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Design and Development of Hybrid Energy Generation System

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***Abstract* - This paper presents the design and development of a hybrid energy generation system that integrates wind, hydro, and solar power into a single compact unit to ensure continuous and reliable electricity generation under varying environmental conditions. The system employs a vertical axis wind turbine (VAWT) fabricated from PVC blades and MDF discs, a detachable Pelton hydro turbine driven by a 12V DC pump, and a 12V solar panel, all coupled to a common dynamo shaft and power management unit. A shaft-engagement mechanism allows selective operation of the wind or hydro turbine depending on resource availability, while the solar panel contributes continuously. The generated power is regulated through an AC-DC converter, stored in a 12V 1.3Ah battery, and made available through a USB charging port with LED status indication. Design calculations for power output, torque, RPM, and battery backup were performed, and a complete bill of material with cost estimation was prepared. The prototype demonstrates that combining multiple renewable sources on a shared drivetrain improves reliability and efficiency over standalone systems, making it a viable, low-cost solution for rural electrification, disaster relief, and off-grid power applications.**

Keywords: Hybrid Energy System, Vertical Axis Wind Turbine, Pelton Turbine, Solar Power, Renewable Energy, Power Management, Off-grid Generation.

I. INTRODUCTION

Renewable energy sources are gaining significant attention due to the increasing demand for sustainable and environmentally friendly power generation. Traditional fossil-fuel based sources are depleting rapidly, creating a need for alternatives that are efficient, cost-effective, and sustainable. Wind, hydro, and solar power stand out among renewable options due to their abundance and potential for clean energy production.

This work integrates these three renewable sources into a single hybrid system that harnesses energy from wind, flowing water, and sunlight simultaneously. The system consists of a vertical axis wind turbine (VAWT) positioned at the top, a Pelton hydro turbine at the bottom, and a solar panel mounted above, all connected through a shared dynamo shaft. When the wind turbine operates, the Pelton turbine can be disengaged, and vice versa, allowing optimized energy conversion based on environmental conditions. The generated electricity is stored in a 12V 1.3Ah battery and made available through a USB charging port, with an AC-DC converter regulating output voltage and an LED indicator displaying generation status.

Objective

- Harness energy from wind, hydro, and solar sources to create a continuous and reliable power supply.
- Optimize power generation efficiency by allowing selective operation of wind and hydro turbines.
- Develop a detachable turbine mechanism to switch between energy sources based on availability.
- Demonstrate practical application by storing generated energy in a battery for USB charging.
- Provide a scalable solution suitable for rural or off-grid areas.

II. PROBLEM DEFINITION

Single renewable energy systems fail to provide continuous power because they depend heavily on weather conditions: solar generation stops at night, wind output is inconsistent, and hydro power requires continuous water flow. Rural and remote areas consequently face unreliable power supply. A hybrid system that combines wind, hydro, and solar power is therefore needed to ensure continuous small-scale renewable energy generation.

- Dependence on a single renewable source limits reliability.
- Solar generation is intermittent and unavailable at night or in cloudy weather.
- Wind energy output fluctuates with variable wind speed and direction.

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- Hydro power requires a continuous water flow that may not be available year-round.
- Rural regions face limited grid connectivity and frequent power cuts.

III. LITERATURE REVIEW

Patel *et al.* (2021) explored the integration of wind, solar, and hydro energy, concluding that hybrid systems provide more reliable continuous power than standalone renewable sources. Kumar and Singh (2020) compared vertical and horizontal axis wind turbines and found VAWTs more efficient at low wind speeds with lower maintenance needs, supporting the choice of a VAWT in this work. Sharma et al. (2019) analysed the effect of jet pressure, nozzle design, and bucket shape on Pelton turbine performance, confirming their suitability for small-scale hydro applications.

Gupta and Verma (2018) showed that solar PV panels provide a stable daytime energy source that complements wind and hydro generation. Choudhary *et al.* (2020) emphasized the importance of efficient energy storage—batteries, supercapacitors, and converters—for managing fluctuations in hybrid renewable output, justifying the battery and AC-DC converter used here. Rao *et al.* (2017) demonstrated that mechanically coupling wind and hydro turbines on a single shaft improves overall conversion efficiency, supporting the shared dynamo-shaft approach adopted in this project. Desai and Mehta (2021) confirmed that 12V DC pumps can effectively pressurize water for Pelton turbine demonstrations, while Singh *et al.* (2022) highlighted the value of low-cost, easy-to-maintain hybrid systems for rural electrification, aligning directly with the objective of this work.

IV. METHODOLOGY

The development followed a systematic approach comprising conceptual design, component selection, fabrication, integration, and performance testing.

A. Conceptual Design

A VAWT was selected for wind conversion, a Pelton turbine for hydro generation, and a solar panel for supplementary input, with a shared shaft enabling a common dynamo for both wind and hydro modes.

B. Component Selection and Fabrication

- Wind turbine: 4-inch PVC pipe with six half-cut blades between two 28 cm MDF discs.
- Pelton turbine: plastic Pelton wheel with a detachable shaft coupling.
- Dynamo: AC synchronous motor for converting rotational motion to electricity.
- Water system: plastic storage tank with a 12V DC pump simulating pressurized flow.
- Solar panel: 12V panel mounted at the top of the structure.
- Power unit: AC-DC converter, 12V 1.3Ah battery, USB module, and LED indicator.

C. Integration and Testing

All sources feed a common power management unit operating in wind, hydro, or solar mode as conditions allow. Rotational speed, voltage, and current were measured for each mode, and the battery charging rate, USB output, and overall efficiency were evaluated and optimized in the final implementation.

V. WORKING OF THE SYSTEM

The VAWT rotates when wind is available, transmitting mechanical energy to the dynamo via the common shaft. The Pelton turbine, mounted on the same shaft through a detachable coupling, is driven by a 12V DC pump that creates a pressurized jet from the storage tank; engaging or disengaging the bolt-coupling allows either turbine to drive the dynamo without interference from the other. The solar panel operates independently and continuously, feeding the power management unit alongside the wind and hydro output. The combined energy is regulated by the AC-DC converter, stored in the battery, and made available through the USB module, with the LED indicator displaying real-time generation status.

VI. COMPONENTS

The frame is fabricated from mild steel for its availability, machinability, moderate factor of safety, and high tensile strength. Medium-density fibreboard (MDF) discs support the turbine blades, chosen for low cost and ease of machining, though limited to indoor/dry-use due to moisture sensitivity. PVC pipe sections form lightweight, corrosion-resistant turbine blades. A 12V DC pump circulates water for the hydro demonstration, a 12V solar panel supplies photovoltaic output, and the power unit comprises an AC-DC converter, a 12V 1.3Ah rechargeable battery, and a low-power LED status indicator.

VII. COST ESTIMATION AND BILL OF MATERIAL

Cost estimation forecasts the total expenditure of material, machining, and labour required to fabricate the prototype. Material costs were divided into fabricated components and standard purchased parts, with rates obtained

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from suppliers and summed to arrive at the total project cost shown below.

Table 1: Cost table

Sr. No.	Part Name	Material	Qty	Cost (₹)
1	Frame	MS	20 kg	3500
2	MDF discs	MDF	1 set	800
3	Shaft, dia. 20 mm	MS	1 No.	600
4	Solar panel	STD	1 No.	1500
5	Battery	STD	1 No.	800
6	Electrical components & wire	STD	—	550
7	Screws, nuts, bolts	STD	1 dozen	150
8	PVC pipe	PVC	10 ft	500
9	Dynamo motor	STD	1	2500
10	Pelton turbine	—	1	650
11	USB charger	—	1	450
12	Water tank	—	1	1000
13	Other expenses	—	—	3000
			Total	16,000/-

VIII. RESULTS AND DISCUSSION

Average monthly wind speeds for the test region (Mumbai, 2025) ranged from about 9 km/h in May to 23 km/h in July, indicating that wind contribution varies seasonally and is highest during the monsoon months. The calculated outputs show the wind turbine contributing approximately 0.94 W and the Pelton turbine approximately 6.87 W under the assumed test conditions, while the solar panel supplies about 50 Wh/day. After accounting for an overall system efficiency of approximately 60%, the prototype delivers a usable output near 10.7 W, sufficient to provide roughly 3.12 hours of backup at a 5 W load from the 12V 1.3Ah battery. These results confirm that combining the three sources on a shared drivetrain and common power unit improves continuity of supply compared with any single source operating alone, validating the hybrid design approach.

IX. ADVANTAGES, DISADVANTAGES AND APPLICATIONS

Advantages

- Utilizes multiple renewable sources (wind, hydro, solar) on one platform.
- Provides more continuous power generation across varying conditions.
- Compact, low-maintenance design suited to small-scale applications.
- Reduces dependence on non-renewable energy with zero carbon emissions.

Disadvantages

- Relatively high initial setup cost and complex component integration.
- Efficiency remains weather- and water-availability dependent.
- Battery storage adds extra cost and weight to the system.

Applications

- Remote area power supply and off-grid homes or cabins.
- Small-scale agricultural irrigation and emergency backup power.

X. CONCLUSION

The designed hybrid energy generation system successfully integrates wind, hydro, and solar power to provide a sustainable and efficient renewable energy solution. By combining a vertical axis wind turbine, a Pelton hydro turbine, and a 12V solar panel on a shared dynamo shaft, the system ensures more continuous power generation across diverse environmental conditions than any standalone renewable source. The 12V battery and AC-DC converter provide stable output for low-power applications such as mobile charging and LED lighting. Although weather dependency, initial cost, and component integration remain challenges, the prototype demonstrates clear potential for further development toward off-grid and rural electrification applications.

XI. FUTURE SCOPE

Future improvements may include IoT-based automation for seamless source switching, higher-capacity batteries, improved turbine aerodynamics with lightweight materials, MPPT solar charge controllers, and scaling the system for 12V/24V loads. The design may also be extended toward microgrid applications and rural electrification programs.

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