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Design And Simulation Of Hybrid Energy Source In Micro Grid System Connected To Grid

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Abstract

This paper presents the design and simulation of a hybrid renewable energy system using MATLAB/Simulink, integrating solar PV and wind turbine sources within a grid-connected microgrid. The system includes MPPT-controlled DC-DC boost converters and a bidirectional inverter for efficient power management. Advanced control algorithms ensure voltage and frequency stability, power quality, and smooth transitions between energy sources and the grid. Dynamic simulations under varying weather and load conditions validate the system's efficiency, reliability, and adaptability, supporting the transition toward clean and decentralized energy solutions.

Index Terms: MATLAB/Simulink, MPPT-controlled, DC-DC boost converters, Bidirectional inverter

1. Introduction

Here is an introduction to the design and simulation of hybrid energy sources in microgrid systems connected to the grid. Overview of microgrid systems is a localized energy system that combines multiple energy source, energy storage and load to provide reliable and efficient energy supply microgrids can operate in both grid connected. Importance of Hybrid Energy Sources Hybrid energy sources which combine two or more energy sources i.e Solar energy and Wind energy. Which offer more benefits, Hybrid systems can provide a more consistent energy supply, reduce the impact of intermittent renewable energy source. Increased efficiency hybrid systems can optimize energy production and reduce energy losses. Hybrid systems can reduce reliance on fossil fuels, lowering greenhouse gas emissions. Components of a hybrid energy microgrid system is Renewable energy sources like Solar and Wind energy. Energy conversion systems Inverters, converters or other power conversion technologies. Increase the voltage level boost converter is connected. MPPT etc these are the components are used.

Simulation Tools and Techniques MATLAB/Simulink is a popular platform for modelling and simulating complex systems. Solar energy is most natural and abundant renewable energy source to need the rapidly increasing energy requirements. A microgrid system is group of energy sources and loads which normally work in connection with utility grid or in standalone fashion. The hybrid system are becoming more popular seems it is cost effectively solving the problems with power supply availability of places located remotely and also stability to the power system. there are many way to integrate a microgrid system using microgrid converters the converter use in the purpose system can be implemented by using simple control algorithm for the power flow management.

2. Methodology:

This section outlines the methodologies and innovative strategies employed in this study, with a focus on developing an energy management system tailored for hybrid microgrids. A unique approach is presented for the modeling, control, and simulation of the system, specifically designed to support autonomous operation. The research is structured around several key stages that guide the development process.

2.1. Modelling the Solar and Wind Sources

First, we created separate models for the solar photovoltaic (PV) array and the wind turbine System For the solar part, we used a standard PV module and included the effects of irradiance and temperature. I also added an MPPT (Maximum Power Point Tracking) algorithm, to make sure the system extracts the maximum power from the solar panels. For the wind side, we created a model of a wind turbine linked to a Permanent Magnet Synchronous Generator (PMSG). The generator's output is AC, so we used a three-phase rectifier to convert it into DC.

2.2. DC-DC Conversion

Both the PV and wind systems were connected to individual boost converters. These converters help regulate the output voltage and maintain a steady DC level. The converters were also controlled in such a way that they would keep the output close to a set voltage, even if the input from the sun or wind changed.

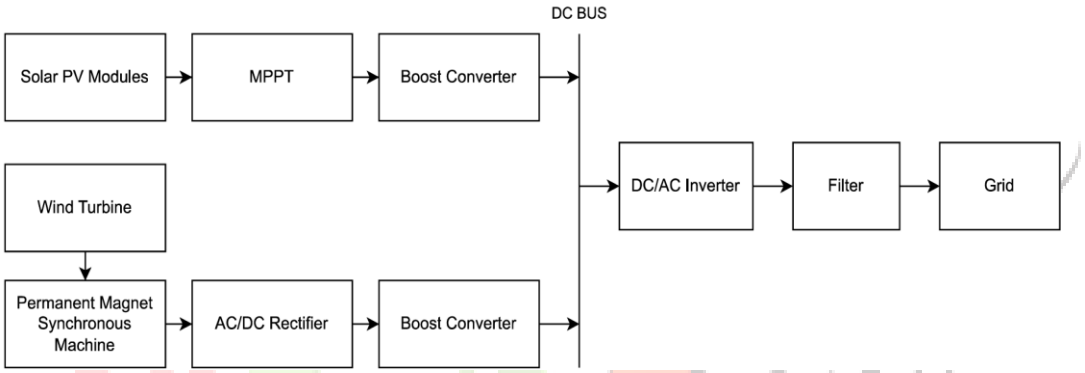

Fig.2(a)Block Diagram

2.3. Common DC-Link

The DC outputs from both the boost converters were then connected to a common DC bus. This DC-link acts as an energy pool where the total power from both sources is combined. I made sure the voltage of the DC-link stayed stable by fine-tuning the converter controls.

2.4. Inverter and Grid Connection

From the DC-link, we used a three-phase inverter to convert the DC power into AC so it could be sent to the grid. I implemented a Phase Locked Loop (PLL) to ensure the inverter output was in sync with the grid in terms of frequency and phase.

2.5. Grid Interface

The output of the inverter was filtered using an LCL filter to smoothen the waveform and remove switching noise.

3. Matlab Simulation

A Matlab simulation of hybrid solar and wind energy is a computer model that combines solar power and wind power systems to generate electricity.

3.1 **Solar PV Module with DC-DC boost converter**

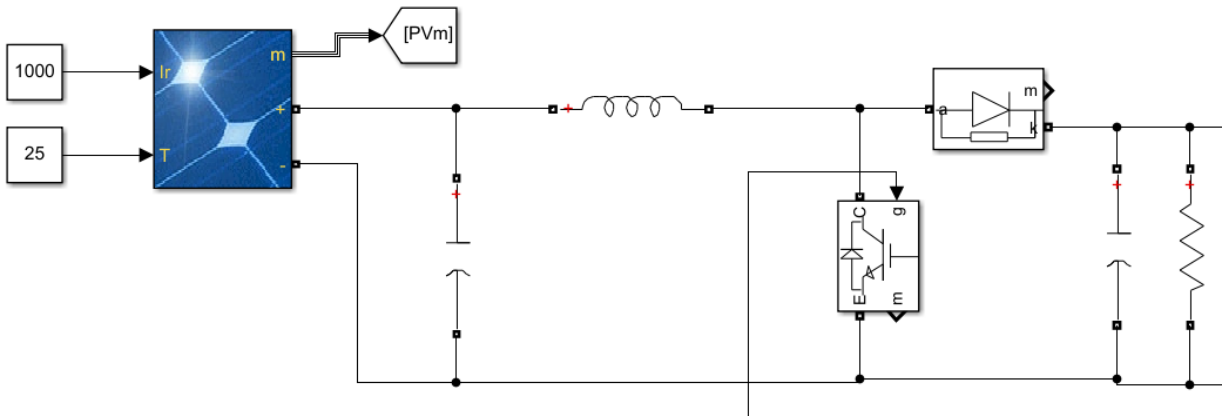

Fig 3.1.1: Solar PV Module with DC-DC boost converter

1. Photovoltaic (PV) Panel

- **Inputs:**
  - **Irradiance (Ir)** = 1000 W/m²
  - **Temperature (T)** = 25°C
- **Output:** Voltage and current from the PV module.
- **Model Block:** Simulates the behaviour of a solar panel under the given irradiance and temperature conditions.

2. Capacitor

- Purpose: Acts as a filter capacitor to smooth the voltage output from the PV panel.
- Connected directly to the PV output to reduce ripple and provide a more stable DC output.

3. Boost Converter (DC-DC Converter)

- **Inductor and Capacitor:** Classic boost converter components to step up the PV voltage.
- **IGBT/Power Switch (with gate control):** Controlled switch that allows energy storage in the inductor and releases it to step up the voltage.
- **Diode (in switch block):** Ensures unidirectional current flow.
- **Purpose:** Matches the load voltage requirement by increasing the PV output voltage.

3.2MPPT Control (Maximum Power Point Tracking)

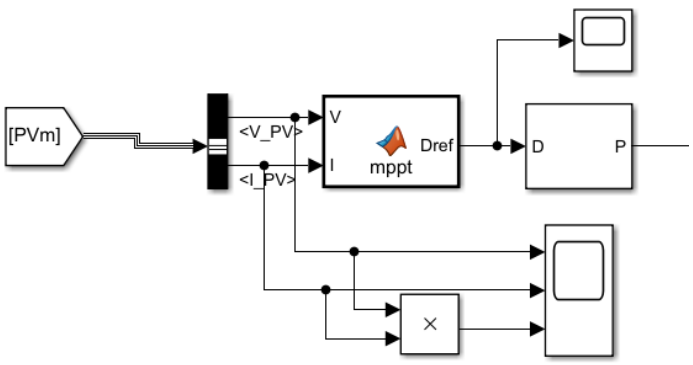

Fig 3.2.1: MPPT Control (Maximum Power Point Tracking)

- **Controller (connected to gate of IGBT):** Implements MPPT algorithm (typically Perturb and Observe or Incremental Conductance).
- **Goal:** Extract maximum power from the PV array by adjusting the duty cycle of the boost converter.

3.3 Wind Turbine with Permanent Magnet Synchronous Generator

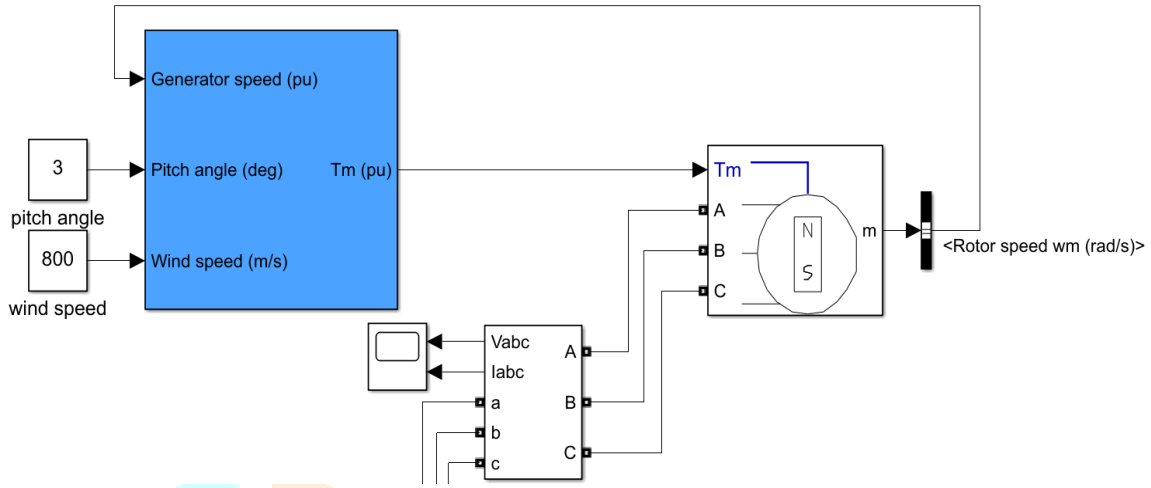

Fig 3.3.1: Wind Turbine with Permanent Magnet Synchronous Generator (PMSG)

The system illustrated above represents a wind energy conversion system (WECS) where mechanical energy from the wind is converted into electrical energy using a Permanent Magnet Synchronous Generator (PMSG), followed by AC to DC conversion for further processing or grid connection.

1. Wind Turbine and Pitch Control

- The wind turbine converts wind energy into mechanical torque.
- Wind speed (measured in m/s) is an input parameter, and the pitch angle (in degrees) is used to optimize power extraction by adjusting the angle of the blades.
- The torque generated (Tm) is a function of wind speed and pitch angle and is fed into the PMSG to rotate its rotor.

2. Permanent Magnet Synchronous Generator (PMSG)

- The PMSG operates as a generator in this configuration.
- It converts mechanical torque from the wind turbine into electrical three-phase AC power.
- The machine speed (rotor speed) is monitored for control purposes, ensuring efficient energy conversion under varying wind conditions.

3. Three-Phase Voltage and Current Measurement

- A 3-phase VI (Voltage and Current) measurement block is used to measure electrical parameters (voltages and currents) from the PMSG output.
- These measurements can be used for monitoring system performance, protection, and control purposes.

3.4Diode Bridge Rectifier

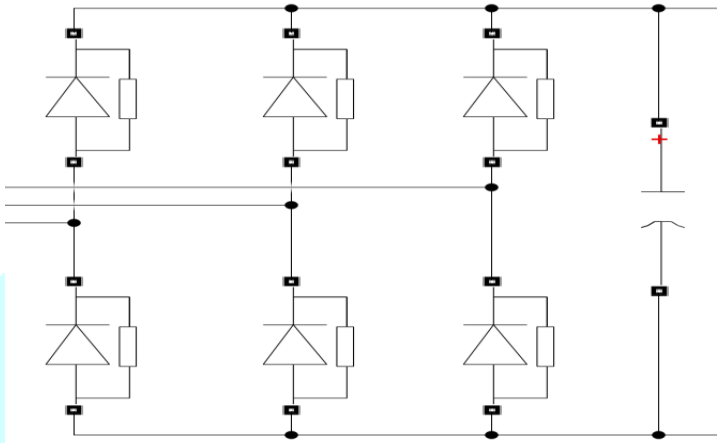

Fig 3.4.1: Diode Bridge Rectifier

The three-phase AC output from the PMSG is fed into a **diode bridge rectifier** to convert the 3-phase AC output from a Permanent Magnet Synchronous Generator (PMSG) into DC.

Here's how it works in your system:

1. **PMSG Output (AC)**:
   - The PMSG generates three-phase AC voltage.
   - The frequency and voltage depend on the rotor speed.
2. **Rectification**:
   - The diode bridge rectifier takes the 3-phase AC and converts it into pulsating DC.
   - This DC is unidirectional (no negative part) and suitable for further processing.
3. **DC Output**:
   - The output from the rectifier is typically connected to a DC link capacitor to smooth the voltage.
   - From there, it can feed a DC load, a battery, or a DC-DC converter (like a buck/boost converter or an inverter for grid tie-in).

3.5Inverter Circuit

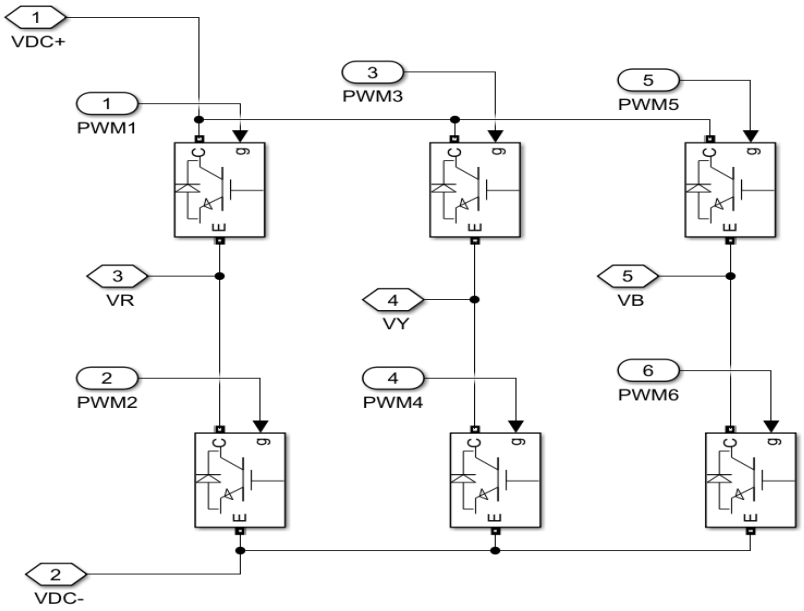

Fig 3.5.1: Inverter Circuit

This is a Three-Phase Voltage Source Inverter (VSI) using six-switch topology, which is the most common type of inverter used in industrial and motor drive applications.

1. **Three-Phase Output**:
   - The outputs labelled VR, VY, and VB correspond to the three AC phases (R, Y, B).
2. **Voltage Source Input**:
   - The inverter is fed from a DC voltage source with terminals labelled VDC+ (1) and VDC- (2), indicating it's a voltage source inverter (VSI).
3. **Six-Switch Topology**:
   - There are six IGBT/MOSFET switches, each controlled by its own PWM signal (PWM1 to PWM6).
   - This is the classical "two-level, three-phase inverter" topology.

3.6 LCL Filter

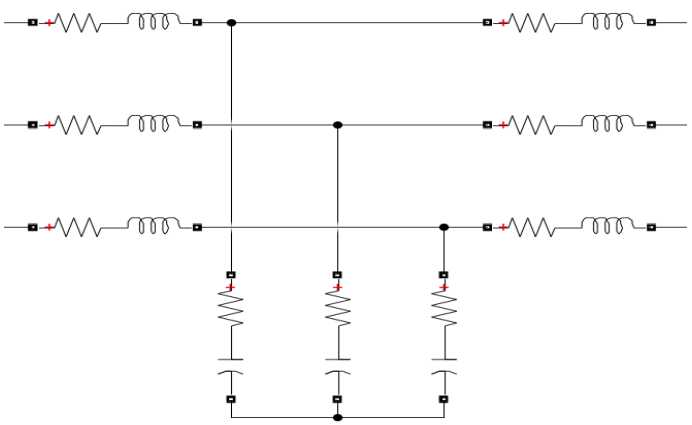

Fig 3.6.1: LCL Filter in Grid-Connected Inverter System

1. Introduction to the LCL Filter

An LCL filter is a three-element filter consisting of two inductors and a capacitor. It is widely used in grid-connected inverter systems to suppress high-frequency switching harmonics generated by Pulse Width Modulation (PWM) inverters. Unlike a simple LC or L filter, the LCL filter provides steeper attenuation, making it more efficient at filtering high-frequency noise.

2. Structure of the LCL Filter

The filter is implemented on each phase of the inverter output. The topology consists of:

- **L1 (Inverter-Side Inductor):**
  Limits the current ripple coming from the inverter.
- **C (Shunt Capacitor):**
  Diverts high-frequency current components away from the grid and provides a low-impedance path to ground for switching harmonics.
- **R (Damping Resistor):**
  Often added in series with the capacitor to dampen resonance that could otherwise be excited by the inverter.
- **L2 (Grid-Side Inductor):**
  Limits the current ripple injected into the grid and improves the attenuation of switching noise.

3. Working Principle

- The PWM inverter switches rapidly to synthesize a sine wave from the DC bus.
- The output of the inverter is passed through the LCL filter.
- The first inductor (L1) smooths the inverter current.
- The capacitor (C) absorbs most of the switching frequency harmonics.
- The second inductor (L2) ensures smooth current injection into the grid and reduces the impact of grid impedance variations.

The result is a clean, near-sinusoidal current waveform delivered to the grid.

3.7 Phase-Locked Loop (PLL) and Voltage Controller:

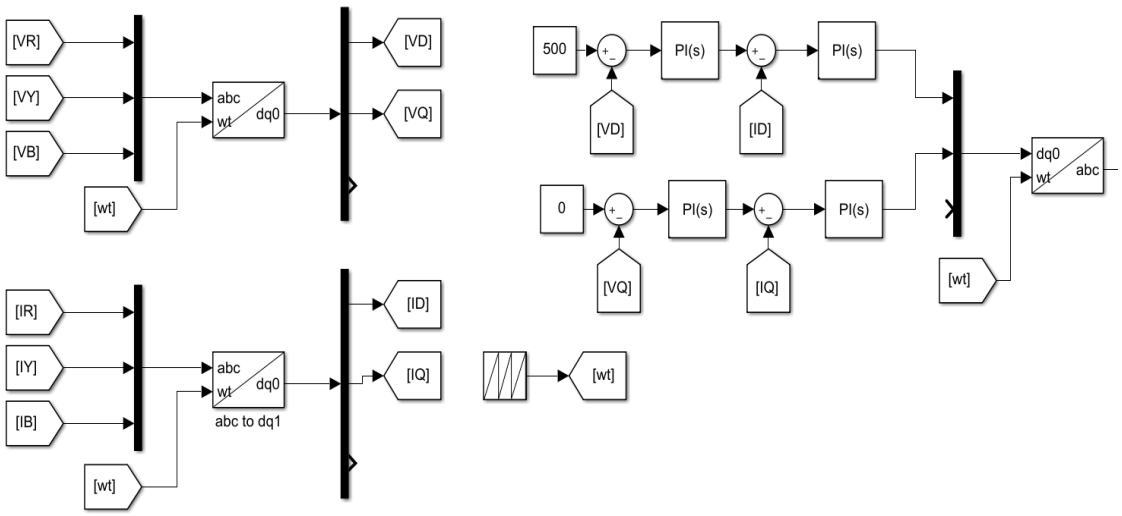

Figure 3.7.1: Phase-Locked Loop (PLL) and Voltage Controller:

1. Phase-Locked Loop (PLL) in Grid Synchronization

Purpose:

The Phase-Locked Loop (PLL) is used to synchronize the inverter output with the grid in terms of frequency, phase angle, and voltage. This is critical for seamless and safe integration of the inverter into the grid.

How it Works:

1. Input Signal: The PLL receives the three-phase voltage from the grid (e.g., VR, VY, VB).
2. abc to dq0 Transformation: The three-phase voltages are transformed into the rotating reference frame (dq0) using Park Transformation.
3. q-Axis Error Detection: In an ideal synchronized state, the q-axis voltage (Vq) should be zero. Any deviation from zero represents a phase angle mismatch.
4. PI Controller: A PI controller processes this Vq error to adjust the estimated grid angle (θ or wt).
5. Angle Generator: This corrected angle is fed back to the transformation blocks to keep tracking the grid frequency and phase.
6. Output: The output of the PLL is a continuously updated angular frequency (wt) used to synchronize inverter control signals.

Result: The inverter produces a voltage waveform that is in phase and frequency with the grid voltage—ensuring smooth power flow without transients.

2. Voltage Controller (Using dq0 Control Strategy)

Purpose:

The Voltage Controller regulates the output voltage of the inverter to maintain stability and deliver the desired power to the grid. It works in the rotating dq0 reference frame for better decoupling and control precision.

How Voltage Control Works in this Model (dq-based):

1. Voltage Sensing and dq0 Transformation

- Takes 3-phase output voltages.
- Converts to VD and VQ using Park transformation.
- wt is the angular frequency from PLL or another synchronization method.

2. Voltage Reference Comparison

- VD_ref = 500, VQ_ref = 0 → These are the desired voltage levels in dq frame.
- Error signals:
    - error_D = VD_ref - VD
    - error_Q = VQ_ref – VQ

3. PI Controllers

- Each error is processed by a PI controller, generating voltage correction signals.

4. Inverse dq0 to abc Transformation

- The control output is converted back to abc.
- These abc signals are used as modulation references for PWM generation to drive the inverter switches.

And the Role of the LCL Filter?

Even in voltage control mode, the LCL filter still:

- Smooths the PWM output.
- Attenuates switching harmonics.
- Helps shape the inverter voltage waveform before it's delivered to the grid.

3.8. Hybrid System

The simulation combines the solar and wind power system to generate electricity. It optimizes the output by considering factors like energy demand, weather patterns and system constraints.

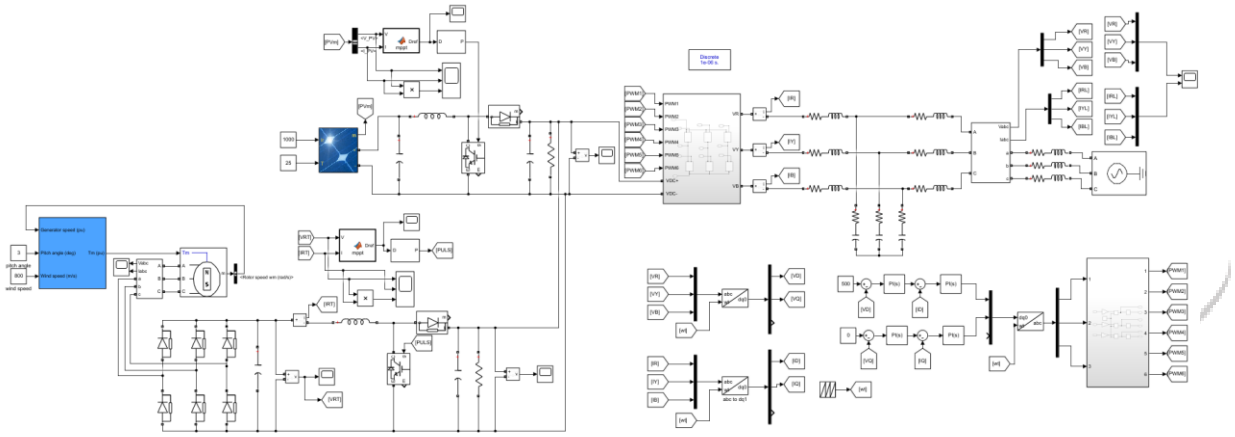

Fig.3.8.1 Hybrid System

4. Results

4.1. Solar PV Voltage and current Output

1. Peak power output: Maximum power output under ideal conditions (e.g., 300W).

2. Average power output: Actual power output over a period, considering factors like sunlight variation.

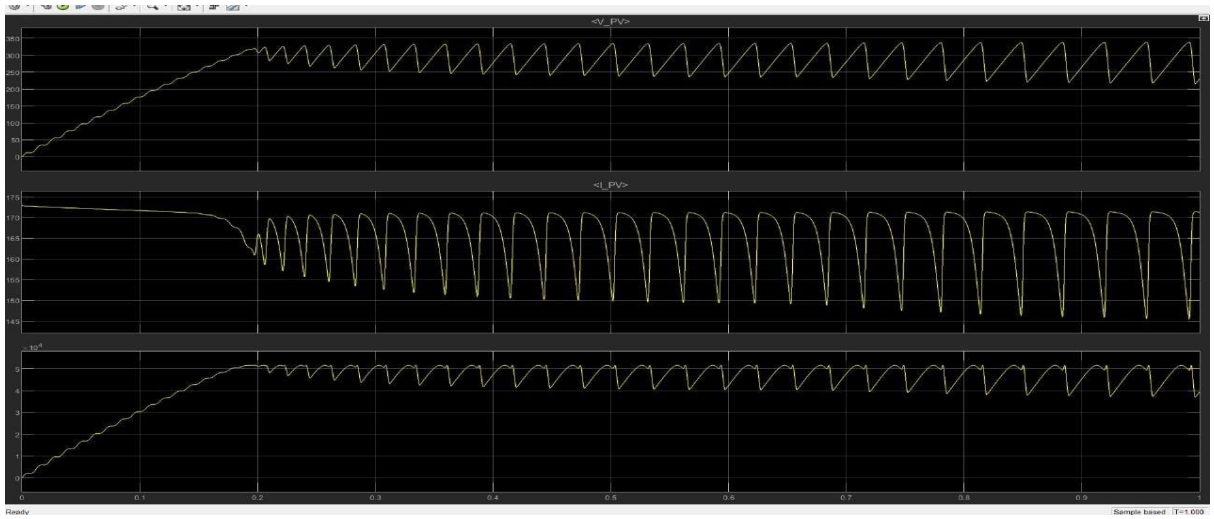

Fig.4(a) Solar PV Voltage & Current

4.2. Wind Energy and Power Output

- **Understanding power output ratings**

Wind turbines have ratings like:

1. Rated power output: Maximum power output under ideal conditions.

2. Capacity factor: Actual power output as a percentage of the rated power output.

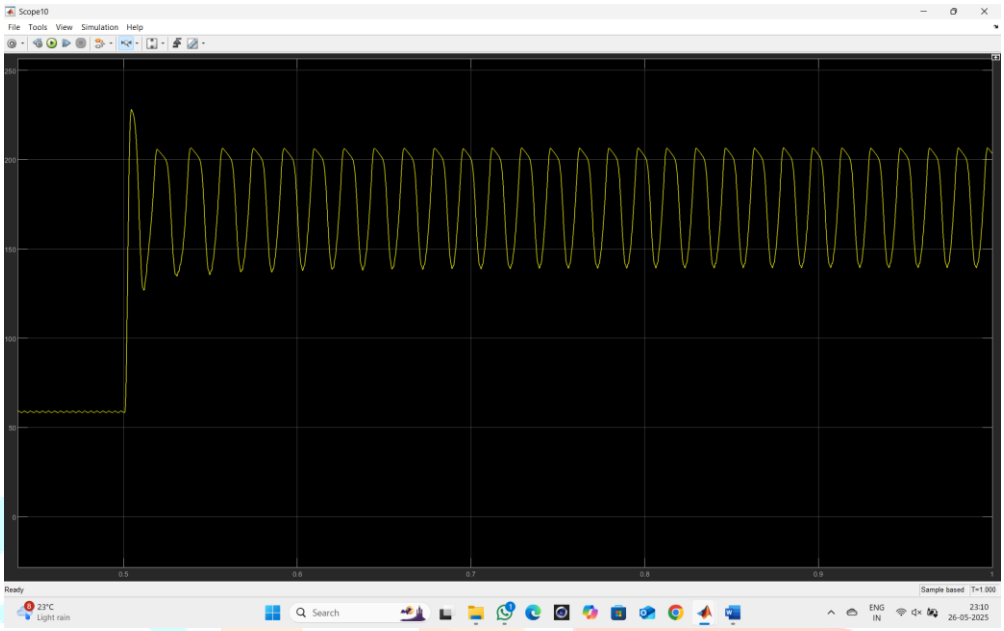

Fig4(b) Wind Turbine output Voltage

4.3. Voltage & current waveform with filter

Voltage and current waveforms show how electricity flows over time. Think of it like a graph showing the ups and downs of electricity.

- **What do waveforms look like without a filter?**

Without a filter, waveforms can be messy and irregular, with lots of "noise" or "distortion". This can cause problems like:

1. Electrical noise: Interference that can affect equipment performance.

2. Inefficiency: Wasted energy due to irregularities in the waveform.

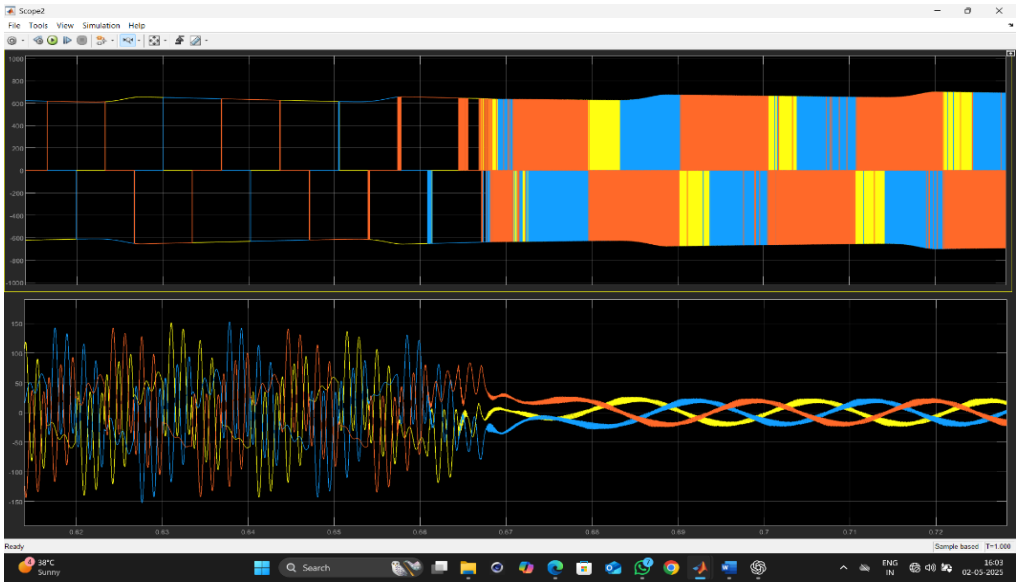

Fig4(c) Voltage & current waveform without filter

- **What happens with a filter?**

A filter helps clean up the waveform, making it smoother and more regular. This:

1. Reduces noise: Minimizes electrical interference.

2. Improves efficiency: Ensures a more stable and consistent flow of electricity.

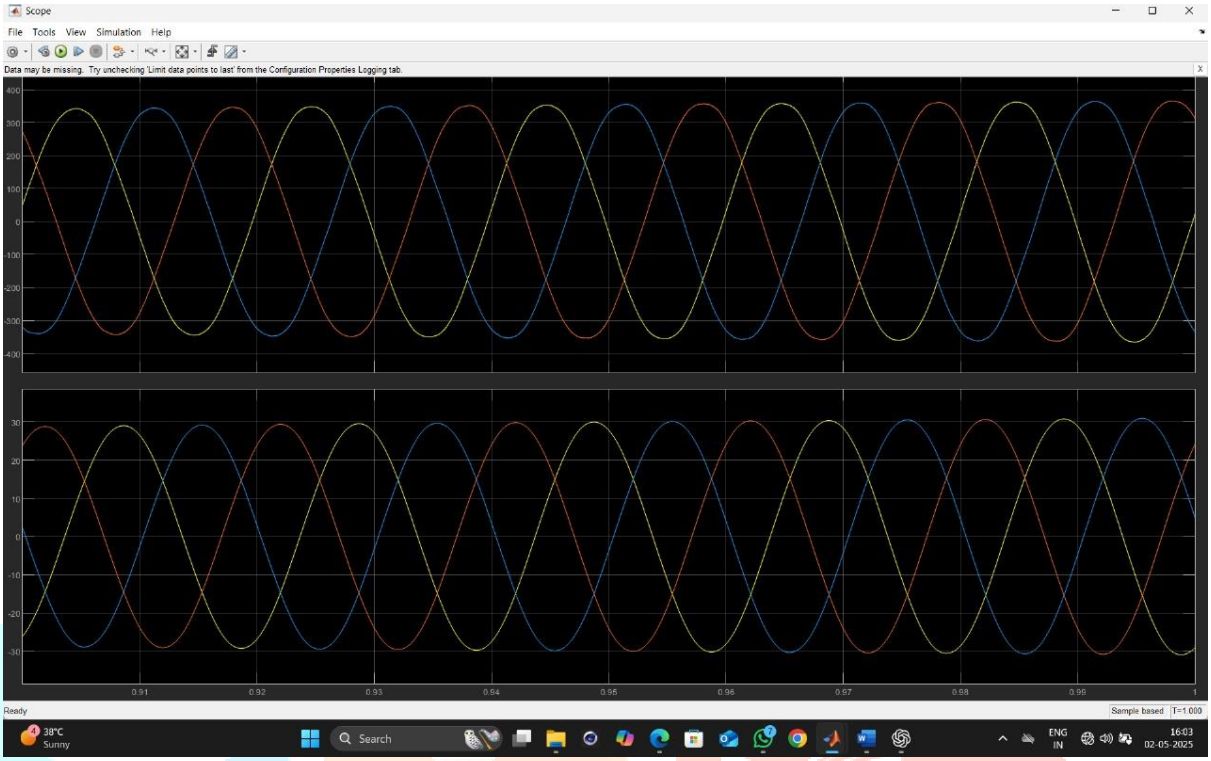

Fig4(b) Voltage & current waveform with filter

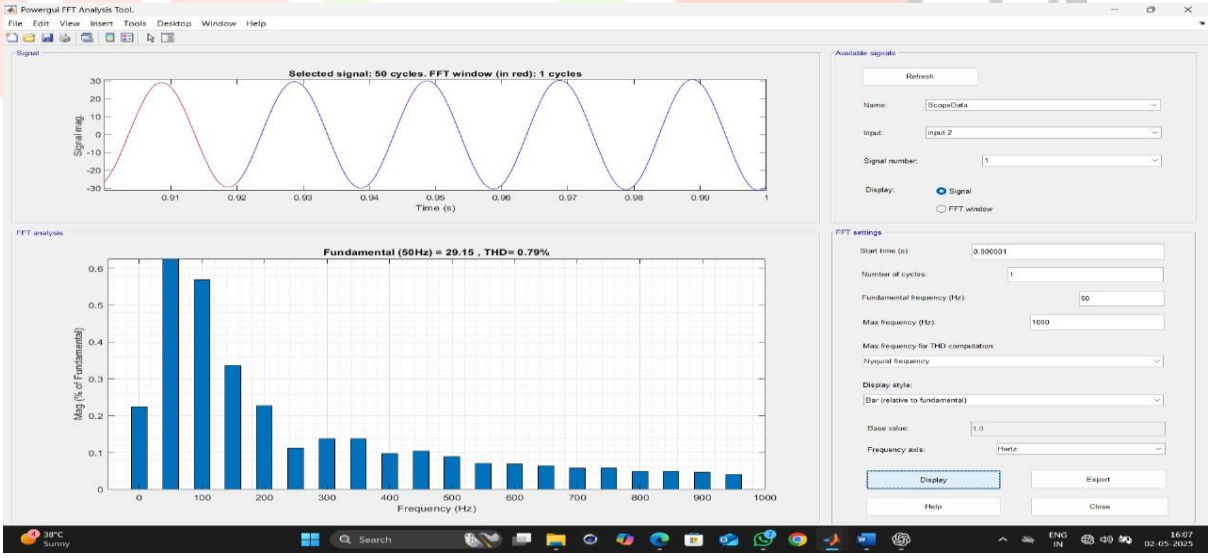

Fig4(c) THD Analysis

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