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Cost of Energy Sensitivity Analysis of PV/Diesel with Hydro Pumped Storage for Mentawai Microgrid System

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***Abstract*—This paper presents the cost of energy sensitivity analysis of PV/Diesel with hydro pumped storage for a microgrid system in a remote community of Mentawai Island to power a load demand of 240.6 kWh/day with a 27.48 kW peak load demand. The effects of different diesel generation fuel cost on the Cost of Energy (CoE) of Mentawai microgrid system is studied. The study also extended to analyse the effects of selection of PV array size on CoE as well as carbon dioxide (CO_2) emission. The simulation results show that the CoE value of the Mentawai microgrid system for configurations with a renewable fraction of 69.6% with fuel prices less than IDR 12,000/L are below than basic cost of provision generation set by the Ministry of Energy and Mineral Resources (MoEMR), which is IDR 3,041/kWh for the Mentawai Islands. The increase in the size of the PV plant is proportional to the decrease in the CoE of the microgrid system as well as the decrease in the fuel cost demand of the diesel generator.**

Keywords—cost of energy, Mentawai microgrid system, fuel cost of diesel generation.

I. Introduction

The rapid development of industry in Indonesia still leaves several remote areas that have not yet had electricity, one of them is the Mentawai Islands Regency, West Sumatra. In response to this, the renewable energy based in local resources can be used as a solution to the lack of equitable electrical distribution developmentt in rural remote areas [1]. A suitable solution for electrifying remote areas where expansion of the distribution network not economical is Microgrid with a hybrid renewable energy source [2][3].

The source of electrical energy in Indonesia is currently still dominated by fossil energy, especially oil, coal and gas [4][5]. Given the decreasing availability of fossil energy resources and increasing awareness of efforts to conserve the environment, this has led researchers to keep thinking of looking for new and renewable energy (NRE) alternatives by utilizing the potential of local resources, as well as being environmentally friendly. Among the sources of energy renewable, integrated solar power generation is the most developed and reliable alternative [6][7].

Various studies have been conducted to analyze the techno-economic feasibility of renewable energy-based campus microgrid system [8],[9] and on island microgrid system [10],[11]. This study examined and compared two energy storage technologies, i.e. batteries and pumped hydro storage (PHS), for the renewable energy powered microgrid power supply system on a remote island in Hong Kong have been reported by Ma, Tao et.al in [10]. The drawbacks of the battery storage system are limited to a small system. However, the use of pumped water storage systems is not very effective for small systems, but very effective for large storage capacities.

In this paper presents the load demand of a community in Mentawai Island was choice for cost of energy sensitivity analysis by PV/Diesel with hydro pumped storage. The effects of difference PV array size and diesel generation fuel cost on CoE as well as CO_2 emission used as sensitivity analysis of the proposed microgrid configuration system.

II. METHODOLOGY

A. Load Profile

Typical similar household of a medium income with 5 family members is considered in this study. The load demand consists of digital TV, Sharp refrigerator, fan, LED lamp and small item of electrical equipment with consumed 4,01 kWh/d/house as shown in Table I. Therefore, 60 housing units will need 60 x 4.01 kWh = 240.6 kWh of electricity per day.

TABLE I. Estimation of Load Demand for a Household

Appliances	Load power (W)	Quantity	Operating time (hour)	kWh/d
LED Lamp	10	5	5	0.25
Fan	25	3	8	0.6
Digital TV	50	1	8	0.4
Sharp Refrigerator	85	1	24	2.04
Small items	30	N/A	24	0.72

Total load demand (kWh/d)	4.01

The daily load profile of the Mentawai Island microgrid system study is shown in Fig. 1. The average daily load is found to be 10.03 kW, with a peak load of 27.48 kW.

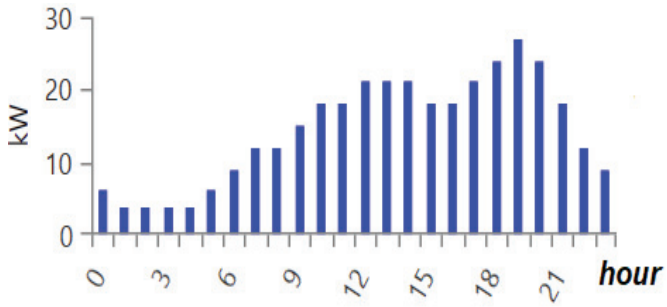

Fig. 1. Daily load demand profile

B. Wheather condition

There are two weather parameters used as Homer's software input parameters for analyzing the optimal design of PV/wind powered a microgrid system in the Mentawai Islands. 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/diesel hybrid system with PHS for Indonesia Remote Island microgrid. The parameters are solar irradiation as shown in Fig. 2 and Temperature as shown in Fig. 3 which downloaded from NASA surface meteorology and solar energy database [12].

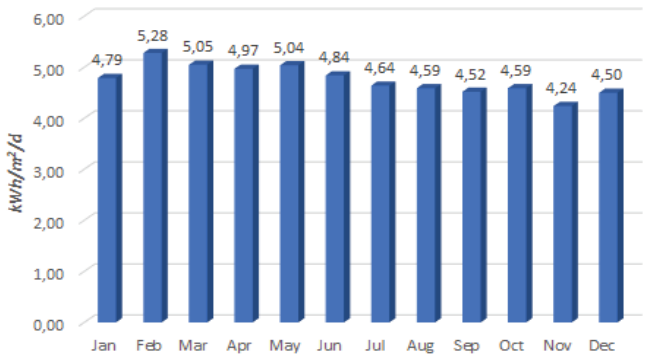

Fig. 2. Monthly average solar irradiation

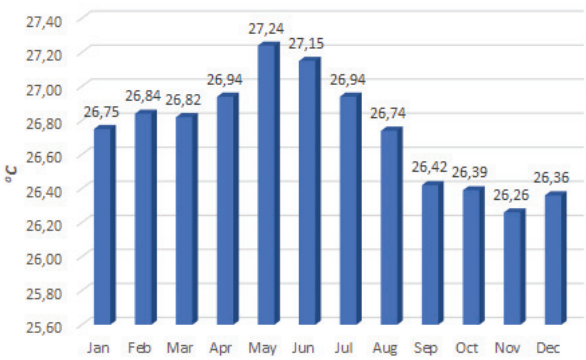

Fig. 3. Monthly temperature

The capacity of diesel generator set is selected based on the daily average maximum load requirements of 27.48 kW as shown in Fig. 1.

C. Microgrid components

The input parameters of Mentawai microgrid power system consists of PV, diesel generator, PHS and inverter show in Table II. For each component in the system, the different inputs such as size, type and cost are determined in detail. The hydro pumped storage PV system designed consists of power circuit or electrical installation, water installation and control circuits.

TABLE II. COMPONENTS COSTS IN HOMER SIMULATION.

PV System		
Type	Sharp ND-250QCS 1 kW	IDR. 10,000,000
Installing MCBs, busbars and fuses cost		IDR. 1,000,000
Total cost		IDR. 11,000,000
O&M Cost		IDR. 200,000
Diesel Generator		
Generic medium genset 1 kW		IDR. 4,500,000
Replacement Cost		IDR. 2,500,000
O&M Cost (IDR/ Operating hour)		IDR. 500,000
Inverter		
Type	Solar Inverter Sinecxel 30 kW	IDR. 50,000,000
O&M Cost		IDR. 0,0
Replacement Cost		IDR. 50,000,000
Hydro Pumped Storage		
Hydro Turbine Generator/Motor and control system		IDR 30,000,000
Water Dam 300 m^3 and pipe installation		IDR. 70,000,000
Replacement Cost		IDR. 50,000,000
O&M Cost		IDR. 500,000

The proposed Mentawai island microgrid system consists of a solar PV, diesel generator, an inverter and a PHS unit. The microgrid components configuration is shown in Fig. 4.

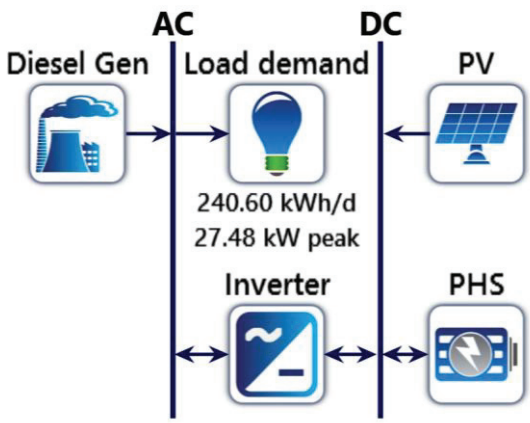

Fig. 4. Schematic diagram of PV/Diesel Gen/PHS

D. Cost of Energy Sensitivity Analysis

One of the parameters that determines the optimal solution of a HOMER simulation is the lower cost of energy. In this analysis, the Cost of Energy can be calculated using Equation 1.

$$CoE = TAC / kWh_{Tot\_Prod} \quad (1)$$

where:
TAC = Total Annualized Cost (IDR)
kWhTot_Prod = Total energy served in a year (kWh)

TAC consist of annualized capital cost, annualised replacement cost and annualised operation and Maintenance cost [13].

In the simulation, a sensitivity analysis can be performed from the input variables entered into the HOMER software. The simulation repeats the optimization process for each input variable value to check how the results are affected. In this study the effects of selection of PV array size and diesel generation fuel cost on CoE as well as CO_2 emission selected as sensitivity analysis of island microgrid system.

III. Result and Discussion

In this study, hybrid PV/Diesel power generation system designed to fulfill load demand of 60 household units. Microgrid system was analyzed and optimized by considering different fuel cost sensitivity parameter. The price of fuel varies from 8,000 to 12,000 as prices vary in the Mentawai Islands. The impact of choosing the size of the PV array on CoE as well as carbon dioxide (CO_2) emissions will be discussed in this paper.

The simulation results of the economic feasibility of the system are as shown in Fig. 5. The most optimal design of the Mentawai microgrid system for this study consist of 50 kW PV modules, 28 kW diesel generator, 1 unit pump hydro storage and an inverter of 30 kW. The lowest CoE price was obtained for IDR 8,000 fuel costs of IDR 2,087/kWh, while the highest CoE price for the highest fuel costs was 2,504/kWh. The lowest NPC value is also obtained at the lowest fuel cost conditions because the need for fuel per year drops to IDR 73.1M/year compared to IDR 110M/year for highest fuel costs of IDR 12,000. This is also in line with the decrease in operating costs for microgrid power generation of IDR 146M/year. Therefore, fuel price fluctuations greatly affect the optimal and feasible microgrid configuration results.

The optimal design of the Mentawai microgrid system for the current study consisting of 50 kW PV module, 28 kW diesel generator, a pump hydro storage unit and an inverter of 30 kW resulted as first priority optimize and economic configuration, as shown in Fig. 6. Compared to the base case without renewable generation, the operational cost incurred is IDR 412M/year, this value is very high, because the operating costs if combined with solar power plants with hydro storage systems only require 146M/year operational costs.

The existence of solar generators with pumped hydro storage systems has reduced the amount of fuel needed for diesel generators from 31,424 L/year to 9,141 L/year as well as reduced operational cost. This has led to a decrease in the fossil generation fraction and an increase in the renewable generation fraction to 69.6%. In addition, the reduction in fossil fuels has resulted in a reduction in carbon emissions from 82,192 kg/year to only 23,910 kg/year as show in Fig. 6.

Sensitivity	Architecture							Cost			
Diesel Fuel Price (Rp/L)	PV (kW)	Gen100 (kW)	PHS	Inverter (kW)	NPC (Rp)	COE (Rp)	Operating cost (Rp/yr)	Fuel cost (Rp/yr)
8,000	50.0	28.0	1	30.0	Rp3.82B	Rp2,087	Rp146M	Rp73.1M
9,000	50.0	28.0	1	30.0	Rp4.01B	Rp2,191	Rp155M	Rp82.3M
10,000	50.0	28.0	1	30.0	Rp4.20B	Rp2,296	Rp164M	Rp91.4M
11,000	50.0	28.0	1	30.0	Rp4.39B	Rp2,400	Rp173M	Rp101M
12,000	50.0	28.0	1	30.0	Rp4.58B	Rp2,504	Rp183M	Rp110M

Fig. 5. Sensitivity results for the hybrid PV/Diesel with PHS system

Architecture				Cost				System		
PV (kW)	Gen100 (kW)	PHS	Inverter (kW)	NPC (Rp)	COE (Rp)	Operating cost (Rp/yr)	Fuel cost (Rp/yr)	Ren Frac (%)	Total Fuel (L/yr)	CO_2 (kg/yr)
50.0	28.0	1	30.0	Rp3.82B	Rp2,087	Rp146M	Rp73.1M	69.6	9,141	23,910
50.0	28.0		30.0	Rp7.26B	Rp3,971	Rp316M	Rp175M	26.1	21,910	57,307
	28.0	1	30.0	Rp8.21B	Rp4,490	Rp381M	Rp229M	0	28,604	74,817
	28.0			Rp8.72B	Rp4,765	Rp412M	Rp251M	0	31,424	82,192

Fig. 6. Optimal system analysis results

Table III shows the effect of the PV capacity injected to the microgrid and fuel variation on the CoE value. The increase in the size of the PV plant is proportional to the decrease in the CoE of the microgrid system as well as the decrease in the fuel cost demand of the diesel generator. Therefore, the smallest CoE value is obtained when the fuel cost is IDR 8,000 with RF 69.2%. Meanwhile, the largest CoE occurs when there are no renewable generators with the largest fuel cost of IDR 12,000.

TABLE III. THE EFFECT FUELCOST VARIATION ON COE (IDR/KWH)

Fuel Price (Rp/L)	Renewable fraction (%)					
	69.2	**56.3**	**42.9**	**28.6**	**13.9**	**0**
8000	2,087	2,645	3,119	3,688	4,229	4,764
9000	2,191	2,794	3,311	3,928	4,516	5,122
10000	2,296	2,943	3,503	4,167	4,802	5,480
11000	2,400	3,092	3,695	4,406	5,089	5,838
12000	2,504	3,242	3,887	4,646	5,376	6,196

The addition of renewable energy generating capacity will reduce the value of the Cost of Energy of the microgrid system. From Table IV, the configurations with 50 kW and 40 kW PV produce CoE values of IDR 2,087/kWh and IDR 2,645/kWh respectively. Based on the MoEMR Regulation No. 55K/20/MEM/2019 [14], basic generation cost for Mentawai Islands is IDR 3,041/kWh. Therefore, CoE for the configuration with PV size 50 kW and 40 kW below Mentawai basic generation cost. These configuration profitable and feasible to implement.

TABLE IV. COE VERSUS RF AND CARBON EMISSION.

CoE (Rp/kWh)	PV (kW)	RF (%)	CO_2
2,087	50	69.2	23,910
2,645	40	56.3	34,269
3,119	30	42.9	44,096
3,688	20	28.6	54,972
4,229	10	13.9	65,854
4,765	0	0	82,192

The influence on the environment is also shown in Table IV, it can be seen that the additional PV capacity has resulted in a reduction in carbon emissions to 23,910 kg/year compared to the base case system of 82,192 kg/yr. This is in line with government targets that by 2030 the installed capacity of the solar power plant will reach 5,342 MW. If this is achieved, it is estimated that this will reduce CO_2 emissions by up to 8 million tons by 2030.

IV. CONCLUSION

A cost of energy sensitivity analysis of PV / Diesel with hydro pumped storage for Mentawai Microgrid System has been carried out. The configuration with 50 kW and 40 kW of PV array produces CoE values below the basic cost of provision of generation by PT PLN (Persero) for Mentawai Island. The lowest CoE price was obtained for IDR 8,000 fuel costs of IDR 2,087/kWh with renewable fraction 69.6%. The integration of PV with pumped hydro storage systems has reduced the amount of fuel needed by diesel generators from 31,424 L/year to 9,141 L/year as well as reduced operational cost. The reduction in fossil fuels has effect in CO_2 emissions reduction from The optimal design of the Mentawai microgrid system for the current study consisting of 50 kW PV module, 28 kW diesel generator, a pump hydro storage unit and an inverter of 30 kW resulted as first priority optimize and economic configuration, as shown in Fig. 6. Compared to the base case without renewable generation, the operational cost incurred is IDR 412M/year, this value is very high, because the operating costs if combined with solar power plants with hydro storage systems only require 146M/year operational costs.

The existence of solar generators with pumped hydro storage systems has reduced the amount of fuel needed for diesel generators from 31,424 L/year to 9,141 L/year as well as reduced operational cost. This has led to a decrease in the fossil generation fraction and an increase in the renewable generation fraction to 69.6%. In addition, the reduction in fossil fuels has resulted in a reduction in carbon emissions from 82,192 kg/year to only 23,910 kg/year as show in Fig. 6.

82,192 kg/year to 23,910 kg/year. The optimal simulation result show that the most economic configuration of the Mentawai microgrid system consisting of 50 kW PV module, 28 kW diesel generator, a pump hydro storage unit and an inverter of 30 kW. Therefore, this configuration is profitable and feasible to implement.

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