DESIGNING OF DC GRID SOLAR-WIND HYBRID POWER GENERATION SYSTEM

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Abstract - Our project's main goal is to create a prototype hybrid renewable energy system that mixes solar and wind power. The system's goal is to directly feed energy from the turbine and solar panels into the DC grid. An inverter is also integrated to provide AC power. Our strategy emphasizes efficiency and simplicity by acquiring both AC and DC electricity from the project. Utilizing the complementing qualities of solar and wind energy, we want to develop a dependable and sustainable power generation system. We hope to show that combining renewable energy sources and maximizing energy output for both AC and DC applications is feasible with this creative design.

Key Words: *Dc grid, solar power generation, wind power generation, batteries, hybrid power generation*

1.INTRODUCTION

Our strategy for creating a DC grid solar-wind hybrid power generation. We hope to show the viability and usefulness of hybrid renewable energy systems by carefully designing and integrating the turbine, solar panels, batteries, inverters, and control systems. Our prototype offers a flexible solution that can be adjusted to different infrastructure configurations and energy demands because it offers both AC and DC supply options. Our strategy demonstrates creativity and inventiveness in tackling global energy concerns and clearing the path for a sustainable switch to renewable energy sources as we move closer to a cleaner and more resilient energy future. The combination of solar panels and a wind turbine to harvest energy from both sources is essential to our design. Our method has an advantage over traditional systems, which usually feed energy straight into the grid. It can provide both direct current (DC) and alternating current (AC) electricity. We can effectively convert the DC output from the turbine and solar panels into AC power by incorporating an inverter into the system, which allows for greater compatibility with the electrical infrastructure that is already in place. Our prototype's dual capacity, offering both an AC and DC supply, creates new opportunities for the distribution and use of energy. In addition to its ability to smoothly feed energy into the traditional AC grid, our system provides the option of directly powering DC loads, which maximizes energy efficiency and minimizes conversion losses. Our dedication to maximizing energy efficiency and advancing sustainability in a variety of settings and applications is emphasized by this all-encompassing strategy.

2. SOLAR POWER GENERATION

The sun is the one and only source of nearly all energy consumed on Earth. Solar panels are created by combining photovoltaic (PV) cells. Photo is short for light, while voltaic is the process of producing electricity. Photovoltaic technology facilitates the use of light to create power. A photovoltaic cell is composed of two semiconductor layers, one positive charged and the other negative charged. Electricity flows through the semiconductor when sunlight strikes its junction between these two layers because of the electric field that results from it. The flow of electricity will be stronger the more intense the light is. PV panels may be used in a variety of ways. Installing the PV tiles that took the place of the traditional tiles is simple. Figure 1.1 illustrates how to install anything. They are installable clean power is produced by the panels using the light that strikes them. There are no moving parts, therefore this procedure is

Fig- 2.1: Solar panel installation process quiet. Direct current is the form of power produced by the panels. The solar energy that is accessible varies according on one's location.

2.1 TYPES OF SOLAR CELLS

A solar cell, also known as a photovoltaic cell, is a device that uses the photovoltaic effect to directly convert light energy into electrical power. Silicon is used in the manufacturing of solar cells. As seen in Figure 2.2, they are divided into three categories according to the kind of silicon material: mono crystalline, polycrystalline, and amorphous silicon cells. Every material has a unique set of operational characteristics, including cost, availability, efficiency, design, and size.

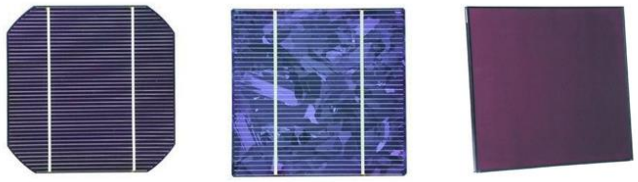


Fig-2.2: Mono crystalline Silicon Cell, Polycrystalline Silicon Cell, Amorphous Silicon Cell

- **Mono crystalline cell:** One silicon crystal is used to create mono crystalline cells. In essence, they are cut from a crystal. These are the most costly to create but also the most effective. 10% to 12% is the typical module efficiency. These are often employed in several applications.
- **Poly crystalline silicon cell:** Polycrystalline, also known as multi crystalline, cells are essentially slices taken from a silicon block that has several crystals in it. Compared to mono crystalline cells, these cells are somewhat less costly and slightly less efficient. The "poly-crystalline" cells function well in low light and on the east and western roof surfaces because of their multifaceted surface. They also produce a lot more electricity per square meter of area, which is another benefit. 10% to 11% is the typical module efficiency.
- **Amorphous silicon cell:** A thin layer of amorphous (non-crystalline) silicon is applied to a variety of surfaces to create amorphous cells. Out of the three varieties, they are the least expensive and least effective to create. The solar panel's flexibility stems from the thin film's amorphous structure. Their very cheap cost per watt of power generated is a significant benefit. Yet, their lower power density can make up for this. For the same power output, more panels are required, which requires more space. The efficiency of a module is between 5% and 7%.

2.2 PHOTOVOLTAIC ENERGY CONVERSION

Sunlight may be converted into electrical energy using a photovoltaic system. The central part of a photovoltaic system is the photovoltaic cell. PV cells may be assembled into modules or panels. Solar arrays are created by assembling modules with many cells linked in parallel or series. The output voltage increases when the panels are linked in series, while the output current increases when the panels are connected in parallel. Semiconductor materials are used to make solar cells. A solar cell produces energy when it is exposed to sunlight. The semiconductor material in the photovoltaic cell absorbs the energy that a photon, or particle of light, brings with it. When the electrons are struck by that energy, they are free to move about. Between the PV cells' positive (P-type) and negative (N-type) layers, an electric field is produced. The free electrons are then compelled by this electric field to flow via a connected wire in a certain direction as direct current (DC) electricity. Figure 2.3 shows the conversion process in its entirety.

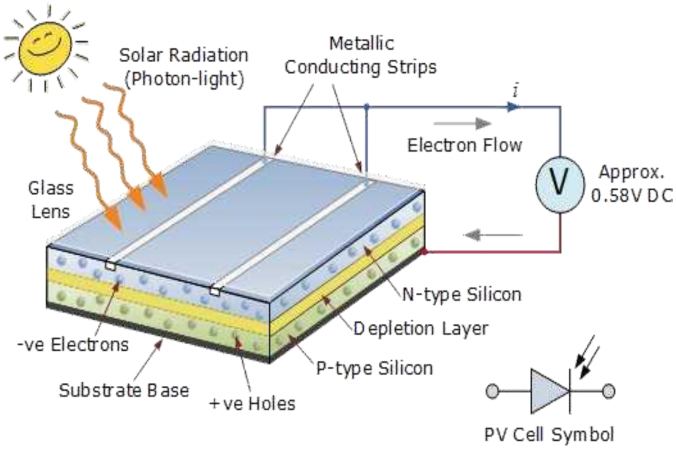


Fig-2.3: Photovoltaic Cell

A PV array system's performance is contingent upon its working environment, as well as the quality of the solar cell and array design. The output current, voltage, and power of a photovoltaic array vary with temperature and sun radiation. Thus, these factors must be taken into account while building the PV array in order to ensure that variations in temperature and radiation will not have an impact on the output, which may be linked to a grid or other kind of standalone electrical load.

2.3 CHARGE CONTROLLER

In order to maintain the voltage output of the solar panels within safe bounds for battery charging, the charge controller monitors and controls it. By doing this, overcharging is avoided, which can shorten battery life and present safety risks. It ensures that the battery receives the ideal charging current by regulating the current that flows from the solar panels to the battery. This protects the battery from harm from high current flow while maximizing the charging process' efficiency. In order to preserve the battery from harm and increase its longevity, charge controllers frequently include functions like temperature adjustment, deep discharge prevention, and overcharge protection. In certain systems, the charge controller may also control how electricity is distributed to linked loads. This keeps the battery from being excessively discharged by ensuring that power is only applied when there is enough energy available.

2.4 BATTERY

Seal-free, maintenance-free valve-regulated lead-acid (VRLA) batteries are widely employed in a variety of applications. They are spill-proof and appropriate for usage in small areas since they employ a recombination process that eliminates the need for the addition of water. There are two primary varieties of VRLA batteries: Gel and Absorbent Glass Mat (AGM). Gel batteries employ a silica-based gel, while AGM batteries use fiberglass mats to absorb and immobilize the electrolyte. For usage in telecommunications, UPS systems, renewable energy storage, and automobiles, among other applications, VRLA batteries provide dependable performance and a high energy density.

2.5 BLOCK DIAGRAM OF SOLAR POWER GENERATION

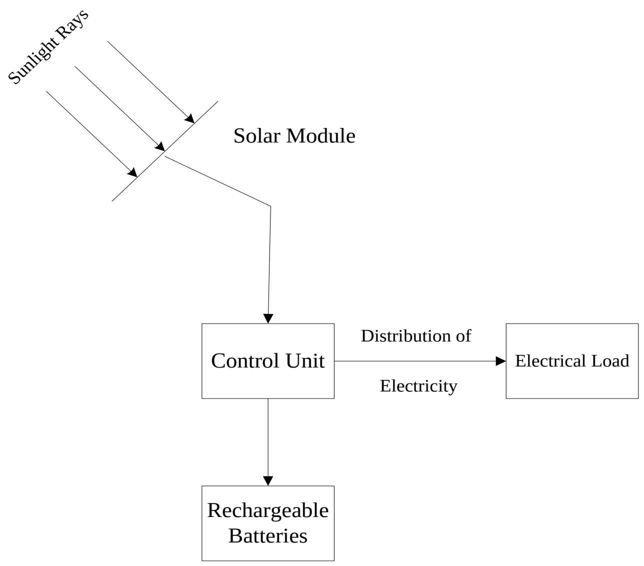


Fig 2.4: Solar Power Generation System

The figure 2.4 shows the block diagram of solar power generation system. Sunlight is absorbed by the solar module, which then turns it into DC power. In situations where there is surplus power, the charge controller directs the flow of electricity to the battery for storage. Even in the absence of sunshine, there is always a power source since the battery stores the electricity for later use. When power is required, the battery's stored energy can be utilized to power DC appliances via switches or, in the event that an inverter is required, it can power electrical appliances by converting the DC electricity into alternating current (AC) that is suited for residential use. A sustainable and dependable supply of electricity for a range of uses is made possible by this integrated system, which makes it possible to efficiently catch, store, and use solar energy.

2.6 SOLAR POWER CALCULATION

The following formula may be used to determine a solar panel's power production at various irradiances:

$$\text{Power Generation} = \text{Panel Area} \times \text{Solar Irradiance} \times \text{Panel Efficiency}$$

Where,

- The total power produced by the solar panel is known as Power Generation.
- The solar panel's overall area, measured in square meters, is called Panel Area.
- The quantity of solar radiation that reaches the panel's surface is known as solar irradiance.
- Panel efficiency is the solar panel's capacity to convert light from the sun into electrical power.

This formula estimates the solar panel's power generation capability under various sun intensity levels by taking into account the panel's area, efficiency, and solar irradiance.

Efficiency Calculation

Solar panel efficiency is calculated by comparing the power output of the solar panel the amount of sunlight it receives. The efficiency expressed as a percentage and determined using the following formula:

$$\text{Efficiency} = \left(\frac{P_{max}}{Area} \div 1000\right) \times 100$$

where,

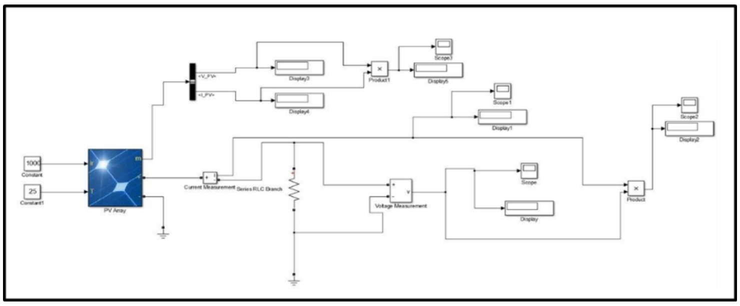
- P_{max} is the maximum solar panel power in watts
- $Area$ is the length multiplied by the width of the solar panel in square meters

For Example: If a solar panel has a maximum power output of 160W and a surface area 2 m^2, the efficiency calculation would be:

$$\text{Efficiency} = \left(\frac{160W}{2m^2} \div 1000\right) \times 100 = 8\%$$

This means that the solar panel can convert 8% of the sunlight that hits it into electricity. Solar panel efficiency is a crucial factor in determining the performance and effectiveness of solar energy systems.

2.7 SIMULATION DIAGRAM OF SOLAR POWER GENERATION SYSTEM



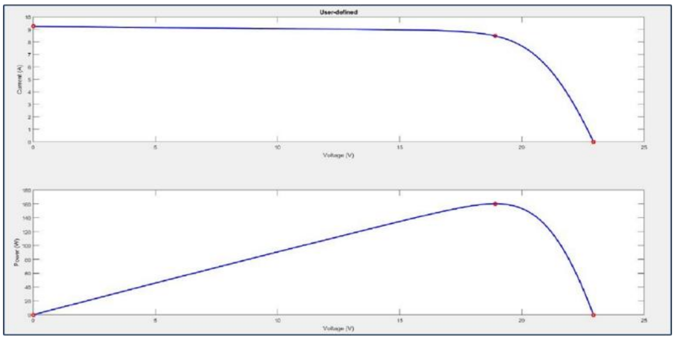


Fig-2.5 I-V &P-V Characteristic of solar module

3 WIND POWER GENERATION

One type of solar energy is wind. Because of the sun's uneven heating of the atmosphere, wind flows. The characteristics of the earth's surface, bodies of water, and vegetation serve as the design factors for wind flow. Modern wind turbines use this motion or wind flow energy to transform kinetic energy into mechanical power. Sometimes, domestic chores like pumping water or grinding grain are done with the use of mechanical power. Typically, a generator is employed to transform this mechanical energy into electrical power for use in small-scale domestic or large-scale utility applications, such as powering homes, schools, farms, or businesses.

Wind turbines are classified as,

- Horizontal-axis wind turbine (HAWT)
- Vertical-axis wind turbine (VAWT)

Horizontal-axis wind turbine (HAWT): The blades of these turbines are positioned perpendicular to the direction of the wind on a horizontal axis. When it comes to wind turbines utilized for utility-scale applications, HAWTs are the most popular kind. Usually utilized for modest commercial, agricultural, or residential purposes. Small wind turbines are intended for dispersed energy generation and typically have a capacity of less than 100 kW. Onshore wind turbines are the most popular variety and are commonly utilized to generate power when installed on land.

Fig-3.1: Horizontal and Vertical axis Wind Turbine

Vertical-axis wind turbine (VAWT): The blades in VAWTs revolve on a vertical axis. Although less prevalent, VAWTs provide benefits in specific situations, such as in cities or areas with strong winds. These turbines are utilized in wind farms to generate grid-connected power and are significantly bigger. The capacity of utility-scale turbines can range from several megawatts (MW) to a few hundred kilowatts. Offshore wind turbines, as opposed to onshore turbines, are installed in bodies of water and capture stronger and more steady winds. Although they may need more space and money to build, offshore turbines have the capacity to produce more electricity.

3.1 GEAR BOX

In many different sectors, gearboxes are crucial for power transfer and speed control. They transmit power from engines to wheels in automobiles, allowing for smooth acceleration and economical fuel use. Gearboxes in heavy machinery, machine tools, and conveyor belts allow industrial machinery to operate precisely by controlling torque and speed. They are also essential to renewable energy systems, such as hydroelectric and wind turbines, since they adjust rotating speeds to provide the most power. All things considered, gearboxes are essential to a great number of mechanical systems since they enable regulated power transmission to satisfy various operational requirements.

3.2 PERMANENT MAGNET SYNCHRONOUS GENERATOR

An electrical generator that uses permanent magnets to generate alternating current (AC) power is known as a permanent magnet synchronous generator (PMSG). Due to their efficiency, minimal maintenance requirements, and dependability, PMSGs are widely used in hydroelectric and wind power systems, among other renewable energy applications. They support sustainable energy generation by transforming mechanical energy from wind or water into electrical power. In order to maximize performance, PMSGs frequently include sophisticated control systems and provide constant output, which is especially important for fluctuating energy sources. Because of their construction, which uses permanent magnets rather than electromagnets, they are dependable and effective options for a range of renewable energy uses.

3.3 RECTIFIER

An electrical circuit called a full bridge rectifier is used to change alternating current (AC) into direct current (DC). The term "full bridge" refers to the configuration of its four diodes, which are arranged in a bridge. When compared to half-wave rectifiers, the circuitry produces a more efficient conversion by allowing the utilization of both halves of the AC waveform.

The bridge rectifier smoothes out the output voltage by ensuring that current flows through the load in a single direction when an AC input is provided. Power supply, battery chargers, and other devices needing DC power from an AC source frequently employ full bridge rectifiers.

3.4 BLOCK DIAGRAM

The Above figure 3.2 shows the wind power generation system. Utilizing wind energy to generate electricity is known as wind power production, and critical components such as a gearbox, permanent magnet generator, and full bridge rectifier play crucial roles in this process. The gearbox maximizes power generating efficiency by raising the rotor's rotating speed to meet the demands of the electrical generator.

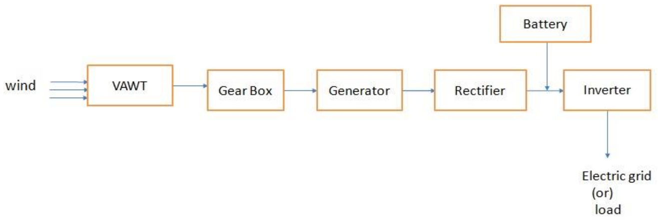


Fig- 3.2: Block Diagram of Wind Power Generation

The permanent magnet generator uses magnets instead of rotor coils and slip brushes to convert wind energy into electricity, simplifying the design. In addition, the complete bridge rectifier ensures a constant flow of current in one direction for a variety of applications by converting the wind turbine's alternating current (AC) into a steady direct current (DC) output. These elements cooperate well to effectively capture wind energy, supporting clean and sustainable.

Wind Power Calculation

The following formula may be used to determine a wind turbine's power generation at various wind speeds:

$$p = \frac{1}{2} C_p \rho A V^3$$

Where,

C_p = Power coefficient, which represents the efficiency of the turbine (typically between 0.25 to 0.45 for a well-designed turbine.

ρ = Air density in our locality the air density at specific location can vary based on factors like altitude temperature and humidity the general approximate air density at sea level is 1.225kg/m^3.

A = Swept area of the turbine blades $A = \pi r^2$.

V = Wind speed in our locality.

This formula shows the relationship between the wind speed cubed, the efficiency factor, air density, and the rotor's swept area and power output of a wind turbine. The cubic connection between wind speed and power output means that when wind speed increases, the wind turbine's power production increases proportionally.

4.SOLAR- WIND HYBRID POWER GENERATION SYSTEM

A renewable energy system known as hybrid solar-wind power generation produces electricity by combining solar photovoltaic (PV) panels with wind turbines. Because solar and wind resources can peak at various times of the day or under different weather conditions, this strategy takes use of their complimentary characteristics. In comparison to standalone systems, hybrid solar-wind installations can produce power production that is more consistent and dependable since they combine these two technologies into a single unit. Combining solar and wind power generation may also optimize infrastructure and land usage, which makes it a desirable alternative for off-grid, isolated, or places with varying energy needs. In order to effectively manage the hybrid system and guarantee optimal usage of the available renewable energy supplies, advanced control systems are frequently utilized.

4.1 BLOCK DIAGRAM OF SOLAR-WIND HYBRID POWER GENERATION

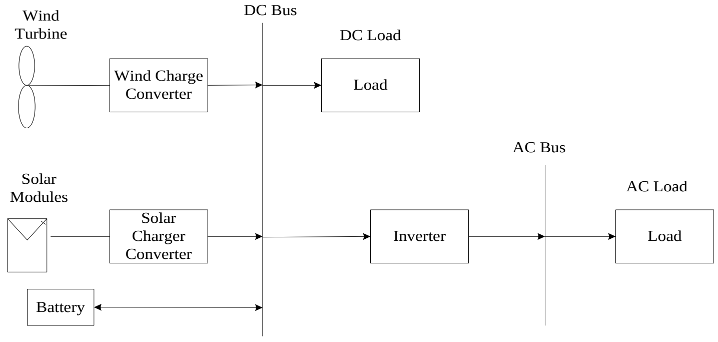


Fig- 4.1: Solar- Wind Hybrid Power Generation System

The Above Figure 4.1 shows the solar-wind Hybrid power generation system and the components are explained below:

DC BUS

The DC bus is a primary conductor for direct current in electrical systems, which makes it easier to distribute power between loads like motors or renewable energy sources and components like rectifiers and inverters. It serves as a connection between power sources and loads, facilitating the bidirectional flow of energy. Whether used in UPSs, motor drives, or renewable energy systems, the DC bus facilitates effective power transfer by switching between AC and DC as necessary. Depending on the need, voltage levels might range from low for automobile electronics to high for industrial or grid-connected systems. In many different systems, the DC bus serves as the foundation for the interchange of electrical power.

GRID-TIE INVERTER

An "alternating current" (AC) supply is often created from a DC (direct current) source using an inverter known as a "grid-tie inverter." Grid-tie inverters are made to match the voltage and frequency of the utility grid. They transform DC electricity produced by batteries or solar panels into AC power that complies with grid specifications. This makes it possible to feed the produced power back into the utility grid for usage by other customers or as a way to reduce the amount of electricity used. Maximum power point tracking (MPPT) is one of the characteristics that grid-tie inverters frequently include to maximize power output from renewable energy sources and guarantee effective conversion. They also have safety measures that allow you to cut off from the grid in the event of maintenance or a malfunction. Grid-connected solar photovoltaic (PV) systems and other renewable energy installations that require the conversion of DC electricity into AC power for usage in residences, commercial buildings, and the utility grid frequently employ these inverters.

AC BUS

In the field of electrical engineering, an AC bus serves as the hub connecting loads, transformers, and generators in a power system. It makes it easier for customers to get alternating current (AC) from power suppliers. Power is produced at power plants, transferred via high-voltage wires, reduced in voltage at substations, and sent to the AC bus. From then, lines are used to deliver it to loads. The effective and dependable distribution of electrical energy to residences, companies, and industries is ensured by this configuration. For the purpose of maintaining system stability, controlling power flow, and balancing electrical distribution networks, the AC bus is essential.

Benefits of solar-wind hybrid power generation

- **Reliability:** Combining wind and solar allows for a consistent supply of electricity since one source can make up for periods when the other is less productive due to weather.
- **Maximized Energy:** By using wind power during the night or during periods of low sunshine, the system more effectively harvests energy from both sources.
- **Stability:** The hybrid system produces a more steady total energy production by counteracting the erratic nature of each source.
- **Effective Land utilization:** When solar and wind turbines are combined, land utilization is maximized, particularly in locations with restricted space.
- **Diversified Investment:** Compared to depending just on one energy source, investing in a hybrid system distributes risk and may yield more reliable profits.
- **Environmental Benefits:** By utilizing solar and wind power, hybrid vehicles lower greenhouse gas emissions and advance sustainability.

4.2 GRID

The linked system of power lines, substations, transformers, and other machinery that transports and distributes energy from power plants to customers is referred to as a "grid" in the context of electricity. To guarantee that energy can flow effectively from where it is created (like power plants) to where it is required (like homes, companies, and industries), it is like a massive network of wires. We may utilize electrical equipment anytime we need to because the grid guarantees a steady supply of power to fulfill consumer demand.

5 RESULT ANALYSIS

The solar-wind hybrid power generation system was designed with the help of solar panel, charge controller, battery, vertical axis wind turbine (VAWT), gearbox, permanent magnet generator (PMG) and rectifier. By considering synchronizing techniques the dc power was fed to the DC bus for regulate output stability with power conditioning, continuously optimize for efficiency and performance. After that by connected switches, the DC power can be used for the appliances like Smart phones, Computers and Laptops. By using grid-tie inverters the DC power can be converted into AC power, the ac power again fed to the AC bus for providing the effective and dependable distribution of electrical energy to residences, companies, and industries.

Table 1: Calculation of solar module output power at different irradiation

S. No	Solar irradiation (W/m^2)	Output power (watts)
1	600	96
2	700	112
3	800	128
4	900	144
5	1000	160

Hence, this system produces power from solar and wind energy together, making it a dependable and sustainable source. It's an easy method of producing sustainable energy and lowering dependency on fossil fuels.

6. CONCLUSION

The goal of our research is to create a hybrid renewable energy system prototype that combines wind and solar electricity. With an integrated inverter providing AC power, the main goal is to directly feed energy from the turbine and solar panels into the DC grid. Our approach focuses on obtaining both AC and DC electricity from the system, giving efficiency and simplicity top priority. Our goal is to develop a dependable and environmentally friendly power generation system by utilizing the complementing qualities of wind and solar energy sources. We hope to show that it is possible to combine renewable energy sources to maximize energy production for both AC and DC applications with this creative design.

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