
Hybrid Renewable Energy Systems for Small-Scale Applications

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Abstract: *Hybrid renewable energy systems have become a suitable solution towards delivery of high consistency and sustainable power in small scale systems especially in rural and off-grid locations. Such systems combine several renewable energy sources like solar photovoltaic, wind turbines and small-scale hydro/biomass systems to increase the reliability of the energy and decrease the reliance on fossil fuels. An integration of a set of energy storage systems with a set of smart energy management systems increases stability and efficiency of the system even more. This paper includes an evaluation of hybrid renewable energy structures that are developed to be applicable in small scale using performance, reliability, cost-efficiency, and environmental advantages. The analysis assesses system aspects such as generators of renewable energy, storage units, and power conditioning units. The important performance indicators are discussed: energy efficiency, system reliability and levelized cost of electricity. The findings prove that hybrid systems have a major positive impact on the stability of power supplies as compared to the single-source renewable systems. Moreover, hybrid renewable systems will help to minimize greenhouse gas emissions and improve access to energy in isolated communities. The research points out the significance of appropriate system design, optimization, and energy management plans to maximize the performance in the small-scale energy.*

Keywords: Hybrid renewable energy, solar photovoltaic, energy storage systems, small-scale power generation, off-grid energy systems.

INTRODUCTION

The world energy demand is still rising due to the growing population and the increasing technological advancement in the developed and developing nations [1]. Meanwhile, the environmental sustainability and climate change issues have further step-up the demand of cleaner energy production technologies. Traditional energy production techniques are dependent and based on fossil fuels like coal, oil, and natural gas, which are the major reason behind the emission of green-house gases and the degradation of the environment [2]. A different solution to this is the renewable energy technologies that utilize naturally available sources of energy like sunlight, wind, water and biomass. They are cheap resources that are eco-friendly and thus appeal to the long-term energy planning. Nevertheless, renewable energy sources are intermittent by nature since they cannot always be available due to the environment. This variability poses problems in the provision of reliable and constant power. This has been followed by the birth of hybrid renewable energy systems as a potential solution to overcome these shortcomings [3][4][5].

Hybrid renewable energy systems take two or more renewable energy technologies together to enhance the energy reliability and performance of the system [6]. To be precise, solar photovoltaic systems produce electricity when the sun is shining whereas wind turbines can be used to produce electricity all day and night when there is access to wind. With such complementary sources of energy, hybrid systems can be able to provide a more consistent and balanced power output. The use of various sources of energy also minimizes chances of power failure due to the variability of one of the sources [7]. Besides renewable generators, hybrid systems usually use other forms of energy storage like batteries to store the surplus electricity to be used later. These storage facilities are used to ensure there is a stable supply of energy during periods when there is a temporary low rate of renewable generation. As a result, hybrid systems are best applicable in off-grid and remote communities where there is little or no access to centralized electricity infrastructure [8].

Small scale energy use is also a major field where hybrid renewable energy systems could be of great value. In most of the rural and remote areas of the world, it is not economically viable to extend the traditional electricity grids owing to the high costs of establishing infrastructure [9]. This has led to the fact that millions of people still depend on untrustworthy or even damaging to the environment energy sources like diesel generators and burning biomass. The hybrid renewable energy systems have offered a decentralized source of energy which can be used without huge power networks [10]. These systems may be programmed to suit the energy needs of small towns, farms, telecommunication centers and residential properties. In addition, the development of

Publication of the European Centre for Research Training and Development-UK renewable energy technologies has made the solar panels, wind turbines, and energy storage systems very affordable. These advances in technology have seen hybrid systems become more affordable and accessible. Therefore, the role of hybrid renewable energy systems in increasing energy access in the world is significant [11].

The optimization and design of hybrid renewable energy systems must be done in consideration of various technical and economic aspects [12]. The system designers should consider the local environmental factors like the amount of solar radiation, wind and water. These parameters affect the performance and viability of various renewable energy technologies to be used in the hybrid system [13][14][15]. Moreover, system reliability is pegged on the effective combination of power electronics, energy storage systems and control measures. High-tech energy management systems are applied to control energy flow between the various sources of energy and provide stable operation. These control systems observe real time electricity demand, level of electricity generation and storage. Hybrid systems can be used to achieve maximum energy efficiency and minimum operation costs by smart control of these elements. Thus, small-scale applications require a good system design to get the best performance [16].

Storage of energy technologies are essential toward the success of a hybrid renewable energy system [17][18][19]. Production of renewable energy does not necessarily keep pace with demand of the electricity as the availability of the resources varies over the days and seasons. When the production is high, excess energy is stored in the energy storage systems and is emitted when production is low. Li-ion and lead-acid batteries are examples of battery technologies typically used in small-scale hybrid system. These storage storage devices enhance the reliability of the system and a consistent flow of electricity even when there is not a lot of renewable resources. Also, battery technology has enhanced energy density, cycle life and charging efficiency. The developments have rendered hybrid energy systems more convenient and affordable. Consequently, energy storage is highly identified as an important aspect of a contemporary decentralized energy system [20].

The other significant benefit of hybrid renewable energy systems is that they will minimize pollution and greenhouse gas emissions into the environment [21]. Off-grid communities often use conventional diesel generators, which emit a lot of carbon dioxide and other toxic wastes. These emissions can be significantly lowered by using renewable energy technologies to replace diesel generation. The hybrid systems are also more efficient in terms of energy consumption as they make use of renewable sources available in the area. Moreover, the renewable energy technologies do not need much infrastructure in fuel transportation and storage, and that means they have lower environmental effects [22][23][31]. Such advantages to the environment are in line with the

Publication of the European Centre for Research Training and Development-UK international sustainability objectives that seek to lower the amount of carbon emission in the atmosphere and to facilitate the development of clean energy. In turn, a growing number of countries consider the hybrid renewable energy systems as an essential part of the sustainable energy policy [24][25][26][27][28][29][30].

In spite of their numerous merits, there are various technical and economic issues in the hybrid renewable energy systems. The cost of renewable energy technologies and storage facilities may be rather expensive at the beginning of investment, as compared to traditional ways of power production. In addition, the system design includes adequate evaluation of resources and adequate coordination of the different components. The result of small system sizing or poor energy management plans may result in inefficient operation and low system reliability. Nevertheless, persistent technological advancement is still grappling with these problems by enhancing efficiency of systems and lowering the cost. There has been a development of digital monitoring and smart controllers, as well as predictive energy management, which is making functional operations of hybrid systems more possible. It is hoped that these developments will further make the hybrid renewable energy technologies more viable in small scale systems. Thus, more research and development are necessary to get the best out of the hybrid renewable energy systems in fulfilling the demands of the entire world.

Table 1

Common Renewable Energy Sources of Hybrid Systems.

Energy Source	Advantages	Limitations
Solar photovoltaic	Abundant and clean energy	Electricity production is reliant on the supply of sunlight.
Wind energy	Can operate day and night	Speed is dependent on wind speed.
Small hydroelectric	Uninterrupted and dependable energy.	Needs the availability of appropriate water resources.
Biomass energy	Uses organic waste materials	Needs the supply of fuel.

Components of Hybrid Renewable Energy Systems

Hybrid renewable energy systems are generally made of multiple related components, which are collaborating to produce, store, and distribute electricity.

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Renewable Energy Generators

These are solar photovoltaic, wind turbine, small-scale hydroelectric generation, and biomass generation.

Energy Storage Systems

Battery storage system is used to store the surplus electricity generated in the peak hours and provides power where the generation is low.

Power Conditioning Units

Power converters and power inverters direct voltage and convert direct current electricity generated by solar panels into alternating current that can be used in household appliances.

Energy Management Systems

Smart controllers organize the work of the system components and optimize the distribution of power under the demand and the availability of the resources.

Table 2: Small-Scale Hybrid System Performance Indicators.

Parameter	Typical Range
System efficiency	70–90 percent
Renewable energy contribution	60–95 percent
Battery storage capacity	5–50 kilowatt-hours
Levelized cost of electricity	0.10–0.35 United States dollars per kilowatt-hour

Solar Photovoltaic Panels

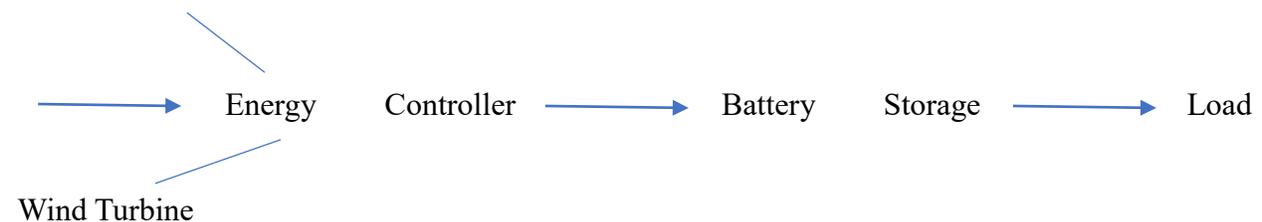


Figure 1 Simple Design of a hybrid energy system.

Figure Explanation

The graph depicts the simplified plan of a small-scale hybrid renewable energy system. The solar photovoltaic panels and wind turbines generate electricity which is controlled by an energy controller. The controller allocates power to battery storage systems and delivers power to the load by energy demand and availability of resources.

Advantages of Hybrid Renewable Energy Systems

Hybrid renewable energy systems have a number of advantages over single-source renewable systems. To begin, they enhance the reliability of energy sources since they integrate more than one energy source with complementary generation characteristics. Second, hybrid systems enhance energy efficiency as a whole as they maximize the use of resources. Third, they lower the emissions of greenhouse gases and environmental pollution which are related to the traditional fossil fuel production. Fourth, they are used to improve energy accessibility in remote and rural locations where the extension of the grid is not feasible. Lastly, the hybrid systems can be tailored to suit the local energy needs, and thus, they can be very versatile on the small scale.

CONCLUSION

Hybrid renewable energy system is one of the viable solutions to the supply of reliable and eco-friendly electricity in smaller scale systems. The hybrid systems combine various renewable energy technologies and energy storage systems, which address the limitations of individual sources of renewable energy. The discussion in this paper has established that hybrid systems could go a long way to enhance energy reliability, minimize environmental impact and energy access in off-grid communities. There must be proper system design, the ability to evaluate the resources, and energy management strategies to attain optimal system performance. The ongoing technological advancements and friendly policy units will also enhance the implementation of the use of hybrid renewable energy systems globally. Hybrid renewable systems will be very important as the world moves towards clean energy since this will encourage decentralized and sustainable production of energy.

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