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Comparative Feasibility and Estimation of Hybrid Renewable Energy Systems: A Case Study of Photovoltaic and Wind Energy Integration in Ranchi- Jharkhand, and Kochi-Kerala

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ABSTRACT

The transition to sustainable energy has accelerated the development of hybrid renewable energy systems (HRES), which combine multiple energy sources like photovoltaic (PV) solar panels and wind turbines. These systems offer a stable energy supply by utilizing the complementary nature of solar and wind resources. This study explores the feasibility, estimation, and optimization of a hybrid PV-wind energy system in two distinct Indian cities—Ranchi, Jharkhand, and Kochi, Kerala—each with unique climatic conditions that significantly influence the performance of renewable energy systems. Ranchi's tropical wet and dry climate, with moderate rainfall and temperature variations, contrasts with Kochi's tropical monsoon climate, characterized by high humidity and significant rainfall. These climatic differences impact the availability and efficiency of solar and wind energy, making Ranchi and Kochi ideal case studies for a comparative analysis of HRES feasibility. The study estimates energy potential by analysing solar irradiance and wind speed data, and optimizes system configurations using algorithms like genetic algorithms and particle swarm optimization. The results reveal that both cities achieve a similar ideal efficiency of 85%, but Kochi outperforms Ranchi in total energy production, generating 389,089.7 watt-hours (Wh) compared to Ranchi's 317,054.6 Wh. This difference underscores the importance of location-specific analysis when deploying HRES, as Kochi's more favourable climatic conditions, particularly higher solar irradiance and consistent wind patterns, contribute to its higher energy output. This research provides valuable insights into the scalability and adaptability of hybrid renewable energy systems in diverse environments, highlighting the potential for tailored sustainable energy solutions. The findings emphasize the need for strategic planning to achieve energy security and environmental sustainability in India, particularly in regions with strong renewable energy resources.

Keywords: - Hybrid Renewable Energy Systems (HRES), Photovoltaic (PV) Solar Panels, Wind Energy, Climatic Feasibility, Analysis Energy Efficiency

1. Introduction

The global shift towards sustainable energy sources has necessitated the development of hybrid renewable energy systems (HRES), which integrate multiple energy sources like photovoltaic (PV) solar panels and wind turbines [1]. These systems are gaining prominence due to their potential to provide a stable and reliable energy supply by complementing the intermittent nature of individual renewable sources [2]. The optimization and estimation of such systems are crucial to ensure their feasibility and efficiency, especially in diverse geographical regions with varying climatic conditions. This study focuses on the comparative feasibility of a hybrid renewable energy system, specifically combining PV solar and wind energy, in two distinct Indian cities—Ranchi in Jharkhand and Kochi in Kerala. Ranchi and Kochi present

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contrasting climatic conditions, with Ranchi experiencing a tropical wet and dry climate, characterized by moderate rainfall and temperature variations, while Kochi has a tropical monsoon climate, with high humidity and significant rainfall throughout the year. These differences significantly impact the availability and efficiency of solar and wind energy, making them ideal case studies for a comparative analysis of HRES feasibility. The objective of this study is to estimate and optimize the potential of a hybrid PV and wind energy system in these locations, taking into account factors such as solar irradiance, wind speed, energy demand, and economic considerations. The estimation of energy potential for both PV and wind systems involves analysing solar irradiance and wind speed data for Ranchi and Kochi over a specific period. For solar energy, parameters such as the tilt angle of PV panels, shading effects, and seasonal variations in sunlight are considered. Wind energy estimation, on the other hand, requires an assessment of wind speed distributions, turbine height, and local topography. By combining these data points, the study aims to determine the most efficient configurations for each location, which could maximize energy output and minimize costs [3]. Optimization of the hybrid system is performed using various algorithms that take into account the energy demand patterns in Ranchi and Kochi. Techniques such as genetic algorithms, particle swarm optimization, and simulated annealing are employed to find the optimal balance between PV and wind energy contributions [4]. The goal is to achieve a system design that provides a reliable energy supply, reduces dependence on conventional fossil fuels, and is economically viable. Factors like the initial installation cost, maintenance costs, and payback period are also considered in the optimization process. Furthermore, this study examines the environmental impact of implementing HRES in Ranchi and Kochi, including potential reductions in carbon emissions and the contribution to India’s renewable energy targets. By comparing the feasibility of hybrid systems in these two regions, the research offers valuable insights into the scalability and adaptability of HRES across different climatic zones in India [5]. The estimation and optimization of hybrid renewable energy systems combining PV and wind power for Ranchi and Kochi provide a comprehensive understanding of the challenges and opportunities associated with renewable energy deployment in diverse environments. This comparative analysis not only highlights the potential for sustainable energy solutions tailored to local conditions but also underscores the importance of strategic planning in achieving energy security and environmental sustainability in India [6-9].

2. RESEARCH BACKGROUND

Thirunavukkarasu et al. (2023) discussed that due to increasing energy prices and pollutants from fossil fuels threatening the climate, there had been a growing preference for renewable energy. They noted that the implementation of hybrid renewable energy systems (HRES) had been a challenging task due to its interference, uncertainty, and unpredictable nature. Furthermore, they observed that HRES came with high net present costs and multi-dimensional architectural facets. They emphasized that it was critical to evaluate HRES using various economic and sizing criteria. Their paper aimed to provide a succinct review of recent progress in the optimization of different HRES using various techniques based on classical methods, artificial intelligence (AI), hybrid algorithms, and software-based optimization tools. They concluded that while comparing classical and AI-based techniques, AI-based techniques were found to be promising and provided a global solution in less time. However, they acknowledged deficiencies in AI-based techniques and suggested that a combination of two or more algorithms, known as hybrid optimization algorithms, could be adopted to solve problems more quickly, reliably, and effectively. They also pointed out that, apart from different algorithms, several popular optimization software tools existed, with the HOMER software tool being one of the most popular due to its ease of use. They noted that as research activities in HRES optimization were increasing, sources such as hydro, geothermal, biomass, and biofuel needed to be given due consideration. This analysis aimed to inform readers about the current and evolving state of optimization approaches for HRES applications and enable them to choose the most appropriate strategy according to their requirements.

Yang, J., Yang, Z., and Duan, Y. (2022) analyzed solar-wind hybrid renewable energy systems, including wind farms, photovoltaic (PV) plants, concentrated solar power (CSP) plants, electric heaters, batteries, and bidirectional inverters, in 36 typical locations in China. They examined the effects of wind and solar energy resources on power supply reliability and economy, as well as the optimal installed capacities. They provided recommendations for regions in China where the development of these systems would be advantageous. Their results indicated that the levelized cost of energy (LCOE) of the system in Huade could be as low as $0.1/kWh when 90% of the annual load demand was met. They found that wind speed and solar irradiation had a significant impact, while the complementary characteristics of wind and solar energy had an auxiliary effect on power supply reliability and system cost. Compared to the system in Tongliao, the LCOE of the system in Qiqihar, with lower wind speed and solar irradiation intensity, was reduced by 9.8% due to the better complementary characteristics of wind and solar energy. They concluded that for systems in locations with varying wind and solar energy resources, the wind farm or PV plant remained the technology with the greatest cost advantage but the poorest power supply reliability. They emphasized that electric heaters with thermal energy storage and power cycles were essential for greatly improving power supply reliability economically. Additionally, they recommended integrating one of the solar fields and batteries into the system based on direct normal irradiance conditions. For regions where high-power supply reliability was desired, they recommended introducing CSP plants, noting that the commercial promotion of CSP plants could bring the most significant economic benefits to the system. Moreover, they observed that as the cost of CSP plants decreased by 30%, the LCOE of the system could be reduced by 20.4%.

Jamshidi et al. (2021) indicated that solar and wind energies were suitable alternatives to fossil-based electricity generation. They mentioned that hybrid utilization of wind and solar generators was preferred to reduce the intermittency of output power. They highlighted that hybrid renewable energy systems (HRES) needed to be sized optimally during the design stage. They noted that wind speed and solar irradiation data had to be measured and collected at short intervals and for at least one year at the site location, which could delay the design and construction of HRES. Their paper aimed to eliminate the need for detailed and long-term data in the HRES sizing process by replacing wind speed and solar irradiation data with averaged and usually-available values of meteorological parameters of the site, such as air temperature, elevation, relative humidity, roughness length, latitude, longitude, and precipitation. They estimated the size of the wind/photovoltaic/battery/diesel HRES as a function of site parameters using polynomial regression and support vector regression models. They studied 105 sites in Iran as training data to build and test these models. Sensitivity analysis showed that estimation accuracy increased with the amount of training data, leading them to expect that by using sufficient training data with global distribution, the accuracy of the models could approach that of current optimal sizing methods while eliminating the time-consuming wind speed and solar radiation data collection. For example, they found that increasing the training data from 40 to 100 sites reduced the mean absolute percentage error (MAPE) of estimating the HRES size by 2.3 to 3.5 times.

Huang et al. (2019) proposed a novel method for estimating the optimal parameters and power outputs for photovoltaic (PV) power generation. They noted that accurate estimation for PV power generation allowed efficient scheduling to meet load demand and reduced the effect of uncertainty for a microgrid. They observed that the parameters provided by the PV manufacturer had a nonlinear relationship with power output and could vary with the aging of the PV cells. To allow finer and more accurate estimation for PV power output, they transformed the parameters of the single-diode Rp model into 13 parameters under various weather conditions. They used principal component analysis (PCA) and an assessment index to eliminate parameters that had little effect on output. Using actual input/output data, they applied a hybrid charged system search (HCSS) algorithm to estimate the optimal parameters. When the parameters were optimized, they concluded that estimation for PV power output could be produced as long as the inputs were given. They tested the proposed method on two different PV power generation systems and verified its performance by comparing the results with those obtained using traditional differential evolution (DE) and particle swarm optimization (PSO) methods.

Anoune et al. (2018) argued that solar and wind energy were considered promising sources of electrical generation. They pointed out that these renewable energies were omnipresent, with free access and a friendly environmental impact. However, they observed that their integration remained technically and economically advantageous for electrical generation in isolated areas (IS). They found that the separate use of solar and wind energy sources could result in considerable over-sizing, making single renewable energy sources very costly to implement. They suggested that using optimization sizing techniques could help guarantee maximum power reliability and minimum system cost for future hybrid implementation. They also highlighted a growing interest in using solar and wind renewable energy sources (RES), which they described as providing a realistic form of electrical generation in isolated areas. Their paper provided an updated literature review of the most applied methods and techniques used in sizing and optimizing PV-Wind-based hybrid systems (PWHS) for isolated areas, aiming to achieve the best compromise between power reliability and hybrid system costs. Additionally, they discussed the most common topologies used for implementing PWHS, presented a mathematical model of the hybrid system components, and emphasized the importance of power reliability and system cost. Finally, they provided an extensive analysis of software tools and algorithm approaches used in sizing optimization.

Fulzele and Daigavane (2018) noted that a hybrid renewable energy system was the combination of two or more energy sources used to supply the targeted load. They highlighted that one of the most important applications of renewable energy systems was the installation of well-designed hybrid energy systems in remote areas where grid extension was very difficult and costly. However, they observed that the proper design of such a system was a challenging task due to the complicated coordination between different energy sources, energy storage, and load. They argued that optimizing hybrid renewable energy systems was the process of selecting suitable components, sizing them, and developing a control strategy to provide efficient, reliable, and cost-effective alternative energy to society. Their paper presented the design of an optimized hybrid renewable energy system consisting of photovoltaic, wind generators with batteries, and converters. They simulated the system optimally using the IHOGA (Improved Hybrid Optimization Genetic Algorithm) tool developed by the Electric Engineering Department of the University of Zaragoza, Spain. They also described the sensitivity analysis of the hybrid system, which helped assess the effect of uncertainty or changes in the variables and find the most suitable solution for the4ybridd system.

Al-Falahi et al. (2017) observed that electricity demand in remote and island areas was generally supplied by diesel or other fossil fuel-based generation systems. However, they noted that due to the increasing cost and harmful emissions of fossil fuels, there had been a growing trend to use standalone hybrid renewable energy systems (HRESs). They found that hybrid systems with solar and wind energy had become the popular choice in such applications due to their complementary characteristics, mature technologies, and availability in most areas. However, they pointed out that the intermittency and high net present cost were the challenges associated with solar and wind energy systems. They argued that optimal sizing was a key factor in achieving a reliable supply at a low cost through these standalone systems. Consequently, there had been a growing interest in developing algorithms for size optimization in standalone HRESs. They noted that the optimal sizing methodologies reported so far could be broadly categorized as classical algorithms, modern techniques, and software tools. They concluded that modern techniques based on single artificial intelligence (AI) algorithms were becoming more popular than classical algorithms due to their capabilities in solving complex optimization problems more quickly and efficiently. They also discussed hybrid AI algorithms and optimization software tools. For example, they cited the Hybrid Optimization Model for Electric Renewable (HOMER) software as the most widely used tool due to its versatility and capability to solve HRES optimization problems using several techniques simultaneously. They reviewed recent studies in optimal sizing algorithms and presented a critical analysis of their advantages and limitations.

Mariam et al. (2016) highlighted that hybrid renewable energy systems (HRESs) were often selected to provide electricity to remote and off-grid locations. They noted that the power management control strategy for such systems was essential for the efficient utilization of energy. Their paper discussed a hybrid renewable energy system consisting of solar PV and wind, with a battery energy storage system (BESS) to meet the energy demand of a typical off-grid household. They proposed a novel intelligent power management control strategy using a fuzzy logic controller (FLC) to ensure stable and efficient operation of the hybrid system. They simulated and compared the proposed FLC-based control strategy with a conventional PI (proportional-integral) controller. They found that the FLC provided better performance in terms of minimizing the energy supply-demand mismatch and improving system reliability. Additionally, they emphasized the importance of optimal sizing of the HRES components to ensure an efficient and reliable power supply while minimizing the system cost. They concluded that the integration of a BESS with the HRES significantly enhanced the system's reliability and stability, especially during periods of low solar and wind power availability.

Belhamel et al. (2016) investigated the optimal sizing and techno-economic analysis of a hybrid solar-wind energy system for an isolated village in the Sahara Desert. They focused on an optimal sizing methodology using a genetic algorithm to minimize the cost of energy (COE) while ensuring system reliability. They considered the harsh desert environment, where solar irradiation was abundant, but wind resources were limited. Their results indicated that the optimal hybrid system configuration consisted of a PV array, a wind turbine, and a battery storage system. They also found that the COE was highly sensitive to the capital cost of the components and the discount rate. They concluded that the hybrid solar-wind system was a feasible and cost-effective solution for providing electricity to isolated desert villages, where grid connection was not economically viable.

Sinha and Chandel (2015) provided an updated literature review on trends in optimization techniques used for the design and development of solar photovoltaic–wind-based hybrid energy systems. They stated that the main objective was to identify the latest promising techniques for optimizing solar photovoltaic

(PV)–wind-based hybrid systems. They reviewed different techniques used by researchers for optimizing renewable-based hybrid energy systems and presented a PV–wind-based hybrid system sizing methodology. They analysed optimization studies conducted over the last 2.5 decades by researchers using traditional and new generation methods and presented sixteen optimization methods, including hybrid algorithms. They observed that new generation artificial intelligence algorithms were mostly used during the last decade, as these required less computation time and offered better accuracy and good convergence compared to traditional methods. The study suggested that hybridization of two or more algorithms should be used to overcome the limitations of a single algorithm. They also identified some other techniques for follow-up research in the design of PV–wind hybrid systems. They believed that this review would be useful for researchers facing the complexity and challenges in renewable energy-based hybrid system research.

Ramoji et al. (2014) presented a new approach to the optimum design of a Hybrid PV/Wind energy system, intending to assist designers in considering both economic and ecological aspects. They found that when standalone energy systems with only photovoltaic panels or only wind turbines were compared with hybrid PV/wind energy systems, the hybrid systems were more economical and reliable according to climate changes. They presented an optimization technique to design the hybrid PV/wind system, which consisted of photovoltaic panels, wind turbines, and storage batteries. They used the Genetic Algorithm (GA) optimization technique to minimize the formulated objective function, which included total cost, initial costs, yearly replacement costs, yearly operating costs, maintenance costs, and salvage value of the proposed hybrid system. They designed a computer program using MATLAB code to formulate the optimization problem by computing the coefficients of the objective function. They proved that the method mentioned in their article was effective using an example of a hybrid energy system. Finally, they achieved the optimal solution using the Genetic Algorithm (GA) optimization method.

3. RESEARCH METHODOLOGY

3.1 Estimation of Hybrid Renewable Energy

A technique that is methodical and makes use of certain equations is required in order to estimate the potential and performance of a hybrid renewable energy system. This kind of system includes different sources of energy, such as solar, wind, hydro, and biomass. For solar energy estimation, the power output from a photovoltaic (PV) system is calculated using the equation

$$\mathrm{P_{solar}} = \mathrm{A} \times \mathrm{G} \times \eta\mathrm{PV},$$

where $\mathrm{P_{solar}}$represents the power output in watts, A is the area of the solar panels in square meters, G denotes the solar irradiance in watts per square meter, and ηPV is the efficiency of the solar panels. In the case of wind energy, the power output from a wind turbine is determined by the equation

$$\mathrm{P_{wind}} = 1/2 \times \rho \times \mathrm{A} \times \mathrm{v}^3 \times \eta_{\mathrm{wind}}.$$

Here, $\mathrm{P_{wind}}$ =is the power output in watts, ρ is the air density in kilograms per cubic meter, A is the swept area of the turbine blades in square meters, v is the wind speed in meters per second, and $\eta_{\mathrm{wind}}$is the efficiency of the wind turbine.

The total energy output of the hybrid system is the sum of the contributions from each energy source, calculated as

$$\mathrm{E_{total}} = \mathrm{P_{solar}} + \mathrm{P_{wind}}.$$

To ensure a reliable energy supply, the generated energy must match the load demand, and energy storage might be needed to balance supply and demand. This balance is represented by

$$\text{Estorage} = \text{Etotal} - \text{Eload},$$

is the energy required for storage and Eload is the energy demand.

where Estorage is the energy required for storage and Eload is the energy demand [7-9].

3.2 Optimization of Hybrid Renewable Energy

A multi-disciplinary strategy that incorporates parts of engineering, economics, and environmental science is required in order to optimize hybrid renewable energy systems. On the basis of the application of mathematical equations and modelling, the following is an example of a generic methodology:

System Definition: We take components of the hybrid renewable energy system, which typically includes PV subsystems, wind turbines, and controllers, with outputs analysed for reliability and performance.

Renewable Energy Sources: We utilized UV (irradiation), temperature, and wind flow data as input variables for our hybrid renewable energy system simulation. The data was sourced from [Weather Online India]

(https://www.weatheronline.in/weather/maps/city), covering the period from January 2020 to December 2023. These inputs were crucial for accurately modelling the performance of the photovoltaic (PV) and wind turbine components in MATLAB Simulink, allowing us to simulate and analyse the system's energy output and reliability under real-world conditions. This comprehensive data set helped in ensuring that the simulation reflects the environmental conditions specific to the locations being studied.

Data Collection

- Solar Irradiance
- Wind Speed

3.3 Mathematical Modelling

3.3.1 Develop Mathematical Models for Each Component

Estimation of Solar Power Generation: Estimating the amount of electricity generated by solar panels requires a number of important stages and factors. The method starts with determining the solar irradiance, which is the amount of solar energy that is received per unit area on a surface that is horizontal. A formula that may be used to find this is as follows:

I represents solar irradiance, Isc denotes the solar constant (approximately 1367 W/m²), and β signifies the solar elevation angle.

The next thing that has to be taken into consideration is the efficiency of the solar panels. The efficiency of solar panels normally falls somewhere in the range of 15% to 20%. This efficiency factor has an effect on the quantity of solar energy that can be turned into electricity. To determine the required area of solar panels, an equation considering energy needs, time period, and average solar irradiance is used:

$$A = \frac{E \cdot T}{I_{avg} \cdot \eta}$$

Where A represents the panel area required, **E** denotes the total energy required in kilowatt-hours (kWh), **T** is the total time period in hours, $\mathbf{I_{avg}}$ signifies the average solar irradiance on the panels, and $\boldsymbol{\eta}$ is the efficiency of the panels. Once the panel area is determined, the estimated energy output can be calculated using:

$$E_{out} = A \cdot I_{avg} \cdot \eta \cdot T$$

Eout denotes the estimated energy output.

In order to arrive at an accurate assessment, it is essential to take into account location-specific statistics, such as the levels of sun irradiation in the area. On top of that, it is essential to take into consideration elements such as system losses brought on by shade, fluctuations in temperature, and the efficiency of the inverter. Alterations in the angle at which the panels are tilted and seasonal shifts in solar radiation are further factors that contribute to the refinement of these estimations.

For the purpose of enhancing system performance and assuring accurate long-term projections of solar power output, it is vital to monitor actual energy production after installation and to alter calculations based on data collected from the real world. In order to optimize energy production and ensure that initial estimations are accurate, this iterative procedure helps to fine-tune them to fit real operating circumstances [10-17].

3.3.2 Solar Power Generation

When optimizing a solar power generating system, it is necessary to strike a balance between the many components (solar panels, batteries, inverters, and everything else) in order to achieve maximum efficiency and reduce expenses. Typically, the approach consists of the following phases, together with the equations and considerations that are pertinent to the situation:

$$I = I_{sc} \cdot \left(\frac{1-\cos(\beta)}{2}\right)$$

3.4 System Modelling

3.4.1 Solar Panel Output Calculation

The power output $\mathbf{P_{pv}}$ of a solar panel can be modelled as:

$$\mathbf{P_{pv}} = A \cdot G \cdot \eta$$

where:

- A s the area of the solar panel (m²)
- G is the solar irradiance (W/m²)
- η is the efficiency of the solar panel

3.4.2 Optimization Algorithms

Objective Function Define an objective function to minimize cost or maximize efficiency. For example, minimizing the levelized cost of energy (LCOE):

$$LCOE = \frac{\sum_{t=1}^{T}(C_{cap} + C_{om} + C_{fuel})}{\sum_{t=1}^{T} E_{gen}(t)} \quad \textbf{[18]}$$

where:

C_{cap} is the capital cost
C_{om} is the operation and maintenance cost
C_{fuel} is the fuel cost (for hybrid systems including generators)?
$E_{gen}(t)$ is the energy generated at time t

3.4.3 Constraints

Ensure system constraints are met, such as:

$$\begin{aligned} &P_{pv}(t) + P_{bat}(t) \geq E_d(t) \\ &SoC_{min} < SoC(t) < SoC_{max} \\ &P_{inv}(t) \leq P_{inv,max} \end{aligned} \quad \textbf{[19]}$$

3.5 Software and Tools

For this study, **MATLAB**, specifically **MATLAB 2013**, was utilized as the primary software for designing and simulating the hybrid renewable energy system, which integrates photovoltaic (PV) and wind energy components. MATLAB Simulink was instrumental in creating detailed models of the PV cells, wind turbines, and the overall hybrid system, allowing for precise simulation of energy production under varying environmental conditions. The software’s robust simulation capabilities enabled us to analyse system performance, optimize efficiency, and assess reliability. Additionally, MATLAB’s command prompt and workspace features were essential for managing inputs, running simulations, and debugging the model, ensuring accurate and reliable results [20-23].

4. SIMULATION AND RESULT

We have designed a hybrid system consist of PV and Portable Wind through MATLAB Simulink. We used MATLAB 2013 for developing the hybrid system. The various inputs and components have been presented though screenshot taken from MATLAB -2013.

4.1 Model Reliability

This section discusses the reliability of the hybrid system model developed in MATLAB Simulink. It includes an analysis of how consistently the model performs under various simulated conditions, such as changes in weather patterns, load demands, and system configurations. The reliability assessment involves testing the model’s ability to accurately predict the output of the PV and wind turbine systems, maintain stable power generation, and respond effectively to fluctuations in input variables like solar irradiation and wind speed. The results are used to evaluate the robustness and dependability of the model in real-world applications.

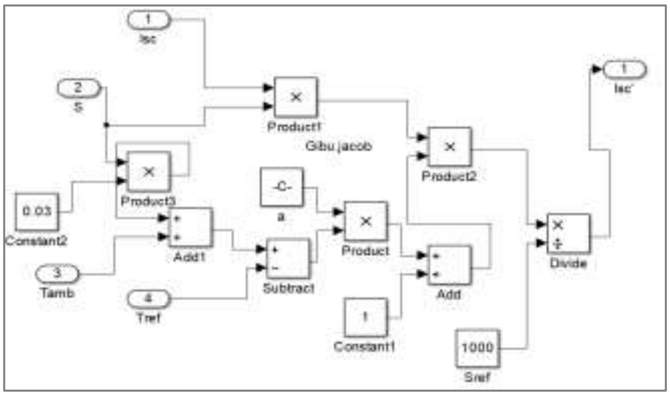


Fig 1: Small PV Cell Designed in MATLAB

This figure shows the initial design of a small photovoltaic (PV) cell created in MATLAB Simulink. It illustrates the basic components and connections used to simulate the behaviour of a single PV cell, including the input parameters such as solar irradiation and temperature, and their effect on the output current and voltage.

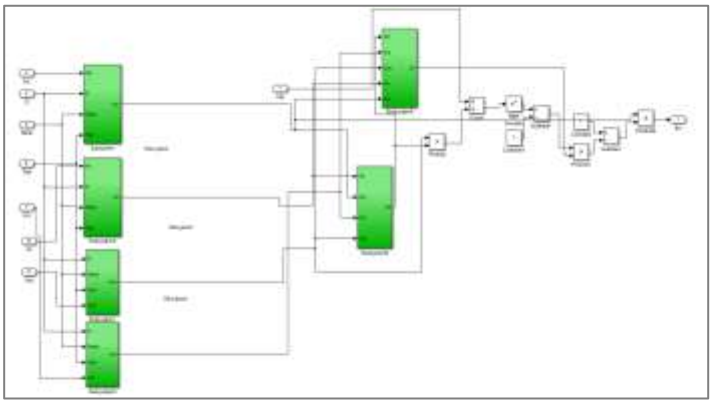


Fig 2: Six PV Subsystems Has Been Used in Hybrid System

This figure presents a screenshot of the six interconnected PV subsystems within the hybrid system. Each subsystem represents a separate PV array, working together to produce a cumulative power output, forming a critical part of the overall hybrid energy system.

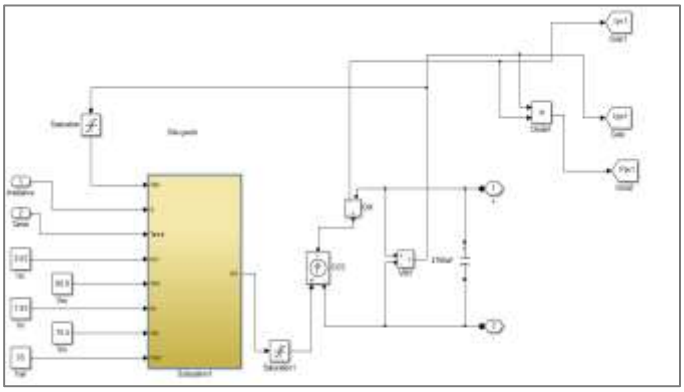


Fig 3: Complete PV System (This Consist of Six PV Subsystems)

This figure displays the entire PV system designed in MATLAB Simulink, consisting of the six PV subsystems. It shows how these subsystems are integrated to form a cohesive PV power generation system, with each subsystem contributing to the overall energy output.

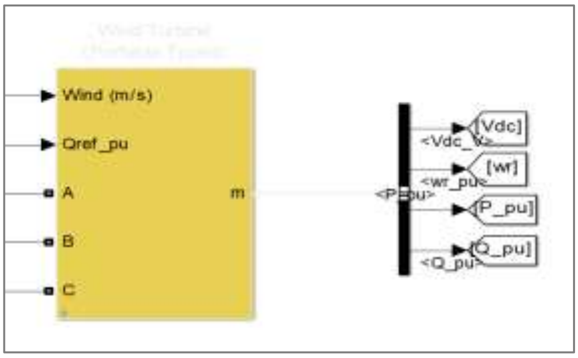


Fig 4: Wind Turbine (Portable Designed Typed for Small Scaled Or House Hold)

This figure presents the workspace in MATLAB where all the variable inputs for the hybrid system are managed. It includes data such as wind speed, temperature, and solar irradiation, which are crucial for simulating the performance of both the PV and wind turbine components.

Fig 5: All Variable Input from Work Space (Wind Data, Temperature Data, Irradiation Data)

This figure presents the workspace in MATLAB where all the variable inputs for the hybrid system are managed. It includes data such as wind speed, temperature, and solar irradiation, which are crucial for simulating the performance of both the PV and wind turbine components.

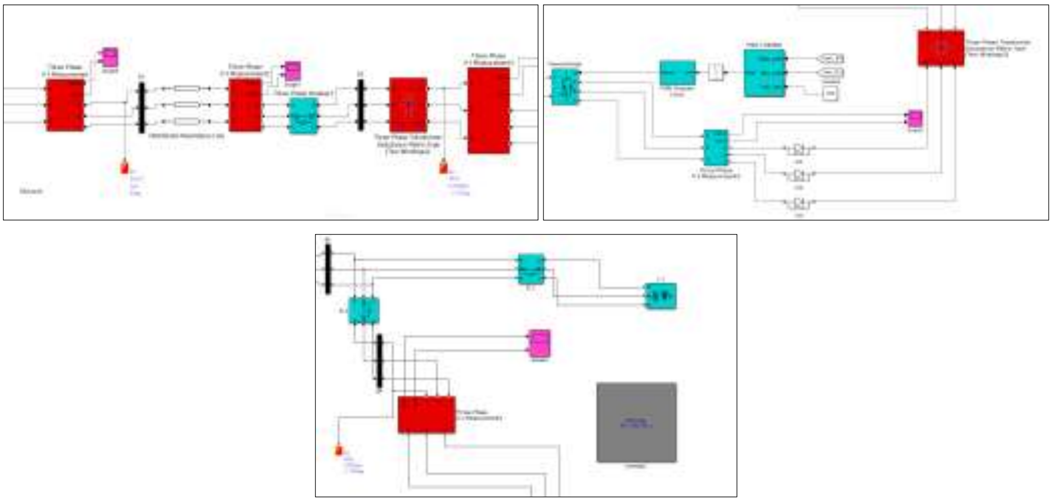


Fig 6: Separate Images of Three Phase VI Measure, Controller, Three Phase Measurements

This figure shows separate images of the three-phase voltage and current (VI) measurement tools, the controller, and the three-phase measurement system. These components are essential for monitoring and controlling the power flow within the hybrid system, ensuring stable and efficient operation.

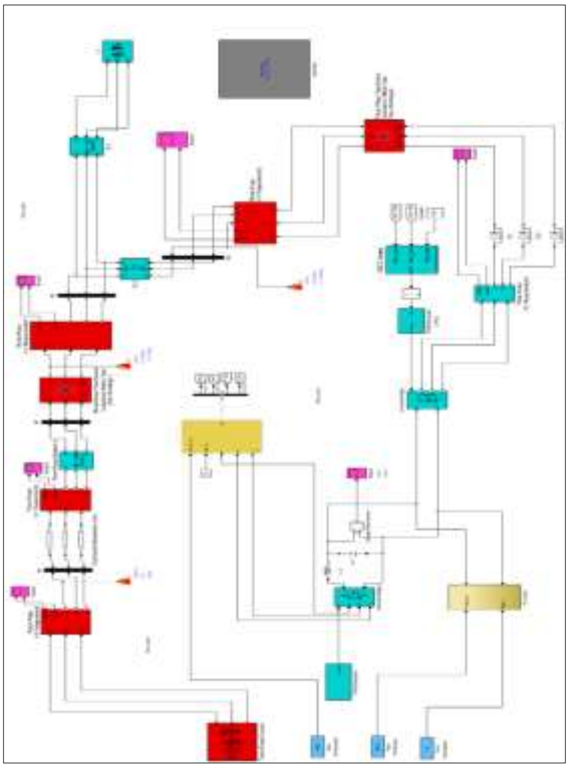


Fig 7: Complete Design of PV And Wind (MATLAB Simulink)

This figure illustrates the full design of the hybrid PV and wind system as modelled in MATLAB Simulink. It integrates all components, including the PV subsystems, wind turbine, and associated controllers, showcasing the complete hybrid power generation system.

Reliability Outcome from Each Stage

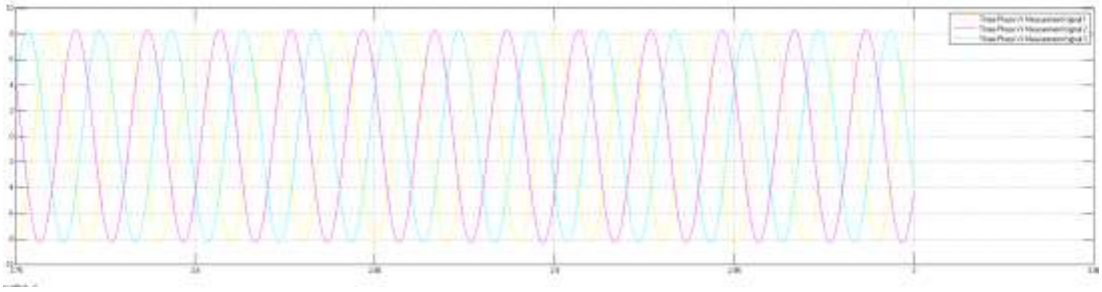


Fig 8: Outcome of Three Phase (Scope 4)

This figure shows the output of the three-phase system as captured by Scope 4 in MATLAB Simulink. It highlights the voltage and current characteristics of the system under operational conditions, reflecting the reliability and performance of the three-phase power transmission.

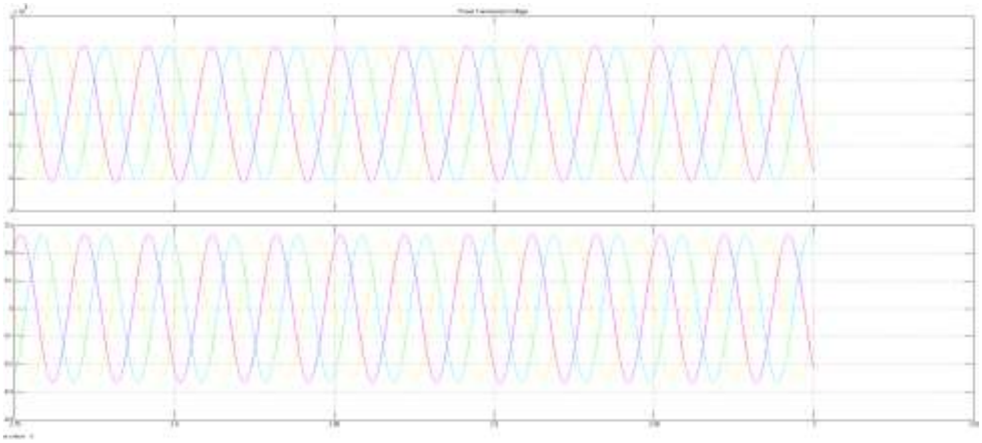


Fig 9: Outcome of Three Phase VI Measure (Scope 1)

This figure presents the results of the three-phase voltage and current measurements captured by Scope 1. It provides insights into the electrical behaviour of the hybrid system, showing how the generated power is managed and distributed.

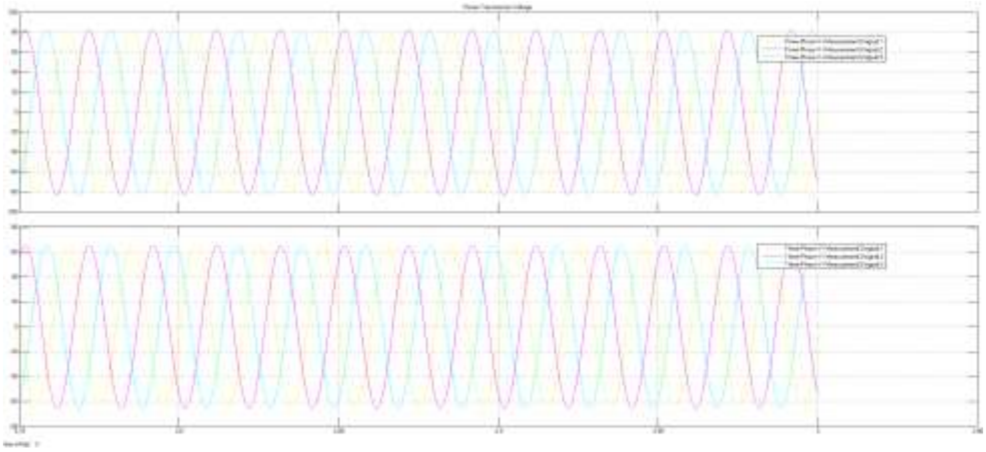


Fig 10: Power Transmission Voltage-From Three Phase Outcome (Scope 2)

This figure displays the power transmission voltage as captured by Scope 2. It shows the voltage levels within the system during the power transmission process, crucial for ensuring the stability and efficiency of the hybrid system.

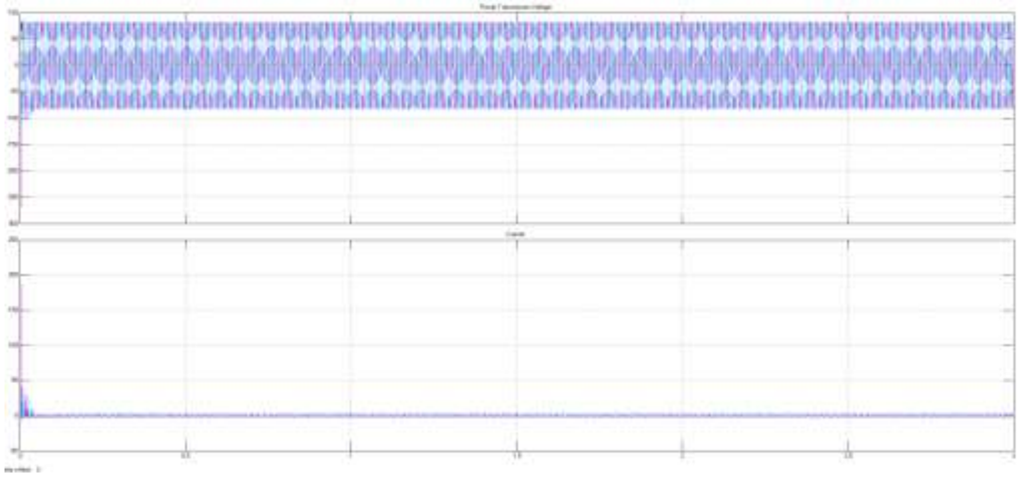


Fig 11: Power Transmission Voltage-From Three Phase Outcome (Scope 3) -When Hybrid Power Has Been Mixed

This figure highlights the power transmission voltage captured by Scope 3, specifically when the PV and wind power are combined. It demonstrates the effectiveness of the hybrid approach in stabilizing the voltage output during mixed power generation.

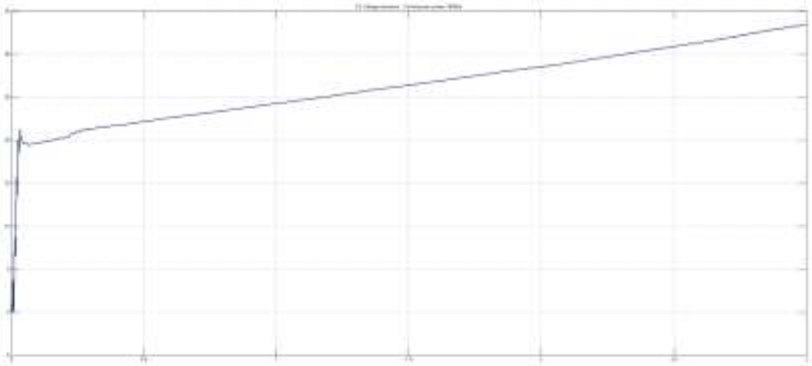


Fig 12: DC Voltage Outcome (Wind Power) After Conversion of Wind Generation

This figure shows the DC voltage outcome from the wind power system after the AC generated by the wind turbine has been converted. It reflects the efficiency of the conversion process and the stability of the DC output for use in the hybrid system.

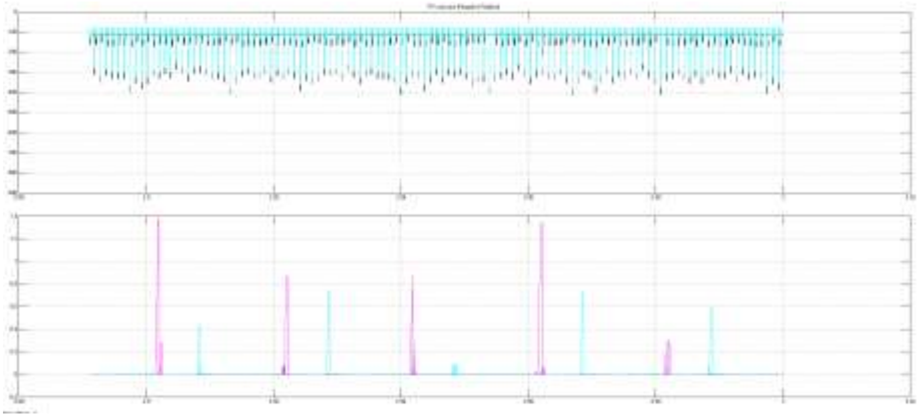


Fig 13: PV Outcome (Consuming the Sun Power So It Reflecting Negative Value in Y Axis)

This figure presents the output of the PV system, where the negative value on the Y-axis indicates the consumption of solar power. The negative reading can be attributed to the PV system's behaviour under certain conditions, such as reverse power flow or measurement configurations.

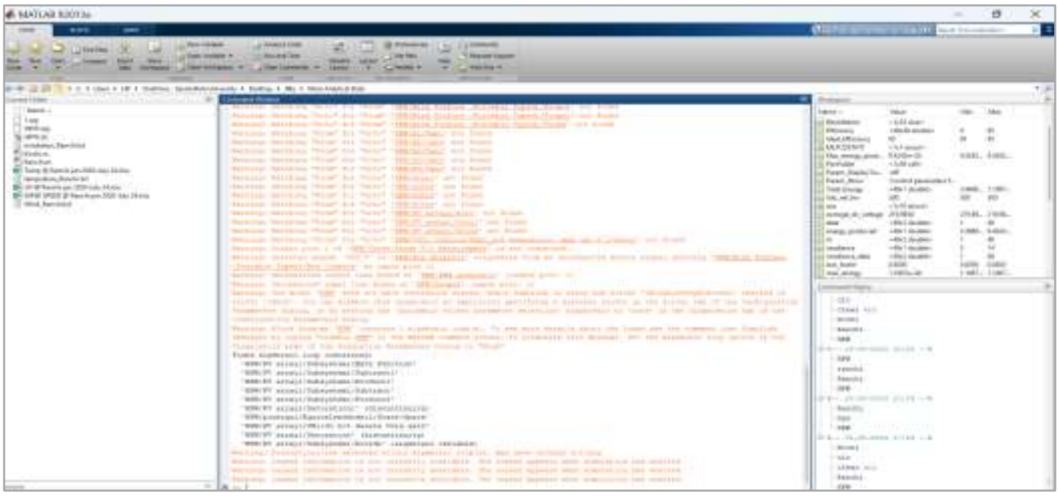


Fig 14: MATLAB Command Prompt

This figure shows a screenshot of the MATLAB command prompt, where users can enter commands and scripts to control the MATLAB environment. It serves as the interface for executing commands related to the hybrid system simulation, including running scripts, initializing variables, and managing the workspace. The command prompt is an essential tool for debugging and interacting with the MATLAB Simulink model, providing real-time feedback and control over the simulation processes.

4.2 Analyse Kochi and Ranchi Data

4.2.1 Analysis of Ranchi Data

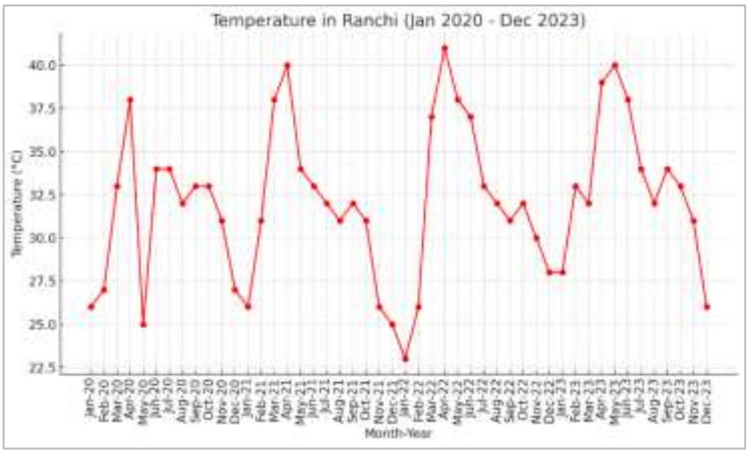


Fig 15: Temperature-Ranchi (Input Data- January 2020 to Dec 2023) -Secondary Data
Source: https://www.weatheronline.in/weather/maps/city

This plot of temperature in Ranchi from January 2020 to December 2023. The chart depicts the variation in monthly average temperatures over the years, showing the typical seasonal trends with higher temperatures during the summer months (April to June) and lower temperatures in the winter months (December to February). The temperature values range from around 23°C to 41°C, highlighting the warm climate of Ranchi, with significant peaks during the summer seasons.

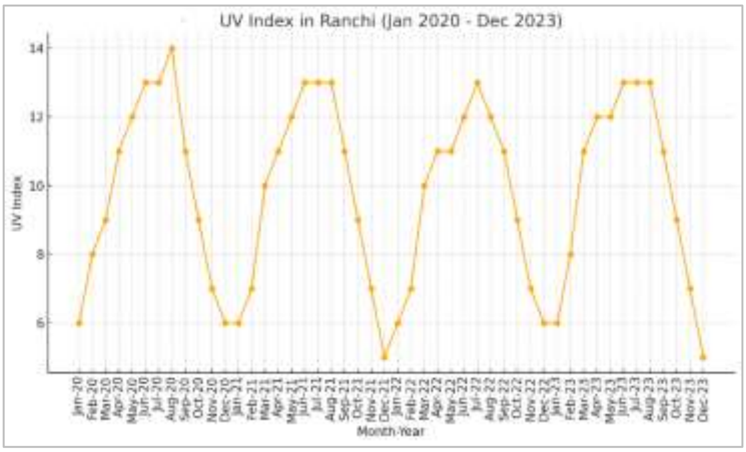


Fig 16: UV Index (Input Data- January 2020 to Dec 2023) -Secondary Data
Source: https://www.weatheronline.in/weather/maps/city

This plot of the UV Index in Ranchi from January 2020 to December 2023. The chart illustrates the fluctuation of the UV Index throughout the period, with peaks typically occurring during the summer months (June to August) and lower values during the winter months. The UV Index values range from 5 to 14, reflecting the intensity of ultraviolet radiation experienced in Ranchi over these years.

Wind Speed (Input Data- January 2020 to Dec 2023) -Secondary Data

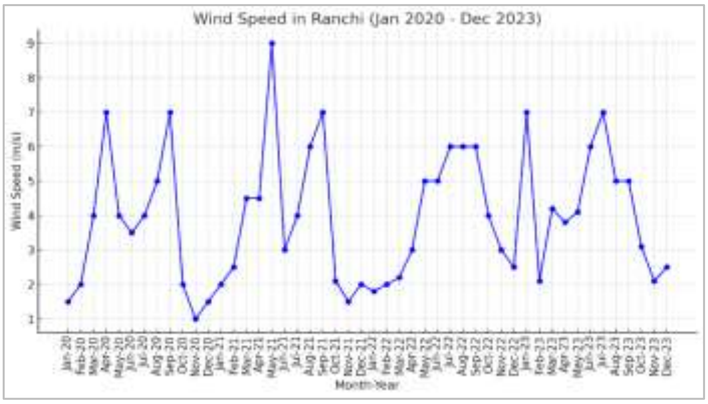


Fig 17: Wind Speed-Kochi (Input Data- January 2020 to Dec 2023) - Secondary Data
Source: https://www.weatheronline.in/weather/maps/city

This above plot of wind speed in Ranchi from January 2020 to December 2023. The data shows the variation in wind speed over this period, with some months experiencing significantly higher speeds, such as May 2021 and January 2023, while others, particularly the late autumn and winter months, show lower wind speeds.

Outcome -Ranchi

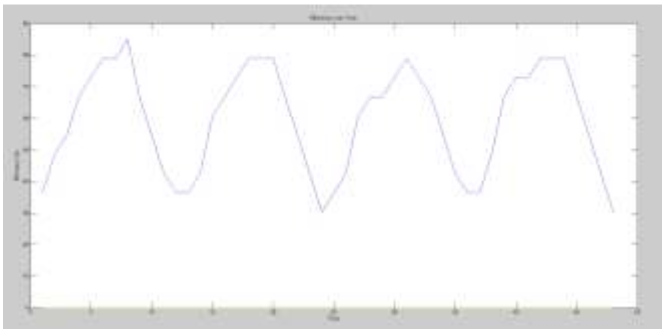


Fig 18: Efficiency Over Time

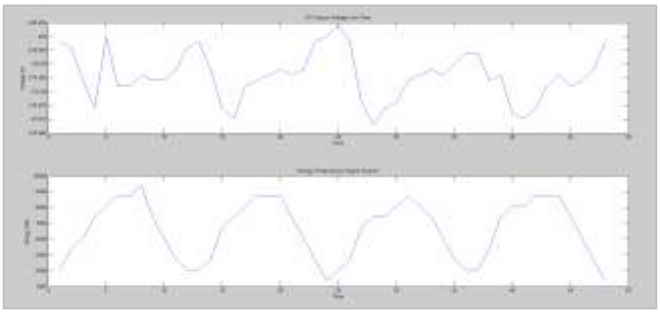


Fig 19: DC Outcome Voltage Over Time (Above Figure), Energy Produced by Hybrid System (Below Figure)

The simulation results for Ranchi show an ideal system efficiency of 85%, indicating that the system is performing close to its optimal capacity. The average DC output voltage is 219.99 volts, suggesting a stable and consistent power supply from the system. The total energy produced, accounting for losses, is 317,054.59 watt-hours (Wh), reflecting the overall energy generation over the specified period. These results highlight the effectiveness of the hybrid system in Ranchi, demonstrating that despite inherent losses, the system efficiently generates and delivers a substantial amount of energy.

Location	Ideal Efficiency (%)	Average DC Output Voltage (Volts)	Total Energy Produced with Losses (Wh)
Ranchi	85	219.99	317054.6

4.2.2 Analysis of Kochi Data

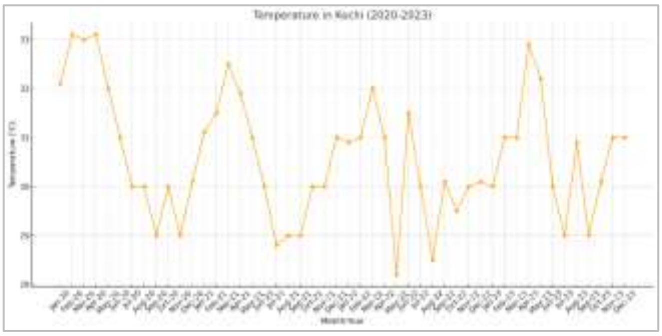


Fig 20: Temperature -Kochi (Input Data- January 2020 to Dec 2023) -Secondary Data

This graph showing the temperature trends in Kochi from January 2020 to December 2023. The plot illustrates the monthly variations in temperature, highlighting the general climate patterns in Kochi over this period. Temperatures typically range between 28°C and 33°C, with some fluctuations across different years and seasons. This visual representation helps to understand the temperature dynamics in Kochi throughout the years.

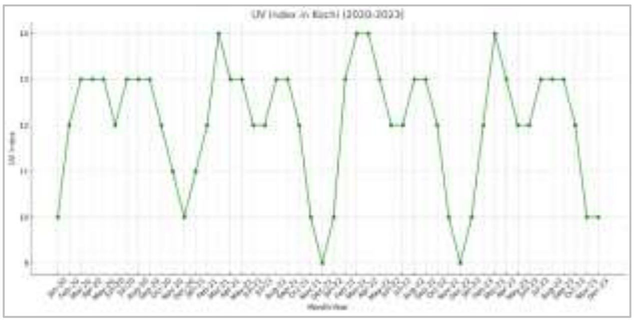


Fig 21: UV -Kochi (Input Data- January 2020 to Dec 2023) - Secondary Data

This graph showing the UV Index in Kochi from January 2020 to December 2023, with complete data for each month. This also shows consistent seasonal patterns. The UV Index peaks in March and April, with values reaching up to 14, indicating high UV exposure during these months. The index slightly decreases during the monsoon months (June to August) and continues to drop in the winter months (November to January), where values range between 9 and 12. This trend reflects the typical climate of Kochi, where the highest UV levels correspond with the pre-monsoon summer period, while lower values occur during the cooler winter season.

Fig 22: Wind Speed -Kochi (Input Data- January 2020 to Dec 2023) - Secondary Data

This graph showing the wind speed trends in Kochi from January 2020 to December 2023. The plot illustrates the monthly variations in wind speed, highlighting how it fluctuates throughout the year and across different years. Wind speeds generally range from 0 to 11 meters per second, with notable variations during different months. This visualization helps to understand the wind patterns in Kochi over the given period.

Outcome -Kochi

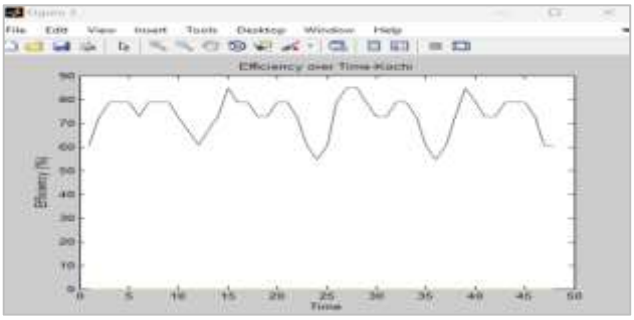


Fig 23: Efficiency Over Time

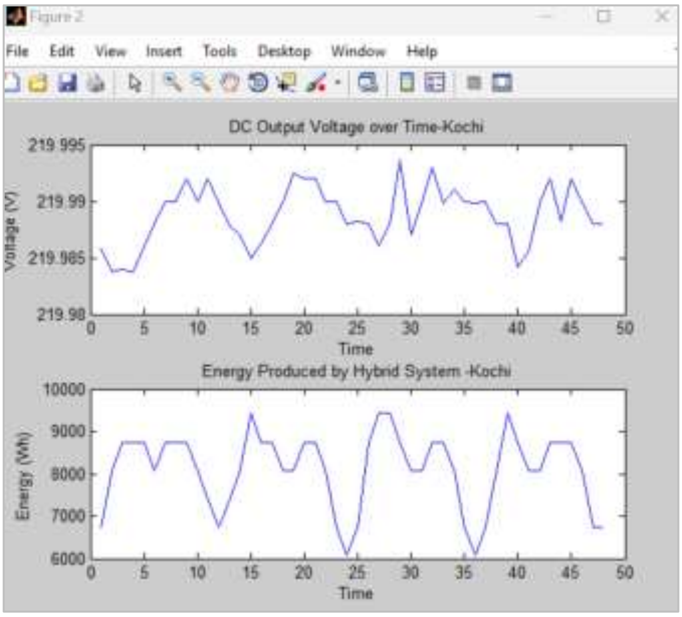


Fig 24: DC Outcome Voltage Over Time (Above Figure), Energy Produced by Hybrid System (Below Figure)

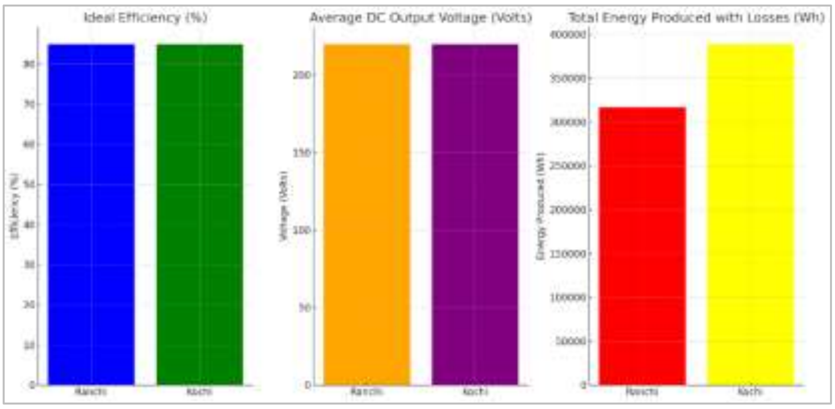
The simulation results for Ranchi show an ideal system efficiency of 85%, indicating that the system is performing close to its optimal capacity. The average DC output voltage is 219.99 volts, suggesting a stable and consistent power supply from the system. The total energy produced, accounting for losses, is 317,054.59 watt-hours (Wh), reflecting the overall energy generation over the specified period. These results highlight the effectiveness of the hybrid system in Ranchi, demonstrating that despite inherent losses, the system efficiently generates and delivers a substantial amount of energy.

Location	Ideal Efficiency (%)	Average DC Output Voltage (Volts)	Total Energy Produced with Losses (Wh)
Kochi	85	219.99	389089.7

4.3 Comparative Analysis

Table 4.1: Comparative Analysis (Ranchi- Kochi)

Location	Ideal Efficiency (%)	Average DC Output Voltage (Volts)	Total Energy Produced with Losses (Wh)
Ranchi	85	219.99	317054.6
Kochi	85	219.99	389089.7



Comparative Analysis (Ranchi- Kochi)

The comparative analysis between Ranchi and Kochi highlights notable similarities and differences in the performance of hybrid energy systems at these two locations. Both locations exhibit an identical ideal efficiency of 85%, indicating that the systems are designed to function at an optimal level under ideal conditions. Additionally, the average DC output voltage is consistent across both locations at 219.99 volts, reflecting stable voltage levels maintained by the systems irrespective of the geographical differences. However, the significant difference lies in the total energy produced with losses. Kochi outperforms Ranchi by generating 389,089.73 Wh compared to Ranchi's 317,054.59 Wh. This disparity suggests that Kochi has more favourable environmental conditions, such as better sunlight and wind patterns, which contribute to higher energy production. The consistency in efficiency and voltage indicates that both systems are well-calibrated and function as expected, but the higher energy output in Kochi underscores its suitability for renewable energy generation. The bar graphs effectively illustrate the consistency in efficiency and voltage, while also emphasizing Kochi's superior energy production. The line graph further reinforces these findings, showing that while efficiency and voltage are stable, the environmental advantages in Kochi result in significantly higher energy output, making it a more viable location for hybrid energy systems.

5. CONCLUSION AND FUTURE SCOPE

The study aimed to explore the feasibility, reliability, and optimization of hybrid renewable energy systems that integrate photovoltaic (PV) solar panels and wind turbines. Focusing on two distinct locations in India Ranchi, Jharkhand, and Kochi, Kerala—we sought to understand how these systems perform under varying environmental conditions and to compare their potential for energy generation. Through detailed simulations using MATLAB 2013, we were able to model and analyze the performance of these hybrid systems, providing valuable insights into their practical applications and effectiveness. The primary findings indicate that hybrid renewable energy systems can significantly enhance energy production and reliability by leveraging the complementary nature of solar and wind resources. While both Ranchi and Kochi showed promising results, the comparative analysis revealed that Kochi, with its more favourable climatic conditions, particularly higher solar irradiation and consistent coastal winds, outperformed Ranchi in terms of total energy produced. Specifically, Kochi's system generated

389,089.73 Wh of energy, compared to 317,054.59 Wh in Ranchi, even though both locations maintained an identical ideal efficiency of 85% and an average DC output voltage of 219.99 volts. This difference in energy output underscores the importance of location-specific analysis when deploying hybrid renewable energy systems. The results from Kochi highlight the benefits of implementing such systems in areas with strong solar and wind resources, while Ranchi's results suggest that even in regions with moderate conditions, these systems can still offer a viable solution for sustainable energy generation. Throughout the study, MATLAB played a crucial role in the design and simulation of the hybrid systems. The software allowed for detailed modelling of both the PV and wind components, as well as the integration of real-world environmental data from January 2020 to December 2023, sourced from [Weather Online India] (https://www.weatheronline.in/weather/maps/city). The inputs, which included UV irradiation, temperature, and wind speed, were essential for accurately simulating the system's performance under various conditions. MATLAB's Simulink provided a robust platform for visualizing and analysing the system's behaviour, ensuring that the model could reliably predict energy output and maintain stable operation across different scenarios. The reliability of the hybrid system was a key focus of the study, particularly in how it responded to changes in weather patterns, load demands, and other operational variables. The simulations demonstrated that the system was capable of maintaining stable power generation and effectively managing fluctuations in input variables. This reliability is crucial for real-world applications, where energy systems must consistently meet demand despite environmental variability. In addition to assessing the current performance of the hybrid systems, the study also explored areas for future optimization. With refining the system's components and improving the integration of solar and wind resources, it is possible to further enhance energy production and efficiency. The research also highlights the potential for expanding the use of hybrid renewable systems to other regions with similar climatic conditions, offering a scalable solution for sustainable energy generation across India.

5.1 Future Scope

The findings of this study open up several avenues for future research and development in the field of hybrid renewable energy systems. The following are key areas where further exploration and innovation can significantly contribute to advancing the technology and its applications:

Advanced Optimization Techniques: While this study focused on basic optimization of the hybrid system, there is considerable scope for employing more advanced optimization techniques. Machine learning algorithms, for example, could be used to predict and optimize energy output based on historical data, improving the system's responsiveness to environmental changes.

Integration with Smart Grids: Future research could explore the integration of hybrid renewable energy systems with smart grid technologies. This would allow for more efficient management of energy distribution, real-time monitoring, and better handling of peak load demands, ultimately leading to more resilient and adaptive energy systems [24].

Expansion to Other Geographic Regions: While this study focused on Ranchi and Kochi, similar analyses could be conducted in other regions of India and globally. This would provide a broader understanding of the feasibility of hybrid systems in various climates and geographical conditions, helping to identify the most suitable locations for deployment.

Cost-Benefit Analysis: Further research could include a comprehensive cost-benefit analysis of hybrid renewable energy systems. This would involve not only the initial investment costs but also the long-term savings from reduced energy bills and the environmental benefits from lower carbon emissions. Such analyses would be valuable for policymakers and investors considering large-scale deployment.

Battery Storage Integration: The integration of battery storage systems with hybrid renewable energy setups could be another promising area of research. Battery storage would allow excess energy generated during peak production times to be stored and used during periods of low production, thereby increasing the overall reliability and efficiency of the system.

Impact of Technological Advancements: As technology evolves, new and more efficient PV panels and wind turbines are being developed. Future research could focus on how these advancements can be incorporated into existing hybrid systems to improve performance. Additionally, the impact of emerging technologies such as floating solar farms and offshore wind turbines could be explored.

Environmental Impact Assessment: Alongside the technical and economic evaluations, it is important to assess the environmental impacts of deploying hybrid renewable energy systems. Future studies could examine the ecological footprint of these systems, including their effects on local wildlife, land use, and ecosystems [25].

Policy and Regulatory Framework: There is a need for research into the policy and regulatory frameworks that support the adoption of hybrid renewable energy systems. This includes analysing current policies, identifying gaps, and proposing new regulations that could incentivize the use of hybrid systems, particularly in regions with high renewable energy potential.

Community and Social Impacts: Understanding the social and community impacts of hybrid renewable energy systems is crucial for their successful implementation. Future research could explore how these systems affect local communities, including issues related to energy access, job creation, and social acceptance.

Hybrid System Scaling: Research could also focus on scaling hybrid renewable energy systems for different applications, from small residential setups to large industrial installations. This would involve developing scalable models that can be customized based on the energy needs and resources available in a particular location [26].

Climate Resilience: With climate change expected to alter weather patterns globally, it is important to assess how hybrid renewable energy systems can be made more resilient to these changes. Future research could focus on designing systems that can adapt to extreme weather conditions and continue to provide reliable energy.

Data-Driven Decision Making: The use of big data analytics to improve decision-making in the design, optimization, and management of hybrid renewable energy systems presents another area for future research. With leveraging large datasets on weather patterns, energy consumption, and system performance, more informed and effective strategies can be developed.

Long-Term Performance Monitoring: Continuous monitoring and analysis of hybrid renewable energy systems over the long term would provide valuable data on their performance and reliability. This could lead to improvements in system design and maintenance practices, ensuring sustained efficiency and output over the system’s lifespan.

Hybrid System Software Development: The development of specialized software tools tailored for hybrid renewable energy systems could greatly enhance the design, simulation, and optimization processes. Future work could focus on creating user-friendly software that integrates the latest advancements in renewable energy technology and optimization algorithms.

International Collaboration: Finally, there is scope for international collaboration in the research and development of hybrid renewable energy systems. By working together, researchers from different countries can share knowledge, technologies, and best practices, accelerating the adoption of hybrid systems worldwide.

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