

HYBRID RENEWABLE ENERGY SYSTEMS FOR SMALL COMMUNITIES

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Анотація

Гібридні системи відновлюваної енергії (HRES) поєднують сонячну, вітрову енергію та накопичення енергії для забезпечення стабільної та сталої електроенергії для малих та віддалених громад. Вони підвищують енергетичну надійність, зменшують залежність від викопного палива та пропонують екологічні переваги, незважаючи на такі проблеми, як високі початкові витрати та управління системою.

Ключові слова: гібридні енергетичні системи, відновлювана енергія, сонячна енергія, вітрова енергія, накопичення енергії, малі громади, енергетична незалежність.

Abstract

Hybrid renewable energy systems (HRES) combine solar, wind, and energy storage to provide stable and sustainable electricity for small and remote communities. They improve energy reliability, reduce fossil fuel dependence, and offer environmental benefits, despite challenges like high initial costs and system management.

Keywords: hybrid energy systems, renewable energy, solar energy, wind energy, energy storage, small communities, energy independence.

Introduction

Global energy demand is rising due to population growth, technological development, and higher living standards. Traditional fossil fuels, however, cause pollution, climate change, and resource depletion. Renewable sources like solar and wind are clean but variable, reducing reliability, especially for small or remote communities. Hybrid renewable energy systems (HRES) address this by combining multiple sources with energy storage, providing stable and continuous electricity. For small communities, HRES improve energy access, independence, and sustainability, reduce fossil fuel reliance, lower long-term costs, and decrease greenhouse gas emissions. This paper examines the structure, operation, benefits, and challenges of HRES, highlighting their potential as a reliable and sustainable solution for the future.

Concept and structure of hybrid renewable energy systems

Renewable energy sources, including solar, wind, biomass, hydro, and geothermal, are essential for transitioning to a sustainable and electrified energy system. Since the 2015 UN Climate Change Conference, many countries have increased their renewable energy share, leading to steady global growth.

Individual renewable sources face challenges such as intermittency, uncertainty, and low energy density. Hybrid renewable energy systems (HRES) address these issues by combining multiple renewable sources, and sometimes fossil fuels, to improve reliability and efficiency. By leveraging the complementary characteristics of different sources, HRES maximize resource use, reduce storage requirements, and enhance system stability. Although HRES research began in the 1980s, significant growth has occurred since 2005, focusing on system configurations, design methods, and operational management.

Solar photovoltaic energy systems

Solar photovoltaic (PV) energy systems are one of the key technologies in the field of renewable energy. They convert sunlight into electrical energy through the photovoltaic effect, which occurs in solar panels composed of interconnected semiconductor cells, most commonly made of silicon. The main advantages of solar PV systems include environmental sustainability, the availability of the energy source, and low operating costs. However, their performance is limited by the intermittency of solar radiation, dependence on weather conditions, relatively high initial investment costs, and the need for energy storage solutions. For this reason, solar PV systems are often integrated into hybrid renewable energy systems to improve reliability and efficiency.

Wind energy systems

Wind energy systems convert the kinetic energy of moving air into electricity using wind turbines, whose blades rotate a generator through electromagnetic induction.

These systems provide clean, renewable power with low greenhouse gas emissions, support energy independence, and have relatively low operational costs. However, their performance depends on wind availability, and they may cause visual and noise impacts. Careful site selection and technological improvements are necessary to maximize benefits and minimize limitations.

System composition and operating principles

A hybrid off-grid system typically includes photovoltaic panels, wind turbines, energy storage, a hybrid inverter, optional grid connection, and electrical loads. Solar panels generate DC electricity, batteries store excess energy, and the hybrid inverter converts DC to AC while managing energy flow.

The system uses intelligent energy management and complementary sources. Solar energy powers loads and charges batteries during the day, while stored energy or wind power is used at night or in low sunlight. If all renewable sources and batteries are insufficient, the system switches to the grid. In case of a grid outage, the hybrid inverter ensures uninterrupted power by instantly switching to battery supply, maintaining critical load operation.

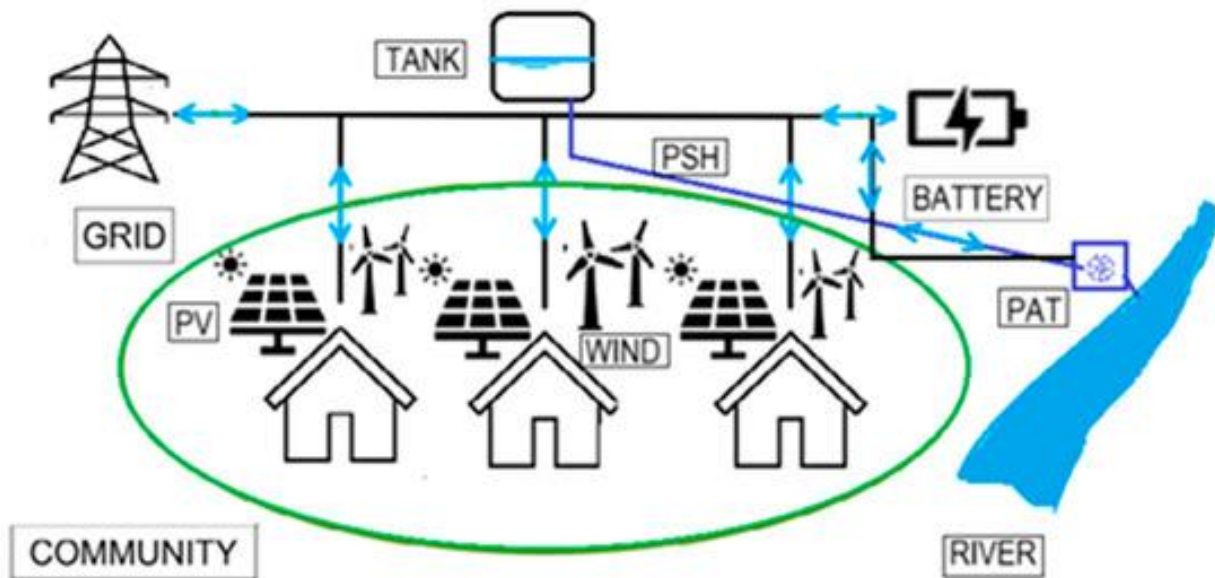


Fig.1. Example of HRES

Advantages of hybrid renewable energy systems for small communities

Hybrid renewable energy systems (HRES) offer significant benefits for small, rural, remote, and island communities. They provide energy independence by generating electricity locally from solar and wind, reducing reliance on imported fuels and external suppliers.

HRES enhance reliability by combining multiple energy sources with storage, ensuring stable electricity even when one source is unavailable. Solar energy can supply power during the day, while wind and batteries cover nights or unfavorable conditions.

In the long term, HRES can lower energy costs, as operating expenses are minimal due to free renewable resources. They also provide environmental benefits by reducing greenhouse gas emissions and pollution, helping mitigate climate change and protect local ecosystems.

Finally, HRES reduce dependence on centralized grids, offering a decentralized and resilient solution for areas with weak or no grid infrastructure, improving energy security during disasters or grid failures.

Disadvantages and challenges of implementation

Despite their advantages, hybrid renewable energy systems (HRES) face several challenges. A major limitation is the high initial investment for installation, including renewable energy equipment, storage systems, and power electronics, which can be a barrier for small communities with limited resources. Regular technical maintenance and skilled personnel are also required to ensure long-term reliability. In remote areas, access to technical support and replacement components may be limited.

The efficiency of HRES depends on local climatic conditions, as variations in solar radiation and wind availability can affect energy production. Moreover, managing multiple energy sources and storage components increases system complexity, requiring effective control and energy management strategies to optimize performance and prevent losses.

Hybrid power plants around the world

Hybrid power plants are increasingly being implemented to combine multiple renewable energy sources with energy storage, providing stable and reliable electricity. Currently, at least 24 notable hybrid power plants operate globally. Examples include:

- **Hönstadt, Germany.** One of Europe's largest, integrating solar, wind, and hydrogen fuel cells.
- **Hornsedale, Australia.** Wind turbines paired with a Tesla battery system for regional grid stability.
- **Pune, India.** Integrates solar, wind, and storage to supply electricity to the city.

These projects highlight the global trend of hybrid systems, demonstrating their ability to deliver reliable, sustainable, and resilient energy solutions for diverse regions, from islands to industrial areas.

Conclusion

Hybrid renewable energy systems (HRES) provide sustainable, reliable, and independent electricity, particularly for small, remote, and island communities. By integrating solar and wind energy with storage, they overcome the limitations of individual renewable sources.

Key benefits include energy independence, high reliability, long-term cost savings, environmental protection, and reduced reliance on centralized grids. Challenges such as high initial costs, maintenance, climatic dependence, and system complexity must be considered.

Global examples in Australia, Germany, Morocco, Greece, and India demonstrate that HRES can ensure stable electricity and support clean energy transitions, making them a promising solution for sustainable development worldwide.

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