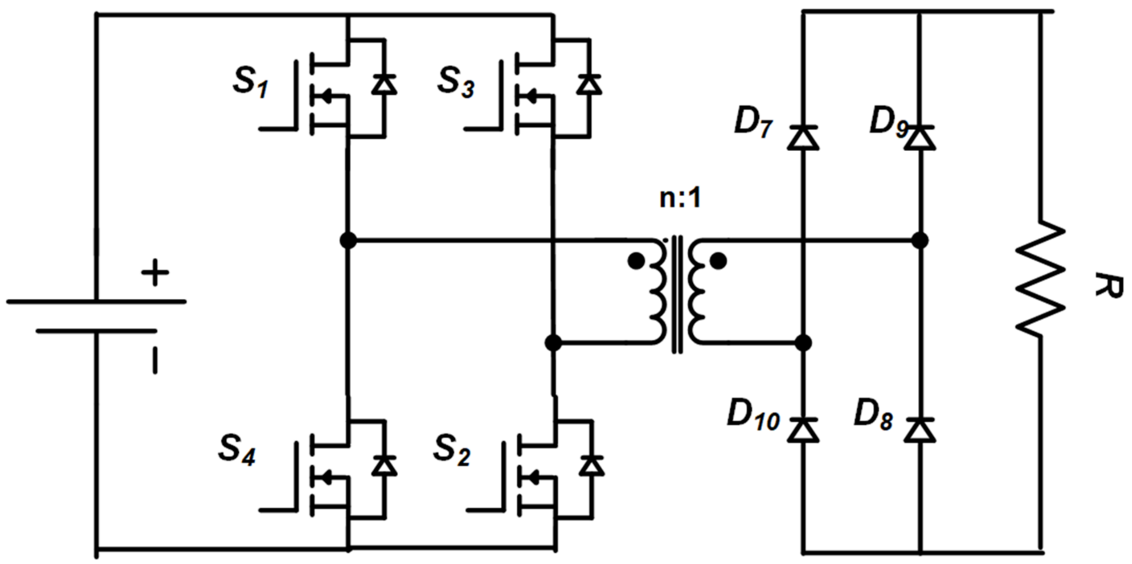


Fig 1.9 Full Bridge DC-DC converter

Key Features:

1. **Electrical Isolation:**
   - Achieved through a high-frequency transformer, which separates the input and output, ensuring safety and noise decoupling.
2. **Bidirectional Energy Transfer :**
   - With appropriate control, it can transfer energy in both directions, making it suitable for energy storage systems.
3. **High Efficiency:**
   - Often employs soft-switching techniques like Zero Voltage Switching (ZVS) or Zero Current Switching (ZCS) to minimize losses.

1.7 Control Circuit for Phase Shifted Full Bridge DC-DC Converter

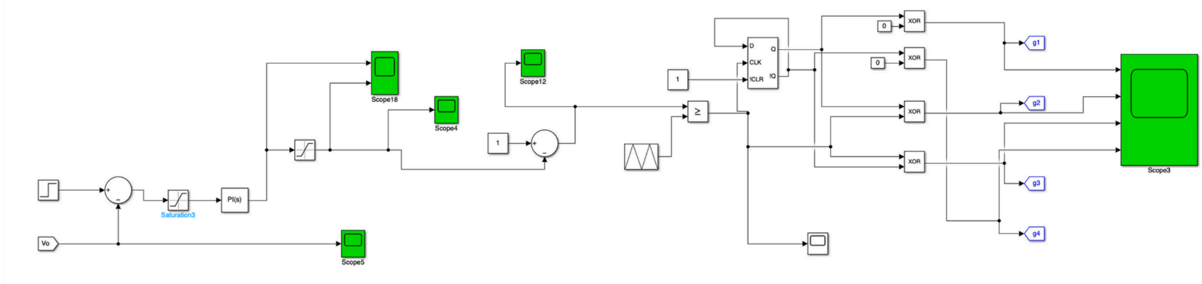


Fig 1.10 Circuit for Phase Shifted Full Bridge DC-DC Converter

- The control circuit is use to regulate output voltage of rectifier. By comparing it with the reference(Vo), producing an error signal which is fed to PID controller, which is followed by current loop for current regulation.
- The Switching of the switches used in H-Bridge is varied as per the response of the error signal produced by the PID controller
- This control circuit help rectifier retrace its output voltage even after load switching.

1.8 Results with both Vienna Bridge and Full Bridge are connected

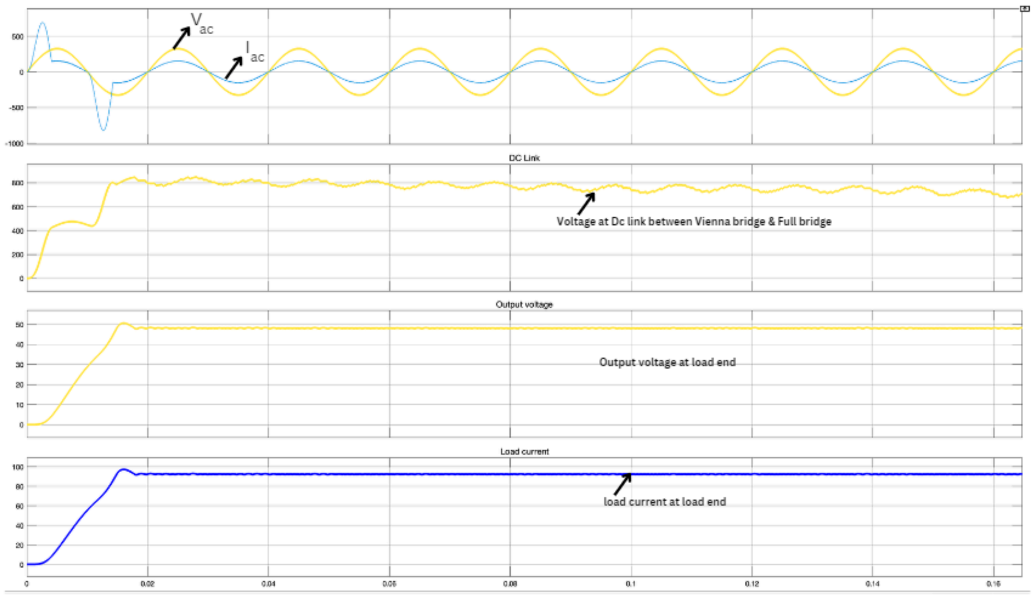


Fig 1.11 Results for Vienna And FULL-Bridge connected in cascade.

1.9 Electrolyser

- Electrolysers are devices used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2) through a process called electrolysis. This process uses electrical energy to breakdown water molecules into their components.
- Electrolysers are typically used to produce hydrogen gas which can be stored and used as clean fuel or chemical feedstock for various chemical processes.

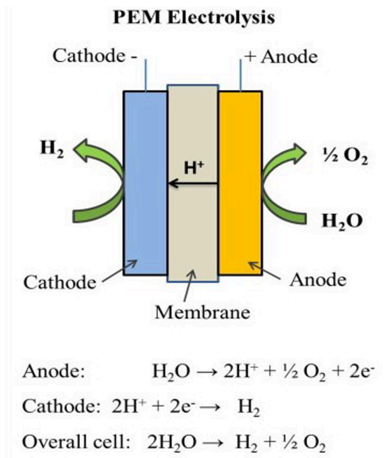


Fig 1.12
PEM Electrolyser

1.10 Constant Power Load

A constant power load (CPL) refers to type of electrical load that maintains a consistent power consumption regardless of variation in supply voltage. This means that as the voltage goes up or down, the current drawn by the load adjusts accordingly to ensure that the power(which is the product of voltage and current) remains constant. Constant power loads are critical in many applications because they ensure stable operation of electrical systems even when supply conditions fluctuate.

The CPL can be mathematically represented by:

$$P(t) = V(t).i(t)$$

$$\frac{\partial P}{\partial t} = V(t).\frac{\partial i(t)}{\partial t} + i(t).\frac{\partial V(t)}{\partial t}$$

$$V(t).\frac{\partial i(t)}{\partial t} + i(t).\frac{\partial V(t)}{\partial t} = 0$$

$$\frac{\partial V(t)}{\partial i(t)} = -\frac{V(t)}{i(t)}$$

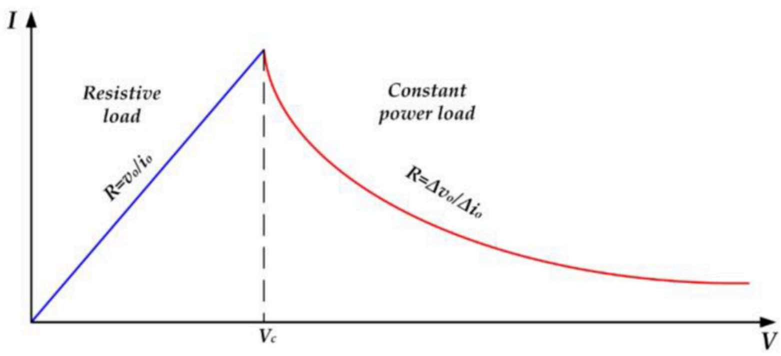


Fig 1.13. I-V characteristics for CPL

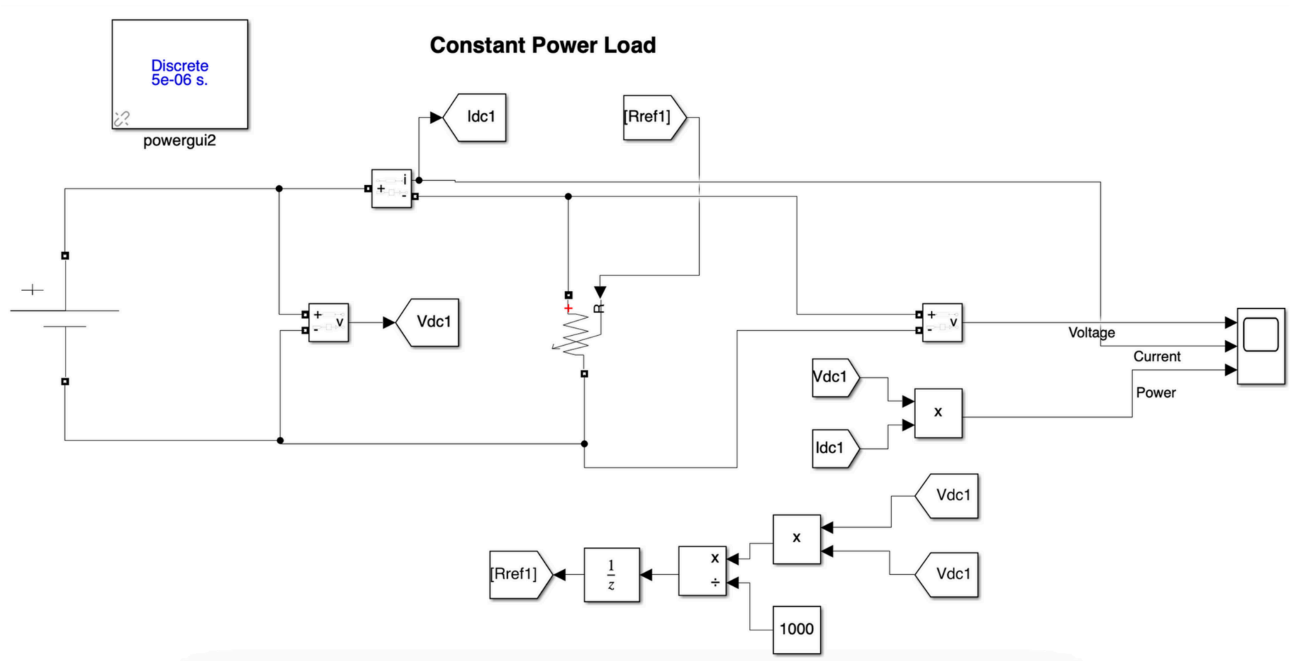


Fig 1.14 MATLAB MODEL FOR Constant Power Load

Chapter 2 :
InterLeaved Buck Converter

2.1 Introduction to Interleaved Buck Converter

An interleaved buck converter is a type of DC-DC buck converter that uses multiple converter circuits operating in parallel, with their operation phase-shifted (interleaved) to improve performance

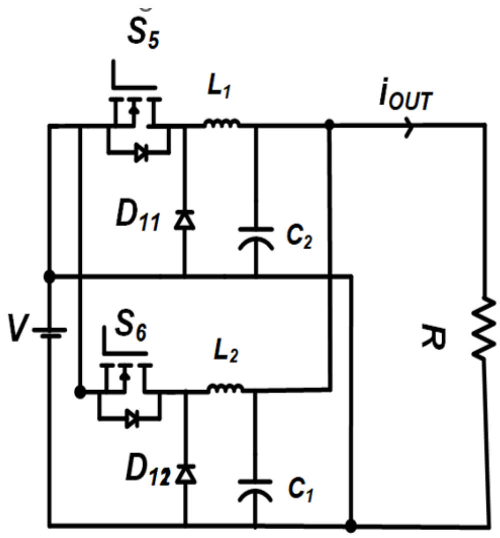


Fig 2.1 Interleaved Buck Converter

Advantages of Using InterLeaved Buck Converter:

- **Reduced Current Ripple**
- **Higher Efficiency**
- **Improved Thermal Management**
- **Higher Power Density**

2.2 Simulation of InterLeaved Buck Converter

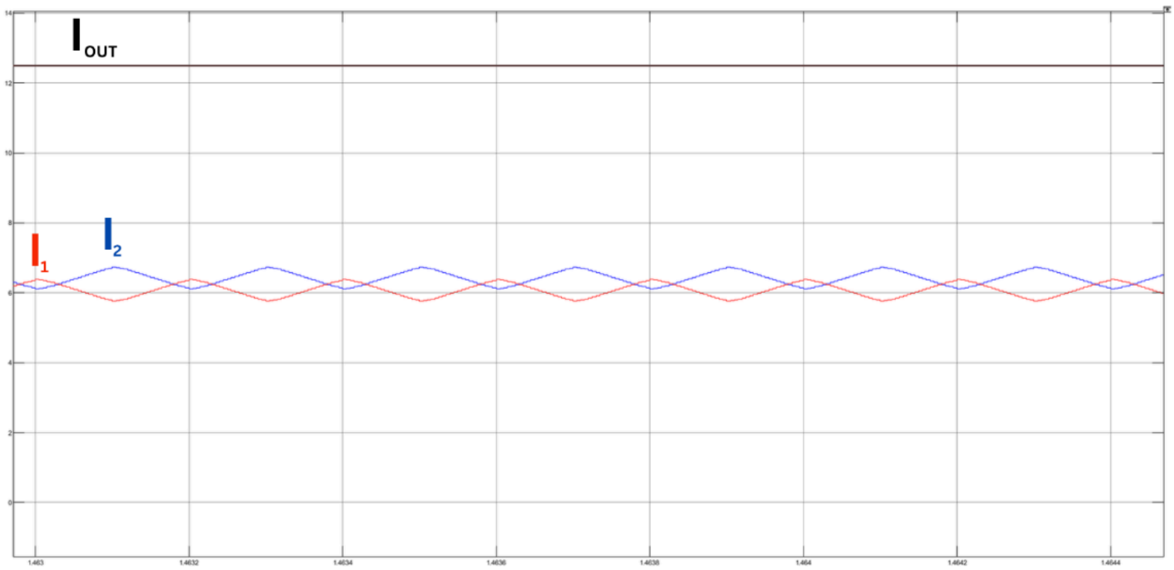


Fig 2.2 Output Current Waveforms of Interleaved Buck Converter

2.3 DSP Code for Duty Generation

2.3.1 What is DSP?

Digital signal processor is defined as- A digital signal processor is a special type of microprocessor which is fabricated on metal oxide semiconductor Integrated circuits.

2.3.2 Why DSP?

DSPs are extensively used in different applications like digital image processing, telecommunications, audio signal processing, speech recognition systems, sonar, radar, etc, and also used in consumer electronics like mobile phones, HDTV (high-definition television) products, disk drives, etc

In this project we have used DSP to give high frequency pulse signals to the gate driver circuits.

1. Include Headers

```
#include "F28x_project.h"

#include "math.h"
```

- **`F28x_project.h`**: Includes device-specific definitions and library functions for configuring peripherals like GPIO and ePWM.
- **`math.h`**: Included to support mathematical operations (though unused in this code).

2. Main Function

The `main()` function is the entry point of the program.

(a) Disable Global Interrupts

```
DINT;
```

- Disables all CPU interrupts to ensure the configuration happens without interference.

(b) Initialize System Control

```
InitSysCtrl();
```

- Configures the system clock and initializes essential peripherals.

(c) Configure GPIO

```
Gpio();
```

- Calls the `Gpio()` function to set up the GPIO pins used by the ePWM module.

(d) ePWM1 Configuration

i. Time-Base Clock Division

```
EPwm1Regs.TBCTL.bit.CLKDIV = 0;
EPwm1Regs.TBCTL.bit.HSPCLKDIV = 2;
```

- Configures the time-base clock:
  - `CLKDIV = 0`: No division for the main clock.
  - `HSPCLKDIV = 2`: Divides the high-speed clock by 4 (2 + 1).

ii. Counter Mode

```
EPwm1Regs.TBCTL.bit.CTRMODE = 2;
```

- Sets the ePWM counter to **up-down count mode** (counter goes up, then down in each cycle).

iii. PWM Actions

```
EPwm1Regs.AQCTLA.all = 0x0060;
EPwm1Regs.AQCTLB.all = 0x0090;
```

- Configures the **Action Qualifier** module to control the PWM output:
  - `AQCTLA.all = 0x0060`: On ePWM1A, set the output HIGH when the counter matches CMPA on up-count, and LOW on down-count.
  - `AQCTLB.all = 0x0090`: Similar for ePWM1B.

iv. Set PWM Period

```
EPwm1Regs.TBPRD = 250;
```

- Sets the period of the PWM signal:
  - `TBPRD = 250`: The counter runs from 0 to 250 (up) and 250 to 0 (down), resulting in a total period of 500 counts.

v. Set Duty Cycle

```
EPwm1Regs.CMPA.bit.CMPA = (EPwm1Regs.TBPRD * (1 - 0.5));
```

- Configures the duty cycle:
  - `(1 - 0.5)` corresponds to a 50% duty cycle, where the output remains HIGH for half the period.

vi. Dead-Band Configuration

```
EPwm1Regs.DBRED.bit.DBRED = 13;
EPwm1Regs.DBCTL.bit.IN_MODE = 0;
```

```
EPwm1Regs.DBCTL.bit.POLSEL = 2;
EPwm1Regs.DBCTL.bit.OUT_MODE = 3;
```

- Sets up dead-band delays to avoid simultaneous switching of complementary outputs:
  - `DBRED = 13`: Specifies a delay of 13 time-base clock cycles on the rising edge.
  - `IN_MODE = 0`: Uses the source signals directly without inversion.
  - `POLSEL = 2`: Configures ePWM1A and ePWM1B as complementary outputs.
  - `OUT_MODE = 3`: Enables dead-band on both rising and falling edges.

3. GPIO Configuration

The `Gpio()` function configures GPIO0 and GPIO1 pins for PWM functionality.

(a) Enable Protected Registers

```
EALLOW;
```

- Allows access to protected GPIO registers.

(b) Configure GPIO Pins

```
GpioCtrlRegs.GPAPUD.bit.GPIO0 = 1;
GpioCtrlRegs.GPAMUX1.bit.GPIO0 = 1;
GpioCtrlRegs.GPAPUD.bit.GPIO1 = 1;
GpioCtrlRegs.GPAMUX1.bit.GPIO1 = 1;
```

- **Pull-Up Disable**:
  - `GPAPUD.bit.GPIO0 = 1`: Disables the pull-up resistor for GPIO0.
  - `GPAPUD.bit.GPIO1 = 1`: Disables the pull-up resistor for GPIO1.
- **Set Pin Multiplexing**:
  - `GPAMUX1.bit.GPIO0 = 1`: Assigns GPIO0 to ePWM1A.
  - `GPAMUX1.bit.GPIO1 = 1`: Assigns GPIO1 to ePWM1B.

(c) Disable Protected Registers

```
EDIS;
```

- Protects GPIO registers again.

This code configures:

1. **GPIO0** and **GPIO1** as ePWM output pins.
2. **ePWM1A** and **ePWM1B** with:
    - 50% duty cycle.
    - Up-down counting mode.
    - Dead-band delay for safe switching of complementary outputs.
3. The code can be further extended for other ePWM channels or additional functionalities.

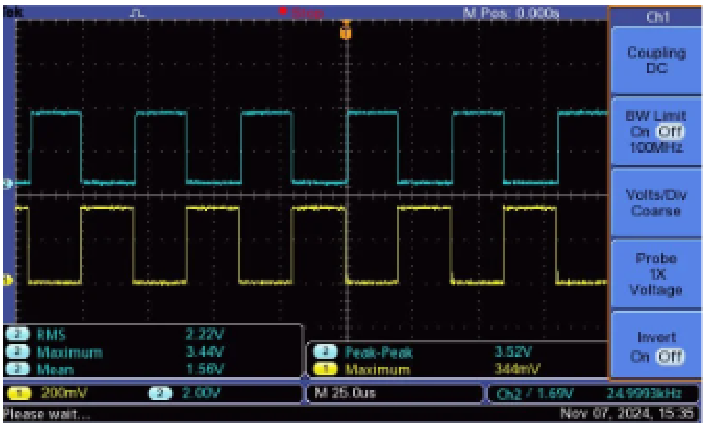


Fig 2.3 Output of DSP

2.4 Gate Driver Circuit For Interleaved Buck Converter

The circuit used to convert DSP low power output pulses to 10V DC pulses.

- **6N137 Optocouplers:** Provide electrical isolation between the control signal and high power circuitry.
- **DIP-8 ICs(Driver ICs):** Amplify optocoupler outputs.
- **Diodes:** Protect against reverse polarity and handle freewheeling for inductive loads.

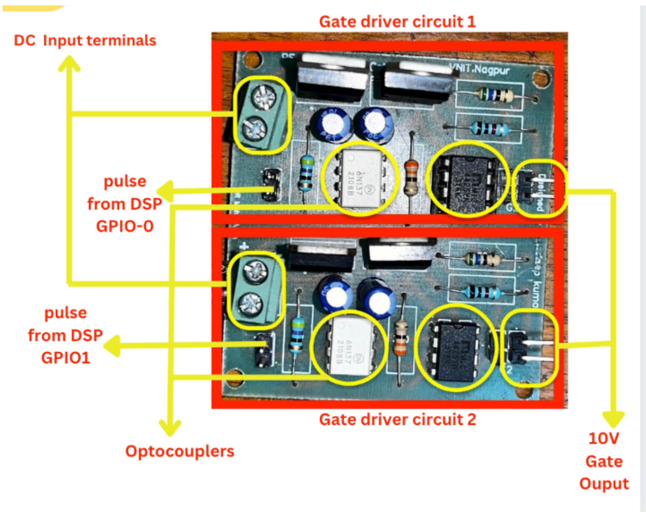


Fig 2.4 Gate Driver Circuit

Input to Gate Driver Circuit=10V
Output Pulse Amplitude=10V
Duty Ratio= 50%

2.5 DC DC Buck Converter Hardware

The buck converter, also referred to as a step-down converter, is a popular topology in power electronics that converts a higher input voltage to a lower output voltage. It is crucial in various applications, from portable devices to automotive systems, where specific components or subsystems require a lower voltage level to operate. The primary advantage of the buck converter is its simplicity, which enables efficient voltage conversion using a relatively small number of components.

The operating principle of the buck converter involves controlled energy transfer from the input to the output through switches, an inductor, and a capacitor. A high-side switch (usually a MOSFET) and a low-side switch (typically a diode) are employed in the buck converter to control the current flow through the inductor. By adjusting the duty cycle of the high-side switch, the average output voltage can be regulated proportionally to the input voltage.

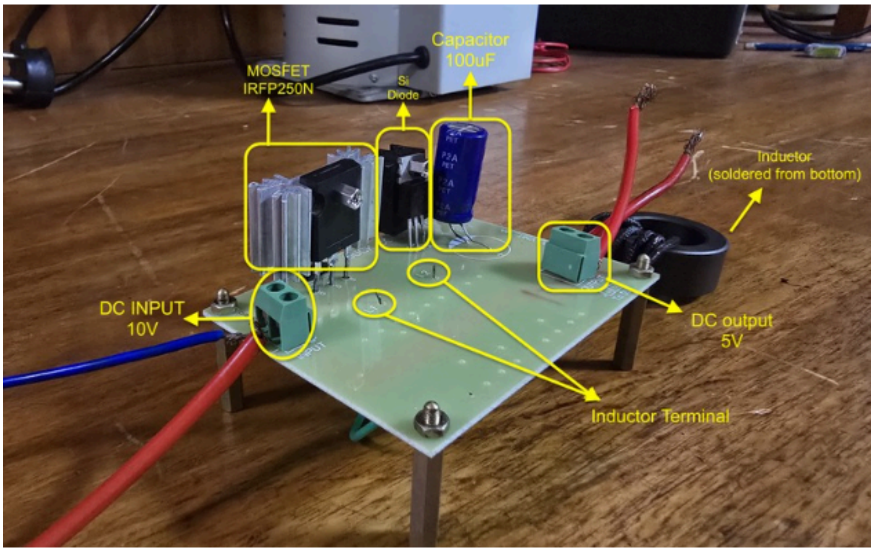


Fig 2.5 Buck Converter circuit (hardware)

When the high-side switch of a buck converter is switched on, it allows current to flow through the inductor, which stores energy in its magnetic field. This stored energy is then transferred to the output, charging the output capacitor and powering the load. When the high-side switch is turned off and the low-side switch is turned on, the inductor's magnetic field collapses, releasing the stored energy and maintaining the current flow to the load. The buck converter is designed to operate within a closed-loop control system, where a feedback mechanism continuously compares the output voltage to a reference voltage to ensure that the output voltage remains stable and regulated, regardless of changes in input voltage or load conditions.

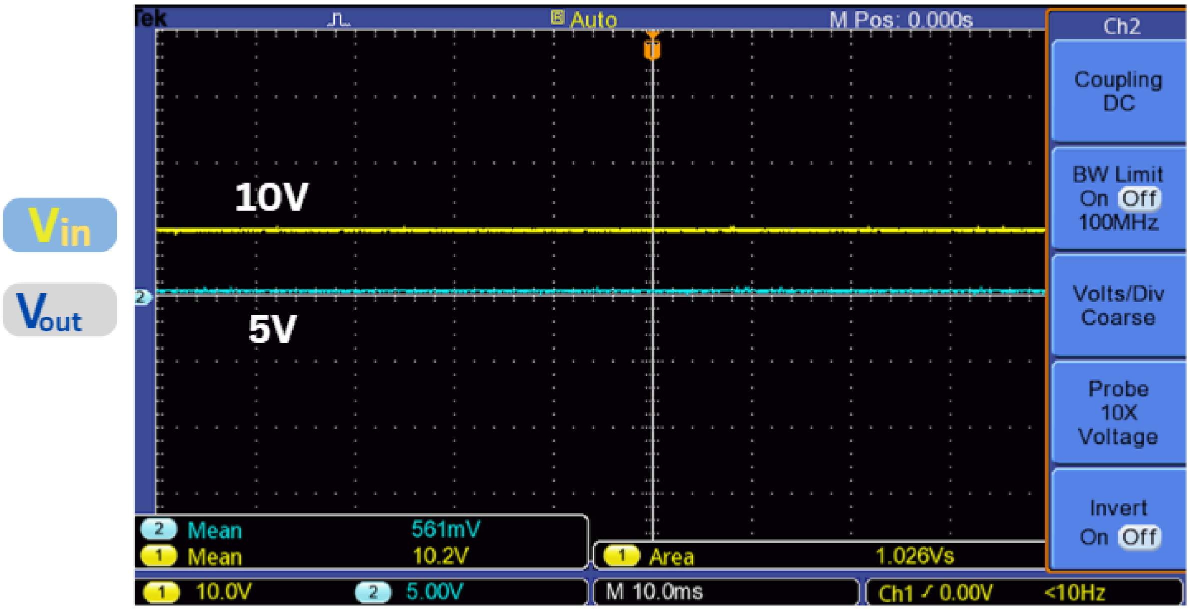


Fig 2.6 Output of the buck Converter obtained on DSO

CHAPTER 3:
PHOTOVOLTAIC MAXIMUM POWER POINT TRACKING ALGORITHMS

3.1. Introduction

With the growing demand for renewable energy sources, photovoltaic (PV) systems have emerged as one of the most widely adopted solutions for clean and sustainable power generation. However, the efficiency of PV systems depends largely on environmental factors like sunlight intensity and temperature. To ensure that these systems operate at their maximum potential, Maximum Power Point Tracking (MPPT) technology is used. MPPT is a technique that allows a PV system to continuously track the maximum power point under varying environmental conditions.

3.2. Objective

The objective of this chapter is to explore the concept of Maximum Power Point Tracking (MPPT) in Photovoltaic (PV) systems, analyze various MPPT techniques, and design and implement an AI MPPT algorithm for optimizing the performance of PV systems under normal as well as shaded conditions.

3.3. Overview of Photovoltaic Systems

A Photovoltaic (PV) system converts sunlight into electrical energy through the photovoltaic effect. The primary components of a PV system include:

- **Solar Panels**: These are made up of photovoltaic cells that convert sunlight into direct current (DC) electricity.
- **Inverter**: Converts the DC power generated by the panels into alternating current (AC) power for household or grid use.
- **Battery (Optional)**: Stores excess energy produced for use when sunlight is not available.

The power generated by the PV system depends on the **irradiance (sunlight exposure)** and **temperature**, which are constantly changing due to time of day and weather conditions. As such, the power output of the system is not constant, and it is essential to extract maximum power at all times.

3.4. What is Maximum Power Point Tracking (MPPT)?

MPPT is a technique used in solar power systems to adjust the operating point of the PV array so that it delivers the maximum possible power at any given moment. This is because the output of a solar panel varies with factors like sunlight intensity and temperature. The maximum power point (MPP) is the point on the voltage-current (V-I) curve where the product of voltage and current is maximized, i.e., the power is highest.

How MPPT Works:

- The power output of a solar panel depends on the voltage and current supplied by the panel.
- By adjusting the operating voltage of the panel, the MPPT controller ensures that the power is maximized.
- MPPT uses algorithms to continuously track the maximum power point as environmental conditions change.

The MPPT controller is usually integrated with the inverter and is responsible for adjusting the voltage from the solar array to achieve maximum efficiency.

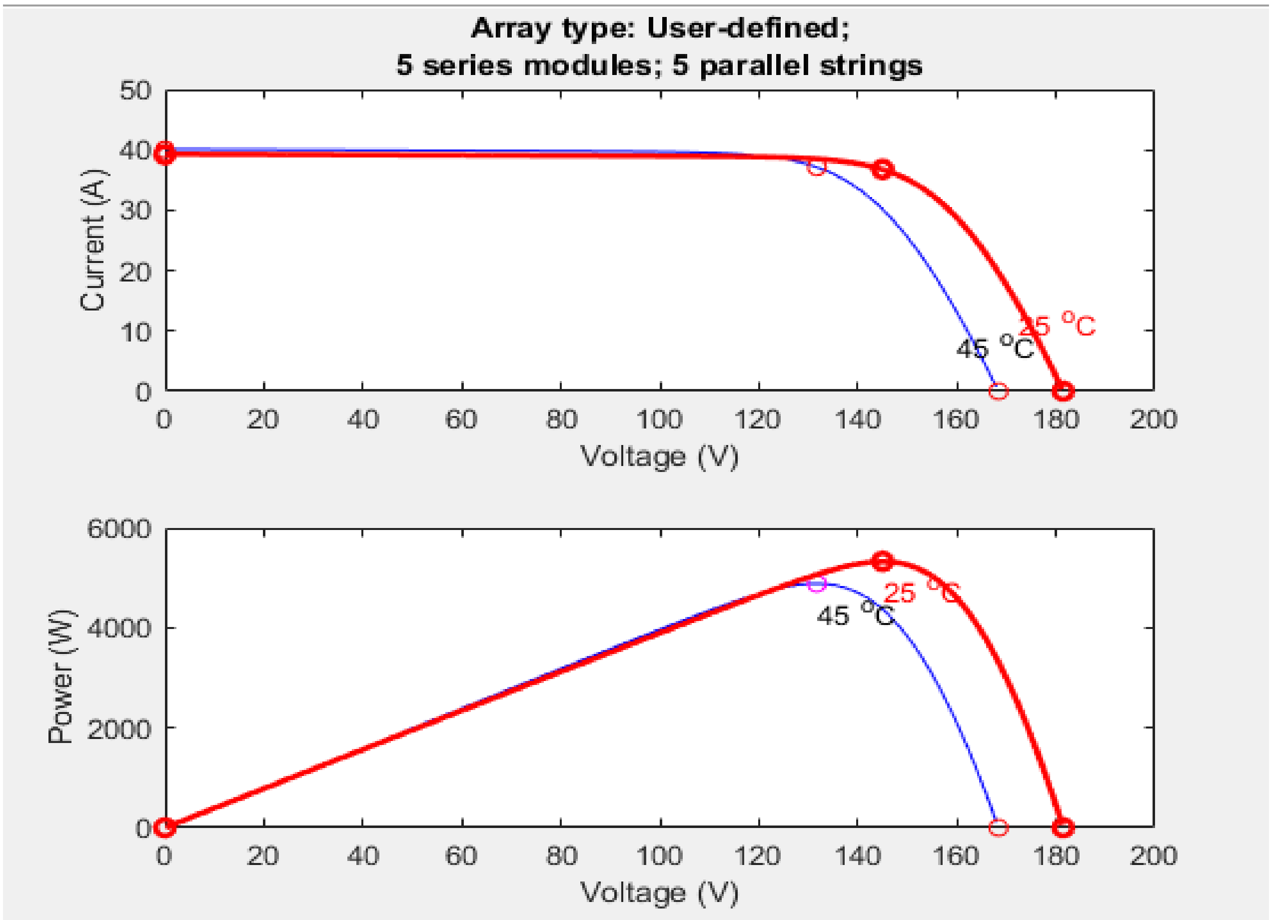


Fig.3.1. I-V AND P-V CHARACTERISTICS OF A PV MODULE

3.5. MPPT Algorithms

Several algorithms are used to perform MPPT in PV systems. Each algorithm has its advantages and trade-offs in terms of complexity, speed, and performance. Some of the most widely used MPPT algorithms include:

1. **Perturb and Observe (P&O)**:
    - The most commonly used MPPT algorithm.
    - The method perturbs (or adjusts) the voltage slightly and observes the effect on power. Based on whether power increases or decreases, the voltage is adjusted accordingly.
    - Simple to implement but can have oscillations around the maximum power point.

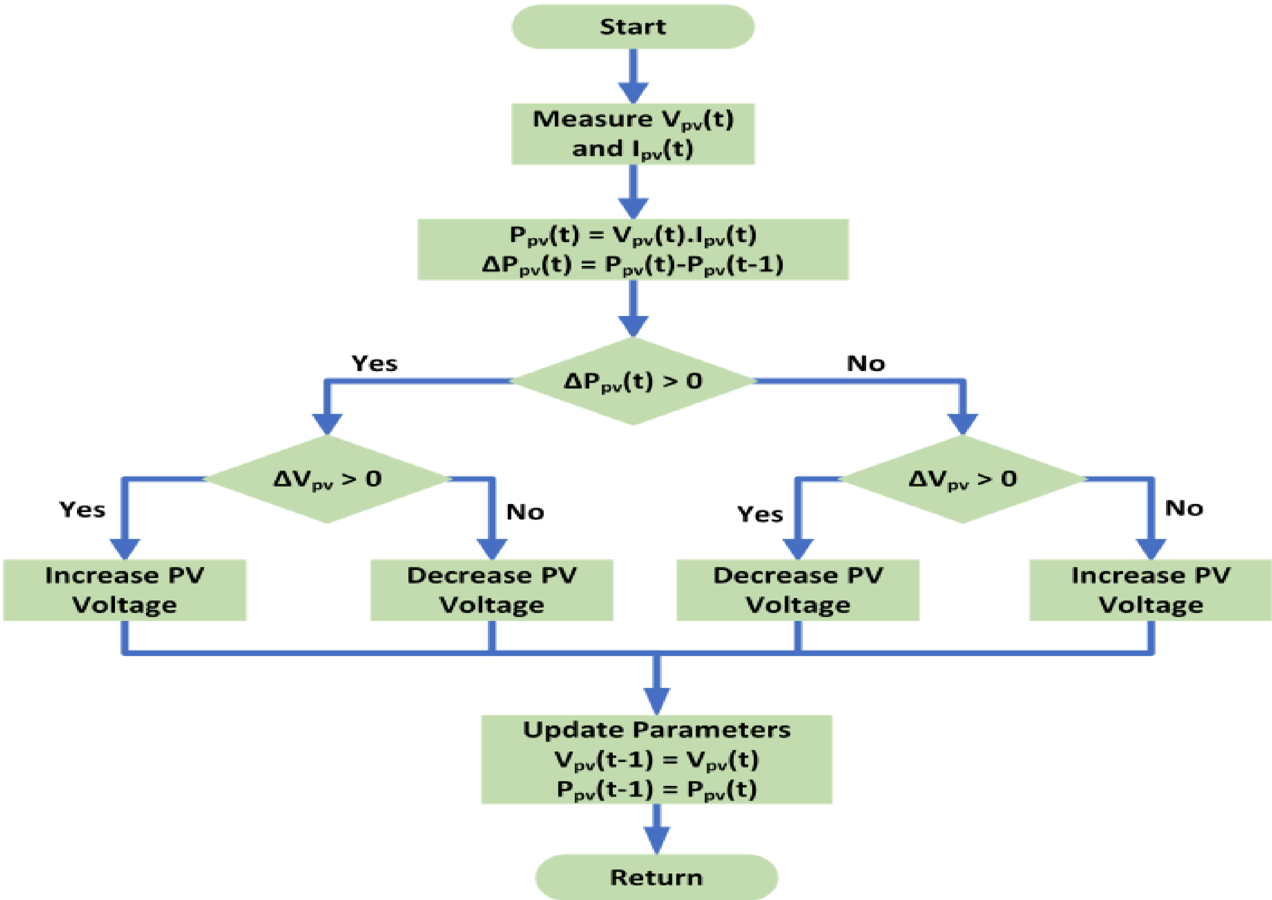


FIG.3.2. P&O ALGORITHM FLOWCHART

2. **Incremental Conductance (IncCond)**:
    - This method calculates the instantaneous conductance and compares it with the incremental conductance to determine the direction to adjust the voltage.
    - More precise than P&O, especially under rapidly changing irradiance conditions, but more computationally complex.

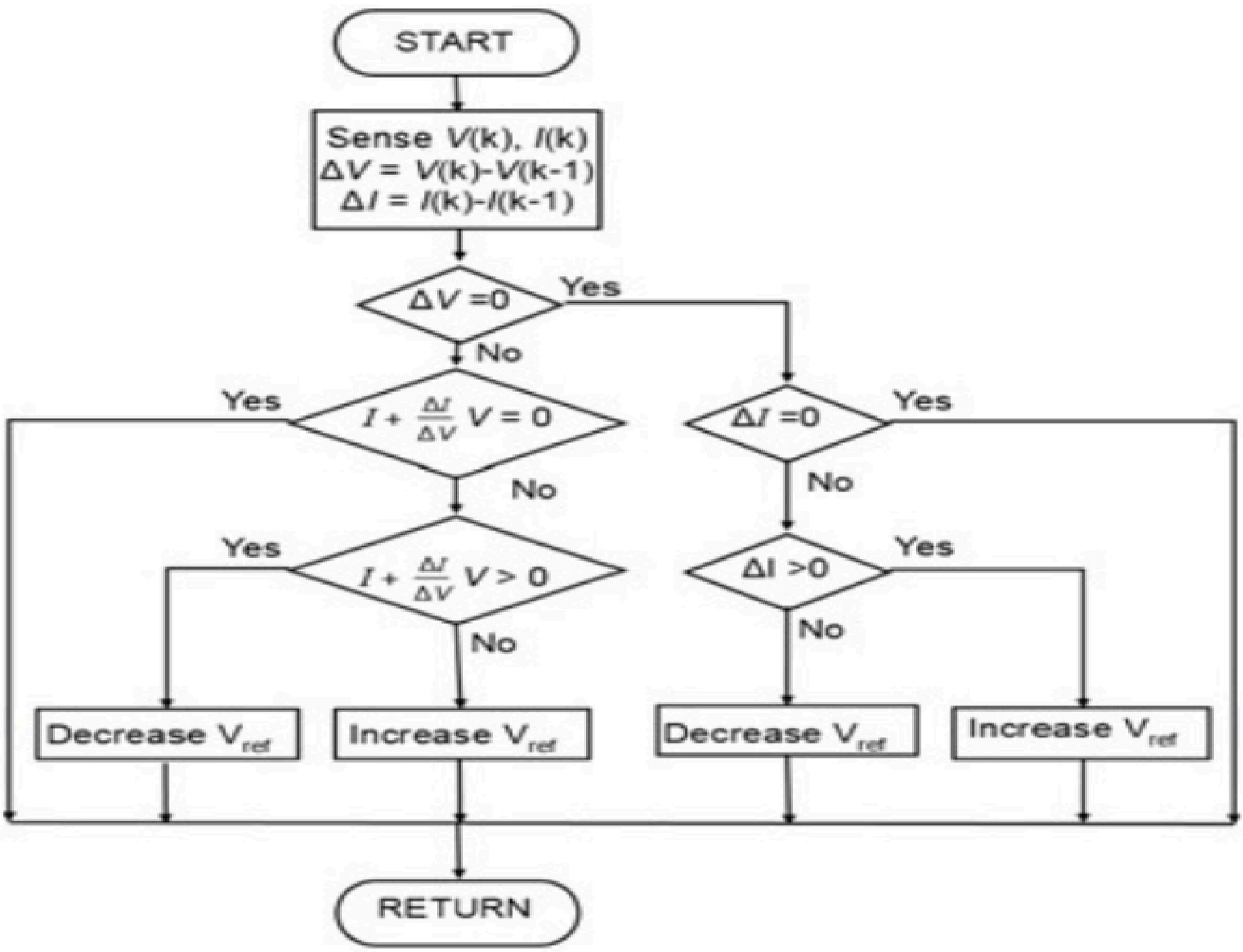


FIG 3.3.INCREASED CONDUCTANCE ALGORITHM FLOWCHART

3. **Constant Voltage (CV)**:
   - This method assumes the PV system operates at a fixed fraction of its open-circuit voltage (Voc) to track the maximum power point.
   - Simple and fast but less accurate and less effective in varying environmental conditions.

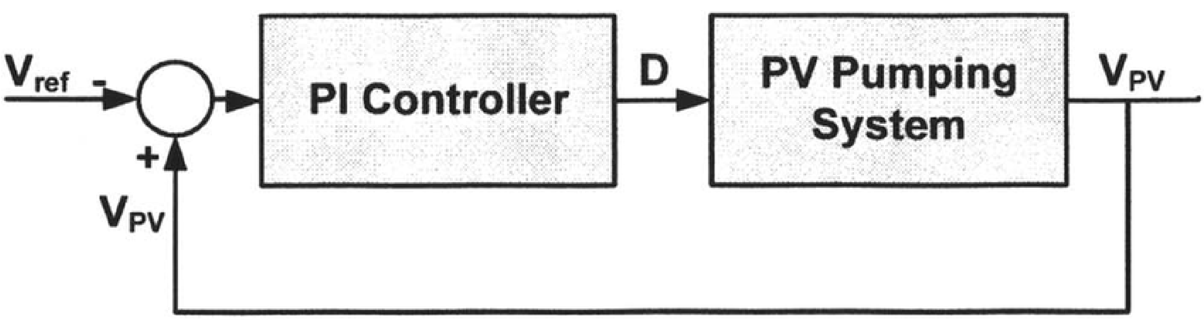


FIG 3.4 CONSTANT VOLTAGE ALGORITHM BLOCK DIAGRAM

4. **Fuzzy Logic Control**:
   - Uses fuzzy logic principles to determine the maximum power point by evaluating several inputs such as voltage, current, and power.
   - Provides better accuracy and performance in varying conditions but is more complex than P&O or IncCond.

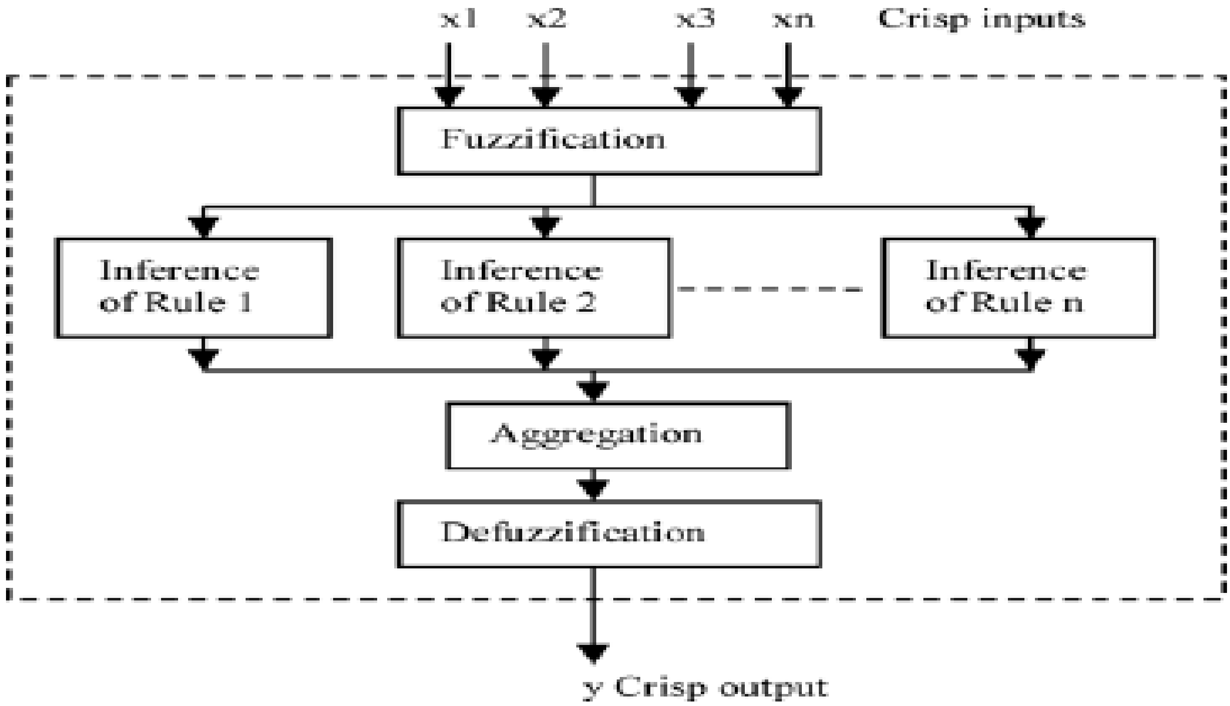


FIG 3.5. GENERAL FUZZY LOGIC ALGORITHM FLOWCHART

5. **Neural Networks and Artificial Intelligence (AI)**:
   - Advanced methods using machine learning techniques that optimize the MPPT process based on historical and real-time data.
   - Typically used in highly advanced PV systems but may require a high level of computational resources.

3.6. MPPT Techniques Comparison

The choice of MPPT algorithm depends on the specific needs and conditions of the PV system:

- **Perturb and Observe**: Simplicity and ease of implementation make it a popular choice for small-scale systems.
- **Incremental Conductance**: Better suited for large-scale systems where performance needs to be optimized under variable light conditions.
- **Constant Voltage**: Used for low-cost, non-critical applications where speed is prioritized over accuracy.
- **Fuzzy Logic and Neural Networks**: Best suited for applications that require high efficiency in highly dynamic environments.

3.7. Design and Implementation of MPPT

- **System Components**:
  - **PV Panel**: The energy source that provides varying voltage and current.
  - **MPPT Controller**: The algorithm implemented in hardware or software to track the maximum power point.
  - **DC-DC Converter**: To adjust the voltage to match the maximum power point and supply it to the load or grid.
  - **Inverter**: Converts DC power to AC power for use by appliances or grid.
- **Control Algorithm Implementation**:
  - A microcontroller or digital signal processor (DSP) is typically used to implement MPPT algorithms.
  - Sensors measure the voltage and current of the PV panel, and the controller adjusts the operating point.
  - The system adjusts the duty cycle of a DC-DC converter (like a buck or boost converter) to optimize the power extracted from the panel.

3.8. Advantages of MPPT

- **Increased Efficiency**: MPPT ensures that the PV system is always operating at its most efficient point, thus maximizing power output.
- **Better Utilization of Solar Energy**: Even with fluctuating sunlight conditions, MPPT algorithms ensure that the maximum possible energy is harvested from the solar panels.
- **Improved System Performance**: MPPT allows PV systems to operate optimally under diverse environmental conditions, ensuring better overall system performance and longer life.

3.9. Challenges in MPPT

- **Complexity in Algorithms**: Advanced MPPT techniques, like incremental conductance or fuzzy logic, can be more complex to implement and require greater computational resources.
- **Oscillations Around MPP**: Simple algorithms like P&O can cause small oscillations around the maximum power point, leading to slightly reduced efficiency.
- **Temperature and Irradiance Changes**: Rapid changes in sunlight or temperature can make it difficult for the system to track the MPP accurately and quickly.

CHAPTER 4:
ARTIFICIAL INTELLIGENCE IN MPPT SYSTEMS

4.1 Background

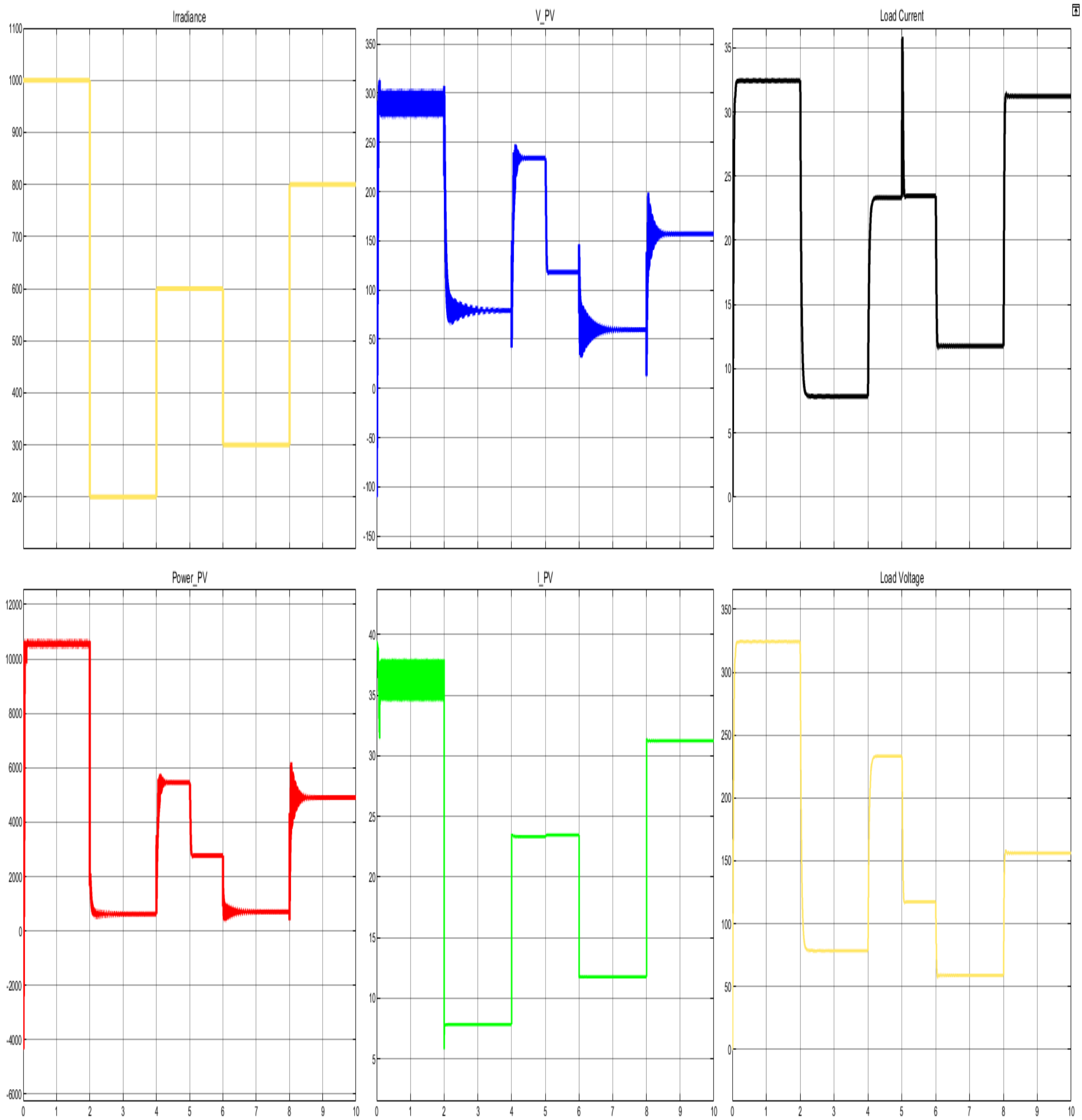
4.1.1. MPPT Algorithms

MPPT algorithms are employed to find the maximum power point (MPP) of a PV system, which varies with environmental conditions. Some of the conventional MPPT methods include:

- **Perturb & Observe (P&O):** Adjusts the operating point of the system periodically to find the MPP by perturbing the voltage or current and observing the change in power output.
- **Incremental Conductance (INC):** This method uses the derivative of power with respect to voltage and adjusts the operating point to find the MPP by evaluating the rate of change in voltage and current.

4.1.2. Limitations of Traditional MPPT Methods

- **Slow Response Time**: Traditional algorithms such as P&O and INC are not always capable of responding quickly enough to rapid changes in environmental conditions. For instance, when clouds pass over or temperature shifts abruptly, traditional methods may struggle to track the MPP accurately.
- **Oscillations**: In steady-state conditions, methods like P&O often cause oscillations around the MPP, leading to slight energy losses even when the system is in equilibrium.
- **Non-Ideal Conditions**: Under non-ideal conditions, such as partial shading or temperature gradients across the PV panel, conventional MPPT methods may fail to find the global maximum power point, leading to suboptimal power extraction.
- **Complexity in Dynamic Environments**: The PV system performance is highly sensitive to dynamic environmental conditions such as wind, clouds, and varying irradiance, which traditional MPPT algorithms are not always designed to handle efficiently.



HIGH DISTORTION UNDER RAPIDLY CHANGING CONDITIONS IN P&O ALGORITHM

4.1.3. The Role of Artificial Intelligence

AI algorithms offer significant advantages over conventional methods by enabling systems to learn from data and adapt to changing conditions in real-time. AI-based MPPT systems can provide more accurate tracking by modeling the complex, non-linear relationship between environmental conditions and power output, leading to more efficient energy harvesting.

4.2. AI Techniques for MPPT

Several AI techniques have been explored for use in MPPT systems:

4.2.1. Neural Networks (NN)

Neural networks can be trained to model the relationship between input parameters (solar irradiance, temperature, etc.) and the maximum power point (MPP). By learning from historical data, a neural network can predict the optimal operating point more accurately than traditional algorithms.

- **Feedforward Neural Networks (FNN)**: Used for predicting the MPP based on inputs such as temperature, irradiance, and panel voltage.
- **Recurrent Neural Networks (RNN)**: Useful for handling time-series data, such as rapidly changing irradiance conditions, to predict and track the MPP more dynamically.

4.2.2. Fuzzy Logic Systems

Fuzzy logic can be employed to model the uncertainties in solar power generation. By processing imprecise environmental data, fuzzy logic controllers can adjust the operating point to approach the MPP.

4.3. Implementation of AI in MPPT

4.3.1. System Architecture

The general architecture of an AI-based MPPT system includes the following components:

1. **Sensors**: To measure environmental conditions like solar irradiance, temperature, and voltage.
2. **AI-Based Controller**: A machine learning model, such as an NN, RL agent, or fuzzy logic system, processes the data and determines the optimal operating point.
3. **Power Converter**: Converts the power from the PV panel to the desired form (DC-AC or DC-DC).
4. **Monitoring and Feedback**: Continuous monitoring of the power output, with feedback loops to adjust the model based on real-time data.

4.3.2. Training the AI Model

To develop an effective AI-based MPPT system, a training phase is required:

1. **Data Collection**: Historical data on irradiance, temperature, and power output is collected under various conditions.
2. **Model Selection**: Based on the problem complexity and data, an appropriate AI model (neural network, RL, etc.) is chosen.
3. **Training**: The AI model is trained using supervised learning (for NN) or reinforcement learning (for RL). The model is trained to predict the maximum power point from the input environmental parameters.
4. **Validation**: The trained model is validated with real-time data to test its generalization ability.

4.3.3 Real-Time Operation

In real-time, the AI model receives sensor data, computes the optimal operating point, and adjusts the PV system's operating parameters to maximize power extraction.

4.4.Advantages of AI-Based MPPT

1. **Higher Accuracy**: AI models can adapt to various environmental conditions, leading to better tracking performance.
2. **Real-Time Adaptation**: AI can continuously adjust to rapidly changing weather conditions (e.g., clouds passing over).
3. **Reduced Energy Losses**: AI can minimize tracking errors and prevent energy losses caused by environmental variations.
4. **Smart Decision Making**: AI models can make decisions based on past data and learned behavior, reducing reliance on heuristic-based algorithms.
5. **Scalability**: Once trained, AI models can be easily scaled to larger or more complex systems.

```
data = xlsread('synthetic_pv_data.xlsx');
inputs = data(:, 1:2:3:4);
outputs = data(:, 5);

% Split dataset into training, testing, and validation sets
[trainInd, valInd, testInd] = dividerand(size(data, 1), 0.8, 0.1, 0.1);
trainInputs = inputs(trainInd, :)';
trainOutputs = outputs(trainInd)';
valInputs = inputs(valInd, :)';
valOutputs = outputs(valInd)';
testInputs = inputs(testInd, :)';
testOutputs = outputs(testInd)';


hiddenLayerSize = [10 20 30 50 30 10]; % 6 hidden layers with 10 neurons each
net = feedforwardnet(hiddenLayerSize);

% Set activation functions
net.layers{1}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{2}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{3}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{4}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{5}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{6}.transferFcn = 'logsig';   % Sigmoid activation for hidden layers
net.layers{7}.transferFcn = 'purelin';  % Linear activation for output layer

% Set training parameters
net.divideFcn = 'divideind';  % Divide dataset using indices
net.divideParam.trainInd = trainInd;
net.divideParam.valInd = valInd;
net.divideParam.testInd = testInd;
net.trainParam.lr = 0.01;       % Learning rate

% Train the neural network
net = train(net, trainInputs, trainOutputs);

% Test the trained network
predictedOutputs = sim(net, testInputs);

% Calculate performance metrics (you can use different metrics based on your needs)
mse = mean((predictedOutputs - testOutputs').^2);
mae = mean(abs(predictedOutputs - testOutputs'));
disp(mse)
disp(mae)
disp(['Mean Squared Error: ', num2str(mse)]);
disp(['Mean Absolute Error: ', num2str(mae)]);
gensim(net)
view(net)
```

FIG 4.1.ALGORITHM FOR AI BASED MPPT

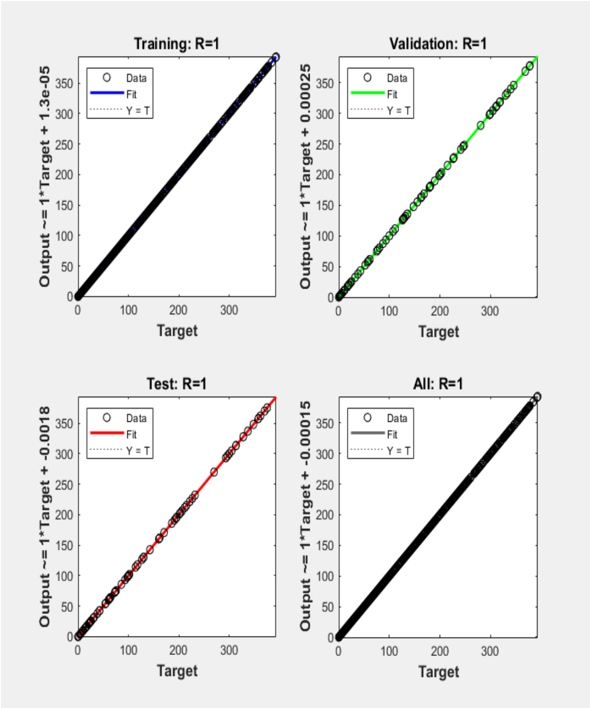


FIG 4.2.REGRESSION PLOT

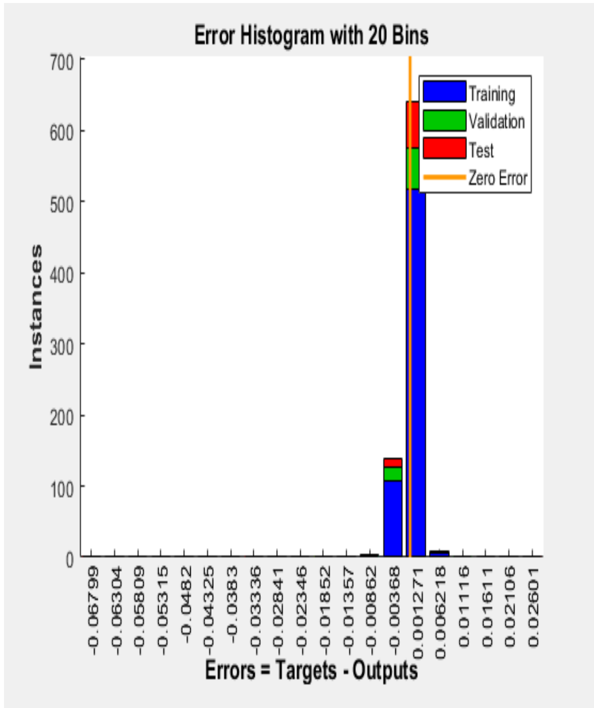


FIG 4.3. ERROR HISTOGRAM

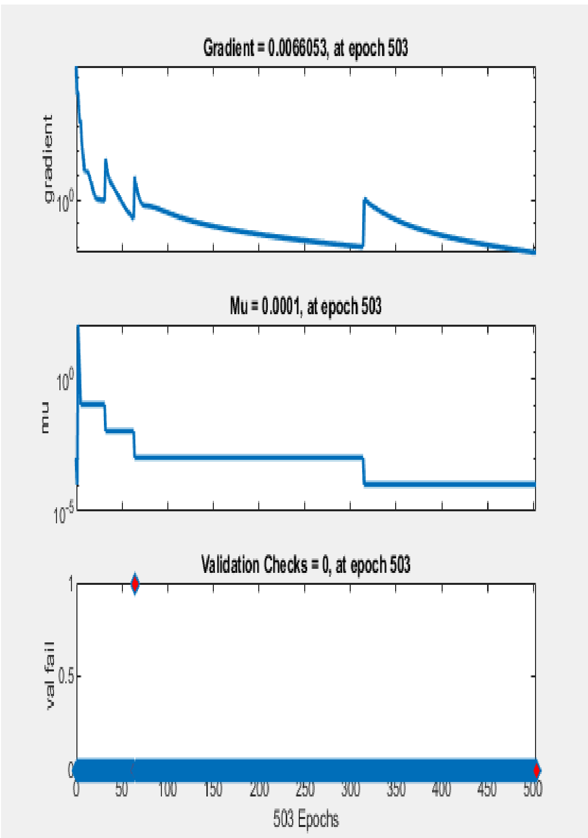


FIG 4.4.TRAINING PARAMETERS

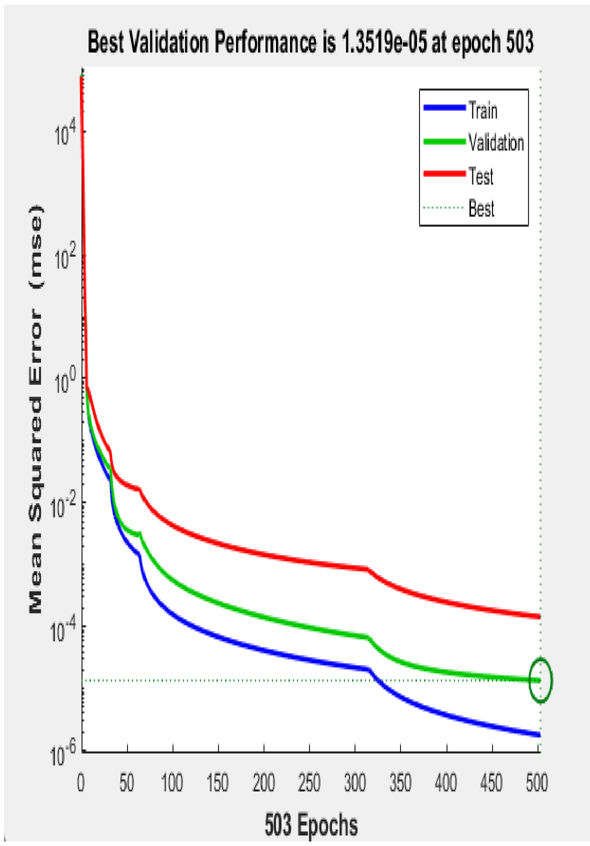


FIG 4.5. VALIDATION PLOT

4.5. Challenges and Limitations

1. **Data Requirement**: AI models require large datasets for training, which may not always be readily available.
2. **Complexity**: Implementing AI algorithms may require additional computational resources, making the system more complex.
3. **Training Time**: The training phase for AI models can be time-consuming and resource-intensive.
4. **Overfitting**: Overfitting may occur if the model is trained on limited or non-representative data, reducing its generalization ability.
5. **Hardware Costs**: Advanced AI algorithms may necessitate more sophisticated hardware, increasing the initial setup cost.

5. Future Work

- Parallel connection of Buck converters for loaded/unloaded condition
- Implementation of hardware for Full Bridge converter along with other components.
- Implementation of hardware for Vienna Rectifier .
- Implementation of ANN for shaded photovoltaic MPPT systems.

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- **A New MPPT-based ANN for Photovoltaic System under Partial Shading Conditions**

Loubna Bouselham, Mohammed Hajji, Bekkay Hajji, Hicham Bouali

- **Modelling and control of VIENNA rectifier a single phase approach**

Thandapani Thangavelu1 ✉, Paramasivam Shanmugam2, Karpagam Raj3

- **Single-Phase Single-Switch Vienna Rectifier as Electric Vehicle PFC Battery Charger**

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