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Design and Analysis of a Standalone PV System in North East India

Sanjib Hazarika[1], Prince Bharadwaj[2], Nilav Nayan Saikia[2], Partha Jyoti Bhuyan[2], Pratap Baruah[2], Bhaskar Jyoti Bora[2]

[1,2] Department of Electrical Engineering, Girijananda Chowdhury University
Azara, Guwahati-781017, Assam, INDIA.
Corresponding Author: sanjib_me@gcuniversity.ac.in

Abstract: The usage of conventional energy sources is being replaced by renewable energy sources. The solar energy is the most widely used renewable energy source. The solar energy can be harnessed from the sun with the help of photovoltaic panels. The photovoltaic panels can be configured to function as a standalone system. The standalone system is more reliable and easier for installation. This paper investigate the power output variations for Morigaon distric of Assam for three consecutive year in Matlab Simulink environment.

Keywords: Performance Ratio; Slope angle

1. Photovoltaic Technology

In our daily lives, electrical energy has become essential. It gets harder for governments to supply people with basic electricity when the nation's population grows gradually. The goal of the Indian government is to supply power to every community. Renewable energy sources, such as wind and solar power, can help realize this goal of electrifying rural areas. Compared to wind energy, solar energy installation is less expensive. Setting up the standalone PV system is simple. A battery backup system can be used to make the standalone system function effectively. By using boost converter and MPPT (maximum power point tracking) the modeling of standalone PV Small Hydro Power contributes around 286.34 MW

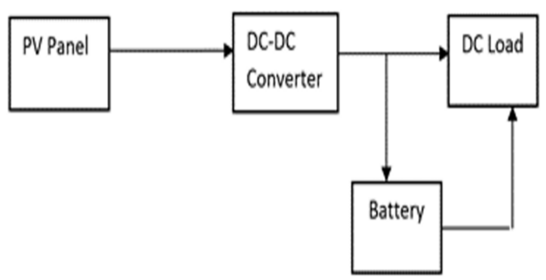

Figure 1: General PV system technology [2]

2. Solar Photovoltaic Energy Conversion Process

The conversion from energy from sun to electricity is based on photovoltaic effect. The light energy is converted to other form of energy that is electrical energy. High configured Solar cells with semiconductor materials are used for this energy conversion phenomenon. Here an artificial electric field is created by help of p-n junction which is constant in nature [3].

A standard PV cell is a thin semiconductor sandwich, with two layers of highly purified silicon. Photovoltaic arrays are nothing more than huge matrices of interconnected semiconductor sandwiches [11]. Usable PV systems comprised all sorts of equipment that protects the user from electrical shock, stores the electricity in battery banks, and converts the direct current (DC) into alternating current (AC), which is what people use in their houses [12].

3. Components of PV Technology

There are different components is photovoltaic system. The photovoltaic panels are the main components in harnessing the energy from the sun. A single PV cell is fabricated to harness a small amount of solar energy. These PV cells can be clubbed together as a module or an array. The PV panels can be arranged in arrays to give the desired output power.

Specification:

1. Module: Mitsubishi electric pv-MF180UD4
2. Maximum power(W): 180.29
3. Open circuit voltage V_{oc} (v): 30.4
4. Voltage at maximum power point Vmp(V): 24.2
5. Cells per module(N_{cell})=50

6. Short circuit current I_{sc}(A): 8.03
7. Current at maximum power point Imp(A)= 7.45
8. Parallel string=33
9. Series connected module=1

India is currently facing a peculiar problem of demand-supply gap in power. The power scenario in India continues to be grim even as the country gears up to expand its power supply to bridge the large demand- supply gap [8]. Economic growth, increasing prosperity and urbanization, rise in per capita consumption, and spread of energy access are the factors likely to substantially increase the total demand for electricity. Solar panel output for location Morigaon District with latitude 26.09 degree and longitude 92.28 degree.

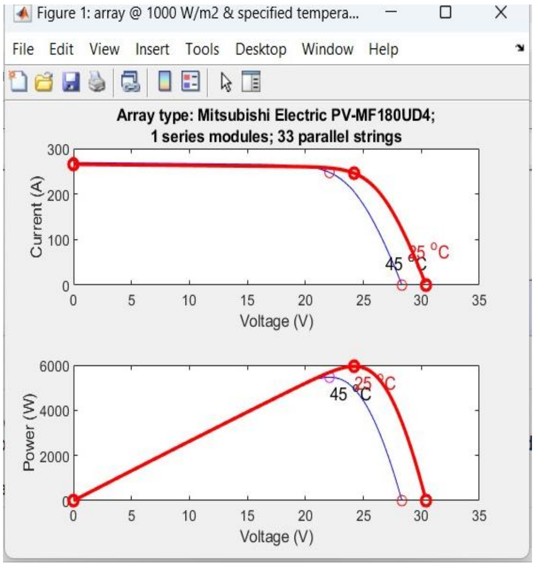

Figure 2: Solar Panel Output for Morigaon District

3.1 Simulation model of PV system

Solar PV system includes different components that should be selected according to your system type, site location and applications. A Balance-of System that wired together to form the entire fully functional system capable of supplying electric power and these components are:

Boost converter: The converters can be of DC-DC converter or DC-AC converter based upon the application. The reliability of the standalone system is carried out by the converters. The DC-DC boost converter topology is the most widely used topology. The boost converter steps-up the input voltage to the desired level of voltage based upon the duty cycle.

This image shows a Simulink model of a DC-DC converter, likely used for a photovoltaic (PV) system. Below is the detailed explanation of its components:

1. Input Connection (Conn1): The input of the converter is connected to a DC source, possibly the PV panel output.
2. Inductor (L): An inductor smooths the current and stores energy during the switching operation. It is essential in regulating the output voltage.
3. Switching Device: The model uses a MOSFET or similar power switch. The gate (g) terminal is controlled by a PWM (Pulse Width Modulation) block to regulate the duty cycle and thus the output voltage.
4. Diode: A freewheeling diode is used to provide a current path when the switching device is off, ensuring continuous current flow in the circuit.
5. Capacitors: Capacitors are used to smooth the output voltage, filtering any high-frequency noise generated by switching operations.

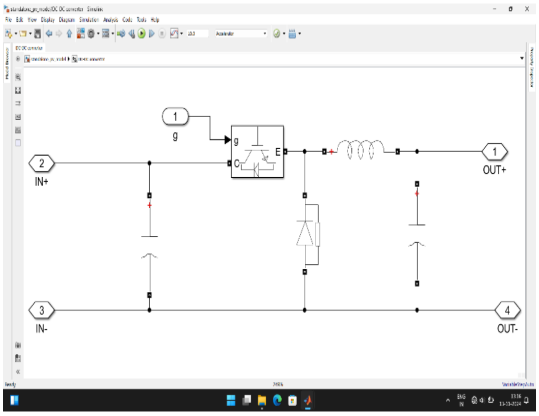

Figure 4(a): Simulink model of boost converter

6. Resistive Load: Two resistors represent the load connected to the converter. They consume the output power.
7. Output Connection (Conn2): The output terminal provides regulated DC voltage, ready for storage (in a battery) or further use.
8. Control PWM Block: This block generates the switching signal to control the MOSFET, based on an algorithm (e.g., MPPT) to regulate the output voltage efficiently.
9. Additional Connections (Conn3 and Conn4): These connections might represent feedback signals or further connections to other subsystems. This DC-DC converter is likely configured as a boost converter (for increasing voltage) or buck

converter (for decreasing voltage) and is critical in matching the PV output to the required load or battery input.

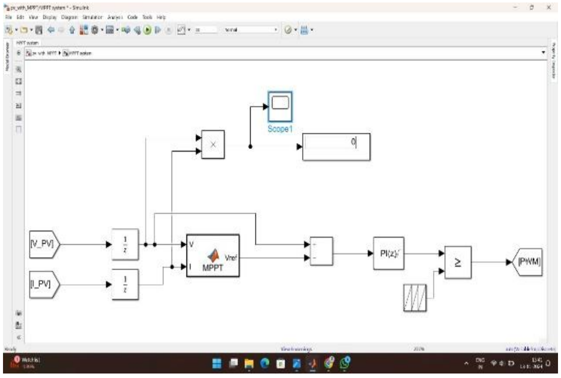

Figure 4(b): Simulink model of boost converter

This MATLAB function implements a Maximum Power Point Tracking (MPPT) algorithm, which is commonly used in solar energy systems to optimize the power output from photovoltaic (PV) panels. The goal of MPPT is to adjust the operating point of the PV system to ensure it operates at its maximum power point, which can vary with environmental conditions such as sunlight intensity and temperature.

4. Battery and Inverter Configurations

The PV standalone system makes use of the battery backup to provide uninterrupted power supply. The battery technology has been advancing. The battery size and shape has been drastically reduced but the capacity has increased. The lead acid battery is one of the oldest and widely used batteries.

Inverter Converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or fed back into grid line. It is one of the solar energy system's main elements, as the solar panels generate dc-voltage. Inverters are different by the output wave format, output power and installation type. It is also called power conditioner because it changes the form of the electric power. This is a Simulink model of an inverter circuit, likely part of the larger photovoltaic (PV) system. Below is the detailed description of its components:

1. Power Input (P): The block at the top left provides power to the inverter, possibly coming from a PV system or a DC source.
2. Switching Device: The main inverter block includes an Insulated Gate Bipolar Transistor (IGBT) with an anti-parallel diode. This switch converts DC input to pulsating AC by controlling the gate signal (g) based on input signals.
3. Inductor (L): The inductor smoothens the current to reduce high-frequency ripple caused by switching.
4. Capacitor (C): A capacitor is used for filtering purposes, ensuring the AC output is smooth and free of noise.
5. Resistive Load (R): The circuit is connected to a load (represented by a resistor), which consumes the AC power generated by the inverter.
6. Voltage Measurement: A voltage measurement block is present to monitor the output voltage of the inverter.
7. Scope: The measured voltage is displayed on a scope to visualize the inverter's performance and output waveform in real-time.
8. Input Signals (1 and 2): These are control signals fed into the inverter block to regulate the switching behaviour, likely generated by a Pulse Width Modulation (PWM) or control algorithm. This inverter is part of a system designed to convert DC power (from a battery or solar panel) into AC power suitable for powering AC loads.

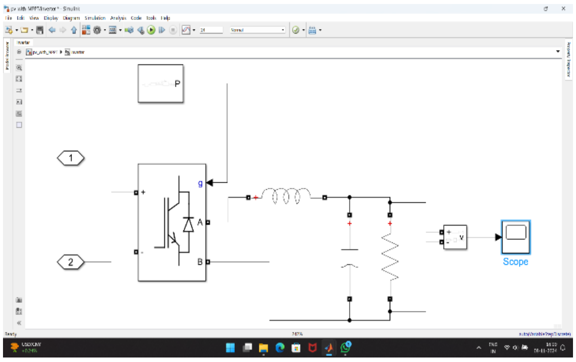

Figure 5(a): Simulink model of Inverter

5. Matlab Simulink Modelling

This is a Simulink model of a photovoltaic (PV) system with a Maximum Power Point Tracking (MPPT) system, a battery for energy storage, and associated power electronics. Here's a breakdown of the key components:

Photovoltaic (PV) Panel: The PV panel generates electrical energy from solar radiation. It is connected to measure voltage (V_{pv}) and current (I_{pv}) outputs.

MPPT System: The MPPT block ensures the PV panel operates at its maximum power point by adjusting the load conditions dynamically.

DC-DC Converter: The DC-DC converter regulates the voltage and current levels from the PV panel to match the battery's charging requirements and other system needs.

Battery: A battery stores energy generated by the PV system. The state of charge (SOC), current, and voltage of the battery are monitored.

Inverter: An inverter converts the DC power from the PV system and battery into AC power for use with AC loads.

Power Measurements: Voltage, current, and SOC are displayed to monitor system performance. For example:

SOC = 97.29%

Current = 18.08 A

Voltage = 7.477 V

Control System: Signals and logic control the MPPT, battery charging, and power conversion processes to optimize performance.

PowerGUI: A PowerGUI block is used for simulating electrical circuits in Simulink, set to a discrete time step of 5e-06 s.

This model appears to simulate a standalone solar energy system focusing on power optimization and storage.

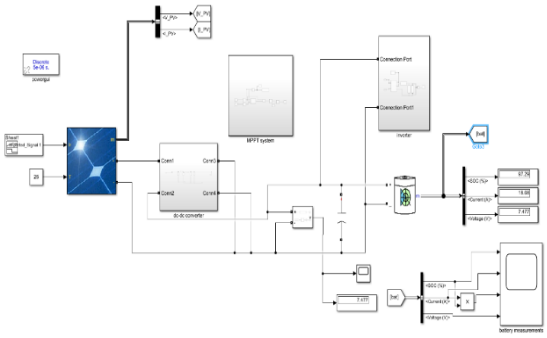

Figure 5 (b) : Matlab Simulink Configuration

6. Matlab Simulink Results and discussion

Matlab simulink model has been designed and solar radiation datas are used for calculation of panel output.

For the year 2021, 2022 and 2023, power output for the photovoltaic panel has been calculated and the results are plotted monthly as follows.

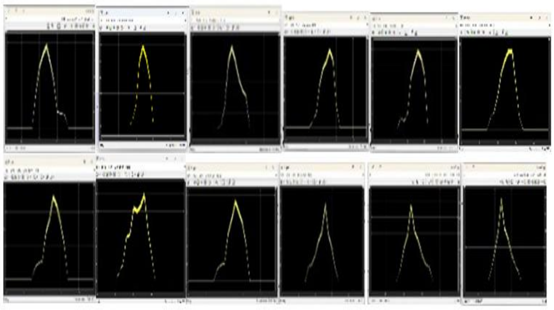

Figure 6(a) : Power output for 2021

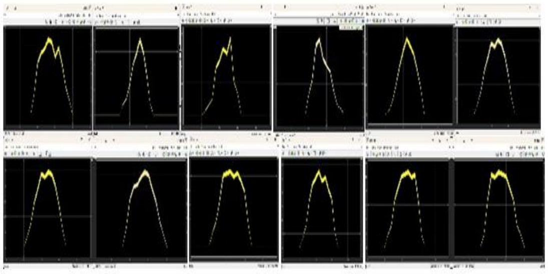

Figure 6(b) : Power output for 2022

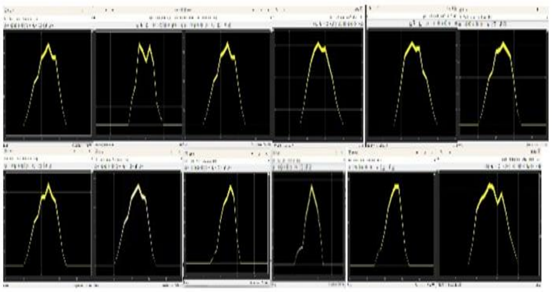

Figure 6(c) : Power output for 2023

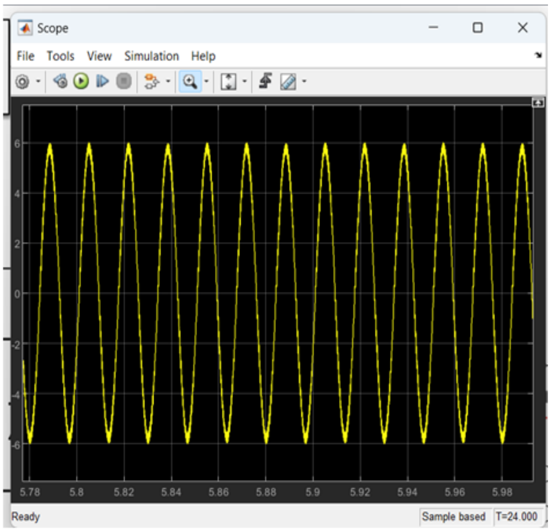

Figure 6(d) : AC Output Voltage waveform

The graph represents the AC output voltage of a solar PV system connected through an inverter. The efficiency of the inverter affects the AC output, meaning not all the DC power produced by the panels will be converted to usable AC power.

Factors affecting AC output, larger and more efficient panels generate more DC power, resulting in higher AC output. The amount of sunlight directly impacts the power generated by the solar panels. Weather conditions, Clouds, shade, and dust can reduce the AC output. The input signal is a replica of average irradiance data of Morigaon (Latitude:26.093151, Langitude: 92.289188)

The input signal which has been taken for simulating the model is the average monthly hourly irradiance data. The data has been taken from **https://power.larc.nasa.gov/** the excel file compress of hourly irradiance that is falling on the specific selected location.

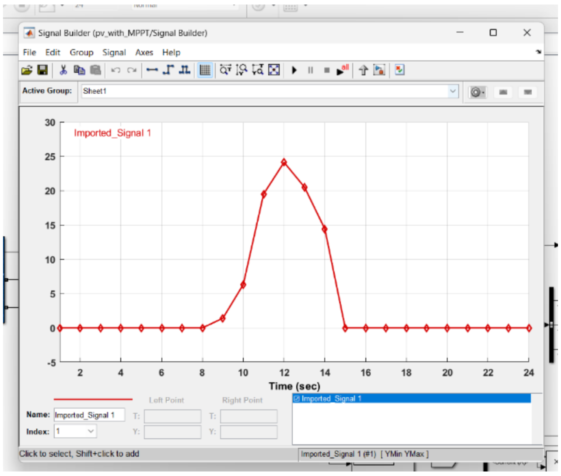

Figure 7 : Input Signal as Irradiance

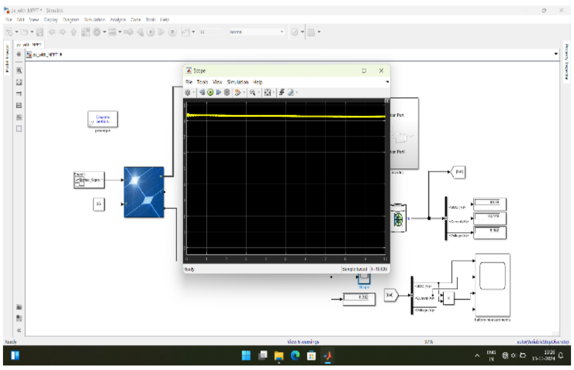

Figure 8 : Output DC Voltage waveform

This is the output DC voltage coming from the solar panel through the boost converter

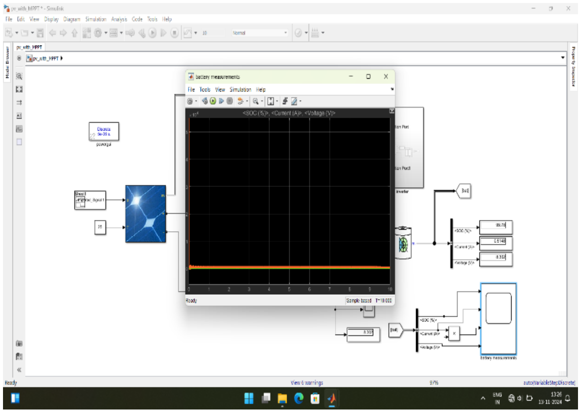

Figure 9: battery measurements including SOC, current, voltage

The short circuit current, DC voltage and current output of the battery is running condition. Battery State of Charge (SOC) is a measure of how much of the battery capacity is available.

7. Conclusions

In conclusion, the MATLAB model simulation of a solar power system has demonstrated the effectiveness of using computational tools to analyze and optimize photovoltaic (PV) energy systems. Through this simulation, we have successfully modeled key components such as solar panels, inverters, and maximum power point tracking (MPPT) algorithms. The simulation results provide insights into the system's behaviour under varying conditions of solar irradiance, temperature, and load demand.

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Author's Profile

Sanjib Hazarika, B.E. (Assam Engineering College) M.Tech, is working as an Assistant Professor in Girijananda Chowdhury University, India. He received his master degree in Energy Technology from Tezpur University (India) in 2010. He is conducting research in the field of photovoltaic energy conversion.

Mr. Nilav Nayan Saikia, 8th Semester, EE Department, GCU. He is conducting research in the field of Renewable energy and their applications.

Mr. Prince Bhradwaj, 8th Semester, EE Department, GCU. He is conducting research in the field of Renewable energy and their applications.

Mr. Bhaskar Jyoti Bora, 8th Semester, EE Department, GCU. He is conducting research in the field of Renewable energy and their applications.

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