Physics-Based Approaches to Enhancing Renewable Energy Efficiency and Sustainability

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Abstract

Solar and wind energy are two of the "renewable energy sources" that are growing the quickest. The element that is most important for optimizing power use is the airfoil. With an emphasis on wind turbine applications, the review article's goal is to provide an overview of the published literature on the many authors' research projects related to optimization in airfoil design techniques and methods. In the realm of alternative energy sources, solar panels are becoming more and more well-liked as a means of producing clean, green electricity. This evaluation is an essential tool that directs future advances and complies with international goals for renewable energy. From the various researcher's study conclude that there are various method to enhance the efficiency of solar and wind energy. By employing the tracking system and mirror-cooling technique to enhance the solar panel efficiency. Additionally, using the thermoelectric generator with solar panel to extract the heat from the panel to enhance the efficiency of solar panel. There is s several method to enhance the wind turbine efficiency which is innovative Blade Design, variable Pitch and Twist Technologies, Advancement in Materials, geometrical parameters, blade angle.

Keyword: Energy, Efficiency, Sustainability

I. INTRODUCTION

Natural resources that are renewable are capable of producing energy at a rate that exceeds its consumption. Two of these reliable sources are solar radiation and wind. A variety of renewable energy sources are accessible to humanity. whereas the formation of non-renewable resources, including coal, oil, and gas, requires millions of years [1]. The emission of hazardous greenhouse gases, including carbon dioxide, into the environment occurs when energy is generated from fossil fuels. When fossil fuels are used, much more emissions are released than when renewable energy is produced. Since fossil fuels currently produce the majority of emissions, switching to renewable energy might be required to address the climate issue. These days, the majority of countries present "renewable energy" it generates nearly as many jobs as fossil fuels, and it is available at a reduced cost [2].

A. Solar energy

Solar energy is the most abundant source of energy, and it can be utilised in cloudy conditions. The Earth absorbs around ten times as much solar radiation as human energy usage. Among other things, solar technology may be utilized to provide fuels, heat, power, cooling, and natural lighting. Photovoltaic panels convert sunlight into electrical energy, whereas mirrors in solar technology focus solar radiation [3]. All nations possess the capacity to use direct sunshine as a significant source of energy, despite differences in the amount of solar radiation that may be obtained. The cost of solar panel production has decreased significantly over the past decade, which has led to their widespread availability and frequent affordability as the most economical power source

. A solar panel's lifetime may be thirty years or more, and the color could change based on the kind of material used to make it [4]

Efficiency and Sustainability of Solar energy Systems

Efficiency in the context of solar panels is the ability to convert sunlight into electrical power. You obtain more electricity from the same quantity of sunshine if the efficiency is better. Different kinds of solar panels have varying degrees of efficiency. Up to 22% of the sunlight may be converted into power by some of the best models. But the majority of solar panels in use today usually have an efficiency of between 15 and 18%. Cost is the primary cause of this efficiency variation. Costlier panels are often the more efficient. Similar to purchasing an opulent sports vehicle, you get optimal performance [5]. Solar energy, a renewable energy source essential for fostering energy independence and lowering greenhouse gas emissions, is abundant in India. The sustainability of solar energy systems involves more than simply producing clean energy; it also involves considering how we do it and the impact it has on the environment [6].

Solar Panel Types by Efficiency

Crystalline solar panels are the most efficient form of panel available.

- Over 20% of monocrystalline panels are rated as efficient.
- PERC panels' passivation layer gives them an additional 5% of efficiency.
- The range for polycrystalline panels is 15–17%.

On the other hand, crystalline silicon is typically 2-3% more efficient than thin-film panels. Generally speaking:

- The efficiency range for CIGs panels is 13–15%.
- The range of CdTe is 9–11%.
- At 6-8%, a-Si has the lowest efficiency.

Table 1 Efficiency of all type of panels

Panel type	Efficiency
PERC	Highest (5% more than monocrystalline)
Monocrystalline	20% and up
Polycrystalline	15-17%
Copper indium gallium selenide (CIGS)	13-15%
Cadmium telluride (CdTe)	9-11%
Amorphous silicon (a-Si)	6-8%

Solar Panel Types by Power Capacity

The single crystal construction of monocrystalline cells enables them to achieve the maximum power capacity, resulting in a more compact package with a higher output rating. Up to 300 volts of electricity can be generated by the majority of monocrystalline solar panels. Polycrystalline solar panels have recently been able to minimise the distance as a result of developments in solar technology. In the present day, a 60-cell polycrystalline panel has the potential to produce between 240 and 300 volts. However, monocrystalline panels tend to perform better than polycrystalline ones in respect to power capacity per cell. There is no common way to quantify the power capacity of thin-film panels since they don't all have the same dimensions, and a thin-film panel's capacity is proportional to its size. Conventional crystalline panels typically produce more power than thin-film panels when their physical footprint and dimensions are identical.

The capacity of a solar panel to produce electricity may be impacted by its temperature. This power output decrease is quantified by the temperature coefficient, which is a measurement of the panel's power output for each degree Celsius above 25°C (77°F). "Polycrystalline and monocrystalline panels" exhibit a temperature coefficient ranging from -0.3% to -0.5%/°C, while thin-film panels display a temperature coefficient that is more in line with -0.2%/°C. This implies that in hotter climates or locations with more annual sunshine, thin-film panels may be a suitable choice.

B. Wind energy

The inertial energy of flowing air is captured by large wind turbines which are deployed on land, in freshwater, or offshore. Wind energy has been utilised for thousands of years; however, "offshore and onshore wind energy technologies" are now able to generate additional power by constructing larger rotor diameters and taller turbines. Electricity production is globally outpaced by wind energy in terms of technical potential, despite the fact that normal wind speeds vary widely between sites. The majority of the planet is capable of supporting a sizable wind energy deployment. Although there are strong winds everywhere in the world, the best locations for wind power generation are often the ones that are furthest away. Offshore wind energy has huge potential [7].

"The vertical axis turbine, or VAWT", is easier to construct and maintain but performs less effectively than "horizontal axis" variations because of its basic rotor blade geometry and high drag. Today, the majority of wind turbines used for residential or commercial power generation are horizontal axis devices.

The Rotor – A modern wind turbine design is primarily composed of this component, which converts wind energy into mechanical power that rotates. Several "rotor blades" are composed of metal, fibreglass, or laminated wood, and the rotor is named after its central axis, together with a protective hub. Unfortunately, in order to properly capture the power of the wind, the air behind the "turbine's rotor blades" would have to halt, which would prevent further wind from going past them. The highest efficiency that the rotor blades of the turbine may potentially harvest from the "wind energy" is between thirty and forty-five percent. Numerous rotor blade factors, including as design, quantity, length, pitch/angle, form, materials, and weight, affect this.

Blade Design – Rotor blade designs employ the principles of lift or drag to extract energy from the moving air masses. The lift blade design generates a lifting force that is perpendicular to the motion channel by employing an identical principle that enables "kites, birds, and aeroplanes to soar." In general, "the rotor blade" is a wing that bears a resemblance to an aerofoil, or the wing of an aircraft. The blade generates a disparity in wind speed and pressure between its upper and lower surfaces as it traverses the environment.

Blade Numbers – The number of rotor blades in a wind turbine is frequently determined by its aerodynamic efficiency and cost. Although the majority of "horizontal axis wind turbine generators" have only one, two, or three rotor blades, the optimal wind turbine design would include numerous narrow rotor blades.

Rotor Blade Length – The air density, wind speed, and rotor area are the three factors that determine the quantity of kinetic energy that a "wind turbine" can extract from the wind. The wind speed is determined by the weather, while the air density is contingent upon one's elevation above sea level. The amount of kinetic energy that a wind turbine can extract from the wind is contingent upon the magnitude of its rotor; however, by extending the rotor blades, we may change the rotational area they sweep.

Challenges of Wind Power

Wind power must be rivaled by other low-cost energy sources. When the energy costs of constructing new power plants are taken into account, wind and solar projects are now more cost-effective than "nuclear, gas, geothermal, or coal-based facilities". Still, wind farms could not be profitable in other areas where the wind is not strong enough. Utilising cutting-edge manufacturing processes, cutting-edge technology, and an improved awareness of the physics governing wind farms might result in further cost savings [8]. Remote areas are generally the best places for wind farms. Installing wind farm electricity in urban locations, when installation barriers exist, is necessary to meet demand. Enhancing the country's transmission infrastructure to link regions with copious wind resources to major urban centers might considerably lower the cost of growing wind power on land. Improvements are also being made in grid links and offshore wind energy transmission. Turbines detract from the surrounding area's natural beauty and produce noise. Despite the fact that wind farms have distinct environmental effects than traditional power plants, there are still many people who are concerned about sound pollution and the visual impact of the turbines on the surrounding region [9].

C. Comparison between efficiency and sustainability of renewable energy sources

The subsequent table contrasts the sustainability and efficacy of numerous renewable energy sources. This illustrates the extent to which each energy source converts basic materials into usable energy, assesses the long-term environmental repercussions, and determines whether the resources are renewable. In order to select the most effective renewable energy solutions, it is imperative to possess a comprehensive comprehension of these factors

Table 2 Comparison of efficiency and sustainability of renewable energy sources

Energy Source	Efficiency	Sustainability
Solar Energy	Moderate to high efficiency (15%-22%)	Highly sustainable, low environmental impact
Wind Energy	Moderate to high efficiency (35%-45%)	Highly sustainable, but some impact on wildlife
Hydropower	Very high efficiency (up to 90%)	Variable sustainability, significant ecological impact
Biomass Energy	Moderate efficiency (20%-45%)	Sustainable if managed well, risk of deforestation
Geothermal Energy	Low to moderate efficiency (10%-20%)	Highly sustainable, minimal emissions and land use

Evaluating renewable energy sources requires taking sustainability and efficiency into account. Renewable energy sources like solar and wind have longer lifespans and are more efficient over time. Hydropower is acknowledged for its efficiency, but because of the possible effects on the environment, it presents serious sustainability challenges. Biomass energy is still very inefficient and requires careful resource management to achieve and maintain sustainability. Geothermal energy is completely sustainable and produces very few emissions, even if it may not be the most effective way to produce electricity. The optimal renewable energy solution often strikes a balance between the need to minimise environmental effect and the pursuit of optimum efficiency, taking into account local circumstances and resource availability.

D. Role of Renewable Energy Technologies in Sustainable Development

Because they improve energy security, lower greenhouse gas emissions, and provide formerly energy-deprived people access to electricity, renewable energy technologies are essential to sustainable development [10].

“Reducing greenhouse gas emissions”: The utilisation of renewable energy sources has the potential to reduce greenhouse gas emissions, thereby potentially mitigating the effects of climate change. By transitioning to renewable energy sources, such as solar and wind power, our dependency on fossil fuels may be reduced, and fewer dangerous pollutants like carbon dioxide are discharged into the atmosphere.

“Improving energy security”: Energy security may be enhanced by the implementation of renewable energy technology, which can reduce dependence on imported fuels and enhance the reliability of the energy supply. Relying less on imported energy and being more self-sufficient may be achieved by countries via the use of locally available alternatives such as “wind and solar power”.

“Providing access to energy”: Thanks to advances in renewable energy technologies, communities who were previously without access to power may now have it, particularly in poor countries. Energy availability may contribute to a reduction in poverty and an improvement in quality of life as it is essential for many daily tasks including heating, cooking, and lighting.

“Creating jobs”: "Renewable energy technologies" have the ability to increase jobs and the economy, especially in the production and setup of renewable energy systems. With the growth of the solar power industry, jobs in the production of "solar panels" and the construction of solar systems, for example, have increased significantly.

“Supporting rural development”: The potential of renewable energy technologies to enhance the standard of living in rural regions, stimulate economic growth, and increase agricultural productivity by providing electricity to those residing in these areas has the potential to stimulate rural development.

II. LITERATURE REVIEW

(Parthiban & Ponnambalam, 2022) [11] On the down side, when ambient temperature rises, photovoltaic efficiency decreases. For each degree Celsius over STC, the output of energy decreases by 0.33%. This means that the load may not be able to be powered by the solar panel's electrical output. It is crucial to acknowledge that in some scenarios, like autonomous electric vehicles, there may not be enough room for an extra solar panel to make up for the lower power production. This overheated temperature might be decreased by putting the cooling arrangements into action. There are two types of cooling procedures that have been used: active and passive. This article reviews how to integrate TEG with solar panels and use various cooling techniques to maximize solar panel efficiency.

(Younas et al., 2022) [12] Solar energy is one of the industries in the current industry that is expanding the quickest due to the increased need for clean energy. Solar technology uses a variety of materials these days. Solar technology is based on photovoltaic materials, which are able to transform a photon into electrical energy. Photovoltaic materials differ in terms of their composition, availability, functionality, applications, and efficiency. The "thin-film solar cells (cadmium telluride)”, perovskite solar cells, and dye-sensitive solar cells are compared in this work. It will also help us choose the finest solar cells made of photovoltaic materials based on stability, cost, efficiency, liability, and application.

(Shawqran et al., 2021) [13] In this work, wind energy performance is enhanced by the deployment of a unique "adaptive fractional order PI (AFOPI) blade angle controller". Fractional calculus is the foundation of the AFOPI controller and is used to compute the fractional gain and integrator order. Using the hybrid equilibrium optimization algorithm (EO) and harmony search algorithm (HSA), the integrator order and controller parameter initialization are improved. The controller gains (Kp; Ki) are then automatically adjusted. The mechanical and electrical characteristics of the wind turbine enhanced using the fractional adaptive PI. More high variation wind speed profiles have been applied to "the adaptive fractional order PI controller" to demonstrate its resilience. The controller demonstrated resilience to changes in the wind speed characteristic and the system's nonlinearity. Additionally, with these extreme fluctuations, the suggested controller (AFOPI) guaranteed uninterrupted wind power production. Furthermore, compared to the other controllers, the AFOPI's active power statistics study revealed a 25% increase in energy collected and a 10% decrease in standard deviation and root mean square error.

(Haupt et al., 2020) [14] To support grid integration and system operation, a contemporary renewable energy forecasting system combines artificial intelligence and physical models. Wind turbines, solar energy systems with storage capacities, and photovoltaic panels may all be found in the park. The dynamical and physical models that are being used complement these AI techniques. The approach for each AI technique, how it is combined, and a preliminary evaluation of its worth in relation to the prediction system are all covered in short in this work. The system is enhanced by each functional AI component. KREPS is the name of one state-of-the-art, fully integrated system for predicting renewable energy.

(Sharma et al., 2020) [15] A summary of the literature on various researchers' approaches and strategies for optimizing aerofoil design, with an emphasis on wind turbine technology, is the aim of this review study. The optimization strategies and methods for improving the performance of wind turbine airfoils were examined in this review study. The study covers a variety of methods, including parameterisation, CFD, genetic algorithms, and other investigations carried out by academics in the field of aerofoil optimisation techniques. The aims and restrictions for optimization, the methodologies used by different researchers for wind turbine airfoils, and the geometric characteristics of the airfoil, which are crucial for performance optimization, have all been carefully examined. Future scholars working on air-foil optimization will find this publication to be a useful guide and thorough review.

III.CONCLUSION

The purpose of this study is to evaluate the many researchers' contributions to the subject of increasing the "efficiency of renewable energy". This essay covered the topics of wind and solar energy. There are many ways to increase the solar and wind energy systems' efficiency. The experimental results for improving solar panel efficiency through tracking systems, mirrors, and cooling techniques were highly promising. The integration of thermoelectric generators (TEGs) into the photovoltaic system, known as PVT-TEG, further enhanced performance by converting excess heat into additional electrical energy. This dual approach not only increased overall energy output but also reduced heat accumulation on the solar panel, leading to a more efficient system.

In a comparable manner, the efficiency of wind turbines can be enhanced considerably by employing innovative techniques. These encompass sophisticated blade configurations that enhance aerodynamic efficiency, adjustable pitch and twist mechanisms that respond to varying wind conditions, and the application of innovative materials aimed at minimising weight while improving durability. Furthermore, the optimisation of geometrical parameters and the adjustment of the blade angle enhance energy capture to a greater extent. The integration of these strategies indicates notable progress in the efficiency of renewable energy, highlighting substantial potential for sustainable energy systems.

Renewable energy evaluation includes efficiency and sustainability considerations. Wind and solar energy sources are becoming more efficient and durable. Although efficient, hydropower has sustainability issues due to environmental impacts. Resource management is crucial for biomass energy sustainability, notwithstanding its low efficiency. Despite poorer power generating efficiency, geothermal energy is sustainable and low-emitting. Depending on local circumstances and resource availability, the best renewable energy option balances efficiency and environmental effect.

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