CO_2 EMISSION AND COST OF ELECTRICITY OF A HYBRID POWER PLANT IN SEBESI ISLAND SOUTH OF LAMPUNG

Herlina[1], Uno Bintang Sudibyo[2], Eko Adhi Setiawan[3]

[1]Faculty of Engineering
University of Indonesia, Depok 16424
Tel : (021) 7270011 ext 51. Fax : (021) 7270077
E-mail : herlinawahab@yahoo.com

[2]Faculty of Engineering
University of Indonesia, Depok 16424
Tel : (021) 7270011 ext 51. Fax : (021) 7270077
E-mail : uno@eng.ui.ac.id

[3]Faculty of Engineering
University of Indonesia, Depok 16424 ms
Tel : (021) 7270011 ext 51. Fax : (021) 7270077
E-mail : ekoas@ee.ui.ac.id

ABSTRACT

Hybrid power plants based on diesel generator and renewable energy sources, like photovoltaic and wind energy, are an effective option to solve the power-supply problem for remote and isolated areas far from the grids

HOMER, a micropower optimization modeling software is used to analyze data for both wind speed and solar radiation in Sebesi Island. The software optimize the system configuration of the hybrid system by calculating energy balance on an hourly basis for each of the yearly 8760 hours, simulating system configurations at once and rank them according to its net present cost [1]. In this paper, configuration design optimization of the hybrid system is analyzed to fulfill the electricity demand in Sebesi Island taken into account the issue of CO_2 emission reduction due to utilization of fossil fuel during diesel generator operation.

Optimization is done with three conditions, a first condition with 2 diesel generating unit 40 kW and 50 kW each, second condition a hybrid system with 25% maximum renewable fraction and a third condition a hybrid system with more than 25% minimum renewable fraction. The result obtained for the PV - wind - diesel hybrid are with 30% renewable fraction : 25% reduced CO_2 emissions or 48 ton / year or 25% from the first condition with 2 diesel generating unit, and the cost of electricity is the highest at $ 0,786 per kWh, the net present cost of $ 1.503.710, the initial capital cost of $ 758.010 and excess power reaching 85.212 kWh or 31.4%.

Key words: *Simulation, Hybrid Power Plant, Renewable fraction, Cost of Electricity, CO_2 emission*

1. INTRODUCTION

The Sebesi island is located south of Lampung Bay with 5° 55 '37.43 "- 5° 58'44, 48" latitude and 105° 27' 30.50 "- 105° 30 '47.54" longitude , close to the Krakatau islands. Administratively, this island is located in the Tejang Village Sebesi Island, Rajabasa Subdistrict, South Lampung Regency. The region consists of 4 (four) villages : Regahan Lada, Inpres, Tejang, and Segenom. The island covers a total area of 2620 ha and is inhabited by more than 2500 people, living mostly on agricultural products and fisheries. The island with a coastlines of 19.5 km has enough resources such as mangrove, the yet, and coral reefs [2].

It is a beauty islands located close to the Krakatau islands making it a tourist destination after the Krakatau islands. Unfortunately, potential tourism island is not supported by sufficient facilities by the local government, such as electricity. Nowadays the island get electricity only at night for about eight hours from 16.00 afternoon until 00.00 at night with a peak load of 49 kW which is supplied by two diesel generators with an installed capacity of 40 kW and 50 kW each.

In this study the electrical demand of the island will be analyzed using 2 units of diesel generating sets of 40 kW and 50 kW as first condition, and comparing them with the optimized hybrid system using HOMER software. Also analyzing CO_2 emissions, cost of electricity, and excess electricity of the system.

ISSN 114-1284

2. THE HYBRID SYSTEM AND ITS COMPONENTS

The hybrid system consists of two diesel generators 40 kW, 50 kW each, a photovoltaic array of 60 WP, a 7,5 kW wind turbine, a battery and an inverter. Figure 1 shows the hybrid system .

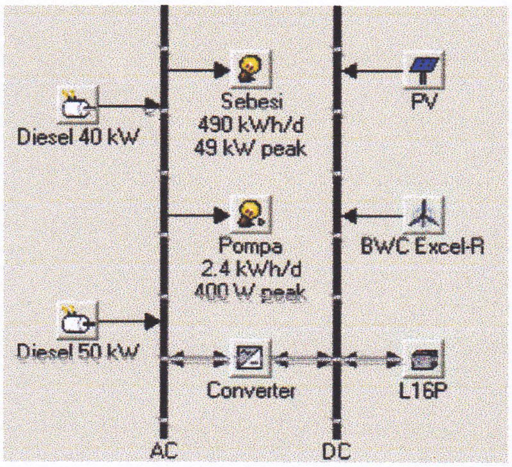

Figure 1. The Hybrid System

The hybrid system is simulated by three conditions, the first condition using 40 kW and 50 kW diesel, second condition a hybrid system with 25% maximum renewable fraction and a third condition a hybrid system with more than 25% minimum renewable fraction. All conditions are simulated with fixed load, wind speeds between 3 m/s 7 m/s, fuel price between 0.4 – 1.0 $/l. Project lifetime of the system is 25 years, interest rate is 8%, the dispatch strategy is cycle charging and the generators are allowed to operate under the peak load.

3.1 The Load Demand

The load demand consists of 2 types, namely:

3.1.1 Primary Load

The electricity is consumpted majorly for household lighting, television and others. The daily average load on the island is about 490 kWh/day with 49 kW peak load from 19.00 till 20.00 o'clock.

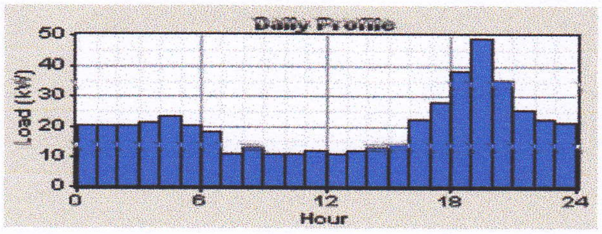

Figure 2. The Daily Load Profile of Sebesi Island [3]

3.1.2 Deferrable Load

A water pump of 400 Watts power has to be operated 6 hours per day to fill a fresh water tank designed to have a storage capacity of two days demand. So, there will be a 2.4 kWh/day average deferrable load or 4.8 kWh for two days storage. The minimum load ratio is 50%. Figure 3. shows the deferrable load of the water pump.

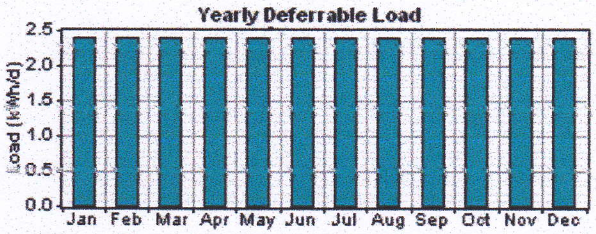

Figure 3. The yearly Deferrable Load of the Water Pump[4]

3.2 Wind turbines

The wind turbine used in this system is a 7.5 kW DC, 20 meter hub height, and a project lifetime of 15 years. Initial capital cost of the 7.5 kW wind turbine is $ 27.170, replacement cost $ 19.950, operation and maintenance cost is $ 1.000 a year

The HOMER software need the wind speed data to optimize the hybrid power plant. The following figure is the average wind speed data in Sebesi island, measured at 10 meters height.

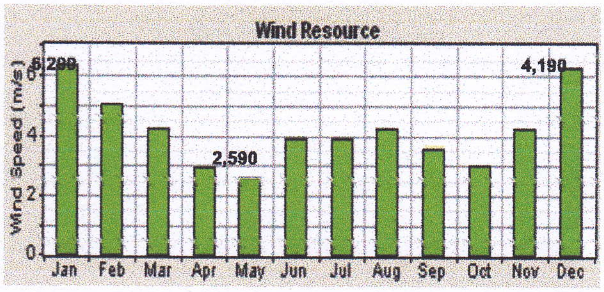

Figure 4. Wind Speeds on the Sebesi Island [5]

3.3 Photovoltaic Modules

The PV module used in this hybrid power plant has a maximum power of 60 Watt Peak (WP). The module derating factor is 90%, at a slope of 5.92 degrees, 180 degrees of azimuth, a ground reflectance of 20%, and a project lifetime of 25 years without tracking. The Initial capital cost for the 12 kW PV module is $ 66,000, replacement cost is $ 66,000 with no operating and maintenance costs.

To optimize the performance of the hybrid system, the software also needs yearly clearness index and daily radiation (kWh/m^2/day) data at the island. The yearly average clearness index is 0,477 and the daily average radiation is 4,761 kWh/m^2/day. In figure 5 the clearness index and daily radiation data of the island is shown.

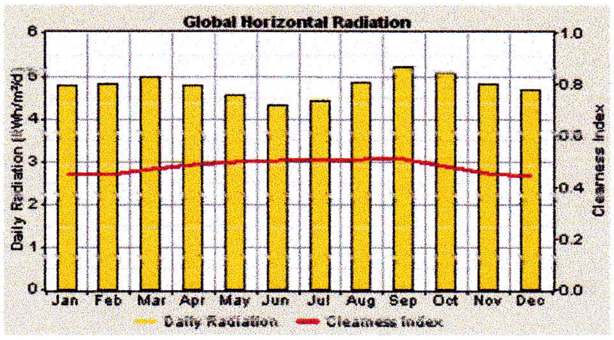

Figure 5. The yearly clearness index and daily radiation of Sebesi island [5]

3.4 The Diesel Generator

Two units of diesel generator is used in the hybrid system with an installed capacity of 40 kW and 50 kW each. The operating hour for each diesel generator is estimated to be 15,000 hours with a minimum load ratio of 30%. The 40 kW diesel generators has initial capital costs of \$ 22,000, a replacement cost of \$ 18,000, an daily operation and maintenance cost of \$ 0.5. While the 50 kW diesel generators have an initial capital costs \$ 27,000, a replacement cost \$ 22,000, and an daily operation and maintenance cost of \$ 0.5.

3.5 The Battery System

The hybrid system is designed to use lead acid batteries with nominal voltage of 6 V, a nominal capacity of 360 Ah, an initial capital cost of \$ 620, a replacement cost of \$ 620 and a 50 \$ yearly operation and maintenance cost.

3.6 The Inverter

A bidirectional inverter (rectifier-inverter) is used in this hybrid system with a 90 % inverter efficiency, and a lifetime of 10 years. The rectifier has efficiency 85% relative to the inverter capacity of 100%. The 8 kW bidirectional inverter has an initial capital cost of \$ 5960, replacement cost of \$ 5,960 and an yearly operating and maintenance cost of \$ 596.

4 CALCULATION OF THE HYBRID SYSTEM DESIGN

4.1 Calculation of the PV Array Power Output

The software uses the following equation to calculate the power output of the PV array:

$$P_{PV} = Y_{PV} f_{PV} \left[\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right] \left[1 + \alpha_p \left(T_c - T_{c,STC} \right) \right]$$

where:

Y_{PV} is the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

f_{PV} is the PV derating factor [%]

G_T is the solar radiation incident on the PV array in the current time step [kW/m2]

$\overline{G}_{T,STC}$ is the incident radiation at standard test conditions [1 kW/m^2]

α_p is the temperature coefficient of power [%/°C]

T_c is the PV cell temperature in the current time step [°C]

$T_{c,STC}$ is the PV cell temperature under standard test conditions [25 °C]

5. SIMULATION RESULTS

Different results of simulation and optimization are using the software in accordance to its minimum renewable fraction.

The result of simulation and optimization of the first condition using two diesel generating units of 40 kW and 50 kW are the cost of electricity (COE) of 0,510 \$/kWh, an excess of electricity of 0.01% and CO_2 emission of 191 ton/year.

Figure 6 is shows the load demand supplied by two diesel generator of 40 kW and 50 kW.

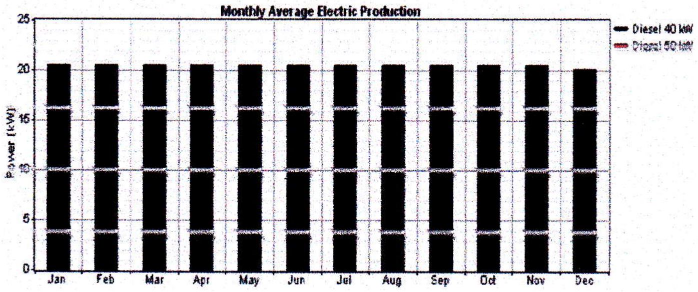

Figure 6. Supply of Load Demand by 40 kW and 50 kW diesel generators

In the second condition the minimum renewable fraction is 0%, the configuration of the hybrid system consist of 1 diesel generating unit – photovoltaic modules (PV) - wind turbines without battery. The results are as follows: for PV - diesel having 0,515 \$/kWh of COE, excess electricity is 1.202 kWh/year or 0.66%, and the CO_2 emission is 188 ton/year. For wind - PV - diesel having COE 0,496 \$/kWh, excess of electricity is 2.288 kWh/year or 1.24%, and the CO_2 emission is 173 ton/year.

The load demand is supplied by the hybrid system consisting of 82% by diesel generating unit, 3% by PV and 15% by wind turbine.

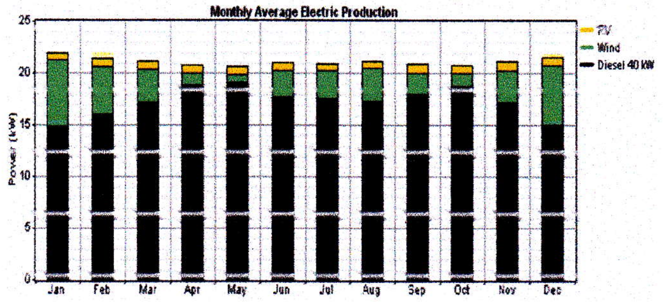

Figure 7. Supply of load demand by diesel, PV, and wind turbine with a maximum renewable fraction of 25%

When the hybrid system is simulated and optimized with 25% of maximum renewable fraction, the CO_2, SOx decrease caused by reduction of fuel consumption of the diesel generating unit. In figure 8, the blue line is the CO_2 emission and the pink line is the SOx. If the renewable fraction is 0% the CO_2 emission is 192 tons/year. CO_2 emission become 174 tons/year if the renewable fraction is 18%, a reduction of CO_2 emission as much as 18 tons/year decrease from 385 kg/year to 349 kg/year for a renewable fraction of 0% to 18%. This means a 36 kg reduction of SOx.

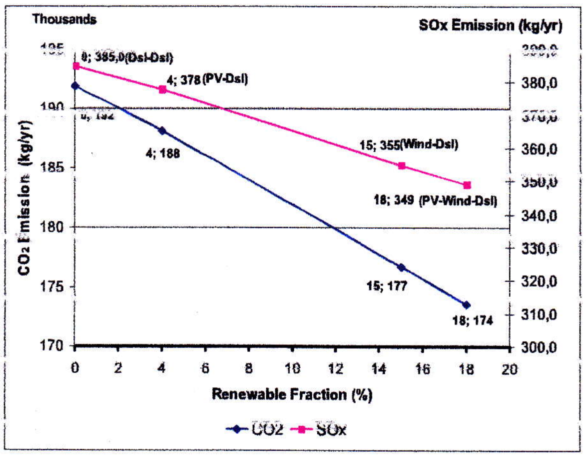

Figure 8. CO_2, SOx emissions – 25% maximum renewable fraction

In Figure 9, CO2 emissions decreased if renewable fraction increased as described above. The value of COE fluctuates with the changement of renewable fraction. When the renewable fraction is 0%, the load is supplied by 2 diesel generating units with a COE of 0,510 $/kWh, total NPC of $ 976.834. While the of renewable fraction is 4%, the hybrid system consisting of PV – diesel without battery, the COE increases to 0,515 $/kWh, NPC increases to $ 986.761. The lowest COE is 0,496 $/kWh if the renewable fraction is 15% and the hybrid system is consisting of wind-diesel with no battery, its NPC is $ 950.510. if the COE increase again to 0,510 $/kWh, the renewable fraction is 18%, the system consists of PV-wind-diesel without battery, its NPC is $ 976,801. Based on the conditions above, the author recommended a hybrid system consisting of wind-diesel.

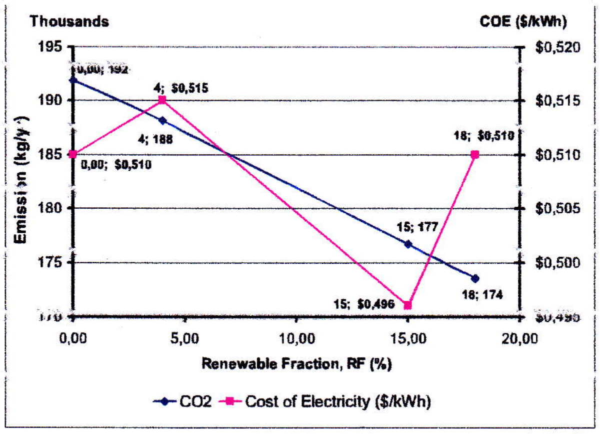

Figure 9. CO_2 emissions – cost of electricity (COE) – 25% maximum renewable fraction

In the third condition with a more than 25% renewable fraction the hybrid system consists of 1 diesel generating unit – PV – wind turbine without battery. The results for this condition are as follows: for PV – diesel, COE is 0,607 $/kWh, excess of electricity 22.464 kWh/year or 11%, and CO_2 emission is 174 ton/year. For wind - PV – diesel, COE is 0,785 $/kWh, excess of electricity 85.212 kWh/year or 31,4%, and CO_2 emission is 144 kg / year.

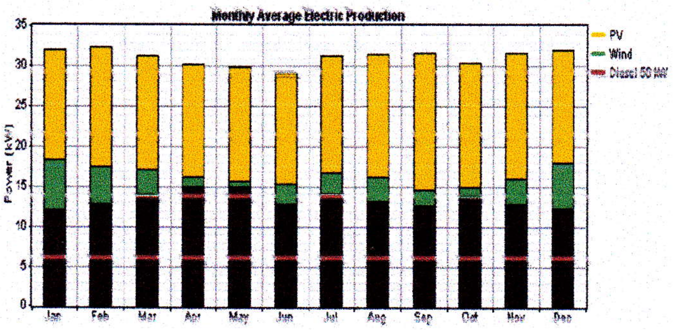

Figure 10. Supply of Load Demand by Diesel Generator, PV, Wind turbine with more than 25% renewable fraction

A Configuration of PV – wind – diesel with renewable fraction more than 25%, COE 0,510 $/kWh having the highest NPC of $ 738,010, excess electricity reaching 85,212 kWh/year or 31.4%, CO_2 emissions decreased as much as 48 ton/year or 25%. The load served by the hybrid system can be seen in figure 10 above.

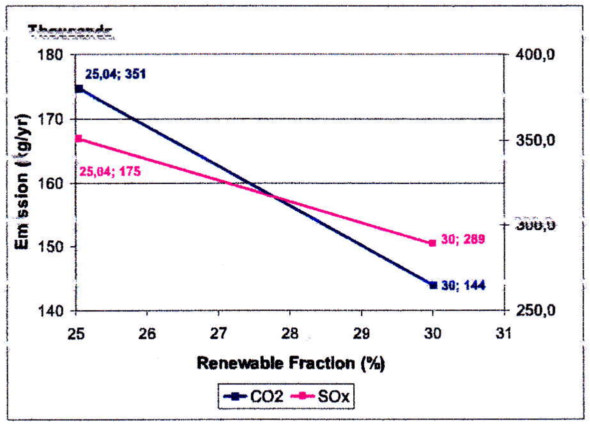

Figure 11. CO_2, SOx emission – more than 25% renewable fraction

In figure 11 above, the hybrid system is simulated and optimized with a more than 25% renewable fraction, the CO_2 and SOx emission levels decrease with decrease of the fuel consumption effect diesel generating unit. The CO_2 emission becomes 144 tons/year if renewable fraction 30% reduced as much as 48 tons/year. The SOx emissions, is reduced from 385 kg/year to 289 kg/year when renewable fraction increase from 0% to 30%. The SOx emission is reduced as much as 96 kg/year.

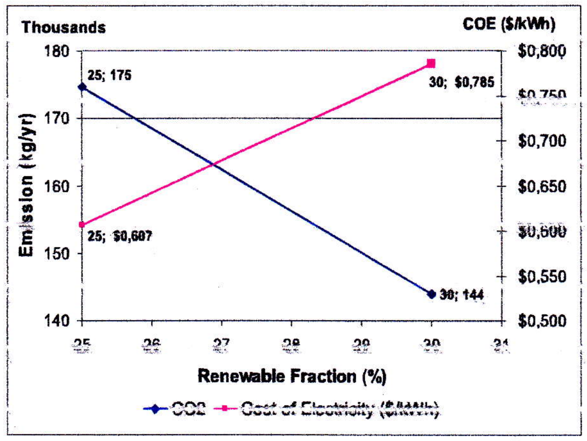

Figure 12. CO_2 emission – with a renewable fraction of 30%

In figure 12 the value of COE increased if the renewable fraction increases from 25% to 30%. If the renewable fraction is 25%, the COE is 0,607 $/kWh and the hybrid system consists of PV - diesel with no battery with 48 kW capacity of PV. Total NPC for this system is $ 1.163.327 with initial capital cost of PV is $ 264.000. If the renewable fraction is 30%, the COE is 0.785 $/kWh, the hybrid system consisting of PV - wind - diesel with no battery. Total NPC for this system is $ 1.503.710, the initial capital cost of 120 kW PV is $ 660.000. Based on results of simulation and optimization with a more than 25% renewable fraction, it is recommended to select a hybrid system consisting of PV-diesel with the lowest value of COE.

6 CONCLUSIONS

The value of COE, CO_2 and SOx emissions and excess of electricity fluctuated on different renewable fraction, it depending on total power generated and the total load served by the system. Which is the same following daily load curve of Sebesi Island? The largest excess power occurred at 30% of renewable fraction. A water pump as a deferrable load can be used to absorb this excess electricity.

The optimum hybrid system at 15% of renewable fraction, consist of wind – diesel with COE 0,496 $/kWh, NPC is $ 950.510 and the CO_2 emissions is 177 ton/year.

ACKNOWLEDGMENTS

The author would like to thank the Renewable Energy and Microgrid research group of the Department of Electrical Engineering University of Indonesia.

REFERENCES

[1] Gilman, P., Lambert, T., "Homer the micropower optimization model software started guide", National Renewable Energy Laboratory of United States Government (2005)
[2] Wiryawan, B., Yulianto I., Susanto, A. H., " Profil Sumberdaya Pulau Sebesi, Kecamatan Rajabasa, Lampung Selatan", Penerbitan Khusus Proyek Pesisir, Coastal Resources Center, University of Rhode Island, Narraganset, Rhode Island, USA (2003)
[3] Apriansyah, "Laporan Data Beban Harian Pulau Sebesi", PT. PLN (Persero) Wilayah Lampung Cabang Tanjung Karang Ranting Kalianda (Februari 2009).
[4] Gilman, P., Lambert, T., "optimization model software", National Renewable Energy Laboratory of United States Government (2005)
[5] www.weatherbase.com, "wind speed for Sebesi island", 2009.
[6] http://eosweb.larc.nasa.gov, "clearly index and daily radiation for sebesi island", 2009.
[7] http://www.solarex-solar.com/pv/pvlist/pvsiemens/pvsiemens.htm, "Price and Product for Photovoltaic Module". (2009)
[8] http://bergeywindpower.com/7.5 kW.htm, "Price and Product for Wind Turbin 7.5 kW DC". (2009)
[9] http://www.powerscity.com/32_Deutz-diesel-engine-TD226B-4D--Stamford-alternator.html (2009).
[10] http://www.sma-america.com/en_US/products/off-grid-inverters.html. (2009)
[11] http://www.affordable solar.com/trojan.battery.116p 390ah.htm. (2009)
[12] Nayar. C. , Tang. M,, Suponthana. W., "An AC Coupled PV/Wind/Diesel Microgrid System Implemented in A Remote Island in The Republic of Maldives", Proceedings of the AUPEC Conference, Perth (December 2007).
[13] Milani. N.P., "Performance Optimization of A Hybrid Wind Turbine – Diesel Microgrid Power System", Master of Science Thesis, North Carolina State University (2006).
[14] Setiawan, A.A., Nayar, C.H., "Design of Hybrid Power System for a Remote Island in Maldives", Department of Electrical and Computer Engineering Curtin University of Technology, Australia (2004).