

Design and Control of a 2 kW Hybrid DC Micro-grid

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Abstract

The system proposed in this paper is a hybrid of two renewable sources of energy, solar power and wind power, to produce electricity to a small, independent (standalone) DC microgrid. In particular, it employs a 1 kW PV array and a 1 kW wind turbine system (WECS). This is aimed at achieving reliability of power supply by relying on both sources, as solar energy is best in sunny situations and wind energy can produce power at other times such as at night or even during bad weather. Both the solar and wind systems are made to generate as much power as possible at all times, even when the weather conditions are constantly varying. The solar (PV) system has a special controller known as Maximum Power Point Tracking (MPPT), which constantly modulates the operation of the panels so the panels can optimize the available energy regardless of the strength or weakness of the sunlight. In a similar fashion, the wind system operates a form of generator known as a Permanent Magnet Synchronous Generator (PMSG), which is powered by its own MPPT to change its operation according to wind speed. This enables the wind turbine to gain the maximum energy both at low and high wind speed. These intelligent control methods combined make the two energy sources effective and provide the optimum power output at different environmental conditions. To store additional energy and provide power on demand, a battery system with a voltage of 220 V is added. It is joined to the main DC line with a special device known as a bidirectional DC-DC converter, which is capable of regulating the direction of flow of electricity. This converter operates under two modes: in buck mode, it decreases the voltage (as in the case of charging the battery) and in boost mode, it increases the voltage (as in the case of the battery supplying power back to the system). It is due to this that the battery is able to store surplus energy produced by the solar and wind sources as well as offer energy during times of low generation. Meanwhile, it maintains the level of DC link voltage and also provides a smooth flow of energy between the energy sources, the battery and the load. The control system is meant to maintain everything at equilibrium with a change of condition. It constantly regulates the amount of power being produced by the solar and wind sources and the amount of power required by the load and then moderates the system to suit. The simulations are implemented in MATLAB and Simulink and the outcomes confirm with the simulation outcomes.

Keywords: Bidirectional converter, DC micro-grid, Hybrid renewable system, Maximum Power Tracking, solar PV, wind energy.

1.INTRODUCTION

The demand for energy is shifting towards clean energy due to its environmental benefits and sustainability. Some of the energy sources that have been found to offer such advantages include solar energy and wind energy. The latter is a sustainable source of energy, which can be exploited by small or large power generators alike. However, its output may not be consistent due to the variability of energy input. For example, the solar energy output will depend on the intensity of sunlight while that of wind will depend on the velocity of winds. Therefore, a strategy to overcome this problem involves designing a hybrid renewable energy system (HRES). It integrates different forms of renewable energy. In our case, solar energy and wind energy sources have been integrated due to the compatibility between them. Solar energy is dependent on sunshine, but the wind energy can generate electricity at any time depending on wind conditions. In order to harvest more energy from these sources, the Maximum Power Point Tracking (MPPT) method is used. Solar cells are regulated using P&O methods to remain operating at their optimal levels in different environmental conditions. Similarly, the output of wind energy is optimized to ensure the system remains effective. Energy Storage in Energy Storage System (ESS). In order to ensure system stability, energy needs to be stored for use at any time. Batteries are the source of energy storage; hence, power can be generated from them in cases of low energy availability from the other sources. A bidirectional DC–DC converter that interlinks the battery pack with the system supplies energy from the batteries in cases of low power from the other sources of energy in the system.

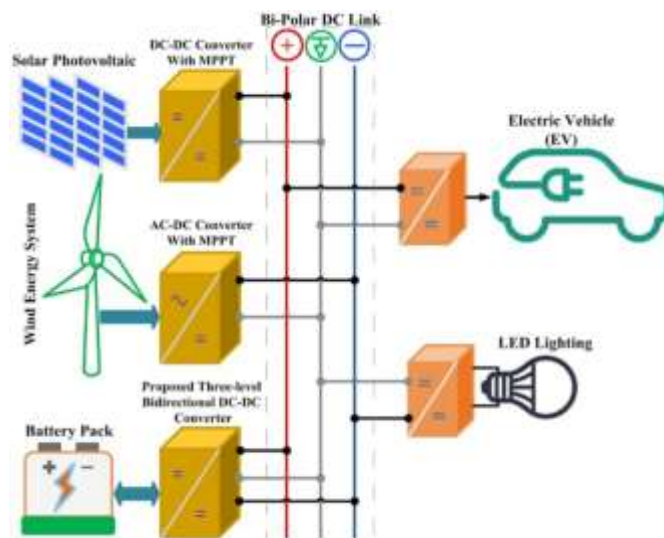


Figure 1. Block diagram

In case of excess energy from the other sources, energy storage occurs. Bi-polar DC Micro-grid. In the proposed system, a bi-polar DC microgrid is employed where all loads and sources are connected via one DC-link as illustrated by the block diagram below. Solar Photovoltaic Source is connected to the system via the DC-DC converter with MPPT. Wind Energy Source is connected via the AC/DC converter with MPPT. Both these energy sources supply power to the DC-link. A battery pack is connected to the DC link through the bidirectional DC-DC converter. The Loads on the DC-link include the EV charging point and the LED lighting. All these loads are powered using appropriate converters to suit their respective needs. This paper studies a mixed system of energy sources, i.e., solar and wind energy sources, and their control to have a consistent source of energy supply. The system aims at maintaining voltage at the dc link, as well as proper distribution of power supply.

2.LITERATURE SURVEY

In recent times, researchers conducting studies in renewable energy systems have focused their attention on the reliability and effectiveness of such energy systems through the incorporation of hybrid energy sources. Numerous research studies have been conducted on hybrid energy sources comprising the use of solar photovoltaic energy sources and wind energy sources. According to Al Badwawi et al. (2015), hybrid energy sources that integrate both solar energy and wind energy sources have higher reliability than others. The study findings indicate that hybrid energy systems that incorporate different energy sources are highly reliable than single-energy-source systems. The above-mentioned current studies conducted on hybrid energy sources were conducted on energy sources based on the AC grid model. Eryilmaz et al. (2021) have found that such energy sources had some weaknesses. For instance, there was the need to synchronize the frequency of the energy sources. As a result, power loss occurred, which prompted the researchers to propose other alternatives to the existing models. Currently, research scholars have established that DC microgrid-based energy systems can serve as a solution. Li et al. (2023) have pointed out that DC microgrid-based energy systems are highly efficient. Efficiency was another aspect of energy systems highlighted in the study; energy systems were found to be more efficient than the current energy systems. In summary, the study found that energy systems have greater compatibility with energy storage systems. The adoption of MPPT techniques has been widely accepted to improve the efficiency of renewable energy systems. Of all MPPT techniques, P&O methods are commonly employed owing to their simplicity. Studies on MPPT techniques showed that effective maximum power point tracking significantly increased the efficiency of solar PV systems at different levels of irradiance (Applied Energy, 2015). The maximum power point in wind energy systems can be tracked using control techniques at different wind speeds. The role of energy storage systems in balancing the power balance in the hybrid microgrid system cannot be underestimated. Battery energy storage systems are commonly used if they are coupled through bidirectional DC–DC converters to

regulate energy in the microgrid system. Such converters regulate the DC bus voltage. However, despite all these benefits of using hybrid microgrids, there are some problems that are still unattended to. They include how to harvest maximum possible energy from energy sources, how to stabilize the DC bus voltage and coordination of different energy sources. If this aspect of energy management is not effectively carried out, it might lead to over-charging of the battery, under charging of the battery, and unstable DC voltage of the bus. The idea behind this study therefore, is to come up with a better control strategy which will integrate various MPPT algorithms, bidirectional converters, and DC bus voltage stabilization technique. In this project, we intend to come up with a Hybrid DC Microgrid System that will integrate different sources of energy like solar energy, wind energy, and batteries as well as conventional energy sources.

3.SYSTEM CONFIGURATION

3.1 PV SYSTEM

The PV simulation model shows a PV generator having one kilowatt of power made from four pieces of 250 W panels connected in series and parallel to ensure voltage and current levels necessary. Solar Array block is fed by solar radiation (I_r) and temperature (T), which affect voltage (V_{pv}) and current (I_{pv}). The output of these signals is measured, then sent to the power calculation block ($V \times I$) to measure the generated power. The Maximum Power Point Tracking (MPPT) algorithm is used to generate optimal power from PV array by changing its operation point according to the input voltages and currents. The MPPT controller sends gating pulses to the DC-DC boost converter consisting of an inductor, switch (MOSFET/IGBT), and diode. The boost converter converts the PV array output voltage and delivers power to the DC link capacitor to regulate its output voltage.

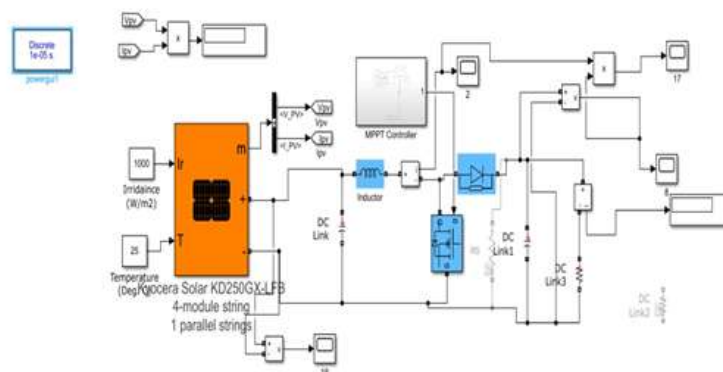


Figure 2. Solar MPPT Simulation Model

To simulate the operation of this system, the power gui (discrete) block is used. Other blocks like measuring voltage and current, scoping, and display are added to study the behaviour of the system. The output is fed to three DC link nodes (DC Link1, DC Link2, DC Link3) where loads or any other subsystem could be connected.

3.2 WIND ENERGY SYSTEM

Wind Energy Simulation Model is a representation of a 1 kW wind energy conversion system operating under different wind scenarios. Wind speed is taken as input to the system, and its mechanical power generation capability is estimated using $P = 1/2 \rho AV^3 C_p$. It is noted that there is a great variation in power generation due to wind speed. Thereafter, wind energy is converted into torque by the wind turbine block to drive the Permanent Magnet Synchronous Generator (PMSG), whose three phase AC output will depend on the speed of rotation and load. There are measurement blocks to estimate generator voltages, currents, and speed. Thereafter, the AC output will be rectified using an uncontrolled rectifier to convert into DC. The output from the rectifier will be fed into a DC-to-DC boost converter made up of an inductor, switch, and a diode to regulate the voltage to match DC bus voltage level. The system will be controlled using an algorithm for Maximum Power Point Tracking to regulate the duty cycle of the converter.

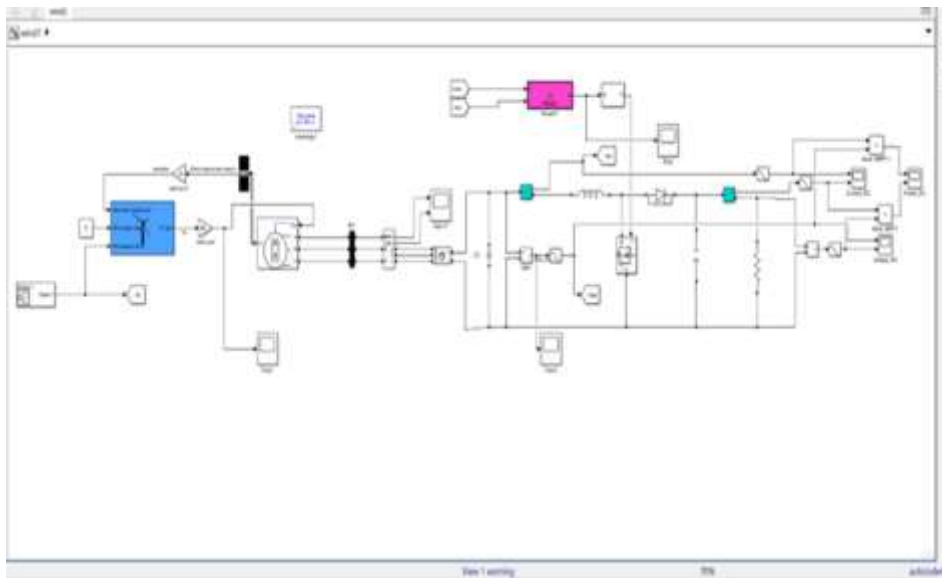


Figure 3. Wind MPPT Simulation Mode

The controlled output is linked to the DC link that interacts with other sub-systems like the PV array and battery. Further elements such as scopes, displays, and power measurement blocks are utilized for performance analysis and response studies.

3.3 MPPT (P&O ALGORITHM)

The Perturb and Observe (P&O) approach is one of the simplest yet most popular approaches for locating the MPP in PV and wind-based power generation systems. It involves making continuous adjustments to the operational point and monitoring the corresponding power change. As illustrated in the flow chart, the algorithm uses voltage $V(t)$ and current $I(t)$ as input parameters and determines their instantaneous power $P(t)$. The difference between present sample values and past sample values $V(t-\Delta t)$ and $P(t-\Delta t)$ is calculated as ΔV and ΔP , respectively.

The main decision-making criterion can be described as follows:

- If a tiny voltage variation (perturbation) results in an increased power level ($\Delta P > 0$), then continue to move in the same direction.
- Otherwise, when $\Delta P < 0$, invert the perturbation direction.

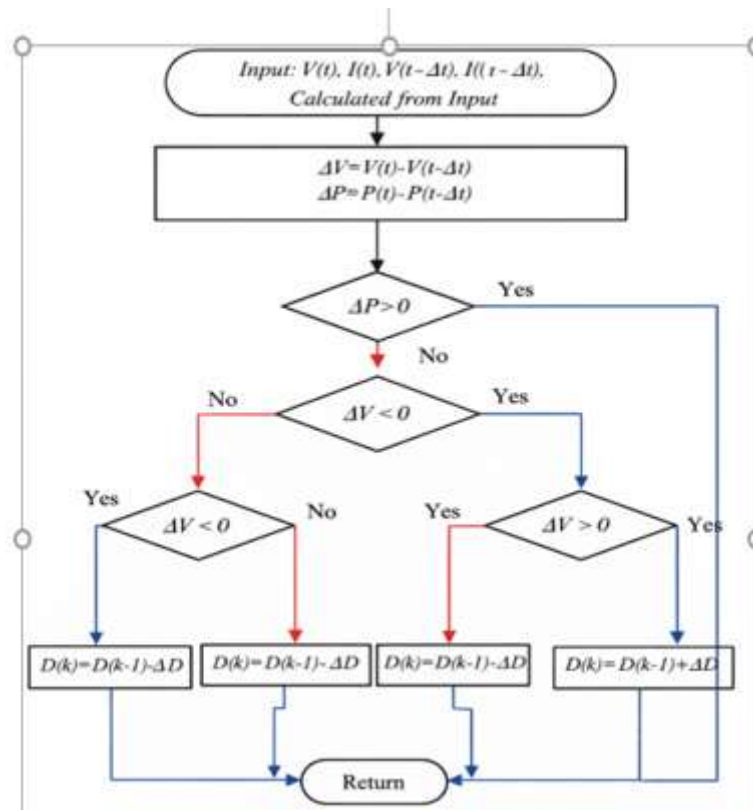


Figure 4. P&O Algorithm Flow Chart

Depending on the signs of ΔP and ΔV , the duty cycle D of the DC-DC converter is changed by ΔD . The algorithm operates continuously, thereby creating oscillations around the MPPT. This strategy guarantees maximum power output in the PV-based power generation system. Likewise, it helps maximize energy production in the wind-based power generation system. The entire process of using the P&O technique is simple and highly effective.

3.4 BI DIRECTIONAL DC-DC CONVERTER

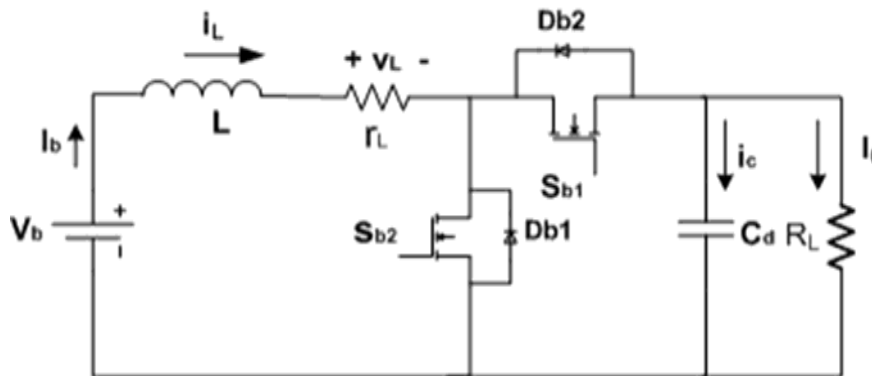
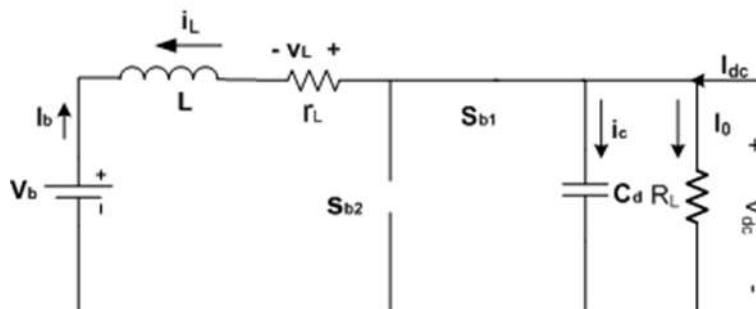


Figure 5. Basic Bi Directional DC-DC Converter

In the proposed model, a bidirectional DC–DC converter is employed to link the battery to the common DC bus. The converter ensures power balance in the microgrid through appropriate regulation based on generation capacity and load demand. Since power generated using solar and wind energy cannot be constant, there must be storage for any excess generated and to provide the necessary power when needed. The converter can either operate in buck or boost mode. During buck mode operation (charging), the output voltage is decreased, and power moves from the bus to the battery. This can be expressed as

$$V_{bat} = D \cdot V_{dc}$$

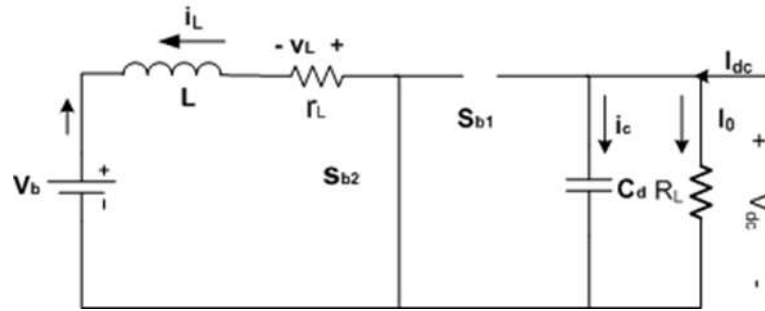
BBDDC in Buck Mode:



Mode1: S_{b1} is ON condition and S_{b2} in OFF condition

$$L \frac{di_L}{dt} = -i_L r_L + v_{dc} - v_b$$

$$C \frac{dv_{dc}}{dt} = -i_L - v_{dc} / R_L + I_{dc}$$



Mode2: S_{b1} is OFF condition and S_{b2} in ON condition

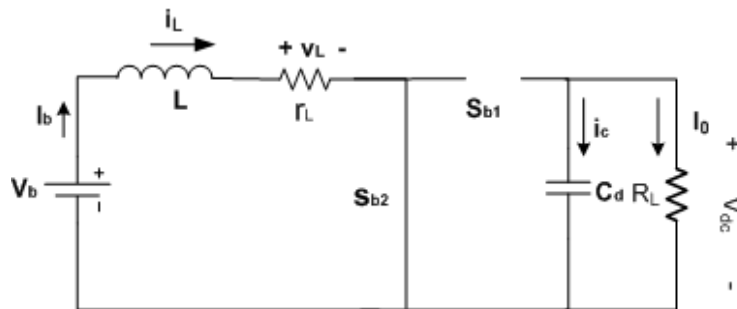
$$L \frac{di_L}{dt} = -i_L r_L + v_b$$

$$C \frac{dv_{dc}}{dt} = -v_{dc} / R_L + I_{dc}$$

During boost mode operation (discharging), the voltage is increased, and energy flows from the battery to the bus. The formula expressing this is given by

$$V_{dc} = V_{bat} / 1-D$$

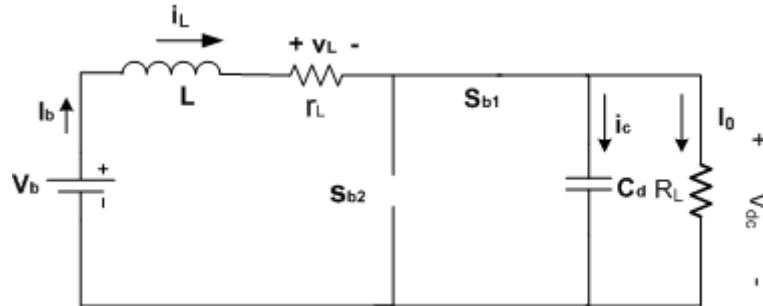
BBDDC in Boost Mode:



Mode1: S_{b1} is OFF condition and S_{b2} in ON condition

$$L \frac{di_L}{dt} = -i_L r_L + v_b$$

$$C \frac{dv_{dc}}{dt} = -v_{dc} / R_L + I_{dc}$$



Mode2: S_{b1} is ON condition and S_{b2} in OFF condition

$$L \frac{di_L}{dt} = -i_L r_L - v_{dc} + v_b$$

$$C \frac{dv_{dc}}{dt} = i_L - v_{dc} / R_L + I_{dc}$$

This type of converter comprises of switches (S_{b1} , S_{b2}), an inductor, and other passive elements which ensure energy transfer through the conversion process. Through appropriate switching action of the switches, energy flow is regulated. For the above processes, a suitable control method should be implemented to ensure that the voltage at the DC bus is regulated at all times.

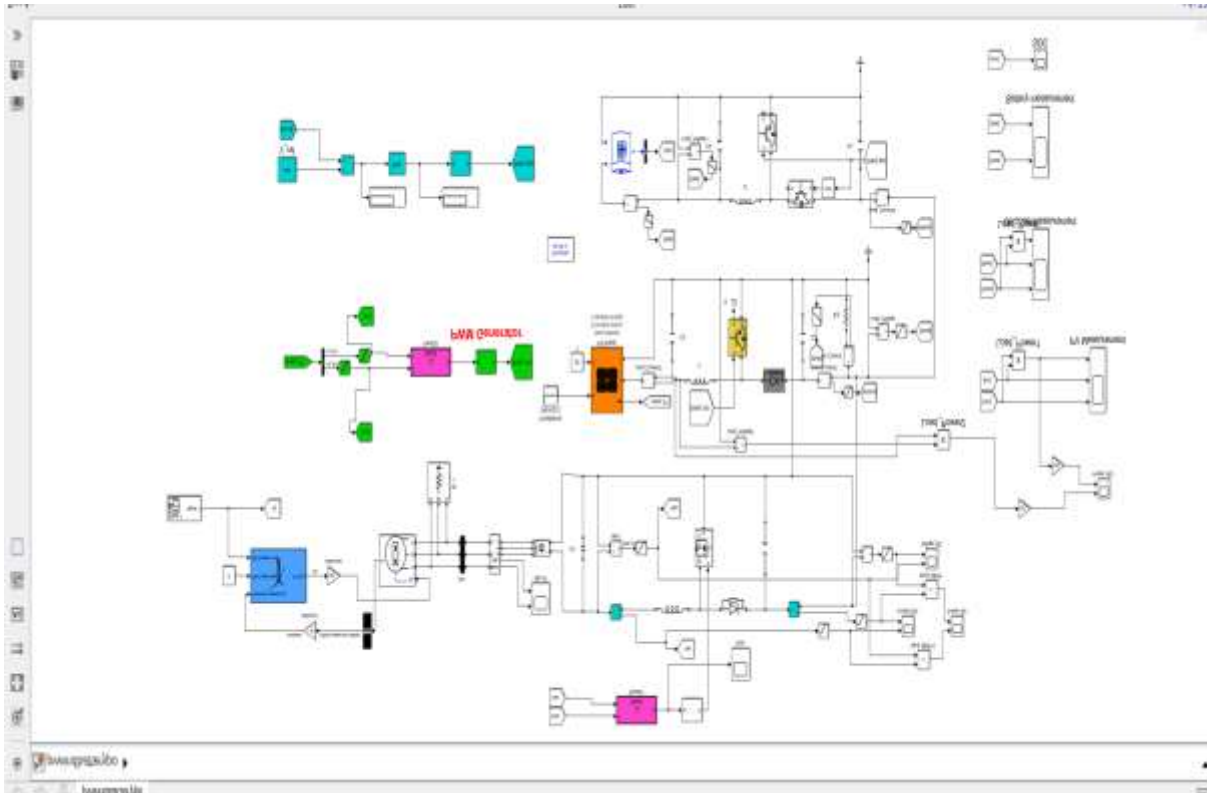


Figure 6. Overall System Simulation

4. SIMULATION RESULTS

The simulation results at different operating conditions are explained below, the Figure 7 shows the simulation results of PV at different irradiation conditions. As shown in the figure, from 0 to 1 s the pv power is 1KW at 1000 w/m². At 1 sec irradiation reduced to 750 w/m², the pv power proportionally reduced to 750 W, at 3 s the irradiation still reduced to 500 w/m² the power reduced to 500W. in all operating time the Dc link voltage is varies when controller is not connected. The voltages are shown in Fig 8.

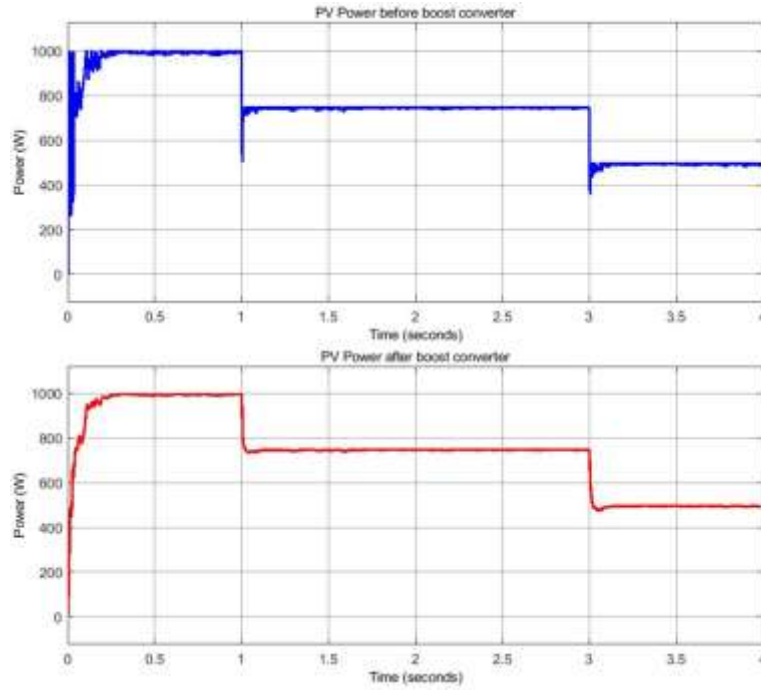


Figure 7. Solar power at different irradianations

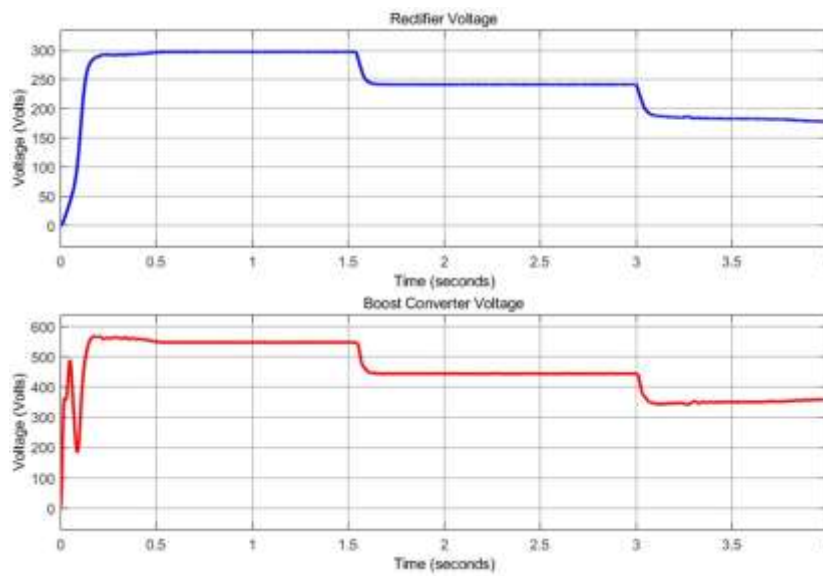


Figure 8. voltages at different irradianations without controller

The same operation is repeated with the controller in figure 9. It shows the voltage is regulated at any operating conditions.

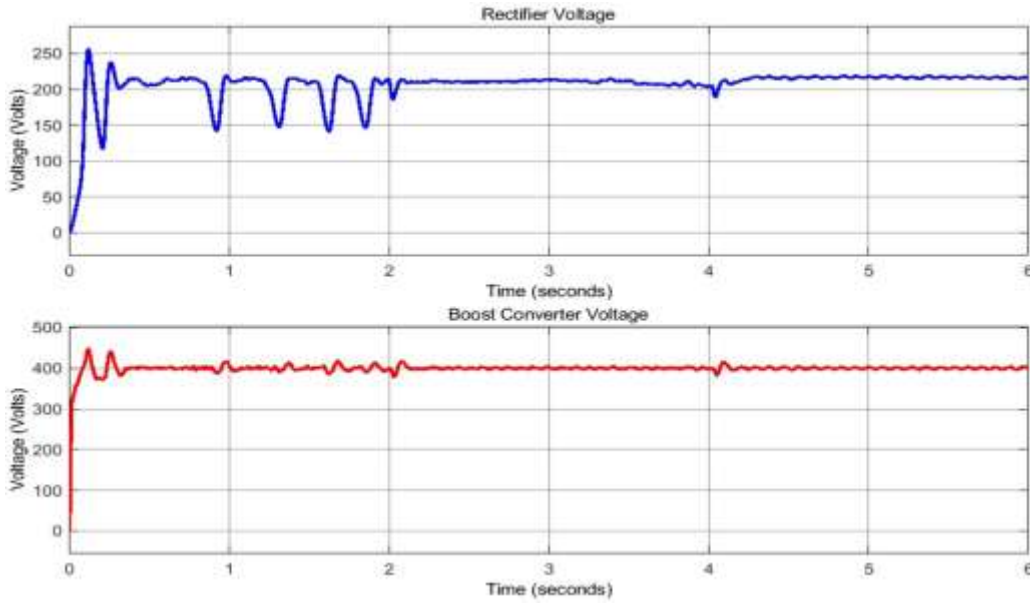


Figure 9. voltages at different irradianations with controller

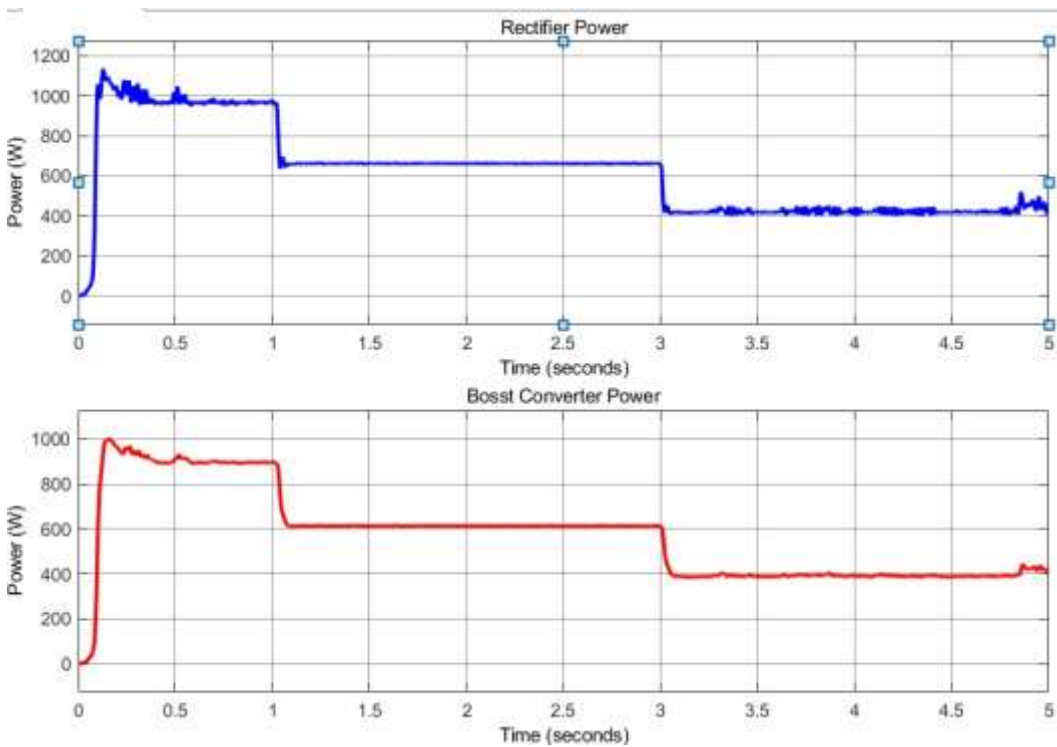


Figure 10. Wind Power at different Wind Speeds

The explanation for the simulation result obtained under different operating conditions is presented below. The simulation results of the rectifier power and boost converter power are shown in Fig. 10. As can be seen from the graph below, from 0 to 1 seconds, the rectifier power is about 1 kW. However, at 1 second, the input condition changes, and there is a reduction in the rectifier power to around 650 W. Again, at 3 seconds, another change in input happens, where the rectifier power is greatly reduced to about 400 W. Just like the rectifier power, the boost converter power also experiences the same changes.

For instance, from 0 to 1 second, the boost converter power is around 950–1000 W. However, at 1 second, the power becomes 600 W, while at 3 seconds, it reduces to 400 W.

5. CONCLUSION

The simulation results of the suggested hybrid DC microgrid system comprising a solar photovoltaic and wind energy system show reliable functionality irrespective of environmental conditions. The design comprises an integrated solar photovoltaic system rated at 1 kW and a wind energy system of 1 kW capacity, controlled by the Perturb and Observe (P&O) Maximum Power Point Tracking controller. Simulation outcomes have proved that the controller is able to track maximum power points regardless of variations in environmental parameters like irradiance and wind speed. The DC-DC boost converters employed in both subsystems play a critical role in regulating and boosting the generated voltage to the required level for the common DC bus. The introduction of the bi-directional DC-DC converter associated with the battery provides a solution for managing electrical energy by allowing both charge and discharge processes. The PI controller sustains constant bus voltage at a reference value of 400 V, despite sudden variations in input/output power. The simulation outcomes clearly show that the combined working of solar, wind, and battery sources guarantees the uninterrupted supply of electricity and the proper sharing of loads. Voltage stability along with minimum power oscillations is maintained by the system, and this can be ensured through optimal control strategy implementation. As a conclusion, we can state that the simulation has justified the effectiveness of the suggested hybrid DC microgrid design for the purpose of renewable energy integration. The DC output stability and increased energy utilization of the system have been demonstrated as well.

6. REFERENCES

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