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Grand Design and Economic Analysis of Solar-Wind Hybrid Renewable Energy Systems in MSTP Jepara

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Abstrak

Marine Science Techno Park (MSTP) Jepara merupakan pusat implementasi teknologi yang bertujuan untuk mendorong pengembangan ekonomi masyarakat di bidang kemaritiman. Saat ini sumber energi listrik Marine Science Techno Park (MSTP) Jepara dipasok oleh Perusahaan Listrik Negara (PLN), dengan pembangkit turbin uap bertenaga batu bara sebagai sumber utama pembangkit energi listrik. Oleh karena itu, diperlukan sarana pembangkit energi listrik yang lebih bersih dan berkelanjutan untuk memenuhi kebutuhan energi yang tinggi. Melihat hal tersebut, Universitas Diponegoro selaku pengusul bekerjasama dengan MSTP Jepara selaku penerima mengusulkan inisiasi pembangunan Pembangkit Listrik Tenaga Hybrid (PLTH) sebagai salah satu cara untuk mendapatkan sumber energi yang ramah lingkungan dan berkelanjutan di masa ini. penelitian serta mengatasi masalah dalam simulasi dan implementasi PLTH sebelumnya. Artikel ini akan membahas berbagai skenario, kelayakan implementasinya, dan keuntungan ekonomi yang diperoleh dari pemasangan PLTH di lokasi.

Keywords:
MSTP Jepara;
HRES;
engineering economic analysis.

Abstract

Marine Science Techno Park (MSTP) Jepara is a center of technology implementation aimed to encourage community economy development in the maritime sector. At present, Marine Science Techno Park (MSTP) Jepara's electrical energy source is supplied by Perusahaan Listrik Negara (PLN), with coal-powered steam turbine generators as the main source of electrical energy generation. Therefore, a cleaner and more sustainable means of electrical energy generation is needed to fulfill the high energy demand. With this in mind, Universitas Diponegoro, as the proposer, in collaboration with MSTP Jepara, as the recipient, proposes the initiation of Hybrid Renewable Energy Systems (HRES) Power Plant construction as a way of obtaining an environmentally friendly and sustainable source of energy in this research as well as addressing the issues in the previous HRES simulations and implementations. This article will discuss various scenarios, their feasibility for implementation, and the economic returns gained from HRES installation on-site.

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1. Introduction

Electrical energy is vital for the development of technology, as shown by the world's total electrical energy usage data collected by the International Energy Agency (IEA) in 2019, which reaches 22,848 TWh with a 1.7% increase compared to the previous year [1]. However, the majority of the total energy used in present days is still obtained by utilizing non-renewable resources. The distribution of electricity generation sources in Indonesia itself still consists of 86.54% fossil energy resources, of which 65.64% are generated using coal resources [2]. Consequently, the coal-combustion steam generation method will inevitably result in several principal emissions, such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2) [3], which have a negative impact on air quality in addition to not being sustainable.

As a demonstration of Indonesia's commitment to reducing CO_2, CH_4, and N_2O emissions established by the United Nations (UN) through the 2016 Paris Agreement [4], and in effort to realize the UN's Sustainable Development Goals (SDG) number 7 regarding clean and renewable energy [5], as well as addressing issues regarding the energy sector in Indonesia's Act number 30 of 2007 concerning energy, the government, in collaboration with the DPR-RI, mandated the formulation of a National Energy Policy of renewable energy source utilization to at least reach 23% of the nation's total energy consumption by the year 2025 and reach 31% by 2050 [6].

Research conducted by the Institute for Essential Services Reform (IESR) using four analysis methods for potential national PV capacity shows that Indonesia has a maximum potential PV capacity of 19.8 TWp, with potential electrical energy that can be generated at around 26,971 TWh/year at 24.4% of the land area (484,455) and a minimum of 3.3 TWp of potential electrical energy that can be generated in around 4,700 TWh per year in 4.34% of the land area, where this energy can be utilized in the plans set out in the Electricity Supply Business Plan (Rencana Umum Penyediaan Tenaga Listrik—RUPTL) 2021–2030 to add 3.7 GW of EBT generating capacity [11].

In previous research conducted by S. Rehman, H. U. R. Habib et al, they carried out design and predictive control for a case study of HRES installation in the residential sector. This research tries to calculate energy requirements from the demand side and supply side in the industrial and commercial sectors in MSTP Jepara. Where the end of this research will be to create a master plan for installing HRES at the MSTP Jepara [9].

To achieve this, measures must be taken to make use of alternative resources and replace the role of fuel oil, gas, and coal with alternative forms of energy such as solar, wind, water/hydro, geothermal, and other renewable energies. For this reason, the potential of renewable resources in a region must be assessed. As a follow-up to the Research and Community Service Offer with the theme of Marine Science Techno Park by the Undip Research and Community Service Institute (LPPM) [7], the location of Teluk Awur, Jepara will be used as an object of research on potential alternative resources.

The concept of Diponegoro Marine Science Techno Park (Diponegoro MSTP) can be defined as an area that can facilitate and initiate the development of maritime science and technology from research and development institutions, universities, and industries so that innovation occurs through the incubation process in order to facilitate the growth of small and medium industries and micro and small enterprises (MSMEs) in the nation, especially the surrounding areas. As quoted from the Director of MSTP, Undip, at the Technopreneurship Camp MSTP 2018 [8], there are three main tasks and functions of MSTP. First, as a center for the application of technology that drives the local economy through research and innovation. Second, to foster the creation of start-up companies and encourage business acceleration, and third, to set up opportunities for partnership in the industrial sector and to draw industries towards the region. Thus, as Undip's contribution to reducing national carbon emissions and in order to fulfill the first main task of MSTP Undip, energy management in accordance with the three main facets of energy security, namely availability of energy sources, affordability of energy supply, and the development of renewable energy sources, needs to be implemented.

Previous studies regarding the implementation of various HRES have been discussed in a case study analysis in the 2020 review by Rehman S. et al. [9], comparing different research papers and findings related to HRES and their respective shortcomings in which we took two examples of research findings lacking in simulation results of the suggested model and economic analysis. These data will be used as a reference to improve the implementation scheme of this current HRES, such as the addition of simulation results of the suggested model as well as model configuration and its feasibility for implementation from an economic perspective. Thus, this research aims to create an optimum HRES implementation scenario for MSTP Jepara additional electric supply. Through this research, it is possible to aid in the realization of MSTP Jepara’s first objective as a center of technology application and education, as well as reduce carbon emissions to create a cleaner and more sustainable means of electrical energy generation.

2. Research Methods

The activities and methods involved in this research involved an on-site survey to gather the required data. This data includes the solar GHI and wind speed at various locations on the site, as shown in Figure 1.

The survey was conducted on October 29th, 2022, at local time of 12:06 p.m. to 3:09 p.m. (UTC+07:00) with the data from each spot recorded for 3 minutes. Table 2 shows the coordinates from the respective points shown throughout the marked spots on the Google Earth imagery.

Figure 1. On-site Data Measurement Points

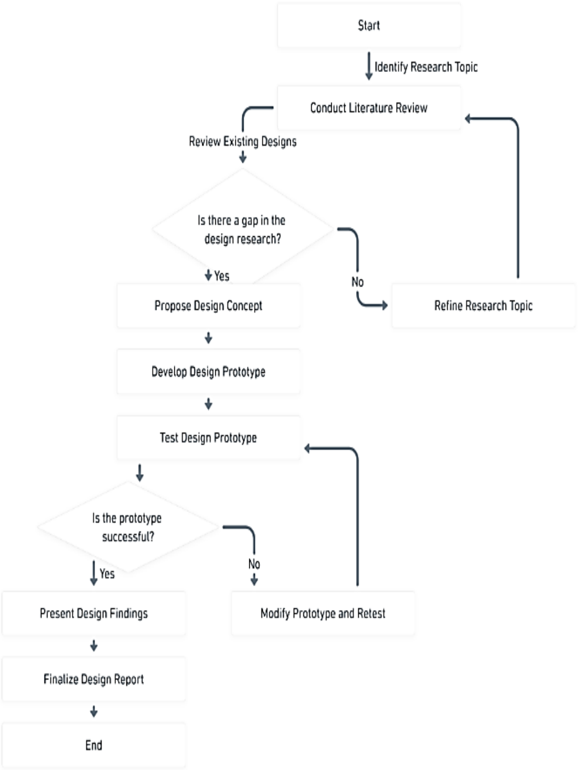

Figure 2. Research Flowchart

The design of the hybrid system is carried out using PVSyst and HOMER Pro to determine the most feasible solution for the system. The aim of the design is to achieve a minimum of 10% renewable penetration with recommended economic returns in the span of 5 years. The parameters that will be simulated for the economic analysis are the net present cost (NPC) and the cost of energy (COE), or the cost required for every kilowatt hour. The break-even point (BEP) can then be calculated using both the NPC and COE calculations. Subsequently, the components' specifications for the hybrid system will be calculated from the simulation using their respective mathematical expressions.

Table 1. Coordinates of Measurements Points

Point	Latitude (°)	Longitude (°)
1	-6.6170916	110.6392983
2	-6.6170909	110.6392962
3	-6.6170909	110.6392962
4	-6.6171621	110.6392256
5	-6.617185	110.6391748
6	-6.6175325	110.6389963
7	-6.6175325	110.6389963
8	-6.6212693	110.6405508
9	-6.6212166	110.6405616
10	-6.621976	110.6403557
11	-6.621976	110.6403557
12	-6.6276126	110.6377346
13	-6.6269866	110.6379593
14	-6.6269845	110.6381797
15	-6.6262862	110.6383619
16	-6.6252544	110.6386287
17	-6.6250346	110.6387305
18	-6.6277098	110.6387124
19	-6.6274812	110.638868

2.1 Wind Turbine

It is estimated that every year, more than 1.7 million TWh of energy is generated in the form of wind. However, the biggest inhibiting factor in utilizing this energy on land is limited land use. For this reason, an estimate in 1991 predicted the potential for wind energy that could be realized globally was 53,000 TWh/year [10].

In Indonesia alone, the average wind speed is only 3 m/s to 6 m/s at a height of 50 meters, less than half the capabilities of areas located in the northern and western hemispheres. Even so, the technical potential of wind resources in Indonesia is estimated at 60.6 GW, with a utilization of only 0.15 GW until 2020, far from the target of the National Energy General Plan (RUEN), which is 0.6 GW [13].

The power output of the wind turbine will be determined by multiple variables, e.g., wind and/or air density, wind speed, and swept area. The following is the expression to calculate the power output of a wind turbine at a given point:

$$P = 0.5 C_p A \rho v^3 \tag{1}$$

Where P is the power generated by the wind turbine (Watt), C_p is the coefficient of power (0.59), A is the swept area of the turbine (m^2), ρ is the wind density (1.225 kg/m^3), and v is the velocity of the wind (m/s). Note that the expression stated in (2) does not take into account the heat losses from the generator and the gearbox. Meanwhile, the swept area can be calculated using the following expression:

$$A = hD \tag{2}$$

where h is the height of the wind turbine (m) and D is the diameter of the wind turbine (m).

2.2 Total Energy Consumption

Energy consumption is determined by multiplying the total power of the individual appliance/load with the usage

Table 2. Monthly Solar Irradiance

Month	Global Horizontal Irradiance (kWh/m^2)	Diffuse Horizontal Irradiance (kWh/m^2)	Temperature (°C)	Incident Global Irradiance (kWh/m^2)	Effective Global Irradiance (kWh/m^2)	Effective Array Output Energy (kWh)	Energy Injected to Grid (kWh)	Performance Ratio
January	130.8	84.63	26.39	121.9	118.4	2288	2167	0.816
February	126.8	76.44	26.26	121.4	118.4	2296	2186	0.8262
March	168.3	86.74	26.64	166.5	163.0	3097	2963	0.816
April	165.6	79.20	27.02	169.5	166.1	3160	3035	0.821
May	170.5	63.77	27.02	182.0	178.3	3390	3260	0.821
June	158.1	61.51	26.63	171.9	168.4	3214	3091	0.825
July	177.6	61.88	26.49	191.8	188.2	3567	3433	0.821
August	198.7	67.27	27.07	208.9	205.4	3845	3703	0.813
September	204.0	69.75	28.02	205.7	202.0	3759	3621	0.807
October	198.4	76.26	28.23	191.9	188.1	3536	3400	0.813
November	159.9	89.51	27.62	150.2	146.3	2796	2674	0.817
December	142.9	88.44	26.85	133.8	130.0	2509	2388	0.818
Yearly	**2001.7**	**905.39**	**27.02**	**2015.8**	**1972.5**	**37456**	**35922**	**0.817**

duration. For safety measures, the resulting energy consumption will then be multiplied by the safety factor of 1.2, as illustrated in (4),

$$E_L = 1.2 P_L t \tag{3}$$

Where E_L is the total daily energy consumption (Wh), P_L is the load power (Watt), and t is the usage duration (hour).

2.3 Solar Panel

Every year, about 1500 million TWh of solar energy reach the earth, of which 47%, or about 700 million TWh, reach the earth's surface. This value reaches 14,000 times the value of energy used by men, amounting to 50,000 TWh used annually. Even though most of this energy is inaccessible due to it being scattered into the ocean, less than 1% of the land area on the earth's surface can meet the world's electricity demand, which is around 15,000 TWh [10].

Meanwhile, according to the NASA Prediction of Worldwide Energy Resource (POWER) database, MSTP Jepara is a coastal region with a potential for solar global horizontal irradiance (GHI) of 5480 $kWh/m^2/day$ as shown on Figure 3, making it a suitable location for a solar power plant [12].

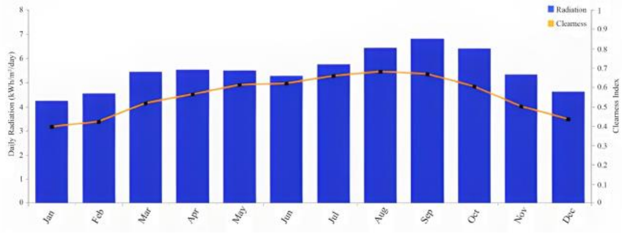

Figure 3. NASA POWER daily radiation data on MSTP Jepara

The number of solar panels varies according to the power of each individual cell and how much energy needs to be generated. It is important to understand that the cells will be assembled in strings. Therefore, the result will be rounded in such a way that we have an even number of cells on each string. The following equation is used to determine number of the required cells:

$$\text{Number of cells} = \frac{E_L \times \text{autonomous day}}{P_{\text{PV}} t} \tag{4}$$

where P_{PV} is the power generated from a single cell (Wp).

2.4 Inverter

In contrast with a converter, an inverter is the device that converts DC power to AC power; as such, the selection of an inverter must consider the voltage of the DC system and the output phase and voltage of the AC system. Inverter capacity can be determined by the load that is going to be covered. We may use the following expression to calculate the power for the inverter:

$$P_{\text{inverter}} = P_{\text{load}} \times \text{safety factor} \tag{5}$$

where P_{inverter} is the power of the inverter (Watt), P_{load} is the power of the load in which is multiplied with safety factor or 1.2 or 1.25. In the case of a grid-connected hybrid system, the ap-propriate type of inverter would be the grid-tie inverter, which has an output voltage similar to that of the grid. On the other hand, a standalone system would require a hybrid inverter with additional terminals connected to the battery.

3. Results and Discussions

As previously mentioned in chapter 1, for the purpose of comparing findings comparison, we took two research examples mentioned in [9], and compiled the results in this section. First is the 2018 research by Priyandarshi N. et al. [15], which discusses the simulation and experiment of a Hybrid PV-Wind, micro-grid development using quasi-Z-source inverter modeling and control experimental investigation. Instead of using dSPACE, the simulation in this paper is conducted using PVSyst and HOMER simulation, with the addition of simulation results of the suggested model, which were not shown in the former.

The second reference is the 2019 research conducted by Guezgouz M. et al. [16], which discusses techno-economic and environmental analysis of a hybrid PV-WT-PSH/BB standalone system supplying various loads. The discussion mainly focused on the emission reduction without highlighting any optimal configuration or economic analysis using GWO as the simulation method. Instead of focusing on the environmental aspects, our research findings are focused on the model configuration and its feasibility for implementation from an economic perspective by considering the break-even point and internal rate of return of the implementation scheme. This section is divided into several parts, each discussing separate HRES component simulations and results.

The data gathered from MSTP Jepara on October 29th, 2022, combined with the data obtained from the NASA POWER database are as follows:

3.1 Solar Data and Simulation

The data in Table 3 shows a yearly intensity of global horizontal irradiance around 2001.7 kWh/year, diffuse radiation intensity of the sun in the horizontal plane around 905.39 kWh/year, and the radiation intensity received by solar panels at about 2015.8 kWh/year due to precise orientation and tilt. The effective radiation intensity is measured at 1972.5 kWh/year with the temperature around the solar cells at about 27.02°C. Meanwhile, the potential for electrical energy generated from the output of the solar cells is 37,456 kWh/year with a large amount of electrical energy injected into the grid by the system of 35,922 kWh/year and performance ratio generated by the solar cells of 0.817.

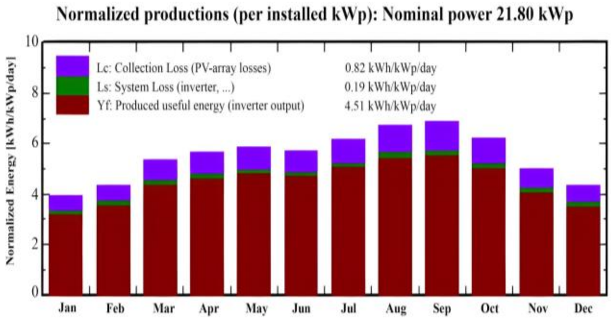

Figure 4. Solar Cells Production Graph.

The graph in Figure 4 shows that the site has various and fluctuating trends in electrical energy production, with average effective electrical energy production of 4.51 kWh/kWp/day, average solar array loss of 0.82 kWh/kWp/day, and average inverter and other component loss of 0.19 kWh/kWp/day.

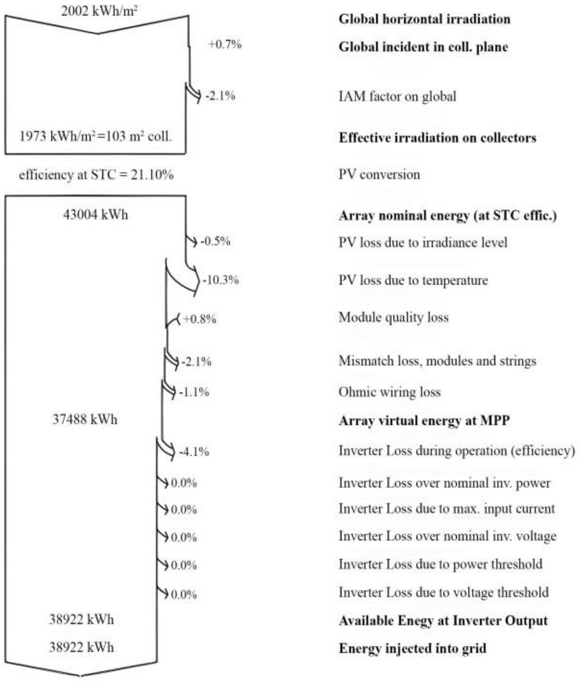

Figure 5. Solar Cells Losses Diagram

Based on Figure 5, the level of solar insolation or solar radiation on a flat plane at the site is about 2,034.3 kWh/m^2. The radiation received by the solar cells experiences losses of 2.1% of the total solar in-solation potential at the site due to the reflective effect of the solar cells' glass cover. The panel efficiency score is 21.10%, with electrical energy generated by the array at about 43,003 kWh/year. Another set of losses incurred by the solar cells is caused by temperature loss of about 10.3%, radiation loss of 0.5%, module and string mismatch of 2.1%, and wiring loss of 1.1%. Therefore, the output power of the solar array at MPP is about 37,456 kWh/year. Lastly, the energy conversion at the inverter causes a loss of 4.1%, resulting in the final output of the solar array that can be injected into the grid being 35,992 kWh/year. The type of cell used in this design is the monocrystalline solar cells which have weak internal resistance and good quantum efficiency compared to polycrystalline modules [17].

3.2 Wind Data and Simulation

The data in Table 3 shows that points 1 through 4 have the fastest wind speed, which can be potentially harvested. Location coordinates of the aforementioned spots will be the installation site for the wind turbine. Wind speed data from NASA POWER database in Figure 5 will be used to simulate monthly wind speed on the chosen installation site.

Yearly average from Figure 6 shows the annual wind speed at 2 meters above sea level at 3.97 m/s. HOMER simulation using one 6-kilowatt wind turbine yields the result as shown on table 4. With the usage of one 6-kilowatt wind turbine, the system produces an average of 1 kW average output with capacitance factor of 16.7%. The system generates a total of 8.78 kWh of energy per year with minimum power output of 0 kW and maximum output of

6.29 kW. The total energy generated by the wind turbine, or the wind penetration, makes up about 2.33% of the total energy generated by the system with an operating time of 7642 hours/year. Figure 6 shows the average monthly energy out-put generated by the turbine.

Table 3. Wind Speed Data

Point	Latitude (°)	Longitude (°)	Wind Speed (m/s)		
			Min	Max	Avg
1	-6.6170916	110.6392983	3.0	5.4	4.3
2	-6.6170909	110.6392962	2.3	4.4	4.0
3	-6.6170909	110.6392962	3.5	5.1	4.4
4	-6.6171621	110.6392256	2.9	4.4	3.2
5	-6.617185	110.6391748	1.5	3.6	2.7
6	-6.6175325	110.6389963	0.1	5.1	2.4
7	-6.6175325	110.6389963	0.9	2.8	1.3
8	-6.6212693	110.6405508	0.0	1.8	1.0
9	-6.6212166	110.6405616	0.0	1.2	0.7
10	-6.621976	110.6403557	0.3	2.6	1.0
11	-6.621976	110.6403557	0.0	1.4	1.8
12	-6.6276126	110.6377346	1.2	2.8	1.9
13	-6.6269866	110.6379593	1.1	2.6	1.9
14	-6.6269845	110.6381797	1.4	3.5	2.0
15	-6.6262862	110.6383619	0.4	2.6	0.6
16	-6.6252544	110.6386287	1.1	2.8	1.8
17	-6.6250346	110.6387305	0.9	2.6	1.8
18	-6.6277098	110.6387124	0.0	0.6	0.0
19	-6.6274812	110.638868	0.0	0.9	0.3

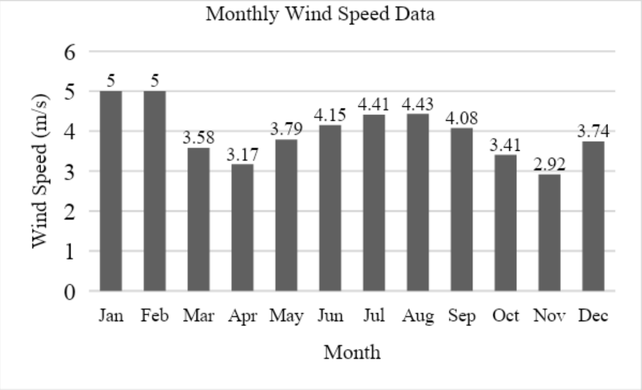

Figure 6. Installation Site Monthly Wind Speed Data

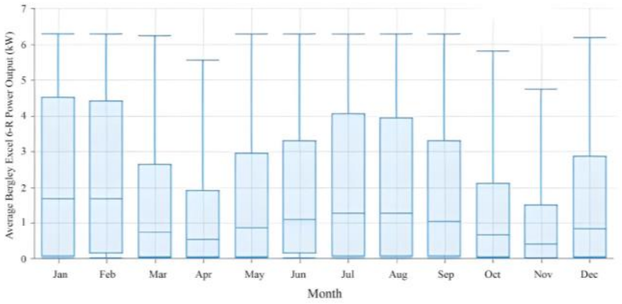

Figure 7. Monthly Wind Generated Energy Output

The graph in Figure 7 shows the average power generated by the wind turbine by January is about 1.68 kW with highest daily average of 4.51 kW, in February, the average power generated by the wind turbine is at 1.67 kW with highest daily average of 4.43. Subsequently, the monthly power average of the wind turbine in March, April, May, June, July, August, September, October, November, and December is 0.74, 0.53, 0.86, 1.09, 1.26, 1.28, 1.04, 0.65, 0.42, and 0.83 kW with highest daily average of 2.63, 1.91, 2.95, 3.3, 1.26, 4.06, 3.94, 3.3, 2.1, 1.49, and 2.88 kW respectively. In order to reduce losses created by friction [18], magnetic levitation vertical turbines will be used.

3.3 Hybrid System Architecture and Simulation

According to the simulation results, the required number of PV cells required in the hybrid solar and wind system is around 40, with 545 Wp of capacity each (equivalent to 218000 Wp configured in 4 strings where each string has 10 series-connected solar panels. We will also need a one piece wind turbine with 6 kWh in capacity, directly connected to the grid from PLN. The hybrid system is equipped with 25 kVA to convert direct current (DC) to alternating current (AC). Table 5 shows the production summary of the system.

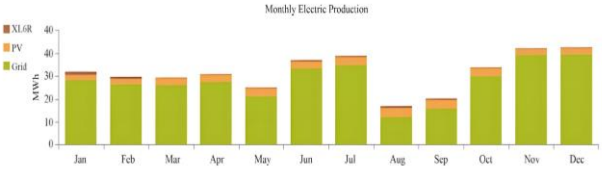

Figure 8. Monthly Electric Production Summary

Table 4 shows the production summary of the system. From the data above and as illustrated by Figure 8, we can see the usage of this hybrid system is capable of covering 11.64% of MSTP Jepara's electric load with the PV system covering 9.32% of electric load and wind turbine covering 2.32% of electric load. The rest 88.4% of the load is purchased from the grid. We are able to achieve the initial target of 10% renewable penetration. Figure 9 shows the general configuration of the system.

Table 4. Production Summary

Production	kWh/year	%
PV	-6.6170916	110.6392983
Wind turbine	-6.6170909	110.6392962
Grid purchases	-6.6277098	110.6387124
Total	-6.6274812	110.638868

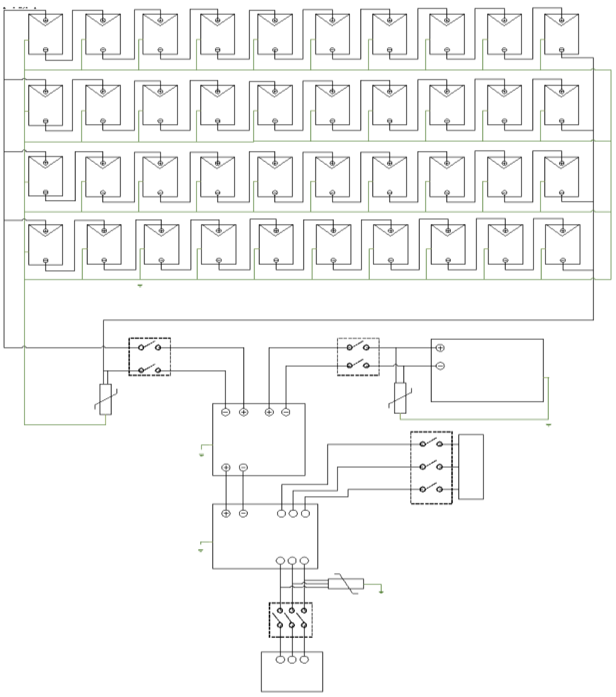

Figure 9. Wiring Configuration of The Hybrid Renewable Systems

3.4 Economic Analysis

HOMER simulation for the hybrid system shows that the operational cost of the MSTP Jepara system can be reduced to Rp487,656,162.00 annually. The investment in this system will reach a break-even point in 4.7 years with an internal rate of return of 23.6%, net present value of $28,712, capital investment of $14,377, and annualized savings of $3,333 as shown on Table 5 and project cash flow on Figure 9. With the initial target of achieving break-even point under 10 years, we can conclude that this design is feasible for implementation.

Table 5. Economic Summary

Parameter	Value
Simple payback	4.17 year(s)
Return of investment	19.2%
Internal rate of return	23.6%
Net present value	$28,712
Capital investment	$14,377
Annualized savings	$3,333

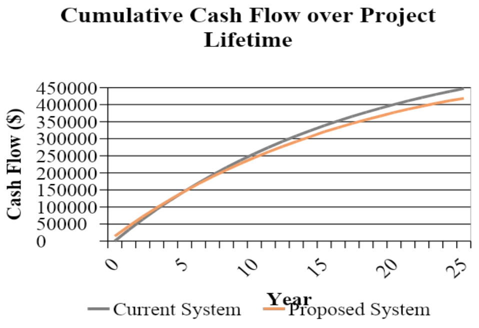

Figure 10. Project's Cash Flow

3.5 Grand Design/Masterplan

The grand design or master plan of the hybrid system on site is illustrated in Figure 11.

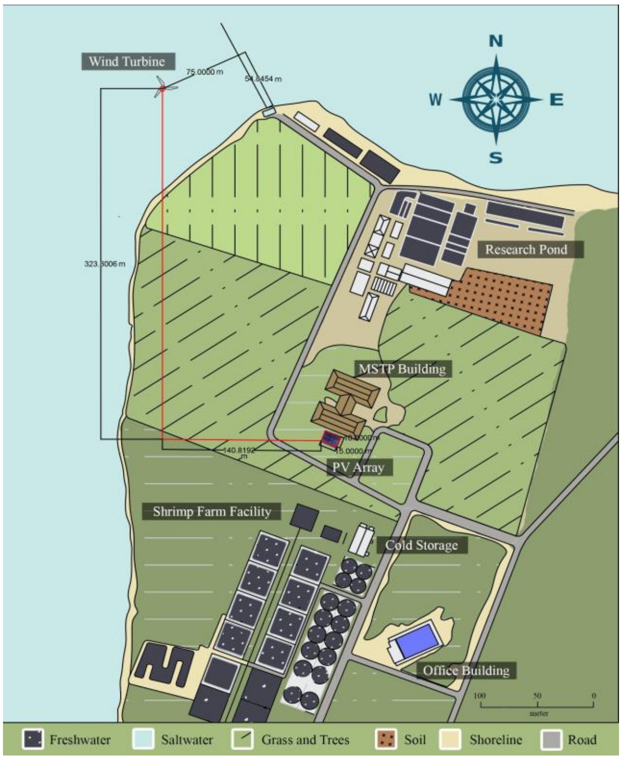

Figure 11. Project Master Plan

4. Conclusion

In this paper, several points of data were taken at MSTP Jepara to observe the potential for solar and wind energy on the site. Calculations were made to determine the general configuration of the system and its feasibility for implementation. Additionally, the aim for 10% renewable penetration is achieved. From the results of the feasibility economic analysis calculation, it was found that the simple payback value was 4.17 years, the return of investment value was 19.2%, the internal rate of return value was 23.6% and the annualized savings was 3000 USD per year. A more comprehensive study regarding each individual component of the hybrid system and power quality evaluation needs to be conducted before implementation.

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References

[1] International Energy Agency, “Electricity consumption,” *Electricity Information: Overview*, 2019. https://www.iea.org/reports/electricity-information-overview/electricity-consumption (accessed Dec. 03, 2022).

[2] D. Jenderal Ketenagalistrikan Kementerian Energi Dan Sumber Daya Mineral, "Laporan Kinerja Direktorat Jenderal Ketenagalistrikan 2021," 2021. Accessed: Dec. 03, 2022. [Online]. Available: https://gatrik.esdm.go.id/frontend/download_index/?kode_category=lakin

[3] U.S. Energy Information Administration, "Coal and the environment," *Coal explained*, Nov. 06, 2022. https://www.eia.gov/energyexplained/coal/coal-and-the-environment.php (accessed Dec. 17, 2022).

[4] United Nations Framework Convention on Climate Change, "Intended Nationally Determined Contribution Republic of Indonesia," Paris, Nov. 2016.

[5] United Nations, "Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All," *Sustainable Development Goals*, Sep. 2015.

[6] Kementerian Energi dan Sumber Daya Mineral, "Energi Baru, Terbarukan dan Konservasi Energi," *Jurnal Energi Media Komunikasi Kementerian Energi dan Sumber Daya Mineral*, vol. 2, 2016.

[7] LPPM Undip, "Daftar PPM Tema MSTP Lolos Tahun 2022," *Info Penelitian, Info Pengabdian*. LPPM Undip, 2022.

[8] Yandip Provinsi Jawa Tengah, "MSTP Undip Bentuk Generasi Technopreneur," *Portal Berita Pemerintah Jawa Tengah*, Jul. 25, 2018. https://jatengprov.go.id/beritadaerah/mstp-undip-bentuk-generasi-technopreneur/ (accessed Dec. 03, 2022).

[9] S. Rehman, H. U. R. Habib, S. Wang, M. S. Buker, L. M. Alhems, and H. Z. al Garni, "Optimal Design and Model Predictive Control of Standalone HRES: A Real Case Study for Residential Demand Side Management," *IEEE Access*, vol. 8, pp. 29767–29814, 2020, doi: 10.1109/ACCESS.2020.2972302.

[10] B. Sorensen *et al.*, *Renewable Energy Focus Handbook*, 1st ed. Oxford: Elsevier, 2009.

[11] D. Arinaldo, H. Diah, P. H. Damayanti, and I. Marciano, "Beyond 207 Gigawatts: Unleashing Indonesia's Solar Potential IESR Nationwide solar potential assessment based on geographic information system (GIS) mapping," 2021.

[12] NASA, "The POWER Project," *NASA Prediction of Worldwide Energy Resource (POWER)*, 2022. https://power.larc.nasa.gov/ (accessed Dec. 03, 2022).

[13] T. Hidayat, "Wind Power in Indonesia: Potential, Challenges, and Current Technology Overview," in *Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives*, Penerbit BRIN, 2022. doi: 10.55981/brin.562.c7.

[14] F. Beaufort, "Beaufort Wind Scale," *National Weather Service (NOAA)*, 1805. https://www.spc.noaa.gov/faq/tornado/beaufort.html (accessed Dec. 03, 2022).

[15] N. Priyadarshi, S. Padmanaban, D. M. Ionel, L. Mihet-Popa, and F. Azam, "Hybrid PV-Wind, micro-grid development using quasi-Z-source inverter modeling and control-experimental investigation," *Energies (Basel)*, vol. 11, no. 9, Sep. 2018, doi: 10.3390/en11092277.

[16] M. Guezgouz, J. Jurasz, and B. Bekkouche, "Techno-economic and environmental analysis of a hybrid PV-WT-PSH/BB standalone system supplying various loads," *Energies (Basel)*, vol. 12, no. 3, Feb. 2019, doi: 10.3390/en12030514.

[17] L. Jiang, S. Cui, P. Sun, Y. Wang, and C. Yang, "Comparison of Monocrystalline and Polycrystalline Solar Modules," in *2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC)*, Jun. 2020, pp. 341–344. doi: 10.1109/ITOEC49072.2020.9141722.

[18] C. v Aravind, S. C. Tay, M. Norhisam, I. Aris, and J. Kumar, "Reduced mechanical oscillations using the MAGLEV concept in Vertical Axis Wind Turbine," in *2013 International Conference on Renewable Energy and Sustainable Energy (ICRESE)*, Dec. 2013, pp. 248–252. doi: 10.1109/ICRESE.2013.6927824.