



Hybrid Energy System Using Photovoltaics and Wind Turbines for Home Use: A Review on Synergy Effects of Solar and Wind Energy for Efficient Energy Solution

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ABSTRACT

The high demand for energy globally combined with the urgent need to control climatic change has stimulated much research into renewable sources of energy for use in homes. A hybrid energy system incorporating photovoltaics and wind power turbines offers a new approach to fulfilling all the energy requirements of the household in a rather sustainable way. This research contributes to the design, integration, and optimization of a hybrid PV-wind energy system designed for residential use. The interfacing of solar and wind energy sources will be analyzed to overcome the inherent limitations in individual sources such as the dependence of solar energy on daylight and variability of wind energy. Therefore, the hybrid system relies on the complementary nature of such renewable sources for reliable and efficient provision of energy in diverse conditions. This work assesses the economic and environmental benefits, the system performance under conditions that would likely occur, and possible barriers to adoption. It provides an integrated framework that outlines the design of cost-effective, scalable, and environmentally friendly energy solutions at residential levels while showing hybrid systems as a feasible pathway toward achieving energy sustainability and reducing dependence on fossil fuels.

1. INTRODUCTION

The demand for energy and environmental challenges of fossil fuels created the interest in renewable sources of energy. Solar and wind energy were found to be the clean and abundant alternatives and well and great options for residential use, but these sources of power are highly dependent on environmental conditions and lead to irregular generation of power. Hybrid energy systems which combine solar panels and wind turbines are known to effectively mitigate these challenges by merely harnessing the strengths from each source [1]. Through such integration, it has been established that the supply of energy will be more reliable and continuous, making this kind of system suitable for household use. Hybrid PV-wind systems have an advantage due to complementing each other as daylight is

yielding sunlight that in turn gives electricity, the system based on solar panels can produce electricity at daylight conditions[2]. The wind turbines are more efficient during nighttime or at times when the wind is turbulent, it is best to use them during nighttime or cloudy conditions. A system composed of a hybrid will thus have high reliability because it is less dependent on weather changes, thus giving the household fewer periods for power downtime. Hybrid energy systems have a lot of economic benefits attached to them, both regarding saving in cost for the house and reduction of dependency on grid energy. It also helps in environmental sustainability by reducing the emission of greenhouse gases. The full gain in cost savings can be achieved by a homeowner with hybrid systems, but it is also in keeping with the

efforts on an international level to reduce carbon footprints. The systems are scalable and useful for urban homes and remote places as well, meaning universal access to energy. Advances in storage technologies and system integration make hybrid energy systems more feasible. Efficient batteries can store excessive energy for future use without any break in power supply during low periods of solar and wind availability. Moreover, smart control systems improve the flow and consumption of energy within a hybrid system, which enhances user convenience and makes them adaptable to today's energy demands[3].

The study intends to provide an all-inclusive framework that covers the designing and optimization of hybrid energy systems based on PV-wind for domestic use, regarding their technical designing, economic feasibility, and environment benefits, within the context of potential utilization in fulfilling a household's energy requirement sustainably and efficiently. The study focuses on both practical benefits and problems in the implementation of hybrid systems within the context of performance analysis of the system under varied environmental and operational conditions. This study proves that the hybrid energy system is not just a technological response to the challenge but rather a step toward a sustainable future for energy in homes across the globe. Wind-PV hybrid power generation turns out to be one of the major solutions for transitioning to renewable energy systems and achieving global carbon neutrality goals because wind and solar energies complement each other in a perfect way to be integrated into modern power systems[4]. These systems have come to be regarded as an unavoidable choice for the development of new, sustainable power infrastructures. However, inherent intermittency, variability, and unpredictability of wind-PV output are massive sources of concern for the safe and stable operation of power grids. This increased integration of wind-PV systems into the grid does raise concerns regarding maintaining system reliability and overall operational stability. It causes problems because the varied fluctuations in energy production create instability in terms of supplying the right amount of power at the time that it is needed[5]. Studies state that high levels of integration can cause changes in the frequency and levels of voltage, requiring more sophisticated

strategies to counterbalance such a phenomenon. Among these strategies, the inclusion of energy storage ES systems has been widely recognized as an effective means of countering the irregularities associated with wind and solar power generation. Energy storage technologies are an integral part in stable control of wind-PV power systems due to their rapid and flexible bidirectional energy transfer. ES systems, by absorbing surplus energy during their generation and releasing energy when it is in low production, are capable of smoothing out power fluctuations and maintaining the grid stability. While a single technology now exists that possesses all the merits and meets the technical and economic requirements for large-scale wind-PV fluctuation suppression, no such technology currently does. Due to this limitation, interest has gained in hybrid energy storage systems (HESS), which integrate complementary advantages from possibly more than two different storage technologies, such as batteries and supercapacitors, allowing the provision of benefits from each technology to be combined to provide an effective solution to these challenges. In recent years, significant momentum has been gathered in integrating power-type and energy-type storage systems into HESS[6]. Power-type storage systems, which include supercapacitors, are able to cope better with rapid short-term fluctuations, whereas the energy types, such as lithium-ion or flow batteries, are more suited for steady energy supply over longer periods with relatively low generation. In this manner, such a complementary approach enhances the potentiality of wind-PV HESS to bring more balance to the variability of power output[7]. Around the world, researchers are focusing on optimized configurations and control strategies for hybrid storage systems to be used in the optimization of their performance and economic viability. The study of hybrid ES systems to stabilize wind-PV power generation will be an important goal as global interests in renewable energy accelerate the transition pace. Such an objective is bound to ensure that renewable energy would be integrated into the existing grid and, at the same time, support autonomous off-grid systems for development. Wind and solar energies combined with advanced storage technologies have the potential to drive forward sustainable, reliable, and efficient power system generations.

2. THEORETICAL FRAMEWORK

The wind as well as solar energy is omnipresent, free and environmental-friendly. The technical viability of the wind energy systems may not be feasible at all places due to lower speed and being more unpredictable than solar energy. The combined utilizations of these renewable energy sources, therefore, are becoming increasingly attractive and are widely being used as the alternative to oil produced energy[8]. The economic viability of such renewable energy sources is promising enough to include them in ever-increasing power generation potential for developing countries. A renewable hybrid energy system comprises two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system[9]. Hybrid energy systems are, hence being increasingly adopted for remote area power due to improvement in the presently known renewable energy sources and a multifold increase in the prices of petroleum products. Research and Development undertakings in solar, wind, and other renewable energy technologies require further continuation with improvement in their efficiency and development of techniques that accurately predict the output, along with reliable integration with other sources of conventional generation. This assesses the current status of the design, operation, and control requirement of the standalone hybrid energy system in terms of combining the use of PV solar and wind systems with a conventional backup source diesel and oil etc[10].

The real electric grid has been developed to provide electricity to the clients from centralized generation. Therefore, with large-scale distributed renewable generation, there is an urgent need for a more flexible, reliable, and smarter grid. Wireless technologies are becoming an important asset in smart grid, particularly the ZigBee devices. Such smart devices have found an ever-growing place not only in building and home automation but also in energy management and optimization services, capable of performing uninterrupted operation for tens of years without any need for maintenance. The new set of comprehensive field tests offered uses open-source tools along with ZigBee technologies in the monitoring of photovoltaic and wind energy systems, and in building and home energy management. Our experimental results demonstrate the efficiency of devices in ZigBee

implemented distributed renewable generation and smart metering systems[11].

ESSs are, therefore very instrumental towards eradicating the intermittency associated with wind and solar energy. Technologies such as lithium-ion batteries, flow batteries, and supercapacitors enable energy to store when produced in peaks thereby releasing when at low generation[12]. Studies conducted suggest that it would be very effective if short-term solutions like supercapacitors were to combine the long-term ones such as battery banks to balance out fluctuations and increase the resilience of the system. This hybrid approach on designing an energy storage system goes well especially for residential applications in which the daily energy demand is frequently fluctuating. Advanced EMS can even provide predictive algorithms to ensure optimal charge-discharge cycles. It uses machine learning to monitor the trends in generating energy and consumption to ensure optimum usage of the storage capacities and waste less energy[13].

Hybrid systems in smart grids imply a drastic novel system of energy management. Smart grids can balance supply and demand by leveraging collected real-time data from sensors and meters. Therefore, this method improves significantly the operational efficiency of hybrid systems by putting more emphasis on energy dispatch according to load requirements and generation capabilities[14]. For instance, during peak load conditions, smart grids possess the exceptional ability to divert the energy stored in the batteries to essential appliances by delaying the less important loads. The functionality explained reduces the strain on the system and improves energy security. Through demand-side management, smart grids also assist by encouraging households to adapt their consumption patterns according to generation predictions.

3. LITERATURE REVIEW

3.1 Related Work

Hybrid integration of wind and photovoltaics has emerged as a potential solution to the intermittent renewable energy resources. Hybrid energy systems therefore harness the complementary natures of solar and wind resources[15]. An increase in the generation of solar energy occurs during daylight hours, whereas an increase in the generation of wind energy occurs usually at night

or in overcast conditions. It leads to alleviating energy shortages as well as strengthening the quality of the system. The results of such research carried out in Europe show that hybridization of wind and photovoltaic systems in several regions enhances the market value of the wind assets by up to 5%, thereby significantly improving the quality of the power supply[16].

Technological developments of a state of art hybrid energy system have resulted from several efforts in the basic research fields, for example, advancement in electrical power conversion enabled by new switch type semiconductor devices has yielded enhanced efficiency, flexibility and reliable operation[17]. Versatile hybrid energy system simulation software development; ongoing bright advances manufacturing process & improving photovoltaic modules efficiency. Creation of innovative, automatic controllers which optimize hybrid energy system integration and minimize operational requirements[18]. Deep cycle lead-acid batteries with enhanced attributes for renewable energy applications. More energy efficient and reliable AC and DC appliances become available that can make up their higher cost during their long working life. With the invention of advanced sensors, controls and systems these so called smart buildings is an example of what our future holds. Buildings would not anymore be passive structures but rather dynamic entities that would adapt responsively to their environment as well as its occupants. They come equipped with the ability to utilize clean energy, maximize the use of that energy and even send surplus electricity back to the grid. Smart building design combines technology, architecture and energy management to produce buildings that respond well to ecological factors and save energy too[19].

The integration of smart systems into buildings brings significant benefits with a primary focus on energy efficiency which affects the environment and the users. As the world is facing an energy crisis and the growing emphasis on sustainability, buildings with built-in smart features have become one of the ways in which energy use is optimized. The use of accurate and responsive technologies that can analyze data and make real-time adjustments, smart systems in buildings can significantly minimize energy wastage, this is important as it means that the energy consumed in buildings can be at par with the needs of the

occupants and the available renewable energy and it has a great impact on energy savings[20].

Smart buildings also play a critical role in reducing the buildings' carbon emissions through the reduction of excess energy use and hence their contribution to climate change. This is a major objective among governments and businesses around the world, whereby it is being advocated for more sustainable concepts in the construction industry and other infrastructures. The continuous surveillance carried out by smart systems can also help identify and address unresolved issues before they become significant problems[21]. This can help to keep maintenance work low-cost and increase the lifespan of such facilities. As a result, the long-term ecological advantages of smart buildings along with further returns on investment make them ideal structures today and in the foreseeable future.

The technology behind these advanced buildings primarily relies on three critical components: Energy Management Systems (EMS), Building Automation, and Advanced Sensors and Controls. EMS is the topmost powerful tool for saving energy, giving building operators a whole range of highly developed tools and performance metrics that allow for monitoring and managing energy use at every level of detail. Through providing hourly, daily, or even monthly increments for energy consumption patterns, these systems allow staff to make adjustments that enable them to do their work in the best possible manner, thus making each of them highly efficient. By ensuring that these systems have been integrated with renewable energy technologies, it provides a way of improving the efficiency of buildings. This guarantees the effectual utilization and distribution of the energy made possible by the utilization of renewable energy. Such integration adds a new dimension to the energy efficiency of the building's operations, thus ensuring more reliance on clean and green sources of energy while still reducing operational costs[22].

Building automation systems constitute an integral part of modern-day edifices and as such, they are a primary component of future smart structures which integrate and control climate, heating, ventilation, air conditioning (HVAC), lighting, and security systems among other systems. The key object of this modernization is the automation of these systems which works in their full interaction,

increasing their efficiency and thus reducing their energy consumption level. Advanced sensors and controllers are a distinctly different kind of advanced technology that, when employed in intelligent systems, form the effective triad of progress. These sensors provide current and continuous information about the parameters of the atmosphere, premises, and equipment for accurate fine-tuning of measurements to create the most accurate working conditions to meet the users' needs and comfort. These physically unnoticeable but functionally efficient sensors constantly monitor various parameters such as temperature, humidity, and occupancy among others and thereby modify these systems instantaneously and in some cases manually while the building is being occupied[23]. The combination of Internet of Things systems results in a shift in the paradigm as it appears to the way in which power is consumed and controlled in buildings. This smart systems development is the greatest advancement in the development of sustainable development as they join the advancements in technology to the preservation of the environment and the achievement of economic success. In addition, implementing smart systems in buildings is fundamental in overcoming contemporary energy problems and is of paramount significance in creating buildings[24].

3.2 Research Gap and Problem Statement

In recent years, the field of renewable energy technology, particularly regarding photovoltaic (PV) systems and wind turbines, has made remarkable strides. This has led to potential solutions for global energy problems. However, the integration of these technologies into hybrid systems for households is still relatively unexplored. Most of the existing investigations have concentrated on large-scale hybrid renewable energy systems, or separate solar and wind systems, leading to a lack of clarity regarding the ways through which such technologies can be effectively deployed in the home environment. Some of the main issues include the absence of universally accepted ways to size and optimize these systems, a lack of data about the efficiency of hybrid setups by studying them under different home energy demands, and an inadequate level of research about how efficient such systems can be in an urban context. In addition, even though the fact that hybrid energy systems can provide stable

power has been accepted, very little has been done to consider the issue of renewable sources' variability through the development of cutting-edge energy storage and control systems for homes. This calls for a detailed review of the present-day knowledge to pinpoint the prospects of improving the residential hybrid system design and settlement.

The faster pace of urbanization and the newer generation's increased use of electrical gadgets is continually leading to the generation of a greater part of residential energy consumption, which will affect the sustainability of energy in the future. Solar and wind energy are the top two commonly utilized renewable sources of energy which can deliver a great deal of power but they are restricted, to some extent, by their inconsistent nature. Solar panels do not generate any electricity at night and wind turbines are reliant on sufficient installation of wind potential. Hybrid PV-wind systems are an attractive option because these complementary sources of energy can be connected together. Nevertheless, the obstacles in the design of the systems, the integration of the components, and the management of the energy still impede the deployment of these technologies at the household level. Further, the lack of a systematic investigation of the total energy consumption of hybrid power and energy systems in the household sector constrains homeowners and practitioners in utilizing the solutions effectively. This issue should be addressed to make sure the residential energy system is transferred to a sustainable system.

4. METHODOLOGY AND RESEARCH DESIGN

The methodology used in this review revolves around efficiently choosing the particular components shown in figure 1, that will play an essential role in the development of a hybrid energy system that can be considered efficient, sustainable and renewable for residential use. Each of the components underwent evaluation according to their functionality as well as integration capacity and their ability to co-live within the structures of the environment in which they are to be utilized, with the end goal being the establishment of a well-working system with optimum performance levels. Overall, this type of approach brings out the importance of harnessing the full force of solar energy and completing it with

the harnessing of wind energy to compensate for the typical variability associated with the use of renewable energy sources.

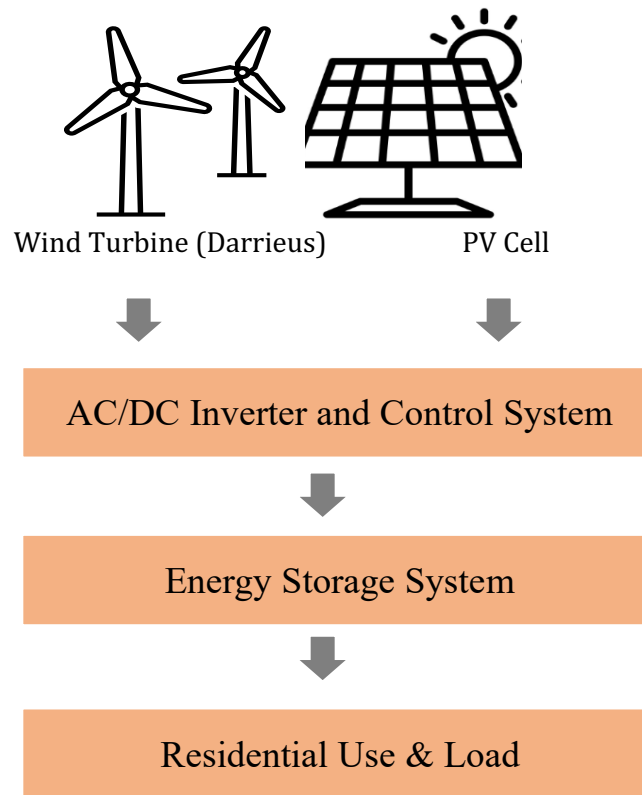


Figure 1: Block Diagram of Hybrid PV Wind System

4.1. Solar Photovoltaic (PV) Panels

In this design process, the choice of photovoltaic (PV) panels is regarded as the initial process and the main energy-generating component during the day period. With regards to this, high-efficiency monocrystalline panels were envisaged as the best suitable option as they do have amazing energy conversion rates and ample energy generation capability on little space and are therefore highly recommendable for urban houses, especially where the roof space is limited. However, just like any other part of the solar energy system, site orientation determines its function in respect of solar energy generation and so the site's solar potential is also determined based on local satellite solar irradiation as well as shading assessment. The proper orientation and tilt of the panels is important in order to maximize their energy production potential since this influences the angle and direction at which sunlight strikes the panels.

Properly sizing of the panels is quite instrumental as it ensures that the panels, district by their own, can provide enough energy to meet the energy consumption requirements of a household, can operate adequately under different weather conditions and ensure reliable energy supply to households. Consequently, this entails scrutinizing and analyzing the daily patterns of electricity consumption of a household and plugging such with daily solar hours that make the generation and consequently long-term energy consumption from the solar panels optimum.

4.2. Wind Turbine (Darrieus Vertical-Axis Design)

The Darrieus wind turbine is a key element in the hybrid PV-wind energy system according to the findings of this research. Being a vertical-axis wind turbine (VAWT), it is the most suitable option for households as it can catch the wind from all directions. This advantage of the device to be installed in the city and some suburbs is the lack of

the need of reorientation, because there the wind direction can be inconsistent and turbulent. Its small outline allows it to be set up in compact areas such as rooftops or backyards, thus, it is a proper decision for families who need to save the plot. The Darrieus turbine in the hybrid energy system works along with the solar PV panels in the generation of energy at night and cloudy days when there is little sunlight. The intertwined design guarantees the supply of power all the time, thus treating and eliminating the intermittency issues associated with renewable sources. The feature of the turbine's whorl blade is that it allows the turbine to work in a wide range of wind speeds which are typical of household environments. Also, it is so quiet that you won't notice any annoying beeping so it is a good option for city residents who are crowded together.

The implementation of the Darrieus turbine in the hybrid system necessarily poses the careful study of the local wind conditions. A thorough wind resource investigation finds out if the average wind speeds are enough in the area for meaningful energy generation. The energy output of the PV panels is first equated with the utterance of the turbine to set zero conditions when the users will consume energy half of their house energy needs and the remaining energy, if any, in the peak conditions. The ease of its use and maintenance due to the least number of its parts, also, makes it a good public choice. However, the Darrieus wind turbine does come with some drawbacks, including a difficulty in self-starting in low-wind conditions. Though, a help from the PV panels is taken in the hybrid system when the turbine cannot start itself. The efficiency generated in these cases will not be up to the horizontal-axis type turbines working in stable high wind conditions. Regardless, it is this particular device that turns out to be natural in the cities with ailerons subtle yet agile to small wind, so it indicates the immense part in this hybrid energy solution. The overall case is, the Darrieus wind turbine comes into the system basically in a balanced way and in a predictable manner so that it works together for the sake of the house as well as the district being environment-friendly.

4.3. Inverter and Control System

The success of integration of renewable energy sources such as solar resource of the annam system requires an elaborate inverter and control system allowing the conversion of the direct current (DC)

obtained from solar panels and wind turbines to an alternating current (AC) which is the one in most household use. The modern-day hybrid inverters to which our company opted are able to accommodate various energy inputs and optimize system efficiency through expansion and regulation and these are the reasons why they are preferred. These inverters are fitted with Maximum Power Point Tracking (MPPT) technology which involves constant adjustments in order to make sure that as much energy is collected as possible from the sun and from the wind[25]. The system also has advanced monitoring capabilities that keep users updated on real-time remote data regarding energy generation, storage, and consumption manners. This means that each user can balance their load on site and receive stable outflowed power for each parameter of the work, be it in the morning sun or windy night hours. Hence the implementation of the inverter and control system allows for efficiently using various energy resources and managing energy flows in the system; the result is economic energy production, environmental protection, and ensuring sustainable development while at the same time improving the quality of life of the people living or working in the area.

4.4. Energy Storage System

The energy supply system was built for family homes and for all the households in general. One of the energy storage systems was added to keep the energy surplus at times when there is a low production of energy and its generation from solar and wind energy is random contributions. The best storage technology currently available today in the form of lithium-ion batteries was selected owing to their high energy density, long lifespan, and efficiency. The sizing of the storage system was carried out in a way that the capacity matched the household's energy demand requirements for those hours of peak usage as well as those of too low renewable generation. Moreover, this integrated battery system was incorporated with the inverter and control system through which all the charging and discharging rates were monitored and managed so that the cycle life of the battery could be extended while all the time ensuring the availability of energy to the end users.

4.5. System Optimization

A collaborative engagement of components was ensured and chosen in order to achieve exemplary

synergy between solar and wind sources. The PV panels and wind turbine are specifically designed to work in tandem and all their output notwithstanding, the inverter and control system ensure an uninterrupted flow of energy. By taking advantage of the hybrid solution, the two most common energy sources were tied together so as to take care of the energy generation while at the same time minimizing dependency on the grid as a back-up. Energy storage, as well as real-time monitoring, have made this system so that it quickly responds to the changing times so that it optimally utilizes all the available resources making the energy supply efficient and sustainable into the future.

5. DISCUSSION ON THE RESULTS

The integration of hybrid energy systems that combine the use of photovoltaic solar panels and wind turbines has the potential to greatly change how energy is provided and used in households. This research study has been organized to make it easier to understand the findings under the following factors: energy efficiency, economic viability, environmental impact, and sustainability of the system. The main advantage of using a hybrid energy system lies in the complementary performances of solar and wind energies, which offer better and continuous energy performance with fewer interruptions. Solar PV panels produce electricity only during clear sun; meanwhile, wind generators work properly when the wind or when there are clouds, ensuring reliable energy throughout the year. Review of relevant case studies shows that up to 60-70% hybrid systems can decrease the dependence on the electric grid and this also happens in diverse climatic conditions. These findings reveal that hybrid systems are very flexible and can respond to the energy requirements of a specific site very well. Besides, their reliability is improved by the integration of storage batteries in these systems making it possible to store the energy generated at peak periods and use it later during off-peak periods. Also, when there is little energy generated from other renewables such as during gentle winds and cloudy periods, this feature of hybrid systems becomes helpful. The study also found that even though initial investment costs for the establishment of hybrid energy systems are rather huge, the sustained benefits of the same in

subsequent years are far greater than the initial costs. The considerable savings in electricity bills in most people's cases ranging from 50% and with the assistance of tax benefits as well as other incentives make consumers return their investments faster. An important feature of the hybrid energy system is its ecological benefits as it minimizes the environmental impact of energy use, making this particular form of energy supply very attractive. By using renewable energy sources, households today can dramatically cut back their carbon footprints by as much as sixty-five percent, helping to contain climate change and lessen reliance on fossil fuels. At the same time, these systems harness excess renewable energy, thereby reducing waste and improving energy efficiency. In addition, the abated greenhouse gas emissions result in cleaner air and a better environment for all, something that people living close to energy-intensive populations will benefit tremendously from. Hybrid energy systems have many positive attributes like flexibility and efficiency; however, some challenges are still standing in their way. One major issue is that they won't perform equally in all places, as some geographical features and climates affect their functional characteristics, mainly if there is not enough wind or sunlight in an area. The large initial investment costs associated with these solutions can also prevent their uptake in underdeveloped economies or areas facing financial difficulties.

The code simulates and plots the wind speed and solar power hourly results of one year (8760 hours), where two key renewable energy datasets are generated: one for wind speed and the other for solar power as shown in figure 2. The purpose of the code is to bring out the energy

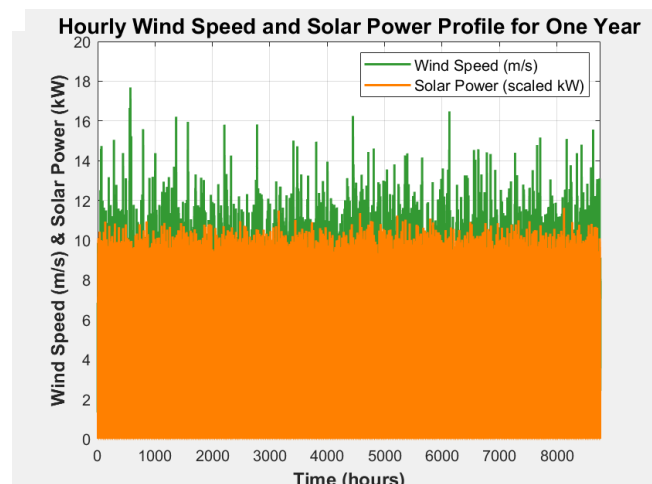


Figure 2: Analysis of Wind and Solar Power Profile

sources during the year, as seen typically in the field, and here are the various changes that can be seen. The first thing that is defined is the variable hours as the total number of hours in a year, where 8760 hours are the total (365 days * 24 hours). This is the time axis of the graphs to be plotted. It serves to be a common standard for data drawing. The Gaussian (normal) distribution is applied to the code for wind speed to ensure randomness. It is determined that the average wind speed will be 6 meters per second (m/s) and the standard deviation will be 3 m/s. Thus, normally the wind speed will be 6 m/s but it will also be affected by the randomness of the standard deviation. The function `randn` produces the random numbers following a normal distribution and these numbers are then applied with the standard deviation and the mean wind speed. The initial wind speed is produced to keep the wind speed in the reasonable range, it is forced into a range with a minimum of 0m/s and a maximum of 18m/s, which reflects the real nature of the wind in the usual environment. The solar energy generation is modeled by a different system. The solar power is characterized in a nature that it follows a daily cycle, so to simulate it the code uses a sinusoidal function which acts as a representative of the increase and decrease of solar energy over a day. The calculation is done in a loop to verify if the time falls in daylight hours (6 AM to 6 PM) or not. During these hours, the solar power energy is produced and outside this period, no energy is received (solar power energy is produced at 0). The generation of solar energy in the light period follows a sine curve during which it attains its peak in the afternoon and decreases towards morning and evening.

The adjustments of the values in the above calculations can be determined by the energy load and characteristics of the residential area of interest. It is worth noting that wind speed and solar power generation can vary by location, time of year, and general local weather conditions.

6. CONCLUSION

This research study principally concentrates on the significance of hybrid technology which includes the integration of photovoltaic (PV) solar panels and wind turbines as a primary step towards

realizing sustainable and effective energy systems for residential applications. The intended project also points out the critical importance of tackling the double dilemma of supply crisis and ecology preservation. The thorough examination of available studies in this article shows that hybrid systems use the advantages of both solar and wind systems as complementary resources to produce a uniform and reliable energy supply for direct usage even when weather conditions fluctuate at any time. The use of lithium-ion batteries as the most advanced form of energy for energy storage guarantees not only efficiency but also the elimination of the intermittent aspect prevalent in renewable energy sources. This analysis provides evidence that hybrid energy systems are not only technically practical but also economically and ecologically friendly, especially for worldwide energy change and climate targets. In conclusion, this project serves as a foundational resource for researchers, policymakers, and practitioners aiming to advance renewable energy integration. The insights gained from this review provide a clear pathway for future research and practical implementation, contributing to the broader goal of creating sustainable, energy-efficient homes powered by hybrid systems. This endeavor not only aligns with global sustainability initiatives but also reinforces the role of renewable energy in shaping a resilient and eco-friendly energy future.

• Recommendations

One of the key factors to be kept in mind for the adoption and operational efficiency of hybrid photovoltaic-wind energy systems is the availability of advanced flexible renewable energy resources based on the current research and best practices in the field. Top priorities include cutting-edge storage technologies. Lithium-ion and flow batteries, among others, have proven to be efficient in saving the excess power the sun and wind produce by photovoltaics and turbines, respectively, and in delivering it to grid consumers when there is a power draw during peak generation. This virtue ensures a continuous and reliable power supply and does not make users overly dependent on the main grid as a means to enhance the energy security and the already existing system of using traditional sources. Systems adapted to local climate and the geographical characteristics of regions enhances their effectiveness. For example, places with high

solar irradiance are more advantageous to use PV panels, whereas regions with uniform wind speeds favor the use of wind turbines. Designs tuned to match the nature of the renewable resources can be at the apex of the energy efficiency performance. Designing modular and scalable systems also ease the adaptation of the systems, enabling the users to increase the capacity gradually along time as they are needed or when there are resources.

Policymakers play a vital role in eliminating economic hurdles that are obstructing the adoption of these systems. Financial incentives such as subsidies, tax rebates, and low-interest loans can help to reduce the upfront costs incurred when one is installing the hybrid systems. Equally, payment-based programs like feed-in tariffs, under which consumers are paid for overproducing power and send it to the grid, are put in place. In this way, the benefits of participating in renewable energy systems and decentralized energy production can be felt to a great extent in the grid.

Community-based approaches are the cost-efficient and socially inclusive solution for the integration of hybrid energy systems. Collective efforts in microgrid solutions entail delivering clean and reliable energy to rural or underserved areas, thus lowering the financial burden on individuals and increasing the benefits. Consisting of both solar energy and wind technologies, these systems are thus effective in the areas where access to conventional grid infrastructure is restricted.

Environmental concerns should also be factored in when hybrid energy systems are implemented. The right recycling procedures for decommissioned PV panels and batteries are extremely important to mitigate the environmental impact. Building renewable energy infrastructure in such a way that it supports circular economies ensures the sustainability and reduction in an ecological footprint of the transition to renewable energy sources. Once these areas are emphasized, the hybrid photovoltaic-wind systems will be the basis of sustainable energy solutions, which will help the world to transition to renewable sources and the climate change problem to be mitigated. This is a multifaceted approach that ensures these systems are not only technologically possible but also socially equitable and environmentally responsible.

REFERENCES

- [1] R. A. Felseghi, I. Aşchilean, N. Cobîrzan, A. M. Bolboacă, and M. S. Raboaca, "Optimal synergy between photovoltaic panels and hydrogen fuel cells for green power supply of a green building—a case study," *Sustainability* (Switzerland), vol. 13, no. 11, Jun. 2021, doi: 10.3390/su13116304.
- [2] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications," Dec. 01, 2023, Elsevier B.V. doi: 10.1016/j.rineng.2023.101621.
- [3] F. Caballero, E. Sauma, and F. Yanine, "Business optimal design of a grid-connected hybrid PV (photovoltaic)-wind energy system without energy storage for an Easter Island's block," *Energy*, vol. 61, pp. 248–261, Nov. 2013, doi: 10.1016/j.energy.2013.08.030.
- [4] V. J. Reddy, N. P. Hariram, M. F. Ghazali, and S. Kumarasamy, "Pathway to Sustainability: An Overview of Renewable Energy Integration in Building Systems," Jan. 01, 2024, Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/su16020638.
- [5] L. Canale, A. R. Di Fazio, M. Russo, A. Frattolillo, and M. Dell'Isola, "An overview on functional integration of hybrid renewable energy systems in multi-energy buildings," Feb. 01, 2021, MDPI AG. doi: 10.3390/en14041078.
- [6] Z. Wang et al., "Potential assessment of large-scale hydro-photovoltaic-wind hybrid systems on a global scale," *Renewable and Sustainable Energy Reviews*, vol. 146, Aug. 2021, doi: 10.1016/j.rser.2021.111154.
- [7] K. Almutairi, S. S. Hosseini Dehshiri, S. J. Hosseini Dehshiri, A. Mostafaeipour, A. Issakhov, and K. Techato, "Use of a hybrid wind—solar—diesel—battery energy system to power buildings in remote areas: A case study," *Sustainability* (Switzerland), vol. 13, no. 16, Aug. 2021, doi: 10.3390/su13168764.
- [8] M. H. Jahangir, A. Shahsavari, and M. A. Vaziri Rad, "Feasibility study of a zero emission PV/Wind turbine/Wave energy converter hybrid system for stand-alone power supply: A case study," *J Clean Prod*, vol. 262, Jul. 2020, doi: 10.1016/j.jclepro.2020.121250.
- [9] H. Mehrjerdi, "Modeling, integration, and optimal selection of the turbine technology in the hybrid wind-photovoltaic renewable energy system design," *Energy Convers Manag*, vol. 205, Feb. 2020, doi: 10.1016/j.enconman.2019.112350.
- [10] L. Al-Ghussain, A. Darwish Ahmad, A. M. Abubaker, and M. A. Mohamed, "An integrated photovoltaic/wind/biomass and hybrid energy storage systems towards 100% renewable energy microgrids in university campuses," *Sustainable Energy Technologies and Assessments*, vol. 46, Aug. 2021, doi: 10.1016/j.seta.2021.101273.
- [11] N. C. Batista, R. Melício, J. C. O. Matias, and J. P. S. Catalão, "Photovoltaic and wind energy systems monitoring and building/home energy management using ZigBee devices within a smart grid," *Energy*, vol. 49, no. 1, pp. 306–315, Jan. 2013, doi: 10.1016/j.energy.2012.11.002.

- [12] S. Speidel and T. Bräunl, "Leaving the grid - The effect of combining home energy storage with renewable energy generation," Jul. 01, 2016, Elsevier Ltd. doi: 10.1016/j.rser.2015.12.325.
- [13] S. D. Prasetyo, F. J. Regannanta, A. R. Birawa, and M. S. Alfaridzi, "Techno-Economic Evaluation of Hybrid Photovoltaic-Wind Energy Systems for Indonesian Government Buildings," *Journal of Sustainability for Energy*, vol. 2, no. 3, pp. 132–144, Sep. 2023, doi: 10.56578/jse020303.
- [14] A. Mahesh and K. S. Sandhu, "Hybrid wind/photovoltaic energy system developments: Critical review and findings," Aug. 22, 2015, Elsevier Ltd. doi: 10.1016/j.rser.2015.08.008.
- [15] L. Zhang, T. Zhang, K. Zhang, and W. Hu, "Research on power fluctuation strategy of hybrid energy storage to suppress wind-photovoltaic hybrid power system," *Energy Reports*, vol. 10, pp. 3166–3173, Nov. 2023, doi: 10.1016/j.egy.2023.09.176.
- [16] Y. Sawle, S. C. Gupta, and A. K. Bohre, "PV-wind hybrid system: A review with case study," 2016, Cogent OA. doi: 10.1080/23311916.2016.1189305.
- [17] B. Bhandari, K. T. Lee, C. S. Lee, C. K. Song, R. K. Maskey, and S. H. Ahn, "A novel off-grid hybrid power system comprised of solar photovoltaic, wind, and hydro energy sources," *Appl Energy*, vol. 133, pp. 236–242, Nov. 2014, doi: 10.1016/j.apenergy.2014.07.033.
- [18] C. Li et al., "Techno-economic feasibility study of autonomous hybrid wind/PV/battery power system for a household in Urumqi, China," *Energy*, vol. 55, pp. 263–272, Jun. 2013, doi: 10.1016/j.energy.2013.03.084.
- [19] O. Lysenko et al., "Modeling a Hybrid Power System with Intermediate Energy Storage," *Energies (Basel)*, vol. 16, no. 3, Feb. 2023, doi: 10.3390/en16031461.
- [20] P. Nema, R. K. Nema, and S. Rangnekar, "A current and future state of art development of hybrid energy system using wind and PV-solar: A review," Oct. 2009. doi: 10.1016/j.rser.2008.10.006.
- [21] R. Al Badwawi, M. Abusara, and T. Mallick, "A Review of Hybrid Solar PV and Wind Energy System," *Smart Science*, vol. 3, no. 3, pp. 127–138, 2015, doi: 10.1080/23080477.2015.11665647.
- [22] A. González, J. R. Riba, A. Rius, and R. Puig, "Optimal sizing of a hybrid grid-connected photovoltaic and wind power system," *Appl Energy*, vol. 154, pp. 752–762, Sep. 2015, doi: 10.1016/j.apenergy.2015.04.105.
- [23] O. F. Orikpote, S. Ikemba, and D. R. E. Ewim, "Integration of Renewable Energy Technologies in Smart Building Design for Enhanced Energy Efficiency and Self-Sufficiency," *The Journal of Engineering and Exact Sciences*, vol. 9, no. 9, pp. 16423–01e, Nov. 2023, doi: 10.18540/jcecv19iss9pp16423-01e.
- [24] A. N. Celik and * Tel, "Optimisation and techno-economic analysis of autonomous photovoltaic-wind hybrid energy systems in comparison to single photovoltaic and wind systems," 2002. [Online]. Available: www.elsevier.com/locate/enconman
- [25] H. Khurshid, B. S. Mohammed, A. M. Al-Yacoubi, M. S. Liew, and N. A. W. A. Zawawi, "Analysis of hybrid offshore renewable energy sources for power generation: A literature review of hybrid solar, wind, and waves energy systems," Oct. 01, 2024, Elsevier Ltd. doi: 10.1016/j.dibe.2024.100497.