

DESIGN OF A HYBRID POWER GENERATION SYSTEM USING SOLAR AND WIND ENERGY IN CIPATUJAH TASIKMALAYA

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INTISARI

Keterbatasan akses listrik di daerah terpencil menjadi hambatan utama dalam meningkatkan kualitas hidup masyarakat. Penelitian ini bertujuan untuk mengatasi permasalahan tersebut dengan merancang dan mengevaluasi sistem pembangkit listrik *hybrid* surya-angin sebagai solusi berkelanjutan di Kecamatan Cipatujah, Kabupaten Tasikmalaya. Kabupaten Tasikmalaya, yang terletak di Provinsi Jawa Barat, Indonesia, secara geografis berada pada posisi 7°02'29" - 7°49'08" Lintang Selatan dan 107°54'10" - 108°25'52" Bujur Timur. Kecamatan Cipatujah di wilayah pesisir kabupaten ini memiliki potensi energi terbarukan yang signifikan, meliputi angin, radiasi matahari, dan gelombang laut. Melalui analisis mendalam terhadap potensi sumber daya matahari dan angin di wilayah tersebut, serta simulasi menggunakan perangkat lunak HomerPro, penelitian ini berhasil mengidentifikasi konfigurasi sistem yang optimal untuk memenuhi kebutuhan listrik masyarakat secara andal dan ekonomis. Hasil simulasi menunjukkan bahwa sistem hybrid ini mampu beroperasi secara efisien, bahkan pada kondisi cuaca yang tidak menentu, serta mampu mengurangi biaya operasional dibandingkan dengan penggunaan generator diesel konvensional. Selain itu, penelitian ini juga mempertimbangkan aspek sosial dan ekonomi, seperti dampak terhadap peningkatan produktivitas masyarakat, pengembangan usaha mikro, kecil, dan menengah (UMKM), serta peningkatan pendapatan masyarakat. Dengan demikian, sistem hybrid ini tidak hanya meningkatkan akses energi listrik bagi masyarakat, tetapi juga berkontribusi pada pertumbuhan ekonomi lokal dan pembangunan berkelanjutan. Hasil penelitian ini memberikan rekomendasi teknis dan ekonomis yang komprehensif, termasuk perhitungan biaya investasi, biaya operasional, dan analisis sensitivitas terhadap perubahan parameter sistem. Rekomendasi ini diharapkan dapat menjadi acuan bagi pemerintah daerah, lembaga swadaya masyarakat, dan investor dalam mengembangkan proyek serupa di daerah terpencil lainnya di Indonesia.

ABSTRACT

Limitations in access to electricity in remote areas are a major obstacle to improving the quality of life for the community. This study aims to address this issue by designing and evaluating a hybrid solar-wind power generation system as a sustainable solution in Cipatujah Subdistrict, Tasikmalaya Regency. Tasikmalaya Regency, located in West Java Province, Indonesia, is geographically situated between 7°02'29" - 7°49'08" South Latitude and 107°54'10" - 108°25'52" East Longitude. Cipatujah Subdistrict, which is a coastal area of the regency, has significant potential for renewable energy, including wind, solar radiation, and wave energy. Through an in-depth analysis of the solar and wind resource potential in the area, as well as simulations using HomerPro software, this study successfully identified the optimal system configuration to meet the community's electricity needs reliably and economically. The simulation results show that this hybrid system can operate efficiently, even under uncertain weather conditions, and can reduce operational costs compared to conventional diesel generators. Additionally, this study considers social and economic aspects, such as the impact on increasing community productivity, the development of micro, small, and medium enterprises (MSMEs), and the increase in community income. Thus, this hybrid system not only enhances access to electricity for the community but also contributes to local economic growth and sustainable

development. The results of this study provide comprehensive technical and economic recommendations, including investment cost calculations, operational costs, and sensitivity analysis of system parameters. These recommendations are expected to serve as a reference for local governments, community organizations, and investors in developing similar projects in other remote areas of Indonesia.

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1. INTRODUCTION

Energy is a primary driver of sustainable development. The global energy crisis has highlighted the critical need to seek alternative, sustainable energy sources. This crisis has spurred significant policy changes, and the importance of energy concepts has grown over time [1]. A nation aspiring to social and economic progress must prioritize sustainable energy utilization. The ever-increasing demand for energy, driven by population growth, rising living standards, and economic development, often outpaces supply [2]. The world's reliance on fossil fuels as the primary energy source has triggered numerous severe environmental issues. Greenhouse gas emissions from fossil fuel combustion contribute to global climate change, leading to natural disasters such as floods, storms, and droughts [3]. The combustion of fossil fuels releases substantial amounts of carbon dioxide (CO₂) into the atmosphere, causing the greenhouse effect and global climate change. Consequently, we are experiencing increased frequency and intensity of natural disasters like floods, droughts, and heatwaves. Additionally, air pollution and environmental degradation such as deforestation are worsening [4]. This poses a challenge in transitioning the existing energy system towards a more environmentally friendly and sustainable model, while also encouraging investment in clean energy technologies [5] [6] [7].

The depletion of fossil fuels and the impacts of climate change have compelled the world to seek cleaner energy alternatives. Hybrid energy systems, which combine various renewable energy sources like solar and wind, offer a comprehensive solution. While solar energy has immense potential, challenges such as high production costs remain a barrier. Therefore, hybridizing energy systems is key to enhancing efficiency and accelerating the widespread adoption of renewable energy [5] [8]. Solar energy is at the core of global energy diversification efforts due to its abundant potential worldwide. Through continuous efforts to develop solar power technology, it is expected to facilitate a significant transition from harmful fossil fuels to cleaner, more sustainable, and environmentally friendly energy sources [11]. Wind power generation technology has advanced rapidly, making it one of the most sought-after renewable energy sources. Wind energy offers an efficient and environmentally friendly solution to meet global energy demands. With technological advancements, the production cost of electricity from wind continues to decline, making it increasingly economically attractive [12]. Fluctuations in wind speed directly impact the amount of electricity generated by wind turbines. These power fluctuations can disrupt the balance of the electrical system and pose risks to the quality and reliability of power supply [12].

Daily electricity demand is increasing with the growth of technology, such as the use of electronic devices that rely on electricity. Human population growth is another factor contributing to the rising demand for electricity. Indonesia, a developing nation with a population of around 250 million spread across more than 17,000 islands [9], requires a substantial electricity supply. Currently, approximately 2,519 villages in Indonesia lack access to electricity. Electricity availability is crucial as it determines the quality of life in a country [10]. Renewable energy is one solution to address electricity availability in Indonesia, as it can be utilized in remote areas that are difficult to reach by the main grid, leveraging the region's potential. Indonesia is committed to increasing the share of renewable energy in its energy mix from the current state, which heavily relies on fossil fuels. The significant potential of sources like hydro, geothermal, and bioenergy is expected to help achieve the target of 31% by 2050. However, this requires careful planning and effective coordination [8]. With the increasing demand for electricity due to the target of full electrification by 2025, Indonesia's electricity demand is projected to surge to 1,611 TWh by 2050. To achieve net-zero emissions, integrating renewable energy sources is a strategic step. Nevertheless, the fluctuating nature of solar and wind energy, which is highly dependent on weather conditions, poses risks of electricity supply instability and needs to be

addressed [8] [13]. The plan to shift the power generation source from fossil fuels to renewable energy is a crucial step in ensuring a more stable electricity supply, enhancing economic value, and protecting the environment [8]. Indonesia is located near the equator, making it endowed with high solar energy potential [14].

Tasikmalaya Regency currently has a low electrification ratio, and some areas still lack electricity. Hybrid power systems can be used as a solution to improve the electrification ratio by utilizing the available renewable energy potential in the region. A hybrid energy system integrates multiple renewable energy sources and other sources to generate electricity that can be distributed to the load center. The potential of renewable energy sources in Tasikmalaya Regency can be an excellent solution to meet the electricity needs in areas not yet reached by the main power grid. Mature and environmentally friendly renewable energy technologies make these sources highly promising to replace conventional fossil fuels that produce greenhouse gas emissions [15] [8]. Tasikmalaya Regency is part of West Java Province, located between $7^{\circ}02' 29''$ - $7^{\circ}49' 08''$ South Latitude and $107^{\circ}54' 10''$ - $108^{\circ}25' 52''$ East Longitude (Kominfo Tasikmalaya, 2021). The Tasikmalaya coast itself has renewable energy potential in the form of wind, solar radiation, and ocean waves. The data on electricity consumption taken from the Karangnunggal GI Tasikmalaya in the southern coastal area of Tasikmalaya, specifically in Cipatujah sub-district, is 20,6917 MW per day [16]. This research aims to design a hybrid power plant in the Cipatujah area of Tasikmalaya Regency. Several designs will be simulated to obtain the most economical value, and eventually, the design can be implemented in the area. The simulation in this research uses HOMER Pro software.

This research aims to design and implement an optimal solar-wind hybrid power generation system in Cipatujah District, Tasikmalaya Regency. Through simulations using HomerPro software, various system configurations will be evaluated to achieve the most economical and efficient design. Given the significant potential of renewable energy resources in Cipatujah District, this study is expected to serve as an example of clean technology application in rural areas. By implementing a solar-wind hybrid system, it is hoped to reduce dependence on fossil fuels and greenhouse gas emissions, as well as increase the electrification ratio in the region

2. METHODS

The research is conducted in Cipatujah Subdistrict, Tasikmalaya Regency. The research area is illustrated in the Figure 1 below.

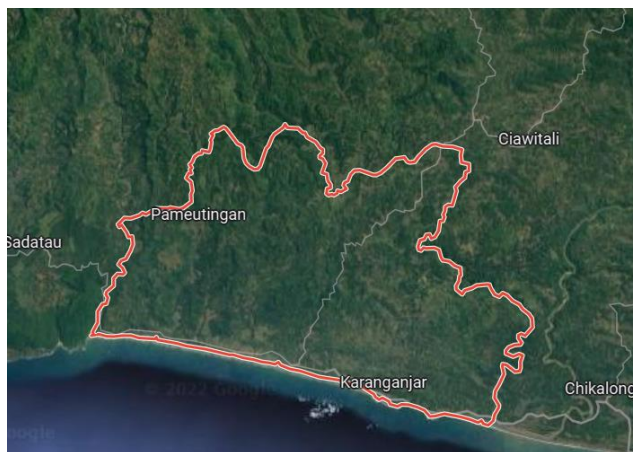


Figure 1. Cipatujah Subdistrict

2.1 Flowchart Research

The flowchart in Figure 2.2 for the research on designing a hybrid power generation system consists of six key stages: selecting the location, collecting data, analyzing that data, modeling the system, designing the hybrid system, and conducting economic and performance analysis. The process begins with identifying the appropriate site, followed by gathering essential information on solar and wind energy potential and electricity demand. This data is then analyzed to assess feasibility and inform system modeling, which utilizes HOMER Pro software to simulate various configurations. Based on the modeling results, an optimal hybrid system design is developed, integrating solar panels, wind turbines, and possibly fuel generators. Finally, the economic

and performance analysis evaluates the system's efficiency, cost-effectiveness, and overall viability, ensuring that the proposed solution meets the energy needs of the local community sustainably.

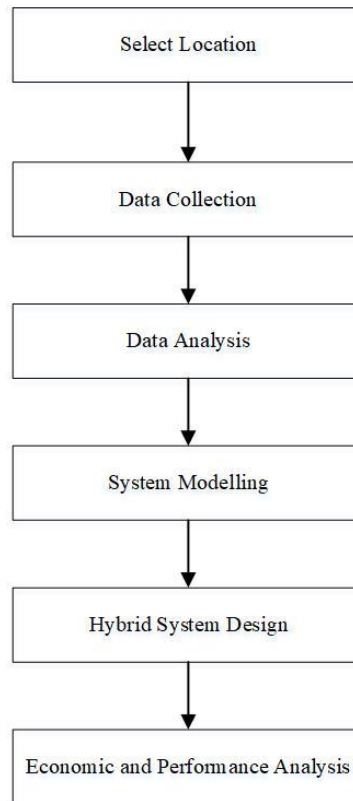


Figure 2. Flowchart Research

2.2 Data Processing

Data processing involves manipulating the available input data to conduct analysis and derive accurate research results. The data required for hybrid system modeling includes solar energy potential data, wind energy data, and load potential data. Both primary and secondary data are utilized. Primary data is collected directly from the primary source, while secondary data is obtained indirectly through intermediary channels. In this study, primary data consists of solar and wind energy potential data obtained through the HOMER software, directly sourced from NASA satellites. The following are the solar and wind energy potential data for the Tasikmalaya Regency in Table 1 :

Table 1. Wind Energy Potential Data

| Month | Average |
|-------------|---------|
| Jan | 4.530 |
| Feb | 4.760 |
| Mar | 4.140 |
| Apr | 4.320 |
| May | 5.080 |
| Jun | 5.450 |
| Jul | 5.960 |
| Aug | 6.120 |
| Sep | 5.810 |
| Oct | 5.230 |
| Nov | 4.560 |
| Dec | 4.410 |
| Rata - Rata | 5.031 |
| Maksimal | 6.120 |
| Minimal | 4.140 |

Based on the analysis of the data, it can be concluded that wind speeds reach their highest peaks in July and August, while reaching their lowest levels in March. These findings indicate the presence of seasonal fluctuations in wind speed, with a greater potential for wind energy in the summer and a smaller potential in the winter. Despite the seasonal variations, the overall average wind speed demonstrates reasonably good consistency, providing promising opportunities for utilization as a reliable source of renewable energy. These findings reinforce the belief that harnessing wind speed as an energy source can be a significant contributor to supporting energy sustainability in this region.

Table 2. Data on Solar Energy Potential in Cipatujah

| Month | Clearness | Daily Radiation |
|-------|-----------|-----------------|
| Jan | 0.405 | 4.370 |
| Feb | 0.416 | 4.500 |
| Mar | 0.442 | 4.640 |
| Apr | 0.472 | 4.600 |
| May | 0.511 | 4.540 |
| Jun | 0.518 | 4.350 |
| Jul | 0.518 | 4.450 |
| Aug | 0.508 | 4.740 |
| Sep | 0.495 | 5.030 |
| Oct | 0.455 | 4.840 |
| Nov | 0.418 | 4.490 |
| Dec | 0.429 | 4.600 |

Table 2.2 illustrates the Brightness Index and Daily Radiation for each month in Cipatujah, providing an overview of the solar energy potential in that region. Brightness Index: This is a dimensionless number between 0 and 1 that indicates the fraction of sunlight reaching the Earth's surface [17] [18]. A higher brightness index implies more sunlight available for solar energy generation. Daily Radiation: Measured in kilowatt-hours per square meter (kWh/m²), this metric reflects the amount of solar energy reaching the Earth's surface each day. Observing the data for each month, it is apparent that May and June have the highest brightness index, indicating these months receive the most abundant sunlight. However, the peak in Daily Radiation occurs in September, signifying that this month has the highest solar energy potential.

Overall, the data indicates that Cipatujah has significant potential for solar energy generation. The high brightness index and substantial daily radiation values suggest that solar panels could generate a considerable amount of electricity at this location

2.2. Instrumentation

This research requires modeling using the HOMER software, which serves as a global standard for optimizing microgrid designs in various regions. HOMER offers three key features: simulation, optimization, and sensitivity analysis. These features enable the comprehensive study of the hybrid power generation system, ensuring that the design is not only efficient but also adaptable to various scenarios. The utilization of HOMER as the primary tool aligns with global standards in microgrid optimization and enhances the credibility and accuracy of the research outcomes

2.3 Simulation with HOMER Pro:

HOMER Pro is a software component of the HOMER suite, facilitating the design of hybrid power generation systems using renewable energy and enabling the comparison of various designs based on technical and economic aspects. HOMER operates on three principles: simulation, optimization, and sensitivity analysis. By utilizing HOMER Pro, we can design hybrid power generation systems that leverage renewable energy sources. The software enables us to simulate, optimize, and analyze the sensitivity of different system configurations, aiding in the development of technically sound and economically viable solutions.

3. RESULT

Cipatujah is situated in the southern part of Tasikmalaya Regency, facing the Indian Ocean and located between 7°43'42"S and 107°57'04"E, with a total area of 24,667 hectares or 246,670,000 square meters. In Figure 4.1, the location of the hybrid power generation system development research is illustrated. Regarding the distribution of energy generation from renewable sources, it is essential to adhere to the maximum limit set by PERMEN ESDM no.19 of 2016, Article 15, which stipulates a maximum contribution of 20%. Therefore, for Cipatujah, out of the total load of 20.7 MW, only 4.13834 MW can be fulfilled according to the regulation. This constraint is crucial to consider in the development of the hybrid power system to ensure compliance with regulatory guidelines.

3.1 Optimization of Energy Source Combinations

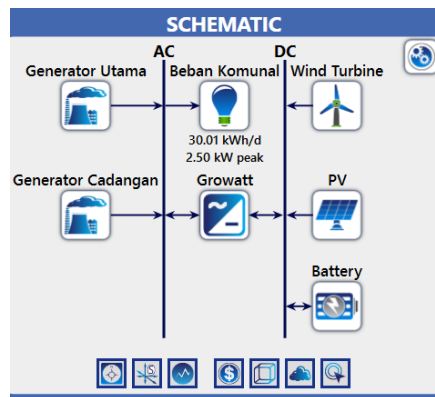


Figure 3. Design System Hybrid in Homerpro

Figure 3.1 show hybrid system for design Ciapatujah. The described hybrid system combines the advantages of renewable and conventional energy sources. The primary and backup generators serve as the backbone of the system, while solar panels and wind turbines provide fluctuating clean energy. Batteries function as balancers, storing excess energy when production exceeds demand and supplying it when production decreases. Inverters play a crucial role in converting DC to AC to match the load. The advantages of this system include reliable electricity supply, reduced carbon emissions, and energy efficiency. However, further analysis is needed regarding component selection, storage capacity, and control systems to optimize system performance. Factors such as solar radiation intensity, wind speed, and electrical load profiles significantly influence system performance. Additionally, economic considerations such as investment and operational costs must also be taken into account

This system consists of two main components: a wind turbine that harnesses the kinetic energy from the wind to rotate a generator and generate electrical power, and solar panels that utilize solar energy to produce electricity. The system operates as follows:

- The wind turbine rotates a generator, producing electrical energy.
- The electrical energy from the wind turbine is directed to an inverter to convert it into alternating current (AC).
- The electrical energy from the inverter is then supplied to loads, such as households, industries, or the power grid.
- Solar panels generate electrical energy, which is directed to an inverter to convert it into alternating current (AC).
- The electrical energy from the inverter is then supplied to the same loads.

If the electrical load exceeds the capacity of the wind turbine, the power shortfall will be supplemented by the solar panels. Conversely, if the electrical load is less than the wind turbine's capacity, the excess power will be stored in batteries. The system diagram indicates that both the wind turbine and solar panels are connected to the same inverter, allowing electrical energy from both sources to be supplied to the loads simultaneously.

In the simulation using HOMER Pro, various combinations of renewable and conventional energy sources are evaluated to find an optimal solution. The results indicate that a combination of solar panels, wind turbines, and fuel generators achieves maximum energy availability while minimizing power fluctuations that may occur with renewable energy sources. Sensitivity analysis is conducted to identify the influence of variable changes such as solar radiation intensity, wind speed, and fuel prices on system performance. This allows for the determination of more adaptive strategies to cope with variations in environmental and economic conditions.

3.2 System Efficiency:

The innovative hybrid power generation system proposed demonstrates an exceptional level of efficiency in its ability to convert available resources into electrical energy. This efficiency is not merely fortuitous but is a direct outcome of the intricately orchestrated synergy between renewable and conventional energy sources seamlessly integrated into the system. This thoughtful integration ensures the optimal utilization of each individual component, thereby enhancing the overall effectiveness of the system.

In-depth scrutiny of system performance involves a comprehensive analysis that extends to key parameters such as system capacity, capacity factor, and the anticipated lifespan of each integral component. This thorough evaluation forms the cornerstone of the system's design strategy, meticulously engineered to yield a consistent, reliable, and sustainable electrical output. Such a strategic design approach positions the hybrid power generation system as a sophisticated and dependable solution tailored to effectively address the energy demands in the Cipatujah Subdistrict. Through this nuanced engineering, the proposed system not only meets the immediate energy needs of the region but also exhibits a forward-looking perspective by providing a sustainable and adaptable solution. This commitment to efficiency and sustainability marks the hybrid power generation system as a trailblazer in addressing the complex challenges associated with energy demands in the evolving landscape of the Cipatujah Subdistrict.

3.3 Economic Feasibility:

Embarking on an exhaustive economic analysis involves a multifaceted exploration of the financial intricacies underlying the proposed project. This intricate process entails a thorough estimation of the initial investment costs, meticulously evaluating the operational expenses incurred throughout the project's lifecycle, and projecting the revenue streams derived from the sale of generated energy. This holistic examination aims to provide a nuanced and comprehensive overview of the financial feasibility of the endeavor, acting as an indispensable compass for stakeholders navigating the complex terrain of project financing [19]. In this evaluative journey, a paramount objective is to strike an optimal balance between the substantial upfront investment required and the prospective long-term returns expected from the operational phase of the hybrid power generation system. This delicate equilibrium is essential for fostering financial sustainability and ensuring the project's viability over an extended period.

Delving deeper into the analytical toolbox, sensitivity analysis emerges as a pivotal component of this financial exploration. This method involves a meticulous scrutiny of potential variations in critical factors, such as fuel prices and equipment costs. By subjecting the financial model to these hypothetical changes, sensitivity analysis unveils insights into the resilience of the project against external economic influences and market fluctuations. This proactive approach not only hones the project's financial foresight but also equips stakeholders with the foresight needed to navigate a dynamic economic landscape effectively.

Furthermore, this comprehensive economic analysis acts not merely as a financial compass but as a strategic risk management tool. By anticipating and quantifying potential financial risks associated with varying economic scenarios, stakeholders are empowered to make informed decisions and formulate robust financial strategies. This forward-looking approach enhances the project's adaptability, fostering resilience against unforeseen challenges and reinforcing its position as a sustainable and economically viable solution for meeting energy needs in the Cipatujah Subdistrict.

Sensitivity analysis indicates that variations in solar radiation intensity significantly affect the energy production from solar panels. On days with low radiation, energy production decreases, relying on energy stored in batteries. Fluctuations in wind speed also impact the energy production from wind turbines. To enhance system reliability, adequate battery storage capacity and smart load management are necessary. The LCOE calculation results show that the cost of electricity production from this hybrid system is higher compared to fossil-based power plants in the first year of operation. However, in the long term, the operational costs of the hybrid system are lower because they do not require fossil fuels. Additionally, this hybrid system also contributes positively to reducing greenhouse gas emissions [20] [21]

4. CONCLUSION

This research has produced an optimal design for a hybrid power generation system in Cipatujah Subdistrict, Tasikmalaya Regency, using HOMER Pro simulations. By considering a combination of solar panels, wind turbines, and fuel generators, the simulation results show the maximum availability of energy while minimizing power fluctuations. The high efficiency of the system and its adaptability to environmental and economic changes emphasize that this approach has significant potential to meet energy needs in rural areas. Economic analysis indicates that investing in this hybrid power generation system is economically viable. Considering the initial investment costs, operational costs, and revenue from energy sales, the project shows satisfactory results. Recommendations based on these findings include the development of supporting infrastructure, training for local communities, and government policy support. Overall, this system design not only offers a technical solution to energy needs but also contributes positively to local economic development and improves the quality of life for the community.

This research makes a significant contribution to the field of sustainable energy development, particularly in the context of rural electrification, and recommends strong policy support from the government

as well as the development of supporting infrastructure to ensure the sustainability of hybrid energy systems in similar areas.

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