Marine-Based Renewable Energy Solution for 3T Areas in Indonesia: Integrating Diesel Hybridization with Floating PV Power Plant

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Abstract. To fulfill Paris Agreement commitments, an effective strategy involves advancing renewable energy (RE) adoption, especially in 3T (underdeveloped, frontier, outermost) regions dependent on diesel power. Nain Island, a 3T area, relies on a 200kW diesel plant operating 7 hours/day for 1004 households. This research aims to extend electricity services to 24 hours/day without extra fuel by integrating a 300 kWp photovoltaic (PV) plant with the existing diesel setup. Determining PV capacity considers parameters like diesel capacity, load profile, households, and outage rates. Implementing the PV plant encounters challenges due to limited land and hilly terrain. The solution proposes floating PV plant technology, globally successful and applicable in Indonesia. Placement on the northern coastal area of Nain Island, near the existing diesel plant, addresses land limitations. Detailed design considerations, including wave patterns, wind speed, and bathymetry, are crucial for successful implementation. Upon deployment, the system promises a substantial increase in electricity service without additional fuel consumption, leading to a reduction of 389 tons/year in CO2 emissions. This innovative approach aligns with global sustainability goals, showcasing the potential for renewable energy integration in remote areas and underscoring the significance of environmentally friendly solutions.

1 Introduction

Due to Zero emission program worldwide, the use of fossil energy as an electrical energy shall be decreased, while the demand for electricity is increasing. With the Paris agreement and General National Energy Plan (*RUEN*) of the Indonesian government has targeting 23% renewable energy of energy mix [1], and have agreed to reduce carbon emissions by 29% in 2030 through law no. 16 of 2016, the use of renewable energy as an energy source is a feasible solution.

Photovoltaic (PV) is a renewable energy source with resources of solar energy which is free and unlimited. Based on the system connection, there are two types of PV system: on grid and off grid. Off grid PV systems are connected to the load and a backup power (battery),

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it usually operates islanding, and on grid PV systems are connected to the grid. In general, the location of PV system installation can be either ground mounted or rooftop, depending on land availability and needs [2]. Lately, floating PV system has begun to be developed in India, Japan, and even Indonesia [3] [4] [5] [6]. Floating PV (FPV) is a PV system that installed on water bodies such as ponds, reservoirs, and seas. Compared to ground mounted PV system, FPV has several advantages, for instance it has natural cooling from water beneath, hence the PV output power will be higher [7] [8]. Furthermore, large areas of land are not required. Generally, for 1 MW PV system, 10,000 m^2 of open land is required, and this is not necessary for FPV.

FPV is very likely to be deployed in Indonesia to meet regional development and electricity needs, in addition to being located on the equator and having high solar radiation potential, whereas Indonesia is an archipelago and has many coasts. Nain Island is one of the 3T areas in Indonesia, which located in North Sulawesi. The power source used by the community is diesel generator with main generator of 200 kW and backup generator of 50 kW. Due to the limited distribution networks, diesel generators can still be found in many rural areas in Indonesia despite the high fuel prices. In this study, a hybrid system integration design will be implemented between the FPV and the existing diesel generator to increase the electricity availability. HOMER hybrid simulation model was developed to determine the configuration and the estimated performance of the Hybrid FPV and diesel power plant, and the CO_2 emission reduction. Previous studies on island hybrid power system recommended onshore placement of PV plant. On-shore placement of PV plant often is not possible considering land usage whether for residential in highly populated island or for tourist facility in tourist destination island [9] [10].

2 Materials and methods

2.1 Floating PV

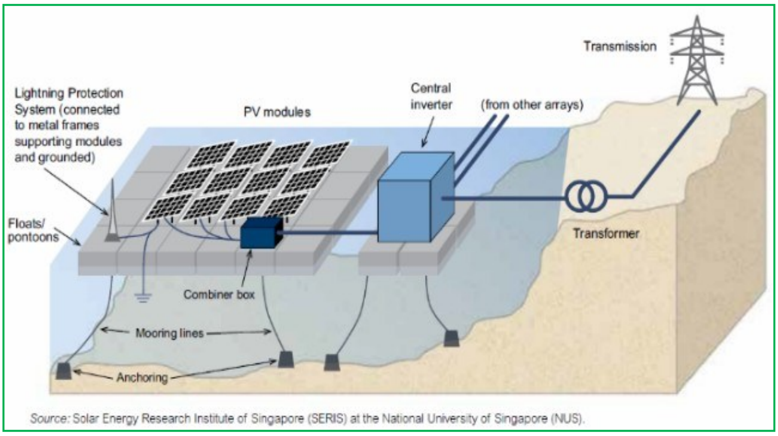

Fig. 1. Model of a floating PV installation

Floating PV (FPV) is a photovoltaic system installed above the water surface. This technology allows it to be applied in areas with limited land and utilizes water surface. Figure 1 shows that a floating PV system consists of floater, pontoons, mooring system, solar panels and submarine cables, and UV resistant cable trays. This system requires a higher installation cost than ground mounted but has several advantages such as generating more electricity due to the cooling system and reducing algae and evaporation in the water.

2.2 Methods

The methodology used in the study includes desk study area and site selection, data collection and site survey, design and technology selection of the floating PV power plant, integration of PV with diesel hybridization, simulations, and performance evaluation as well as statistical analysis. Conducting desk study to find system references, and types of components, and secondary data, followed by site survey, components selection, system design conducting simulations to determine PV system capacity as part of hybridization. In a PV-diesel hybrid system, solar panels (PV), generator(s) and batteries are connected and collaborate to supply all connected power consuming appliances with energy [9].

2.2.1 Desk study area and site selection

The first step in a desk study for area and site selection is to gather available data relevant to the project's objectives. It includes geographical information, climate data, land use maps, infrastructure details, demographic statistics, and any existing reports related to the study area. Nain Island is in Wori District, North Minahasa District, North Sulawesi Province. Nain island has an electricity supply from diesel generator owned by PLN, with limited hours of operation from 18:00 WITA to 01:00 WITA with primary generator capacity of 200 kW and backup generator of 50 kW. There are areas where electricity is still not available due to its remote location from PLN's diesel generator and limited distribution network. The location of existing diesel engine can be seen in Figure 2. The floating PV plant may be placed on coastal area with shallow water and low waves located in the northern part of Nain Island adjacent to existing diesel plant. The system design will depend on maximum expected loads for the system which need to be calculated based on several parameters such as waves, current and wind speed, and bathymetry. The plant would be best built in calm maritime area,with waves less than 4 m and wind speed less than 15 m/s [10]. While there are no certain limitation, deeper water level and harsher environment will directly affect floater system cost.

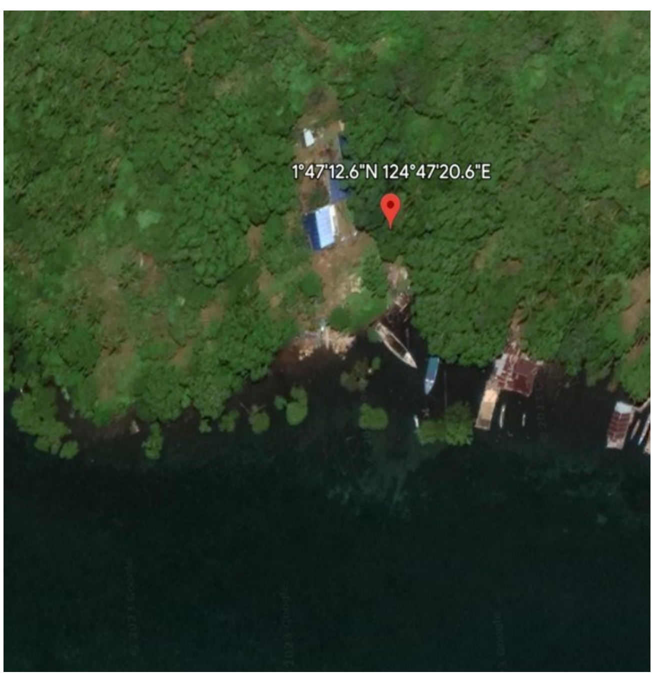

Fig. 2. Existing diesel engine location.

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2.2.2 Data collection and site survey

Sizing design of the hybrid FPV system capacity requires completed data of the electricity load profile to find out the energy demand in the area. The actual 7-hours load profile of the Nain Island were measured and can be seen in the following Figure 3. Data extrapolation approach is performed to obtain daily load profiles with reference to island load profile characteristics that were considered similar. The load increase is assumed to be 30% due to the very active pattern of the Nain Island community and the existence of fishing and seaweed farming activities.

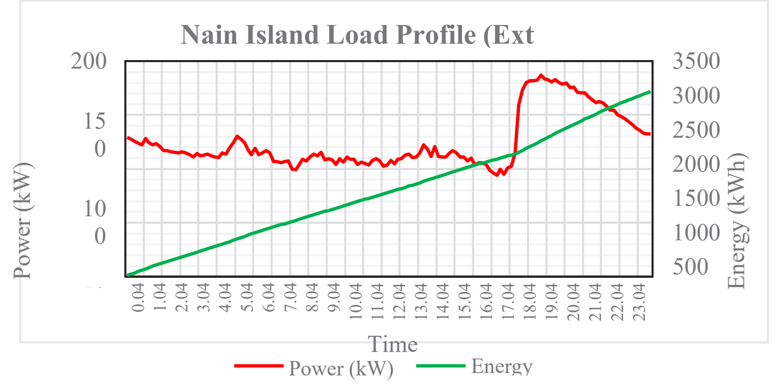

Fig. 3. The measured and extrapolated electricity load profile of the Nain Island.

The capacity of the main diesel generator is 200 kW while the backup diesel engine is negligible. Diesel fuel is assumed to be $0.75/liter and fuel consumption is capped at 300,000 L/year. The diesel engine is modeled to idle during daytime loads (06:00-18:00) and operates during nighttime to provide the maximum load with PV system (see Figure 4).

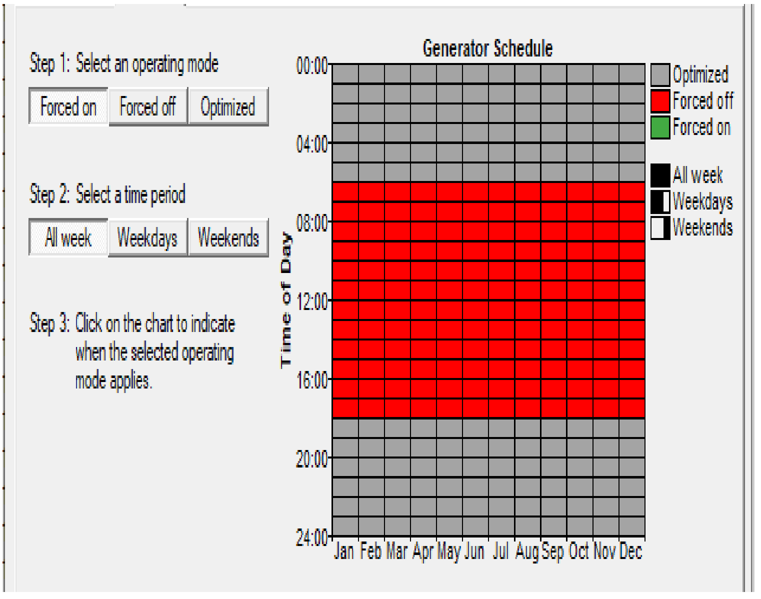

Fig. 4. Scheduling of the diesel deactivation.

Solar radiation data and other parameters at the plant site is obtained from Meteonorm 8.0 software (global meteorological database) which is shown in Table 1.

Table 1. Daily solar radiation at the site plant.

Month	Daily radiation ($kWh/m^2/d$)
January	4.57
February	4.41
March	5.41
April	5.72
May	5.40
June	5.21
July	5.69
August	5.76
September	5.77
October	5.56
November	5.08
December	4.82

The average daily radiation in a year at the site plant is 5.289 kWh/m2/day, the lowest radiation occurs in February, while the highest is in the July-October period.

2.2.3 Design of the hybrid FPV and diesel power plant

Adding PV system to an existing system is a possible development plan that can increase diesel engine runtime from 7 hours/day to 12 hours/day. The system design is planned to use a hybrid model in which one of the systems (both PV and diesel) can supply the load automatically or synchronously. Diesel capacity in this hybrid system is planned to continue using existing generators. The electrical load parameters were used as hourly interval data from the extrapolated data, the daily and hourly variability were 2.5% and 5% respectively. Based on this hypothetical data, the total energy demand is 3,150 kWh/day. Solar modules with capacity of 335 Wp were selected, with a specification (under standard test condition of irradiance 1000 W/m2, spectrum AM 1.5 and cell temperature of 25°C) as shown in Table 2. The selected solar module configuration can be considered from 100 kWp to 800 kWp capacity.

Table 2. Electrical data of the solar module used in the study

Electrical specification	Name plate
Nominal max. power (Pmax)	335 Wp
Opt. operating voltage (Vmp)	37.4 V
Opt. operating current (Imp)	8.96 A
Open circuit voltage (Voc)	45.8 V
Short circuit current (Isc)	9.54 A
Module Efficiency	17.23%

The selected batteries were Valve Regulated Lead Acid (VRLA) which is considered easy tomaintain and minimizes the risk of battery depletion leading to premature failure. Although lithium is better recognized in this reference [9][10][11][12] [13], there has not been a success stories related to the use of lithium BESS in Indonesia [14]. This usually happens due to a BMS failure that cannot be repaired promptly due to limitation of readiness, availability of the technology and difficult access of location in Indonesia, where the BMS is a critical component of a lithium battery [15]. The considered battery in simulation was asingle battery with a capacity of 1500 Ah to facilitate on-site device mobilization. Inverter units of 100 kVA rated capacity with 91% efficiency were selected, and range of inverter capacities considered from 80 kW (1 inverter) to 1200 kW (15 inverters).

2.2.4 Simulation and analysis of the hybrid FPV and power plant

The purpose of a PV-Diesel hybrid power generation system is to take advantage of the functions of each component and integrate them to provide greater value to the system. The PV output power is intermittent since it relies on solar radiation. This can be overcome with the use of battery, yet the battery state of charge (SOC) should be considered to maintain the life of the battery. Diesel generator can also be used to overcome PV intermittency in certain scheme. Besides it should be considered as well that repeated switching on and off will cause a damage the generator. The PV-Diesel hybrid operating system is designed to be as efficient as possible for optimal system operation. PV-Diesel hybrid operating system as shown in the Figure 5.

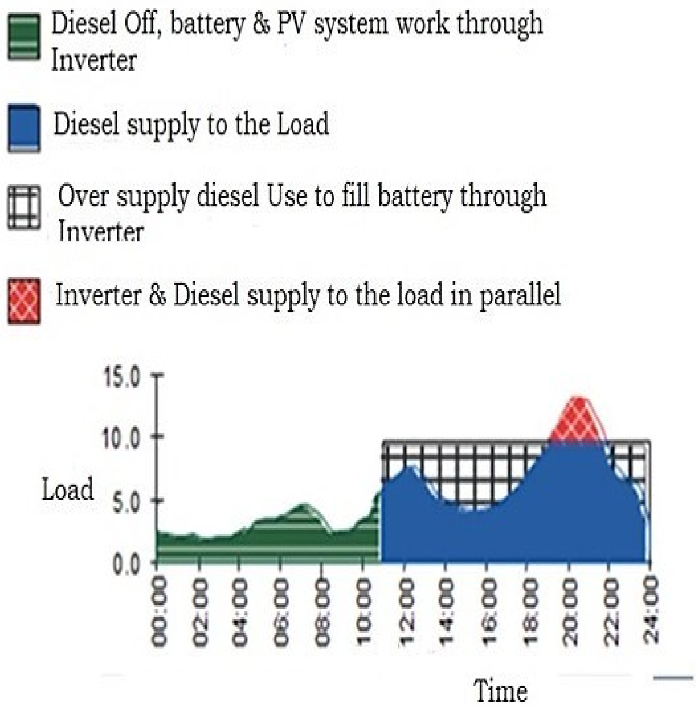

Fig. 5. Operation of the hybrid FPV-diesel power plant.

When the load is low, it will be supplied by the PV. When the output of the PV is higher thanthe load, some of the generated energy will charge the battery. When the load starts to increase beyond PV output, the control system will start the diesel engine. If the load is still lower than the output power of the diesel engine, the diesel engine will supply the load and charge the battery. When the load increases beyond the capacity of the diesel engine, the diesel and the battery will synchronously supply the load through the inverter. If the maximum load is exceeded and the load starts to decrease, the diesel engine will stop working and the load will be supplied from the battery through the inverter. A HOMER hybrid simulation model was developed to run the simulation of the hybrid FPV-diesel power plant, as shown in Figure 6.

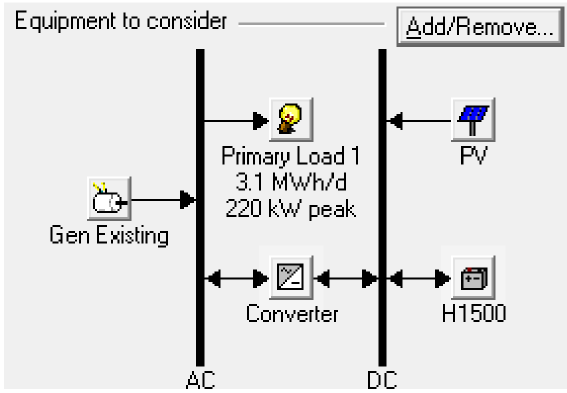

Fig. 6. The HOMER hybrid simulation model of the hybrid FPV-diesel power plant

3 Result and discussion

3.1 Proposed system

Based on the design and simulation results, there are several recommendations for the capacity of the FPV-Diesel hybrid system. In this study, considering the lower initial investment cost and the availability of land for the placement of photovoltaic panels. Figure 7 shows the recommended design capacity of the system to use the existing of 200 kW diesel engine, with an additional of 300 kWp FPV, 2 strings of battery banks (360 pieces), and 2100kVA/80kW inverter units. The layout design of the Nain Island FPV-Diesel hybrid system is as shown in Figure 8 with a 4x50 kWp and 1x 100 kWp configurations of solar PV arrays, which can operate simultaneously with 1-unit existing 200 kW diesel engine.

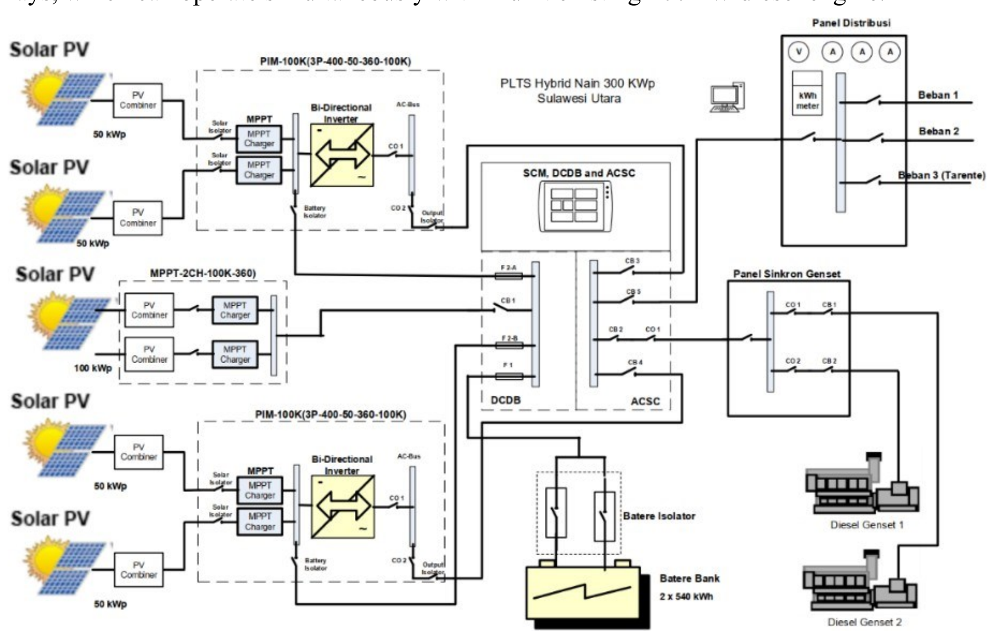

Fig. 7. Proposed system configuration for the hybrid FPV-diesel power plant

Fig. 8. Layout of the proposed hybrid FPV-diesel power plant.

3.2 Power production

Electrical power generated from the FPV-Diesel system throughout a year can be seen at Table 4. It is shown that 37% of total generated power is derived from renewable energy(i.e., PV Array).

Table 3. FPV-Diesel hybrid production.

Production	kWh/yr	%
PV Array	429.058	37
Gen existing	725.161	63
Total	1,154.219	100

Table 4. Excess & unmet electricity.

Quantity	kWh/yr	%
Excess electricity	4.296	0.37
Unmet electricity load	89.416	7.78
Capacity shortage	104.882	9.12

In Table 5, this system has an unmet loss/no-load ratio of 7.78%, possibly due to depletion of stored energy in the battery bank and low daily radiation.

3.3 Load profile projection

At high radiation, the power profile on Nain Island is shown in Figure 9. The load is alternately supplied by an inverter (FPV) and a diesel engine. Excess energy generated by solar modules during the day and by generators at night is used to charge the battery of the bank. This is done considering that the generator will operate efficiently if it reaches the rated load.

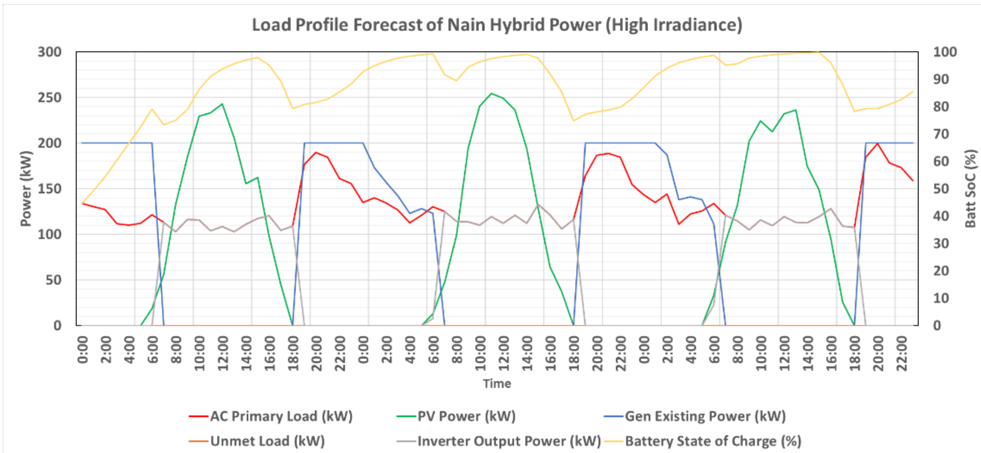

Fig. 9. Load profile of the FPV-Diesel system during high radiation

Under low radiation conditions, the power profile is shown in Figure 10. The SoC (state of charge) dropped to 30% on the third day and powered off. If the bad radiation continues, there will constantly be a power cut during the day.

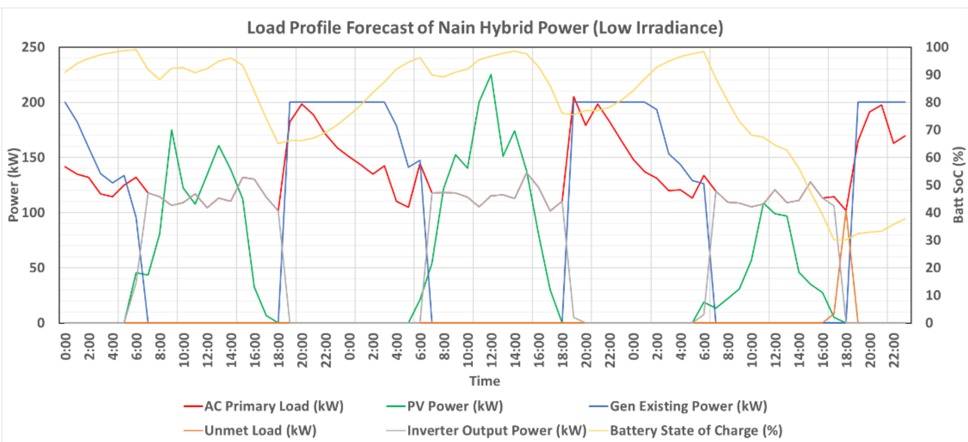

Fig. 10. Load profile of the FPV-Diesel system during low radiation

3.4 Fuel savings and CO2 emission reduction

Table 5. FPV-Diesel hybrid production and diesel only comparison

	FPV-Diesel Hybrid	Diesel Only
Initial Cost ($)	661,200	0
Operating Cost ($/yr)	250,061	359,480
Cost of Electricity ($/kWh)	0.29	0.316
Fuel consumption (lt/yr)	256,755	456,178
Carbon emission (ton/yr)	679	1,068

Fuel consumption and carbon emissions shown in Table 5. With the addition of FPV, fuel consumption is 257,755 litre/year. Meanwhile, assuming full use of diesel engine, fuel consumption is 456,178 litre/year as shown in Table 5. Thus, there is a difference in fuel consumption of around 200,000 litres of diesel/year. The carbon emissions are also reduced to 389 tons/year. The amount of emission reduction is calculated from the system energy output which is then converted to CO_2 emission reduction with a multiplier factor of 0.76 kg/kWh [16].

4 Conclusion

The study formulated a Floating PV-Diesel Hybrid Power System tailored for Nain Island, characterized as a 3T region with restricted electricity access. Comprehensive simulations were conducted to determine the optimal FPV-Diesel configuration. The outcome revealed a 300 kWp floating PV coupled with a 200 kW diesel configuration, effectively catering to Nain Island's electricity requirements with lower cost of electricity at $0.29/kWh compared to diesel only option at $0.316/kWh. The integration of FPV significantly bolstered the island's electricity availability from 7 hours to 24 hours/day. In contrast to exclusive diesel consumption, the hybrid system showcased the potential to curtail carbon emissions by a remarkable 389 tons/year. Further investigations are needed for this system, which design will depend on maximum expected loads for the system which need to be calculated based on several parameters such as waves, current and wind speed and bathymetry.

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