INTEGRATED OFF-GRID POWER CONVERSION FRAMEWORK USING SEPARATE AND COMBINED WIND SOLAR INPUTS WITH MULTI-BATTERY STORAGE, HIGH-EFFICIENCY INVERTER STAGE, AND HYDROGEN PRODUCTION MODULE

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Introduction:

The global demand for energy is rapidly increasing due to population growth and industrial development, leading to a greater reliance on conventional fossil fuels. However, these energy sources are limited and contribute significantly to environmental pollution and climate change. As a result, there is a growing need for sustainable and renewable energy solutions. Among the available options, solar and wind energy have emerged as the most promising and widely used renewable sources due to their abundance and eco-friendly nature.

However, both solar and wind energy systems suffer from intermittency, as solar power depends on sunlight availability and wind power relies on varying wind speeds. This limitation affects the reliability and consistency of power generation. To overcome these challenges, hybrid renewable energy systems that combine multiple sources have gained importance. By integrating solar and wind energy, it is possible to ensure continuous and stable power output under varying environmental conditions.

In this project, an innovative hybrid system is developed using an Archimedes spiral wind turbine and solar photovoltaic panels. The Archimedes turbine is particularly suitable for low wind speed conditions and urban environments due to its unique design and high efficiency. The solar panels complement the system by generating power during daylight hours, thereby improving overall energy availability.

The generated energy is stored using a multi-battery system and supplied to loads through a high-efficiency inverter. Additionally, excess energy is utilized for green hydrogen production through electrolysis, providing a clean and sustainable method of energy storage.

This integrated approach not only enhances energy efficiency and reliability but also supports off-grid applications, especially in rural and remote areas. The system aims to contribute to the development of sustainable, decentralized, and environmentally friendly energy solutions for the future.

Figure 1: Proposed model of the integrated solar-wind renewable energy system

Objectives:

1. To design and develop a hybrid renewable energy system integrating an Archimedes wind turbine and solar PV panels for continuous power generation.
2. To maximize energy capture and conversion efficiency under varying wind and solar conditions.
3. To implement an intelligent energy management system for optimal power distribution between load, storage, and hydrogen production.
4. To provide a reliable and sustainable off-grid power solution for rural and remote areas with limited or no grid access.
5. To utilize excess renewable energy for green hydrogen production through electrolysis for long-term energy storage.

Methodology:

The proposed system follows a structured methodology for integrating wind and solar energy sources into a single hybrid framework. The system consists of an Archimedes spiral wind turbine and a solar photovoltaic (PV) array, both working together to generate continuous electrical power under varying environmental conditions.

Initially, the Archimedes wind turbine is designed and fabricated using lightweight materials and mounted vertically to capture low-speed and multidirectional wind. The turbine is mechanically coupled to a DC generator, which converts the rotational motion into electrical energy. This generated output is rectified and regulated using a charge controller to ensure a stable DC supply.

In parallel, the solar subsystem consists of photovoltaic panels mounted at an optimized tilt angle to maximize solar irradiance. The output from the solar panels is fed through a Maximum Power Point Tracking (MPPT) charge controller to extract maximum available power efficiently.

Both wind and solar outputs are integrated into a unified DC bus system, allowing combined energy utilization. The generated power is stored in a multi-battery system consisting of lithium-ion and lead-acid batteries to ensure uninterrupted energy supply during fluctuations in generation.

An intelligent switching mechanism is incorporated to prioritize energy sources and manage power distribution between storage and load. The stored DC energy is then converted into AC using a high-efficiency inverter to power household appliances and other loads.

Additionally, a dedicated solar subsystem is used to drive an electrolysis unit for hydrogen production. Excess electrical energy is utilized to split water into hydrogen and oxygen, enabling long-term energy storage.

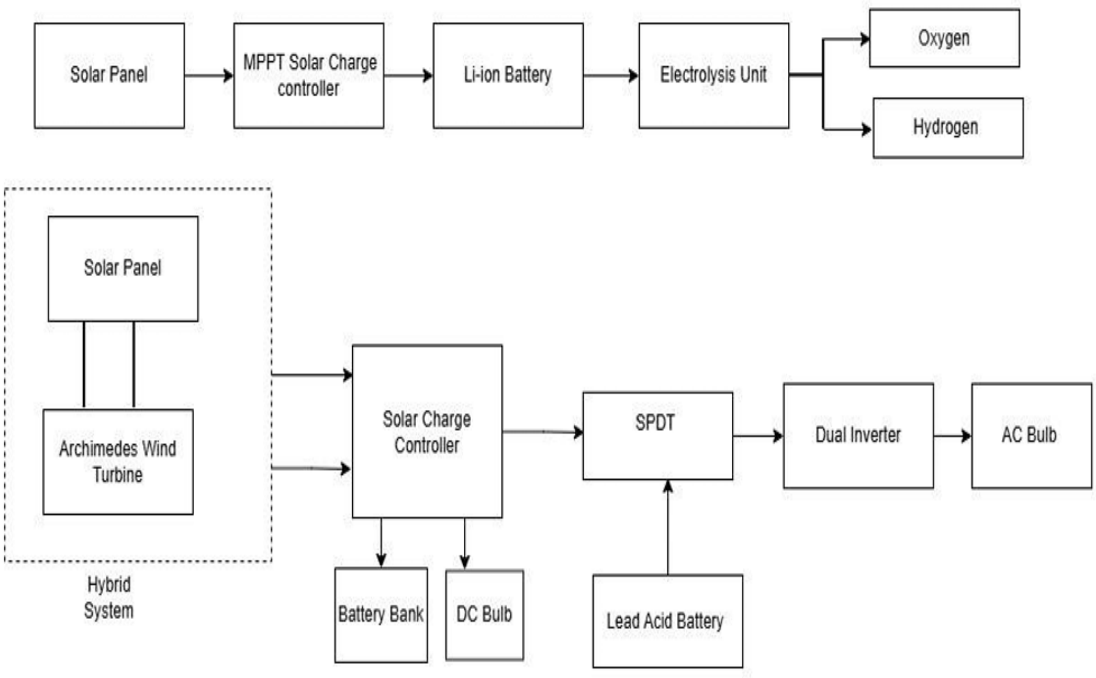

Figure 2: Proposed block diagram of the project

The system performance is monitored using voltage and current sensors at different stages, ensuring efficient operation and real-time analysis. This modular and integrated approach enhances system reliability, efficiency, and scalability for off-grid and rural applications.

Result and Conclusion:

The hybrid renewable energy system was experimentally tested under real-time environmental conditions to evaluate its performance. The system integrates a solar photovoltaic (PV) panel and an Archimedes wind turbine to ensure continuous power generation.

During testing, the following values were measured:
Solar Voltage, V_s = 18 V
Wind Voltage, Vw = 3.7 V
Load Current, I = 0.9 A

The total hybrid voltage is calculated as:
$V_h = V_s + Vw = 18 + 3.7 = 21.7$ V

The hybrid power output is calculated using:
$P_h = V_h \times I$
$P_h = 21.7 \times 0.9 = 19.53$ W

The standalone solar power output is:
$P_s = V_s \times I$
$P_s = 18 \times 0.9 = 16.2$ W

Therefore, the total power generated by the system is:
$P_t = P_h + P_s$
$P_t = 19.53 + 16.2 = 35.73$ W

Battery performance was also evaluated. For the lithium-ion battery:
V = 14.8 V, I = 3 A
$P = V \times I = 14.8 \times 3 = 44.4$ W

The system demonstrated stable performance under varying conditions. During low solar input, the wind turbine provided supplementary power, ensuring uninterrupted supply. Excess energy was successfully utilized in the electrolysis unit for hydrogen production.

The overall system efficiency was observed to be approximately 13–14%, validating the feasibility of the hybrid design.

In conclusion, the experimental results confirm that the proposed system provides reliable, efficient, and sustainable energy generation. It is suitable for off-grid and rural applications and supports future energy storage through green hydrogen production.

Project outcomes and industry relevance:

The proposed hybrid renewable energy system demonstrates a practical and scalable solution for modern energy challenges faced by industries. By integrating solar photovoltaic and Archimedes wind turbine technologies, the system ensures continuous and reliable power generation under varying environmental conditions.

This project aligns with current industry trends toward decentralized and off-grid energy systems, reducing dependency on conventional fossil fuels. The incorporation of multi-battery storage and efficient power management reflects real-world industrial practices in energy optimization and backup systems.

The use of a high-efficiency inverter for DC to AC conversion is directly applicable to residential, commercial, and industrial power supply systems. Additionally, the implementation of Maximum Power Point Tracking (MPPT) techniques highlights industry-standard methods for maximizing energy extraction from renewable sources.

A key industrial relevance of this project is the integration of hydrogen production through electrolysis, which supports the growing demand for green hydrogen in sectors such as transportation, power generation, and chemical industries.

Furthermore, the system can be deployed in rural electrification, microgrids, telecom towers, and remote industrial operations, where reliable power is essential.

Overall, the project reflects current advancements in hybrid renewable energy systems and provides a foundation for sustainable, cost-effective, and future-ready energy solutions in the industry.

Project outcomes and learnings:

The project successfully demonstrated the development of a hybrid renewable energy system using solar PV and an Archimedes wind turbine. Continuous power generation was achieved by combining multiple energy sources under varying environmental conditions.

An efficient energy storage system using lithium-ion and lead-acid batteries was implemented. A high-efficiency inverter was designed to convert DC power into usable AC supply. The system effectively utilized excess energy for hydrogen production through electrolysis. Practical knowledge of renewable energy technologies and hybrid system integration was gained.

Hands-on experience in circuit design, hardware setup, and system testing was developed.Understanding of power electronics components such as charge controllers and inverters was enhanced. Knowledge of energy management and storage techniques was improved. The project provided insights into sustainable energy solutions and real-world applications in off-grid systems.

References:

1. [1] "DESIGN AND ANALYSIS OF ARCHIMEDES AERO-FOIL WIND TURBINE BLADE FOR LIGHT AND MODERATE WIND SPEEDS" Dr S. Srinivasa Rao, Kota Shanmukesh, M K Naidu, Praveen Kalla Associate Professor, 2 Postgraduate student Department of Mechanical Engineering, MVGR College of Engineering (A) Vizianagaram, Andhra Pradesh., India
2. [2] "INFLUENCE OF THE NUMBER OF BLADES OF THE ARCHIMEDES WIND TURBINE ON ITS PERFORMANCE" by Ivan mihalik1, Marian lazar1, Lukas simocko1, Natalia jasminska1, Tomas brestovic1, Romana dobakova1 1department of energy engineering, faculty of mechanical engineering, technical university of Kosice, Kosice, Slovakia Doi: 10.17973/mmsj.2024_12_2024043
3. [3] “A CORRELATION STUDY BETWEEN AERODYNAMIC STRUCTURAL CHANGES AND AERODYNAMIC NOISE CHARACTERISTICS OF ARCHIMEDES SPIRAL WIND TURBINES” by Baohua Li, Zetao Deng, Yuanjun Dai, Lei Zhong and Jianping Wang (2024)
4. [4] “RECENT ADVANCES OF WIND-SOLAR HYBRID RENEWABLE ENERGY SYSTEMS FOR POWER GENERATION: A REVIEW” by pranoy roy 1 (graduate student member, ieee), jiangbiao he 1 (senior member, ieee), tiefu zhao 2 (senior member, ieee), and yash veer singh3 (member, ieee)
5. [5] “A REVIEW OF HYBRID RENEWABLE ENERGY SYSTEMS: SOLAR AND WIND-POWERED SOLUTIONS: CHALLENGES, OPPORTUNITIES, AND POLICY IMPLICATIONS” by Qusay Hassan, Sameer Algburi, Aws Zuhair Sameen, Hayder M. Salman, Marek Jaszczur
6. [6] “AN OVERVIEW OF GREEN HYDROGEN PRODUCTION SYSTEM THROUGH LOW TEMPERATURE WATER ELECTROLYSIS USING SOLAR ENERGY” by Arbye S, Fransisco D. WIJAYA, and Arief BUDIMAN
7. [7] “RECENT ADVANCES IN FLEXIBLE SOLAR CELLS; MATERIALS, FABRICATION, AND COMMERCIALIZATION” by Maoz, Zohair Abbas , Syed Abdul Basit Shah and Vanni Lughi
8. [8] Kumar, S. T. O. N. A. R. Y. Singh, and P. M. R. E. F. I. X. Verma, "PATHWAYS TO A GREEN HYDROGEN ECONOMY: INTEGRATED RENEWABLE ENERGY AND ELECTROLYSIS SYSTEMS," RENEWABLE AND SUSTAINABLE ENERGY REVIEWS, vol. 182, p. 113362, 2023.

9. [9] Y. Zhang and H. Li, "TECHNO-ECONOMIC ANALYSIS OF A WIND-SOLAR HYBRID SYSTEM WITH HYDROGEN STORAGE FOR OFF-GRID APPLICATIONS," IEEE Transactions on Sustainable Energy, vol. 13, no. 2, pp. 1120-1131, 2022.
10. [10] F. Garcia, M. Rossi, and E. Bianchi, "AERODYNAMIC PERFORMANCE AND STARTING BEHAVIOR OF ARCHIMEDES SPIRAL WIND TURBINES: A COMPUTATIONAL AND EXPERIMENTAL STUDY," JOURNAL OF ENERGY RESOURCES TECHNOLOGY, vol. 143, no. 4, 2021.
11. [11] X. Chen and S. Park, "DYNAMIC POWER MANAGEMENT FOR RENEWABLE HYBRID SYSTEMS CO-PRODUCING ELECTRICITY AND HYDROGEN," IEEE Transactions on Industrial Informatics, vol. 18, no. 9, pp. 6234-6243, 2022

Future Scope:

1. The proposed hybrid renewable energy system can be further enhanced by improving the efficiency of individual components such as solar panels, wind turbines, and energy storage systems. Advanced Maximum Power Point Tracking (MPPT) algorithms can be implemented to maximize energy extraction under varying environmental conditions.
2. The integration of smart energy management systems using IoT and artificial intelligence can enable real-time monitoring, predictive control, and optimized power distribution. This will improve system reliability and performance.
3. The system can be scaled up for larger applications such as microgrids, smart cities, and industrial power systems. Incorporating advanced battery technologies with higher energy density and longer lifespan can further enhance storage capabilities.
4. Future developments can focus on improving hydrogen production efficiency and safe storage techniques, making green hydrogen a more viable long-term energy solution.
5. Additionally, grid integration can be implemented to allow surplus energy to be fed back into the grid, improving overall energy utilization.
6. The design can also be optimized for cost reduction and mass production, making it more accessible for rural electrification and remote applications.
7. Overall, the project has significant potential for expansion into a fully automated, scalable, and sustainable energy system for future energy demands.