Economic Feasibility Study on PV/Wind Hybrid Microgrids for Indonesia Remote Island Application

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Abstract **– This paper presents the economic feasibility of hybrid microgrid power system for three remote islands of Sumatra, Indonesia. The microgrid system simulated and analysed using Homer Pro software. Optimization results showed that the combination of photovoltaic (PV), diesel generation (G) and batteries (Batt) for microgrid power system in Mandeh and Lagundri Island area were the most economical configuration. Meanwhile, for Mentawai area, the combination of PV, Wind Turbine (WT), G, Batt was the most optimal since it has higher wind speed then the other two areas. The Mandeh area has the highest solar radiation compared to the other two areas, resulting in the lowest CoE of $0.096/kWh as well as the lowest investment and operational costs. For the fixed PV 100 kW scenario, the optimal configuration is obtained with 86 kW supplied by WT for the Lagundri location, and 67 kW supplied by WT for the Mentawai area, while the WT installation area is not recommended for Mandeh location. The power management analysis showed that the average and patterns of weather parameters including solar radiation and wind speed effect both PV and Wind electrical power production.**

Keywords **– economic feasibility, hybrid microgrid system, PV/Wind and Indonesia remote application.**

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1. Introduction

The electricity supply to remote islands can improve the socio-economic status of the community. Today, many researches focused on renewable energy technologies because they play important role in improving the quality of life by fulfilment of electricity needs and being environmentally friendly [1], [2]. Among these renewable energy technologies, the generation of electrical energy from primary energy sources such as sunlight and wind is an option that is currently being developed and will be widely used in the future [3], [4]. Both resources are abundant and do not produce greenhouse gas emission [5], [6]. The integration of renewable energy into existing energy grids not only reduces dependence on fossil fuels but also provides sustainable solutions for future power generation [7].

Indonesia as one of the developing countries where the power plant is still dominated by fossil energy-based generators is trying to increase the use of energy from renewable sources. Through the National Energy Policy (NEP), Indonesia has targeted the use of new and renewable energy by 23% in 2025 and 31% in 2050 [8]. According to the Indonesia Energy Outlook 2016, there is about 135.5 GW installed capacity required in 2025, and 45.2 GW will be coming from renewables [9]. Therefore, research that analysed the use of renewable energy in various regions in Indonesia is urgent to be done.

Indonesia is an archipelago country and is crossed by the equator [10], has natural beauty and abundance of solar [11] and small wind speed energy potential [12]. The beauty of Lagundri beach in the Nias archipelago, Mandeh island resort and beaches in the Mentawai islands are the main attractions for both foreign tourists and domestic tourists. The islands of Nias, Mentawai and Mandeh are priorities for the development of electricity access because of the potential for beautiful tourism sites. Therefore, these three areas were taken in this study as a case study location for the development of a hybrid microgrid for coastal areas. These islands coastal area were chosen, because the electricity network from the state electricity company of Indonesia (PLN) is not yet reached.

2. Materials and Methods

The present study focuses on the optimal configuration and energy production analysis of renewable hybrid energy system for electrification of the coastal community located on the Sumatra coastal area, Indonesia. The proposed hybrid microgrids are a study for three different locations in Sumatera coastal area as shown in Fig. 1. for Lagundri, Mandeh and Mentawai coastal area. These locations have potential natural resources and are enriched with wind and solar availability.

HOMER software is used for microgrid system design and simulation. This software is widely used to study the technical and economic feasibility of developing renewable energy plants to date [13], [14]. This software can also be used to determine the most optimal generator configuration as well as to see the flow of generation power in serving the load of a microgrid system [15], [16]. The HOMER software was used to design and optimize the hybrid microgrid system with the diesel system presented as the base case. Several data need to be prepared before carrying out HOMER simulations including load demand data, weather condition data and technical and economic data from each system components.

Figure 1. Geographical position of three coastal areas in Sumatera, Indonesia under study

2.1. Load profile of Mentawai Island Microgrid

The electricity load of remote island case study consists of two kinds of electrical demand: household and commercial/public demand. The household minimum load is 180 W to cover refrigerator, warm rice cooker and small item and maximum load is 90% of 900 VA = 810 W. Sixty households were used in this study with average load of 16.73 kW, and a peak load of 50,36 kW. The load factor is equal to the average load divided by the peak load. Therefore, the load factor is 16.73 kW/50,36 kW = 0.33. Based on the usage pattern, the average load energy consumption is 401.40 kWh/day. Whereas the commercial/public demand consumed 33.68 kWh/day as tabulated in Table 1.

Table 1. Community load profile

Type	Load (W)	Qtity	Op.Time (hour)	kWh Consp
Household	810	60	8.26	401.4
Total Residential (60 household) Demand (Load I)				401.4
Small Business load	400	2	12	9.6
Street light	30	4	9	1.08
School	1500	1	10	15
Community office	1000	1	8	8
Total Commercial/Public Demand (Load II)				33.68

2.2. Solar and Wind Resources

The weather data of solar radiation and average wind speed of the three coastal areas are shown in Table 2. and 3. The average annual solar radiation value is 4.73 kWh/m^2/day, 4.8 kWh/m^2/day and 5.23 kWh/m^2/day for Lagundri, Metawai and Mandeh area respectively. The maximum average solar radiation recorded in February and April is 5.54 kWh/m^2/day for Mandeh area while the minimum average solar radiation is recorded in November, which is 4.26 kWh/m^2/day for Lagundri area.

Table 2. Average radiation in kWh/m^2/day

Month	Average Radiation (kWh/m^2/day)		
	Lagundri	Mentawai	Mandeh
Jan	4.90	4.77	5.22
Feb	5.25	5.21	5.54
Mar	4.97	5.10	5.48
Apr	4.78	4.97	5.54
May	4.98	4.97	5.34
Jun	4.87	4.82	5.28
Jul	4.56	4.69	5.12
Aug	4.54	4.75	5.09
Sep	4.51	4.77	5.28
Oct	4.51	4.69	5.11
Nov	4.26	4.36	4.78
Dec	4.57	4.54	4.96
Average	**4.73**	**4.8**	**5.23**

The average annual wind speed value is 3.51 m/s, 3.82 m/s and 2.89 m/s for Lagundri, Metawai and Mandeh area respectively. The maximum average wind speed recorded in September is 4.42 m/s of Mentawai area while the minimum average wind speed is recorded in November, which is 2.60 m/s for Mandeh area. Based on both weather data, it shows that Mandeh area has the highest solar radiation, whereas the Mentawai area has the largest wind speed.

Table 3. Average wind speed in m/s

Month	Average Wind Speed (m/s)		
	Lagundri	Mentawai	Mandeh
Jan	3.31	3.86	2.76
Feb	3.30	3.80	2.79
Mar	3.50	3.71	2.89
Apr	3.30	3.34	2.73
May	3.06	3.13	2.60
Jun	3.27	3.39	2.65
Jul	3.53	3.66	2.80
Aug	3.54	4.33	3.12
Sep	3.71	4.42	3.10
Oct	3.98	4.10	3.10
Nov	4.09	4.08	3.16
Dec	3.52	4.05	3.00
Average	**3.51**	**3.82**	**2.89**

These two weather parameters are used as input for Homer's software for analysing the economic feasibility of PV/wind powered microgrid system. The wind speed and solar radiation profiles are close to the weather patterns in various remote islands in Indonesia. Therefore, the results of this study can become a consideration for the development of PV/Wind hybrid microgrid for Indonesia remote island application.

2.3. System Configuration

The proposed coastal microgrid system comprises of five components, mainly diesel generator, PV system, wind turbine, AC-DC converter, and battery bank as shown in Fig. 2. All of these components are connected through AC or DC bus. Two type of load demand are connected to AC bus for residential load and commercial/public load.

The specifications of remote island microgrid system components are provided in Table 4. The current fuel price adjustment is based on the implementation of the Ministerial Decree of ESDM No. 62 K/12/MEM/2020 concerning basic price formula in calculation of retail sales prices for general fuel oil types of gasoline and diesel oil distributed through public fuel filling stations or fishermen filling stations. The price of diesel genset fuel cost is $0.68 per litre. The economic parameter inputs of the project for inflation target and the nominal discount rate are 3% and 4.5 %, respectively.

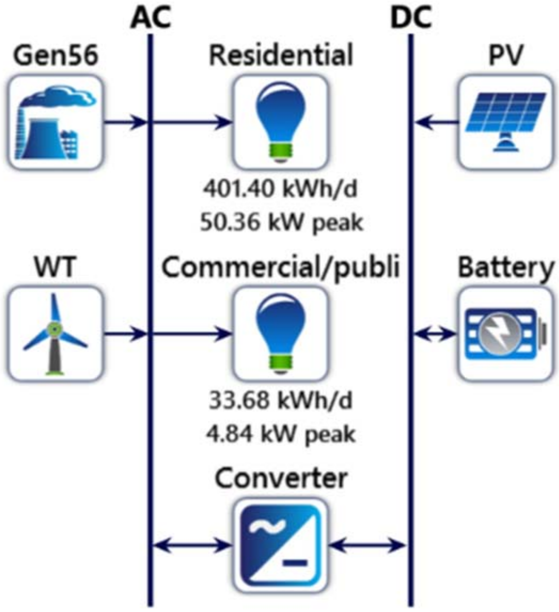

Figure 2. Proposed microgrid system components

Table 4. Microgrid power system components cost

Component	Capital ($/kW)	Replacement ($/kW)	O&M Cost	Life time (yr)
PV System	643	0	5 $/yr	25
WT Gen	750	250	10 $/yr	20
Genset	500	450	0.03 $/Op.hr	15
Battery	215	215	0	12.5
Inverter	150	150	0	15

The output of the simulation results is in the form of an optimal system design model to be analysed. By considering economic parameters: net present cost (NPC), cost of energy (COE), the optimal hybrid microgrid power system configurations (PV/WT/D/Battery) for the remote island area are determined. The NPC is calculated using the following expression:

$$NPC = CC + RC + O\&M\ Cost + FC - Salvage \quad (1)$$

where:
NPC = Net Present Cost (IDR)
CC = Capital Cost (IDR)
RC = Replacement Cost (IDR)
O&M Cost = Operation and maintenance cost (IDR)

COE is the average value of electrical energy per kWh produced by the system in a project. The COE has criteria if it is less than the basic cost of providing electricity, then it is feasible to continue, if it is greater than it is not feasible to continue. The calculation of the COE value can be done using the following equation:

$$CoE = TAC / kWh_{Tot\_Prod} \quad (2)$$

where:

TAC = Total Annualized Cost (IDR)
kWh_{Tot_Prod} = Total kWh production (kWh)

3. Result and Discussion

Technical and economic feasibility simulation conducted through the HOMER base optimalization and PV fixed optimalization by varying project location. In the first scenario, the HOMER search space automatically to optimize system fulfilling the electricity load. The second scenario uses fixed capacity of 100 kW PV system, while the other components search space automatically to optimize system fulfilling the electricity load.

3.1. Optimal Configuration

In the simulation process, HOMER estimates the cost and at the same time determines the feasibility of hybridized systems over the year with a list of system configurations and their capacities are sorted based on the lowest CoE and NPC. The simulation results of the optimal microgrid system configuration for the study site in Lagundri, Nias Islands are shown in Table 5.

Table 5. Optimal results based on HOMER optimization for all components

Config	PV (kW)	WT (kW)	Genset (kW)	Battery (unit)	Inverter (kW)
PV/G/Batt	169		56	416	51,3
PV/WT/G/Batt	170	1	56	416	53,0
PV/Batt	242			488	55,6
PV/WT/Batt	349	1		340	49,1
WT/G/Batt		552	56	384	117,1
PV/G	331		56		37,8
PV/WT/G	328	2	56		42,3
G/Batt			56	12	12,7
WT/G		5	56		
G			56		

Based on Table 5., PV installation is more profitable than WT and diesel generator, but if PV is not available then WT is better than diesel generation + limited PV combination. Therefore, PV is priority while WT is more competitive than Genset.

The economic comparison results for of optimal configuration of proposed Lagundri microgrid system is shown in Table 6. The optimal configuration has $0.104 per kWh cost of energy and lowest NPC of $342,372.80. Although the PV/G/Batt configuration requires a large initial capital of $234,085.50, the operating costs are small at $5,198.85. The PV system has no operating cost, it is available in nature, thus the largest portion of 98.07% renewable fraction is PV/G/Batt configuration as shown in Table 6.

The proper power management is required to achieve reliability of the hybrid microgrid system. In this system, diesel generator is operated on least priority, when PV, WT and batteries are unable to meet the residential and public load demand.

Table 6. Optimal result based on HOMER optimization for all components

Config	NPC ($)	CoE ($/kWh)	RF (%)
PV/G/Batt	342,372.80	0.104	98,07
PV/WT/G/Batt	342,947.30	0.104	98,13
PV/Batt	386,179.10	0.117	100
PV/WT/Batt	427,652.30	0.129	100
WT/G/Batt	1,127,107.00	0.341	69,86
PV/G	1,396,037.00	0.422	24,13
PV/WT/G	1,396,921.00	0.422	24,19
G/Batt	1,416,108.00	0.428	0
WT/G	1,524,253.00	0.461	0
G	1,524,350.00	0.461	0

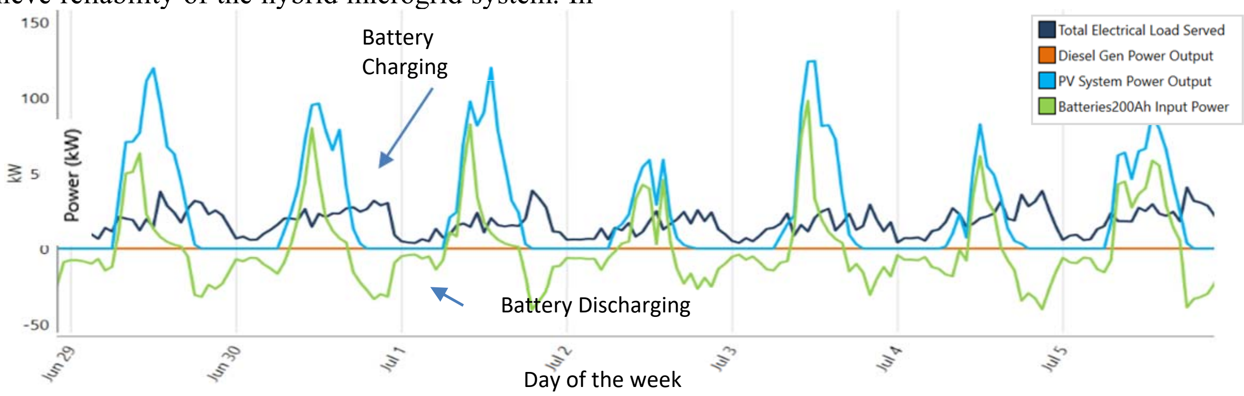

Figure 3. Power management for Lagundri microgrid

The simulation results of the optimal microgrid system configuration for the three locations of microgrid system study area are shown in Table 7. From these results, only the Mentawai area is feasible to use WT, while the other two locations are not. This is because the average wind speed in the Mentawai location is greater than the other two areas as shown in Table 3. above.

Table 7. Optimal result based on HOMER optimization for the three areas under study

Location	PV (kW)	WT (kW)	Genset (kW)	Batt	Inverter (kW)
Lagundri	169		56	416	51,3
Mentawai	164	2	56	416	51,0
Mandeh	146		56	420	51.3

The economic comparison results of optimal configuration of three proposed microgrid systems are shown in Table 8. The lowest NPC and CoE values were obtained for the case study in Mandeh location with NPC $316,275.60 and CoE $0.096/kWh. Likewise, the initial investment costs and operating costs are the lowest among the tested systems. This is because the largest fraction of renewable energy generation occurs in the microgrid system for the Mandeh location, which is 98.76%.

Table 8. The economic comparison results for the three areas under study

Location	Config	NPC ($)	CoE ($/kWh)	RF (%)
Lagundri	PV/G/B	342,372.8	0.104	98.07
Mentawai	PV/WT/G/B	338,617.2	0.102	98.17
Mandeh	PV/G/B	316,275.6	0.096	98.76

3.2. Designed Configuration

Another scenario was designed for the configuration with a fixed PV capacity. This scenario is intended to see the feasibility of installing WT for a microgrid system on the coast of Sumatra. In this study, the PV capacity is set at 100 kW while the other components are free to follow the Homer optimization system. The simulation results are shown in Table 9., at Mandeh location it is not feasible to build WT. This is due to the low wind speed in Mandeh region. Although Mentawai has a higher average annual wind speed, the lagoon microgrid system can install 86 kW of wind power because the wind distribution pattern is better than the Mentawai area.

Table 9. Optimal configuration result based on 100 kW PV designed

Location	PV (kW)	WT (kW)	G (kW)	Batt	Inverter (kW)
Lagundri	100	86	56	364	48,0
Mentawai	100	67	56	368	47,6
Mandeh	100	-	56	404	52,3

Based on economic comparison results as shown in Table 10. for three different areas of study. The lowest NPC and CoE values were obtained for the case study in Mandeh location with NPC $430,434.6 and CoE $0.114/kWh. Meanwhile, the lowest operating cost is obtained in the Mentawai microgrid system because it has the largest fraction of renewable energy generation, which is 93.84%. Even though the initial investment cost of Mandeh microgrid system is low, the operational costs are high among the three systems tested. This is due to the small fraction of renewable energy producers. Thus, the configuration of the microgrid generator, the wind speed pattern affects the optimization results of the microgrid system design.

Table 10. Optimal economic result based on 100 kW PV designed

Location	Config	NPC ($)	CoE ($/kWh)	RF (%)
Lagundri	PV/G/B	430,434.6	0.130	92.64
Mentawai	PV/WT/G/B	394,911.3	0.119	93.84
Mandeh	PV/G/B	377,919.6	0.114	92.02

4. Conclusion

The economic feasibility study of hybrid microgrid power system for three remote islands of Sumatra, Indonesia have been carried out. The simulation results showed that the installation of WT is not feasible for the microgrid area at the Mandeh location because the wind speed is relatively low. But the Mandeh area has a large amount of solar radiation compared to the other two areas, resulting in the lowest CoE of $0.096/kWh and low investment and operating costs as well. For the fixed PV 100 kW scenario, the optimal configuration is obtained with 86 kW supplied by WT for the Lagundri location, and 67 kW supplied by WT for the Mentawai area, while the WT installation area is not recommended. From the results of the evaluation of the loading pattern not only average weather parameters affect PV/Wind electrical power production but weather patterns have effect in PV/Wind electrical power production.

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References

[1]. Sadat, S. A., Faraji, J., Babaei, M., & Ketabi, A. (2020). Techno-economic comparative study of hybrid microgrids in eight climate zones of Iran. *Energy Science & Engineering*, *8*(9), 3004-3026.

[2]. Khan, M. A., Aziz, M. S., Khan, A., Zeb, K., Uddin, W., & Ishfaq, M. (2019, July). An optimized off-gird renewable AC/DC microgrid for remote communities of Pakistan. In *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)* (pp. 1-6). IEEE.

[3]. Thomas, A., & Racherla, P. (2020). Constructing statutory energy goal compliant wind and solar PV infrastructure pathways. *Renewable Energy*, *161*, 1-19.

[4]. Rajeh, M. A., & Bensenouci, A., (2019). *Design a Hybrid Wind-Solar Power System for Remote Areas of Saudi Arabia*. Proceedings of the International Conference on Industrial Engineering and Operations Management Riyadh, Saudi Arabia, November 26-28.

[5]. Chaudhary, V. P., Chandra, R., Chaudhary, R., & Bhattacharyya, R. (2021). Global warming potential and energy dynamics of conservation tillage practices for different rabi crops in the Indo-Gangetic Plains. *Journal of Environmental Management*, *296*, 113182.

[6]. Hrnčić, B., Pfeifer, A., Jurić, F., Duić, N., Ivanović, V., & Vušanović, I. (2021). Different investment dynamics in energy transition towards a 100% renewable energy system. *Energy*, *237*, 121526.

[7]. Islam, M. S., Das, B. K., Das, P., & Rahaman, M. H. (2021). Techno-economic optimization of a zero emission energy system for a coastal community in Newfoundland, Canada. *Energy*, *220*, 119709.

[8]. Islami, M. S., Urmee, T., & Kumara, I. N. S. (2021). Developing a framework to increase solar photovoltaic microgrid penetration in the tropical region: A case study in Indonesia. *Sustainable Energy Technologies and Assessments*, *47*, 101311.

[9]. National.Energy.Council, "Indonesia Energy Outlook 2016," (2016). [Online]. Retrieved from: https://www.esdm.go.id/assets/media/content/content-indonesia-energy-outlook-2 %0A016-versi-inggris-my33nxb.pdf. [accessed: 20 March 2021].

[10]. Putra, I. N., Hakim, A., Pramono, S. H., & Leksono, A. S. (2017). The effect of strategic environment change toward Indonesia maritime security: Threat and opportunity. *International Journal of Applied Engineering Research*, *12*(16), 6037-6044.

[11]. Winanti, N., Purwadi, A., Halimi, B., & Heryana, N. (2018, October). Study and Design of Energy-Saving Solar Lamp for Small Island in Indonesia: Matakus Island. In *2018 Conference on Power Engineering and Renewable Energy (ICPERE)* (pp. 1-5). IEEE.

[12]. Surjosatyo, A., Dewantoro, B. R., Saragih, B. R., Nainggolan, F., Dwianto, W., & Darmawan, T. (2018). Selecting and testing of wind turbine blades of the local-wood growing fastly on local wind characteristics. In *IOP Conference Series: Earth and Environmental Science* (Vol. 105, No. 1, p. 012095). IOP Publishing.

[13]. Nrel, "Homer Powering Health Tool," (2020). Retrieved from: https://poweringhealth.homerenergy.com/. [accessed: 28 March 2021].

[14]. Okedu, K. E., & Uhunmwangho, R. (2014). Optimization of renewable energy efficiency using HOMER. *International Journal of Renewable Energy Research (IJRER)*, *4*(2), 421-427.

[15]. Olatomiwa, L. (2016). Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. *Energy Reports*, *2*, 141-146.

[16]. Kazem, H. A., Al-Badi, H. A., Al Busaidi, A. S., & Chaichan, M. T. (2017). Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island. *Environment, Development and Sustainability*, *19*(5), 1761-1778.