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Comparative Study of Energy Generation from a Hybrid Vertical-Axis wind Turbine

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Abstract: *The project "Design and Development of Energy Generation System" discusses a hybrid solution to renewable energy by combining wind, hydro, and solar power in one system. The structure consists of a vertical axis wind turbine (VAWT) on top, a Pelton hydro turbine at the bottom, and a solar panel placed above—the three sources of energy work together to produce electricity effectively using a shared power management unit.*
The system enables the selective use of the wind or hydro turbine based on environmental factors. An interchangeable mechanism facilitates switching between the two turbines, and a DC pump is employed for pressurized water flow simulation in the hydro system. The energy produced is stored in a battery and converted for viable use, with a USB charging output and an LED power generation status indicator.
This project showcases a novel and versatile energy harvesting system, maximizing multiple renewable sources for round-the-clock power generation. It is a functional prototype of sustainable energy technology and shows the potential of hybrid systems in actual use.

Keywords: Vertical Axis Wind Turbine, Solar Photovoltaic Panel, Battery Charging, Sustainable Energy, Low Wind Speed Operation

I. INTRODUCTION

This project, "Design and Development of Energy Generation System," is designed to combine these three renewable sources into one hybrid system that can tap energy from wind, running water, and the sun. With the combination of these energy sources, the system optimizes power generation efficiency and provides a continuous supply of energy even when one source is not available or not enough

The system proposed includes a vertical axis wind turbine (VAWT), a Pelton hydro turbine, and a solar panel mounted on the same structure. The VAWT is mounted at the top of the system to harvest wind energy using PVC blades and MDF discs to transmute the energy in wind into motion—the Pelton turbine at the bottom harvests mechanical power using the high-pressure flow of water. A 12V DC pump is used to supply pressurized water as an example of hydro power generation. The solar panel installed at the top of the system also increases energy generation by collecting sunlight and converting it into electricity.

Renewable energy resources are highly important because of the growing need for sustainable and green power production. Conventional sources of energy like fossil fuels are dwindling at a very fast rate, resulting in the demand for new options that are efficient, affordable, and sustainable. Of the different renewable energy resources, wind, hydro, and solar energy are good alternatives because they are widespread and capable of producing clean energy

SCOPE

The scope of this project encompasses the design, development, and performance evaluation of a hybrid renewable energy system that integrates a Vertical Axis Wind Turbine (VAWT) with a solar photovoltaic (PV) panel. The primary goal is to create a compact, efficient, and reliable power generation unit capable of supplying energy for applications such as battery charging and electric vehicle (EV) charging, especially in areas with limited or no access to conventional power grids.

Key areas covered in the scope include:

Design and Fabrication

Energy Management and Storage

Application Focus

Performance Evaluation

This project is not intended to replace large-scale grid systems but rather to demonstrate the viability of small-scale hybrid energy solutions that can supplement existing infrastructure or operate independently in remote or eco-conscious settings.

II. METHODOLOGY

The methodology of this project involves a systematic approach to designing, fabricating, and testing a hybrid energy generation system that integrates wind, hydro, and solar power. The process includes component selection, system assembly, integration of energy sources, and performance evaluation. The methodology consists of:

1. Conceptual Design and Planning - The first step involved identifying the key components required for the hybrid energy system. A vertical axis wind turbine (VAWT) was selected for wind energy conversion, a Pelton turbine was chosen for hydro energy generation, and a solar panel was included for additional power input.

2. Component Selection and Fabrication - The next step was selecting suitable components based on performance requirements and availability.

3. Integration of Power Sources - To ensure efficient energy generation, all three power sources were connected to a common power management unit. The system was designed to function in the following modes:

- Wind Mode: When sufficient wind is available, the VAWT rotates, transferring mechanical energy to the dynamo via the common shaft.
- Hydro Mode: When water is available, the Pelton turbine operates, and the wind turbine can be disengaged using a shaft locking mechanism.
- Solar Mode: The solar panel continuously contributes to power generation, supplementing the other two sources.

4. Testing and Performance Evaluation - Once assembled, the system underwent testing to evaluate its efficiency and functionality.

5. Optimization and Final Implementation - Based on test results, adjustments were made to improve system performance

III. LITERATURE REVIEW

Several studies and research works have been conducted on renewable energy systems, hybrid energy generation, and power management techniques. This literature review provides an overview of existing research related to wind, hydro, and solar energy integration and highlights the key findings relevant to this project.

1. Hybrid renewable energy systems: a review

A study by Patel et al. (2021) explores the integration of wind, solar, and hydro energy for efficient and sustainable power generation. The research highlights the advantages of hybrid systems over standalone renewable energy sources, emphasizing improved reliability and energy output. The study concludes that hybrid energy systems can effectively provide continuous power, even in varying environmental conditions.

2. Vertical-axis wind turbines for small-scale applications

Research by Kumar and Singh (2020) investigates the use of vertical-axis wind turbines. for urban and residential power generation. The study compares with horizontal-axis wind turbines, showing that are more efficient in low-wind-speed environments and require less maintenance. This research supports the use of a in the proposed project to maximize energy capture in various wind conditions.

3. Performance analysis of Pelton turbines for small hydro power plants

A paper by Sharma et al. (2019) discusses the efficiency of Pelton turbines in hydro power applications. The study analyzes factors such as water jet pressure, nozzle design, and bucket shape that influence power generation. The findings indicate that Pelton turbines are well-suited for small-scale hydroelectric systems, making them a viable option for the proposed hybrid system.

4. Integration of solar power in hybrid energy systems

Gupta and Verma (2018) explore the role of solar photovoltaic (PV) systems in hybrid renewable energy models. The research explains how solar panels provide a stable energy source during the day and complement wind and hydro power generation. This study supports the inclusion of a 12V solar panel in the hybrid system to ensure a continuous power supply.

5. Energy storage and power management in hybrid renewable systems

A study by Choudhary et al. (2020) discusses various energy storage solutions for hybrid systems, such as batteries, supercapacitors, and power converters. The paper highlights the importance of efficient energy storage to manage fluctuations in renewable energy sources. This research justifies the use of a 12V 1.3Ah battery and an AC to DC converter in this project to stabilize power output.

6. Experimental study on wind and hydro hybrid power systems

An experimental analysis by Rao et al. (2017) evaluates the feasibility of combining wind and hydro turbines on a single shaft to generate power. The results indicate that mechanically coupling both turbines to a shared dynamo improves overall efficiency. This supports the project’s approach of using a common dynamo shaft for both the wind and hydro turbines.

7. Role of DC pumps in small-scale hydro power generation

A research paper by Desai and Mehta (2021) examines the use of low-voltage DC pumps to simulate water flow in small hydro power demonstrations. The study confirms that 12V DC pumps are effective in generating pressure for Pelton turbines, making them a suitable choice for controlled hydro power demonstrations in this project.

8. Advancements in hybrid renewable energy for rural electrification

Singh et al. (2022) discuss the potential of hybrid renewable energy systems in providing electricity to rural and remote areas. The study emphasizes the importance of low-cost, easy-to-maintain energy solutions and highlights case studies where hybrid wind, solar, and hydro systems have successfully powered small communities. This research aligns with the objective of the proposed project, which aims to develop a cost-effective and scalable hybrid energy system

IV. WORKING

The Design and Development of Energy Generation System operates on the hybrid renewable energy generation principle by integrating wind, hydro, and solar power into a single system. The working mechanism involves multiple energy sources connected to a common power management unit, ensuring continuous energy generation under varying environmental conditions.

1. Wind Energy Generation: The system includes a Vertical Axis Wind Turbine (VAWT), which consists of six half-cut PVC blades mounted on a 20mm central shaft between two MDF discs (28 cm diameter). When the wind blows, the VAWT rotates, transmitting mechanical energy to the dynamo (AC synchronous motor) through the common shaft. The dynamo converts rotational motion into electrical energy, which is processed through a power conversion circuit. There is no operational cost and no fuel cost, which results in minimal greenhouse gas emissions. this has led to the global

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adoption of wind energy. Countries such as the US, China, and Germany are at the forefront of this adoption. Wind farms vary in size and can be used to power individual homes and whole communities. Wind energy offers diverse energy sources that enhance energy security and reduce reliance on fossil fuels. Wind energy further provides economic growth to rural farmers through land lease incomes, along with new job opportunities in the installation and maintenance of these turbines. While there are many advantages, wind energy still has some disadvantages, which include the variability of wind speed. Wind energy utilizes kinetic force harnessed by the wind in an eco-friendly approach, which is renewable. This is achieved through wind turbines, which transform kinetic force into electrical power. These turbines primarily consist of huge rotor blades fixed on a towering casing. Wind current causes the blades to rotate, which spins the shaft coupled with the generator, leading to the production of electricity. Wind energy systems can either be installed offshore or onshore, with offshore farms receiving stronger winds on a more regular basis.

2. Hydro Energy Generation (Pelton Turbine: A Pelton turbine is mounted on the same dynamo shaft but with a detachable coupling. A 12V DC pump is used to create a pressurized water flow from the blue plastic storage tank mounted at the base of the system. When the pump is activated, the water jets strike the Pelton turbine buckets, causing them to rotate. The shaft engagement mechanism allows either the wind turbine or the Pelton turbine to drive the dynamo, depending on the available energy source. If wind energy is dominant, the Pelton turbine is disconnected by loosening the bolt. Conversely, when hydro power is used, the wind turbine can be disengaged to prevent resistance. Water's kinetic energy can be converted into electricity through turbines and generators in the form of renewable energy known as generation or hydroelectric power. Dams built on streams and rivers are flooded to create reservoirs, which are an initial source of hydroelectric power. Also, release control dams,
run-of-river plants, pumped storage plants, and off-river hydroelectric plants specialize in keeping energy reserves in the form of moving water by releasing it from reservoirs at various levels. Countries like Norway, Canada, and Brazil serve as leading users showcasing abundant resources of water while riding into the green hydroelectric energy, making it the primary electricity source in Canada and Brazil, both of which benefit from modern can hydro-syphon farming and off-grid river hydro electricity. Peru, alongside Brazil, is powering up their national grid utilizing primary and central grid reserves. Other countries, like Norway, can power units in uninhabited areas, supporting local satellite farming, showing off-grid power autonomy. Smaller systems support stable baseload power, keeping the grid fed continuously while quick hunger gaps are easily allowed via adjustable output on demand. And off-grid systems to smaller stationary units supporting industrial work. plays an important role wherein lies integrated water management, construction irrigation, and aid towards municipal water supply and flood control. Additionally, pumped-storage hydro plants act like batteries on a bigger scale.

3. Solar Energy Generation: The process of converting sunlight into usable energy is called solar energy generation. This can be in the form of electricity or even heat. The method most widely used to generate electricity from sunlight is through photovoltaic (PV) systems. Such systems employ solar panels that contain semiconductor materials, which usually comprise silicon, to soak up sunlight and change it to direct current, also called (DC) electricity. An inverter alters the direct current; nowadays, most homes and businesses run on alternating current (AC) electricity, hence the DC electricity would need ‘changing’. Some systems are made with batteries so energy can be used when sunlight is not available. Mirrors or lenses can be used to focus sunlight onto a smaller area to produce heat, this is where the steam is created to drive the turbine responsible for electricity generation as well. This latter method is referred to as concentrated solar power (CSP). In addition, solar thermal systems are capable of capturing sunlight to heat water or air directly, which can then be used domestically or in industry. Solar energy stands out due to its being cleaner in comparison to other sources of power. Furthermore, there are no emissions, and the electricity bills would be greatly reduced, which is always an added benefit alongside minimal maintenance.

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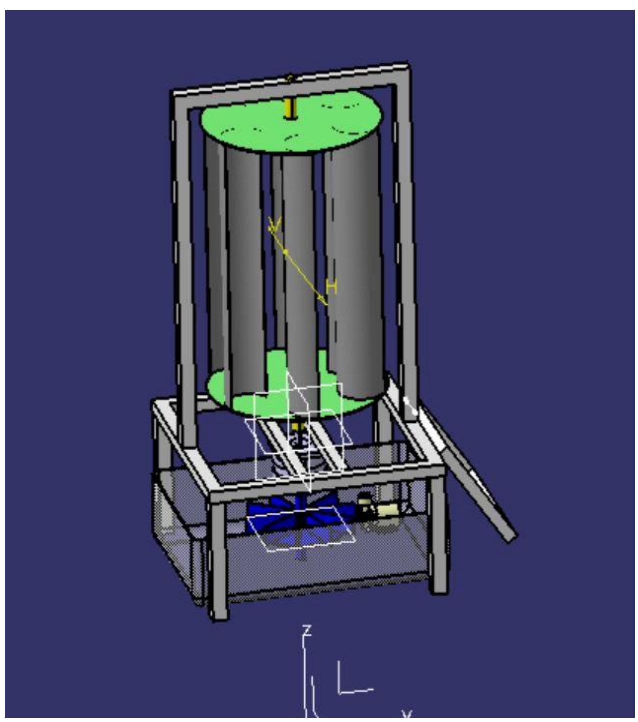
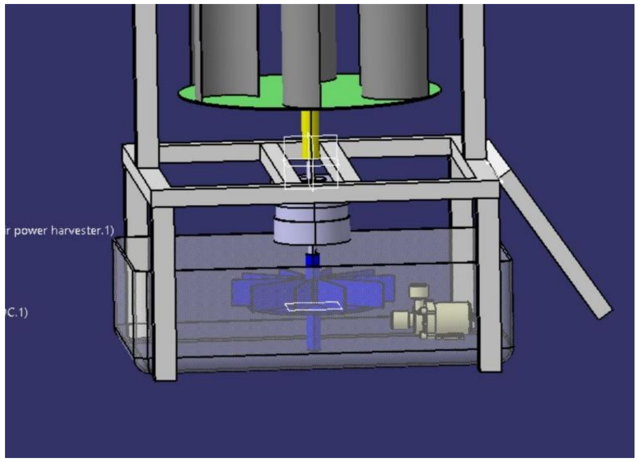
V. RESULT

Our hybrid vertical-axis wind turbine system, though producing less power from wind alone, achieves a balanced and efficient energy output by integrating solar and hydro energy. It is well-suited for remote, off-grid, or portable Applications where reliability and diversity of energy input are more valuable than peak wind-only performance.

Feuture	Conventional Wind Turbine	Hybrid Vertical Wind Turbine
Wind Power Output	10–50 W	≈ 0.94 W
Additional Power Sources	None	Hydro + Solar
Total Usable Power	~ 10–30 W	≈10.7 W
Energy Reliability	Low (depends on wind only)	High (multi-source input)
Maintenance & Suitability	Needs orientation mechanism	Simple, omnidirectional
Application Potential	Limited to wind-rich areas	Works in mixed environments





VI. CONCLUSION

The designed Energy Generation System successfully integrates wind, hydro, and solar power to provide a sustainable and efficient hybrid energy solution. By utilizing a vertical-axis wind turbine, a Pelton hydro turbine, and a 12V solar panel, the system ensures continuous power generation in diverse environmental conditions. The combination of these renewable sources enhances reliability and efficiency, making it suitable for off-grid applications and remote areas.

The project demonstrates the feasibility of hybrid renewable energy systems by efficiently combining different power sources into a single storage and distribution unit. The use of a 12V battery and AC-DC converter ensures stable power output for various low-power applications like charging mobile devices and LED lighting.

Although challenges such as weather dependency, initial cost, and system integration exist, the project highlights the potential for further advancements in renewable energy solutions. Future improvements could focus on higher efficiency components, automation for seamless power switching, and increased energy storage capacity.

This project serves as a step toward a greener and more sustainable energy future, reducing reliance on fossil fuels and promoting environmentally friendly power generation.

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