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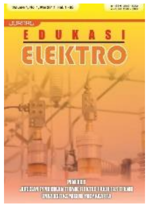

Optimization of Hybrid Power Plant System to Increase Reliability by Maximizing Renewable Energy (Case Study: Semau Island)

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Abstract— Semau Island is one of the islands in the 3T region. Semau Island's electricity system is supplied by 5 diesel engines, Solar Power Plant, and battery storage, with a renewable energy mix that reaches 13%. This is not in accordance with the target renewable energy mix in Indonesia in 2025 which is 23%. The generation operation pattern applied on Semau Island experiences blackouts due to intermittent conditions when the Solar Power Plant fully supplies the load during the day and the battery is unable to back up. So, to mitigate the intermittency nature of the Solar Power Plant while still increasing the penetration of renewable energy, it is necessary to optimize the integrated generation operation pattern between the Solar Power Plant, the diesel engine and the battery storage. In this research, optimization is carried out using HOMER software. The HOMER application uses a derivative-free algorithm in the HOMER Optimizer feature to find the cheapest system. The optimization results in the existing scenario found that the use of 2 diesel engines, namely DG Mdec, DG Adec in base load operations and a combination of PV and batteries can optimize the operating pattern with NPC costs of $9762426, O&M costs of $583589 and LCOE value of $0.1999/kWh.

Keywords: diesel engine, solar power plant, battery storage, homer.

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1 Introduction

Fulfilment of electricity needs today not only considers the availability of energy sources, but also must meet indicators of system reliability, economy, and renewable energy [1]. Semau Island is one of the islands in Indonesia located in the Nusa Tenggara Timur region and is included in the disadvantaged, frontier, and outermost areas. Semau Island's electricity system operates in isolation, which means that the system only has its own electricity center and is not interconnected with the main electricity network in Kupang city. Semau Island's electricity system is supplied by five diesel engines that are hybridised with PV plants and equipped with battery storage. To fulfil the electricity demand on Semau Island, the Indonesia Electricity Company, called PLN, has implemented the penetration of renewable energy mix by using PV plant. However, until now the renewable energy mixes on Semau island have only reached 9%. This is not in accordance with the target of renewable energy mix in Indonesia in 2025 which is 23% [2].

The electricity generation system on Semau Island works with an operating pattern during the day using PV as a base load supported by battery storage as a load follower. While the operating pattern at night uses diesel engines as isochronous mode generators to replace solar power plant and batteries. The current operating pattern of the electricity system applied on Semau Island often experiences failures or blackouts. This is due to intermittent conditions when solar power plant is fully supplying the load during the day. Where the solar power plant irradiance at that time is 0 and the battery condition is not able to back up when intermittent occurs. So as to mitigate the intermittency nature of solar power plant while still increasing the penetration of renewable energy, it is necessary to optimize the operation pattern of integrated plants between solar power plant, diesel, and battery storage [3].

In this research, optimization is carried out using HOMER software. The HOMER application uses a derivative-free algorithm in the HOMER Optimizer feature to find the cheapest system. The optimization results of HOMER Pro software can display several scenarios of generation operation patterns sorted by net present cost (life-cycle cost) that can be used to compare system design options [4]. Financially, Homer simulations are conducted to determine the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) values of the plant design. The smaller the NPC and LCOE parameter values of each operating pattern scenario, indicating that the designed electricity system is optimal [5].

It is expected that the optimization of operations on the Semau Island electricity system can be used as a recommendation in the operation of integrated power plants on Semau Island to mitigate the intermittency of PLTS, produce the cheapest operating costs, maximize the potential of renewable energy, and prepare an optimal Semau Island electricity system based on sensitivity to discounted rate values and inflation [6].

2 Basic Theory

2.1 Power Generation System

The power generation system is the process of producing electrical energy from various energy sources to be distributed to consumers [7]. A good power generation system is one that can produce electrical energy efficiently at low cost and is environmentally friendly [8]. Based on its configuration, the power generation system can be divided into centralized generation system and distributed generation system [9].

2.2 Microgrid

Microgrids can be considered as miniature power grids that can operate independently or be connected to a larger power grid [10]. Simple microgrids are widely used in the industrial field for the purpose of improving power quality at peak loads and for cogeneration of heat and power. Recently, microgrids that use renewable energy sources are increasingly used to generate electricity for communities in remote areas. [11].

2.3 The Economic Aspect

The economic aspect of electrical energy generation systems is an important consideration in the process of planning, operating, and installing power plants. Economic analysis can be done to determine whether the plant is feasible to build and operate. The investment criteria considered in techno-economic analysis are the net present cost and levelized cost of energy values of a generation system [12].

2.3.1 Net Present Cost

Total Net Present Cost (NPC) is the total cost incurred over the lifetime, minus the present value of all revenues earned over the lifetime. The costs include capital costs, replacement costs, O&M costs, fuel costs, emission penalties, and the cost of purchasing power from the grid. The economic model for the HOMER simulation uses NPC which is the total installation and operation cost of the system over the lifetime of the project. The total NPC of the system is calculated by equation [13]:

$$C_{NPC,tot} = \frac{C_{ann,tot}}{CRF\ (i,R_{proj})} \quad (1)$$

To determine the amount of the capital recovery factor, it can be calculated using the equation:

$$CRF\ (i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

In the HOMER application, calculations are made using the annualised real interest rate rather than the nominal interest rate in the calculations. However, the annual real interest rate can be obtained from the nominal interest rate using the equation [13]:

$$i = \frac{i' - f}{1+f} \quad (3)$$

2.3.2 Levelized Cost of Energy

Levelized Cost of Energy is a calculation of the average cost per kWh of useful electrical energy. To calculate the LCOE value can be done by dividing the annual cost of generating electricity by the total cost of production. The LCOE calculation is formulated as [14]:

$$LCOE = \frac{Cann,tot - Cboiler\ Hserved}{Cann,tot - Cboiler\ Hserved\ Eserved} \quad (4)$$

2.4 Renewable Fraction

Renewable Fraction is the fraction of energy delivered to the load that comes from renewable resources. The HOMER Pro application can calculate the renewable fraction using the following equation [15] :

$$Fren = 1 - \frac{Enonren + Hnonren}{Eserved + Hserved} \quad (6)$$

3 Method

The research process begins with the process of collecting data inputs needed for simulation in the HOMER application [16]. If the data requirements have been met, the optimization simulation can be carried out. The scenario will determine how many diesel engines are operating with penetration from PV and battery storage. The purpose of this scenario is to accelerate dieselization program and produce a system with the lowest cost. HOMER simulation results will show operating scenarios sorted by NPC and LCOE values. Based on these scenarios, the most optimal operating pattern can be selected to improve system reliability and maximize renewable energy on Semau Island.

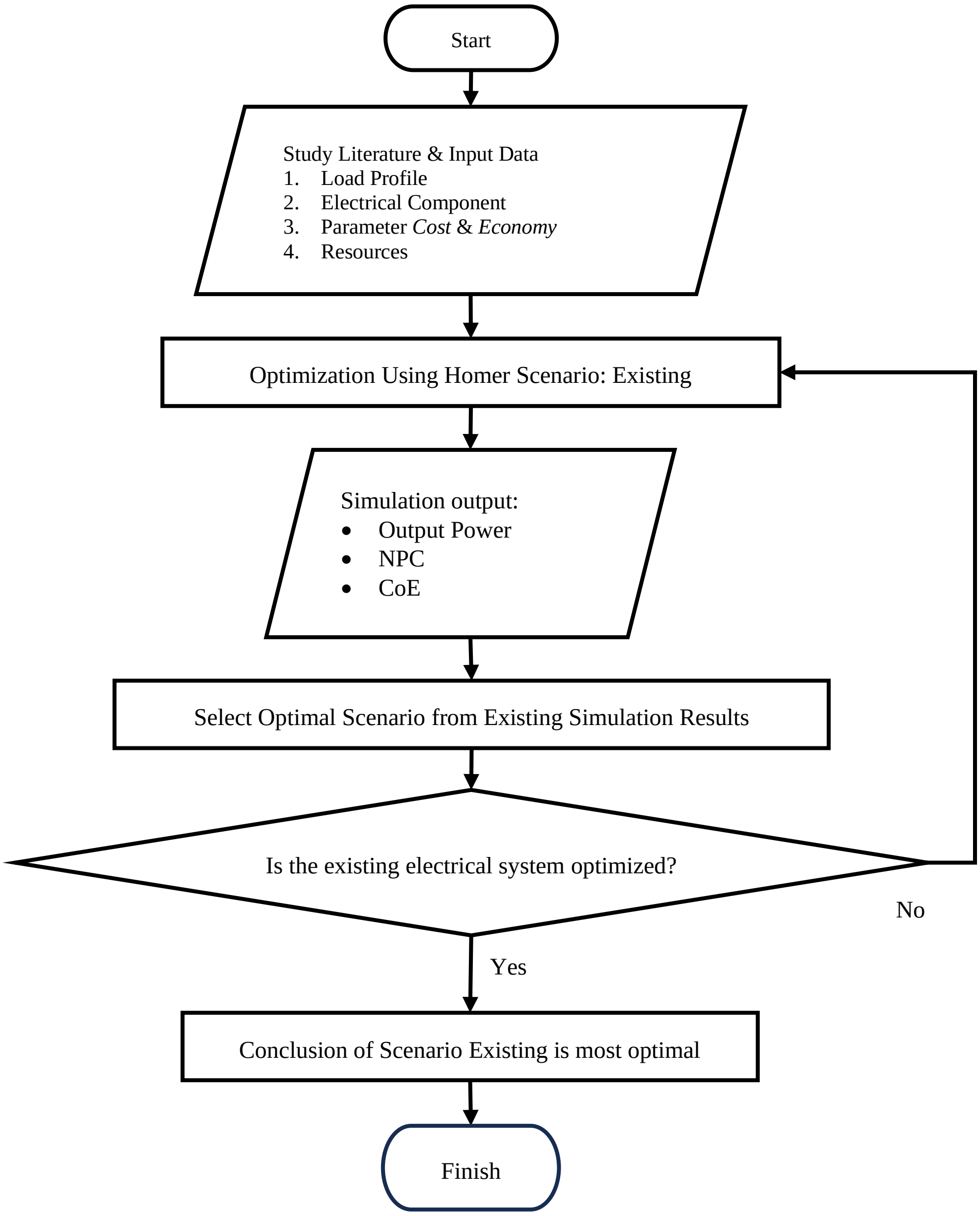

Fig. 1. Research flowchart

4 Semau Island Electricity System

Semau Island has an isolated electricity system with a capable power capacity of 1010 kW and a peak load that reaches 710kW in 2023. Currently, the Semau Solar Power Plant system configuration is designed with an On Grid Hybrid pattern between Genset and Solar Power Plant to serve the electricity load on Semau Island as shown in Fig. **2**. The DG unit is interconnected with the PLTS unit through a 5 km 20 kV network.

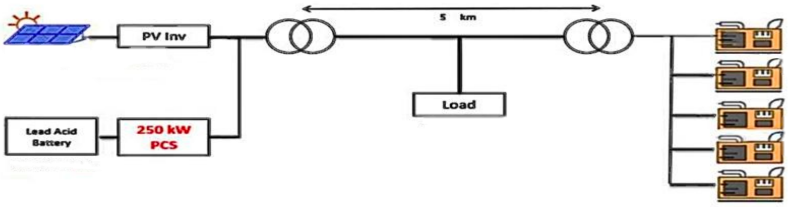

Fig. 2. Design and power capacity of Semau Island electricity system

4.1 Diesel Generator Model and Parameters

On Semau Island has 5 diesel engines that have different capacity ratings and capable power ratings for each diesel engine. The following is a resume of diesel engine data on Semau Island.

Table 1. Semau island diesel engines data specifications

No	Name	Rating (kW)	Capable Power (kW)	Condition	SFC (liter/kWH)
1	DG Volvo	250	100	Standby	0.3684
2	DG Deutz	240	150	Operation	0.33
3	DG MTU Mdec	528	280	Operation	0.384
4	DG MWM	112	70	Operation	0.315
5	DG MTU Adec	528	350	Operation	0.384
Total		1658	1010		

The electricity system on Semau Island is currently supplied by a 450kWp solar power plant and a 250 kW Energy Storage System (ESS) accompanied by a generator with a total capacity of 1010kW, the capacity can still be increased, especially for photovoltaic modules, where there is still vacant land.

Table 2. Economically specification of Semau diesel engines

Parameter	DG Volvo	DG Deutz	DG MTU Mdec	DG MWM	DG MTU Adec
Lifetime (Hours)	15000	15000	18000	10000	18000
Min Load Ratio (%)	25	25	50	20	50
Cost of Investment	$0/kW	$0/kW	$0/kW	$0/kW	$0/kW
Cost of Replacement	$17,165	$17,165	$81,979	$10,350	$81,979
Cost of O&M	$10	$10	$7	$10	$3.5

Table 3. Generation cost of Semau diesel engines

Fuel Properties	DG Volvo	DG Deutz	DG MTU Mdec	DG MWM	DG MTU Adec
Fuel Price ($/L)	0.67	0.67	1.1	1.1	0.67
Lower Heating Value (MJ/kg)	43.2	43.2	40.6	40.6	43.2
Density (kg/m^3)	820	820	750	750	820
Carbon Content (%)	88	88	94	94	88
Sulfur Content (%)	0.4	0.4	0.65	0.65	0.4

4.2 PV and Inverter System Model

The total PV capacity installed on Semau Island is 450kWp with a 400kW Inverter. From this data it can be ascertained that during the day most of the load can be supplied by PV with a little power from the diesel engine[17]. However, with limited solar irradiation, it is also necessary to consider when the power generated by PV is minimal. If Semau Island wants renewable energy penetration to be increased, the thing that needs to be added is in terms of Inverter capacity and PCS (Power Conditioning System) in the battery. So that dependence on diesel engines can be reduced. Based on data obtained from Semau Island, it is known to have a solar radiation level of 2120.6 kWh/m^2 per day with a monthly average of 169.4kWh/m^2.

Table 4. Irradiation data for 2023 on Semau Island

Parameter	Value	Unit
Direct Normal Irradiation	2028.1	kWh/m^2 per day
Global Horizontal Irradiation	2120.6	kWh/m^2 per day
Diffuse Horizontal Irradiation	710.6	kWh/m^2 per day
Global Tilted Irradiation at Optimum Angle	2183.1	kWh/m^2 per day
Optimum Tilt of PV Module (OPTA)	15/0	°
Air Temperature	27.2	°C
Terrain Elevation	76	m

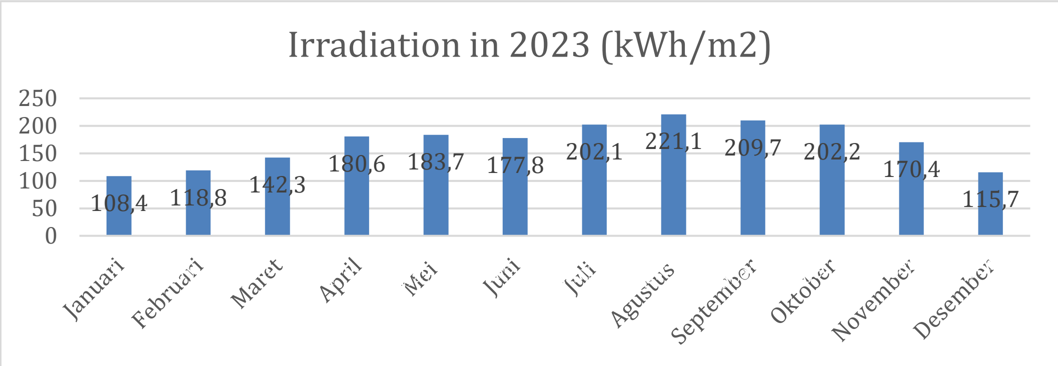

Fig. 3. Direct normal irradiation

The PV representation selected and used in the simulation modelling uses flat plate PV with a rating in accordance with the existing system of 450kWp with a derating factor of 80%. In addition, Semau Island PV is also equipped with an inverter with a capacity of 400 kW. Where in this case the maximum limit of power distribution from PV is 400 kW. The specifications of the PV and Inverter can be seen in Table 5 .

Table 5. Specifications of existing solar power plant and inverter

Equipment	PV	Inverter
Capacity (kW)	450kWp	400 kW
Capital ($)	$1800/kW	400
Replacement ($)	$1500/kW	400
O&M ($/Year)	15	20

4.3 Battery Storage Model

The battery used in the smart grid of Semau Island is a lead acid type battery. Lead acid batteries have a capacity of 2V, 2000Ah or 4000Wh with a total of 720 pieces that can be used for 10 hours of operation. In addition, to support the needs of the battery, it is equipped with a PCS (Power Conditioning System) with a bidirectional system of 250kW. Where the battery can be charged either through PV or diesel engine with a limitation of 250kW. The use of this battery module is used when the diesel engine is not operated or when the system requires additional power supply other than PV or diesel engine. The following specification data from Battery and PCS on Semau Island are shown in Table 6.

Table 6. Specification of lead acid and PCS batteries

Equipment	Battery	PCS
Capacity (kW)	2900 kWh	250 kW
Capital ($)	0	0
Replacement ($)	290000	61250
O&M ($/Year)	10	20

4.3.1 Load Profile of Semau Island

The average load demand of Semau Island in 2023 is about 565 kW for peak load while the average load is 342 kW and the minimum load in each month is about 244 kW which occurs at 1 pm. Of course, with the increase in load, it is necessary to change the operating pattern of the existing generation system so that the output produced is more optimal.

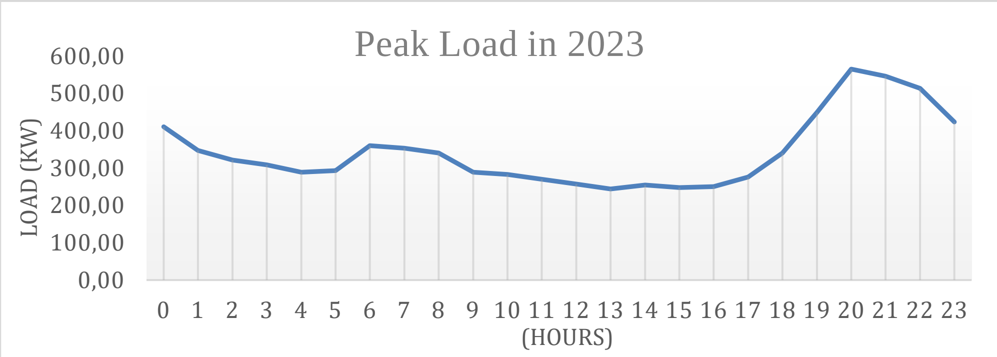

Fig. 4. Semau Island load profile in 2023 (*peak month*)

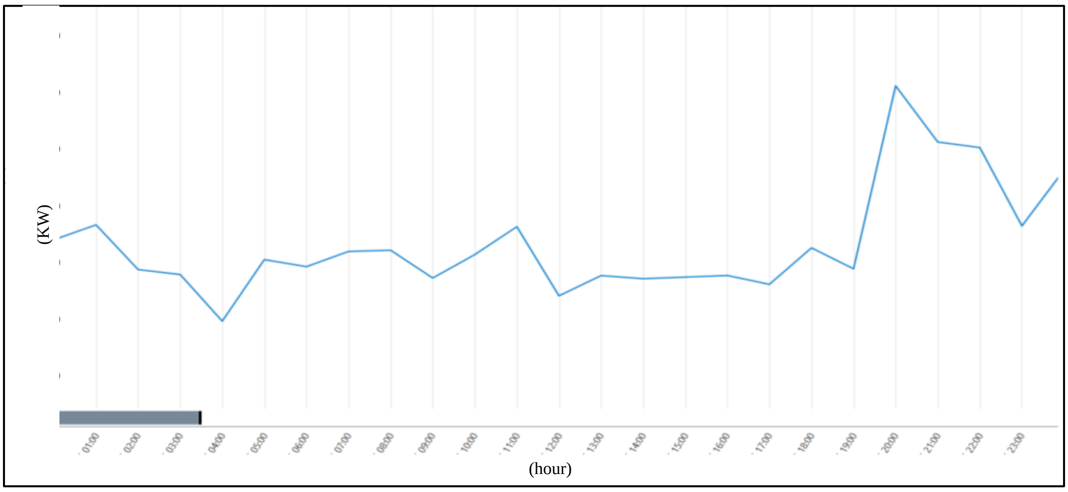

Fig. 5. Semau island load profile in 2023 (hour)

The Homer application will model the simulation results for electricity load consumption for 1 year. If converted into hours about 8760 hours and can add several random variable parameters, such as random variables for each day and time step variability. So that in every hour, day or month the electricity load will not be exactly same. So that by adding random variables, the electricity load will look more the same between the simulation results and the actual data.

5 Simulation and Analysis Result

5.1 Optimization Results

In the existing electricity system, it will be determined how many diesel engines are operating with the penetration of PV and battery storage. The purpose of this scenario is to accelerate dieselization program. Currently on Semau Island there are 5 diesel engines that all operate in supporting the electricity system on Semau Island.

After the process of inputting the data needed to perform modelling and simulation, Homer will display several scenarios that can be taken into consideration in conducting operating patterns by looking at techno-economic factors. In doing modelling and simulation in Homer must pay attention to the components (equipment), the bus bar scheme installed. The following **Error! Reference s ource not found.** modelling in simulation on the semau island electricity system. Simulation results of all scenarios that have been generated by Homer on Fig. **7**.

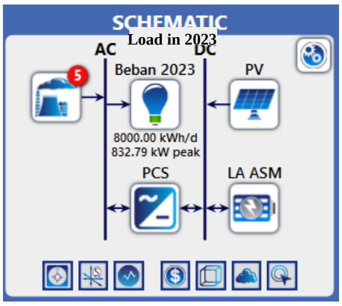

Fig. 6. Modelling and simulation of Semau island electricity system

Homer will display several scenarios that can be taken into consideration in conducting operating patterns by looking at techno-economic factors. When all input data has been filled in including economic parameters, it will produce various scenarios generated by Homer. But the results of the Homer application also choose the best scenario from several existing scenarios seen from economic parameters, operating patterns, emissions, and electricity production for a year. The following is a display of scenarios that have been generated by Homer.

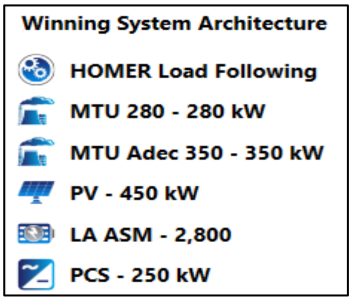

Fig. 7. Homer optimization result

The parameters used in modelling and simulation of this research using 2 discount rate values, namely 4.92 and 5.54. Then by also considering the inflation rate by using 2 values as well, namely 3.1 and 4.6. The value is taken based on data from www.bi.go.id. The optimization results from Homer in this modelling amounted to 2000 scenarios. Because there are 4 parameters, i.e. 2 values of the discount rate and 2 values of the inflation parameter, the total scenario results are (4x2000), which is worth 8000 scenarios.

The optimization results of the Homer simulation show that of the 5 diesel engines as actual data input, only 2 diesel engines are needed as shown in Fig. **7**. From 8000 scenarios, the optimal results have been listed and sorted by Homer software in terms of economics such as (NPC, LCOE and Operating Costs). From the existing scenario, the output will be shown using several DGs for the dieselization / diesel reduction scenario by utilizing the renewable energy mix based on the Homer optimization results, which are:

1st order Optimization Result: 2 DG, PV, Battery
2nd order Optimization Result: 3 DG, PV, Battery
3th rder Optimization Result: 4 DG, PV, Battery
4th order Optimization Result: 5 DG, PV, Battery

The recap table of differences in the results of optimization of existing scenarios 1-4 can be seen in Table 7. In addition, we can also compare that with more use of diesel engines, the penetration of renewable along with energy storage will be less in percentage.

Table 7. Existing optimization result

Scenario Existing					
Equipment	***2 DG, PV, Battery***	***3 DG, PV, Battery***	***4 DG, PV, Battery***	***5 DG, PV, Battery***	***Unit***
DG Deutz	-	150	150	150	kW
DG Volvo	-	-	100	100	kW
DG MWM	-	-	-	70	kW
DG MTU Mdec	280	280	280	280	kW
DG MTU Adec	350	350	350	350	kW
PV	450	392	383	183	kWp
Battery	2800	2100	700	350	kWh
PV Inverter	400	400	400	400	kW
PCS	250	245	208	83.3	kW
Renewable Penetration	36.4 %	28.7%	25.8%	13.4%	%

The Hower software optimization results with the load following dispatch strategy illustrate that of the 5 Diesel Engines where actual data is used as input, for existing conditions now only requires 2 DGs to operate. In an effort to meet the electricity load, it will be combined by using Solar Power Plant and battery storage available in the Semau Island electricity system. Based on Table 7 by optimizing the output of Solar Power Plant and battery storage will make the renewable penetration on Semau Island more and more. It is proven that by only using 2 diesel engines, i.e. DG MTU Mdec and DG MTU Adec with a base load of 280 kW for Mdec and 250 kW for Adec.

In addition, by utilizing the installed capacity of Solar Power Plant and battery storage from the scenario of 2 DG, Solar Power Plant, and battery storage the output rating for Solar Power Plant is 450 kW while for battery storage to meet the electricity needs on the island of Semau can utilize a capacity of 2800Ah of the 2900Ah installed. In addition, it is also evident that by utilizing a more renewable energy mix, the use of PV, Inverters, PCS, and storage batteries is also greater where the configuration uses a PCS that connects the DC system to the AC bus as a common coupling point from the load and also the diesel engine. From the energy mix using more renewable energy, the penetration of renewable energy is also greater as shown in Table 7.

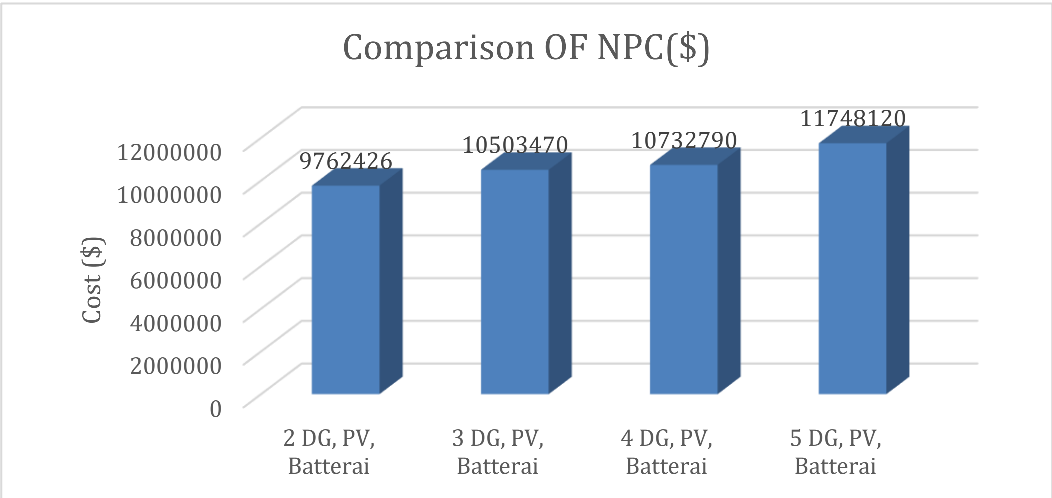

Fig. 8. Comparison of NPC cost

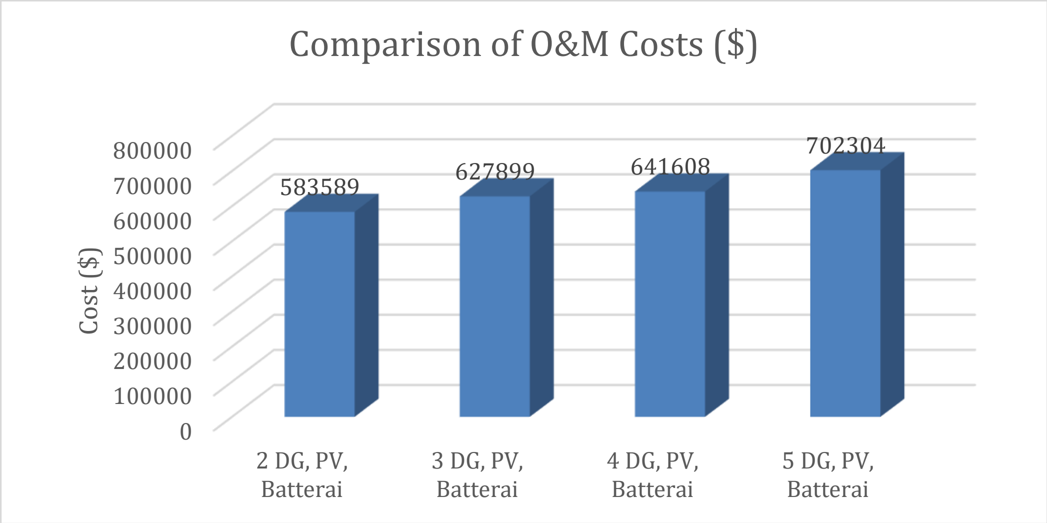

Fig. 9. Comparison of O&M Costs

To dieselization and increase the renewable energy mix on Semau Island, the scenario 2 DG, Solar Power Plant, and Battery Storage is the most optimal based on Net Present Cost, where a Net Present Cost (NPC) value of $9.7 million is obtained. The operational and maintenance costs per year of all scenarios are also considered in the discussion. In addition, it can also be seen that using 2 DG operation and maintenance costs are also cheaper than using 3, 4 and 5 diesel engines referring to Fig. **9**.

Table 8. Comparison of LCOE, emissions and fuel consumption in scenario existing

Scenario	**2 DG, PV, Battery**	**3 DG, PV, Battery**	**4 DG, PV, Battery**	**5 DG, PV, Battery**
LCOE ($/*kWh*)	0.1999	0.215	0.2197	0.245
co_2Emitted (*kg/yr*)	2118401	2159751	2223577	2483780
Fuel Consumption (*L/yr*)	809916	825725	850127	949609

The results of the system optimization, by using 2 diesel engines, PV and battery storage, will result in a Levelized Cost of Energy (LCOE) value of $0.19 per kWh that is less than other scenarios. LCOE is a parameter used to measure the average cost per unit of energy produced by the system in units of currency/kWh. In this case, the smaller the resulting LCOE value indicates that the operating pattern of the scenario can produce electrical energy at an optimal cost, in terms of optimal understanding costs are said to be the cheapest of the various scenarios. So that scenario 2 DG, PV and Battery Storage produces the lowest cost compared to 3, 4 and 5 DG referring to the calculated LCOE. The optimization results also resulted in co_2 emitted emissions of 2118401 kg/year and fuel consumption requires about 809916 liter/year. This shows that the results of the most optimal scenario, which is 2 DG, PV and Battery Storage, have less impact on the environment compared to using more conventional energy sources that use fossil fuels referring to co_2 emitted. To reduce greenhouse gas emissions and deal with climate change, the use of renewable energy systems such as the one proposed can make a positive contribution in reducing the carbon footprint. In addition, the optimization results are in accordance with the initial objectives for the DG plant de-dieselization program by reducing the use of DG currently operating on Semau Island and also further optimizing the use of new renewable energy sources, such as PV and also regulate the operating scheme between DG, PV, and battery storage to meet the needs of the existing electricity load on Semau Island. The optimization results also display several scenarios so that more variations can be implemented into the Semau Island electricity system. In the results of the operating pattern simulation, several scenarios will be shown by considering the output power of PV which is divided into high and low output power from each DG configuration used. The results of this operating pattern can be used as a reference to create an active DG scheme by considering intermittent PV.

- *Scenario: 2 DG, PV (Low Power Output), and Battery*

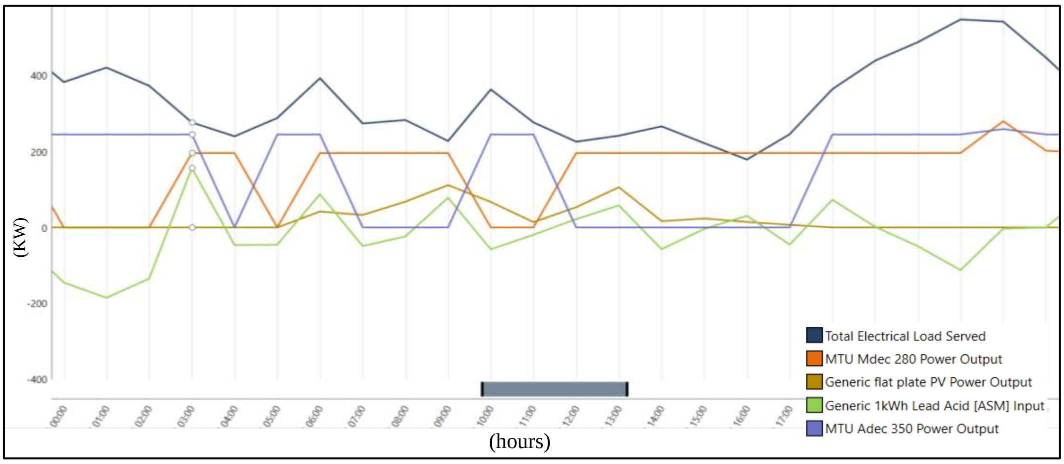

Fig. 10. Scenario operation 2 DG, PV (low power) and battery storage

Based on Fig. **10** is an operation pattern using 2 DG Battery storage and PV. However, as we know that the output of PV is intermittent. This condition depends on the intensity of sunlight, the weather on that day. The operating pattern in Fig. **10** shows that from 00.00-02.00 the diesel engine operating is MTU Adec and Battery Storage in discahrging condition while the condition of DG MDdec is in off condition. At 02.00 DG Mdec will operate while the battery condition is in charging condition. when the load drops at 04.00 DG MTU Adec is off and DG MDec will bear the electrical load and the battery is in discharge condition.

The condition of the switch on and off between DG Mdec, Adec and the charging and discharging conditions of the battery will take place in the morning. We can see at 4 am - 5 am the battery condition is discharging to meet half of the load conditions at that time. In addition, if we look at the graph, the PV starts to output power from 6 am but only 40 kW and then increases to peak at 120 kW at 10 am. During the day at 12:00 to 14:00 the batteries are in charging condition. Peak load conditions occur at night with a load of 550 kW at 21:00. To meet the above conditions DG Mdec, DG Adec is in operating condition and the battery is in discharge condition.

- *Scenario : 2 DG, PV (High Power Output), and Battery*

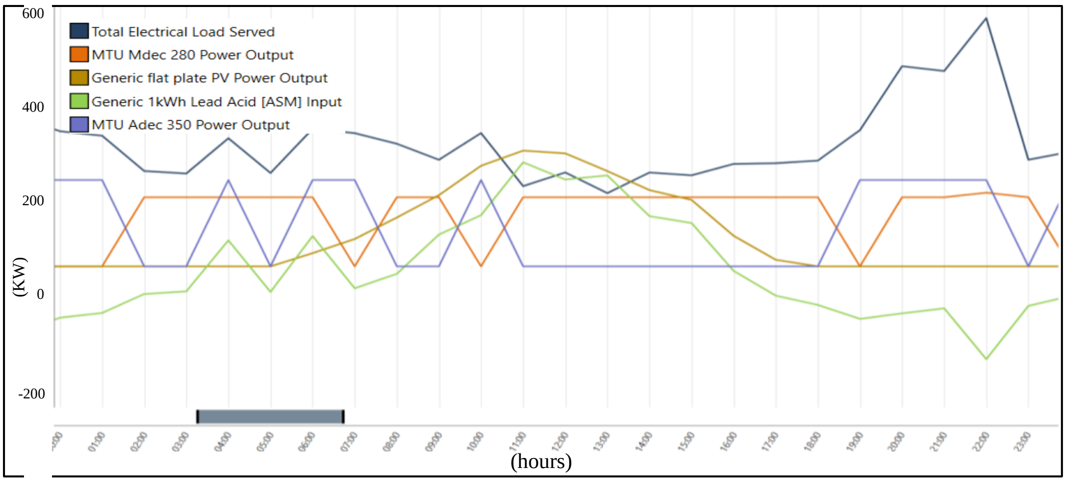

Fig. 11. Scenario Operation 2 DG, PV (High Power) and Battery Storage

Based on Fig. **11** is an operating pattern using 2 diesel engines. Battery storage and PV (high power). The operating pattern in Fig**. 11** shows that from 00.00-02.00 the diesel engine operating is MTU Adec while the battery condition at that hour is discharged to support the needs of the electricity load. At 02.00 - 04.00 when the load rises the battery which was originally in a discharging, condition changes to a charge condition and DG Mdec will operate while DG Adec is off.

Condition 2 DG and battery operate until 6 am. Then in the morning the PV starts to start releasing power until it peaks at 300 kW at 11 am and stays in the 200kW range until 1 pm. The condition from 10 am to 12 am is supplied by the Mdec power plant with PV. Battery conditions from 12:00 to 15:00 charging conditions from excess power from PV where excess power is made for charging batteries to help the diesel engine operate at night. At 18.00 the operating pattern starts using 2 MDec and Adec DGs along with the battery in discharge condition.

6 Conclusion

In the existing scenario based on the optimum results, it is found that the use of 2 diesel engines, which are DG Mdec and DG Adec in base load operation and the combination of PV and battery storage in maximizing the operation pattern. To overcome intermittent in PV has been presented for low and high PV power output in supporting the load on Semau Island. So that the problem of operating patterns on Semau Island so as not to rely fully 100% from Solar Power Plant during the day or from battery storage. The Solar Power Plant output power is only in the 120kW range, the operation of 2 diesel engines is maximized while the high-power Solar Power Plant output is 300kW so that it can use only 1 diesel engine and the excess power at that time is given to the battery storage for charging. By looking at the value of NPC, Operating Cost and LCOE parameters, the most optimal result is to use 2 DGs along with 450kWp PV and battery storage. The use of existing PV and battery storage produces maximum output. From these results, the NPC cost is $9762426, the O&M cost is $583589 and the LCOE value is $0.1999/kWh.

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