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Feasibility Analysis of a Renewable Autonomous Power Supply System at a Coastal Area in Indonesia

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ABSTRACT

The Indonesian government program in providing solutions of electrical energy distribution problems to get to remote or isolated areas is to optimize the potential of renewable energy in an area. The combination of conventional power plants (diesel generators) with renewable energy (photovoltaic and wind turbine) power plants is expected to solve the problem of electricity service in isolated areas in southern Tulungagung regency, namely residential area in Brumbun Beach. The existence of government assistance in the form of solar panels distributed to each family head still can not optimize the utilization of electrical energy for 24 h in a day, this is because the generation of diesel generators and solar panels are done separately. This research focuses on the design and analysis of renewable autonomous power supply system which consists of centralized solar-powered diesel generator (solar panel – wind turbine – diesel generator) systems using HOMER software. This software is in addition to being used to create designs, is also capable of performing the most optimal system design evaluation by sorting based on overall cost, basic electricity tariff, and carbon dioxide gas emissions. The research from the design of four power plant configurations shows that the use of 10 kW diesel generators, 8 kW solar panels, and 6 kW wind turbines is the best solution, from the combination of the three energy sources shows the net present cost value of US $ 44,680, Cost of Energy of 0.268 kWh/$, CO_2 emissions of 1,077 kg/year, and diesel generator use only 54 min a day.

Keywords: Cost of Energy, Hybrid Power Generation, HOMER, Net Present Cost, Renewable Energy
JEL Classifications: C63, C88, Q42

1. INTRODUCTION

Increasing population will increase the demand for electrical energy. The need for electrical energy now has shifted from secondary needs to primary needs, the need for equal distribution of electrical energy so that every layer of society in both urban and rural areas can enjoy the utilization of electrical energy. The expansion of electricity grids by electricity service providers in solving the problem of electricity distribution in isolated settlements is often hampered by geographic conditions to get to the area. The main roads that are difficult to pass vehicles cause new electrical grid material is difficult to reach the area. In 2010, the government provided solar panels in isolated areas to meet the needs of electrical energy by optimizing available renewable energy to be able to reduce people's dependence on the use of fossil fuels through the Self-Sufficient Energy Village program (energypedia.info, 2019).

Development of hybrid power plants by many countries continues to increase in number, ranging from power generation to tens of watts to tens of kilowatts. The increasingly expensive use of fossil fuels can be reduced by applying power generation from renewable energy sources that generate clean and environmentally friendly electrical energy with very minimal levels of carbon dioxide gas.

2. SYSTEM DESCRIPTION

Hybrid power plant system is a power plant consisting of two or more renewable energy sources that are operated together to obtain an efficient and optimal system in supplying electrical energy in accordance with the load demand. The combination of various renewable energy sources can provide the balance and stability of a power plant system (Magarappanavar and Koti, 2016). The advantages of this system (Sopian et al., 2005, Nayar et al., 1993), among others: (1) Increasing the reliability of the system in serving the load demand, (2) reducing the use of fossil fuels, (3) utilization of electricity within 24 h, (4) system or component of the plant, and (5) the use of electrical energy effectively and efficiently.

Component required in hybrid power generation (Sopian et al., 2005), among others: (1) An inverter with a power rating of 60% greater than the loaded power required, (2) one or two generator diesel generators with a larger or minimum capacity (3) electrical energy storage using lead-acid batteries; (4) use of solar panels equipped with regulators and controllers; and (5) microprocessor-based or system-based controls microcontroller for monitoring and system automation.

The configuration of the hybrid power plant system is based on the working principle (Madziga et al., 2018, Nayar et al., 1993), among others: (1) Series hybrid system, (2) hybrid system switch, and (3) parallel hybrid system. In serial system configurations, all power plants (generators, PV panels, wind turbines) are converted in DC form and equipped with a charge controller to charge the battery charge, to serve the load with AC voltage specifications required by the inverter. In this system, the electrical energy generated is paralleled by the battery, so the battery life becomes less durable and reduces the efficiency of the system, then the generator occurs voltage losses because of the AC voltage to DC to supply the load is converted again into AC voltage using the inverter. In a switched switch system, the diesel and the inverter can be operated as an AC voltage source capable of directly supplying the voltage during the average load and peak load conditions thus increasing the efficiency of the system, the excess energy generation of the diesel generator can be allocated to charge the battery charge. At low loads, the diesel generator becomes inactive and the electrical load requirements are only supplied by renewable energy and battery by converting DC voltage into AC voltage using inverter. In parallel configuration systems, the need for electrical loads can be served in parallel from both the diesel generator and from the inverter. Bi-Directional Inverter (BDI) serves to bridge between components that produce DC voltage source and AC voltage source generated from diesel generator, BDI can charge battery from diesel generator while operating as rectifier (AC-DC Converter) or from renewable energy source (PV panels and wind turbines), BDI can also operate as an inverter (DC-AC Converter) while serving AC-powered AC loads. The advantages of parallel hybrid configuration (Nayar et al., 1993), among others: (1) Optimal in the supply of electrical energy at the load, (2) efficient in the operation and maintenance of electrical energy generating equipment, and (3) minimization of components so as to reduce initial investment costs. Figure 1 is a hybrid power plant system configuration (Madziga et al., 2018, Nayar et al., 1993).

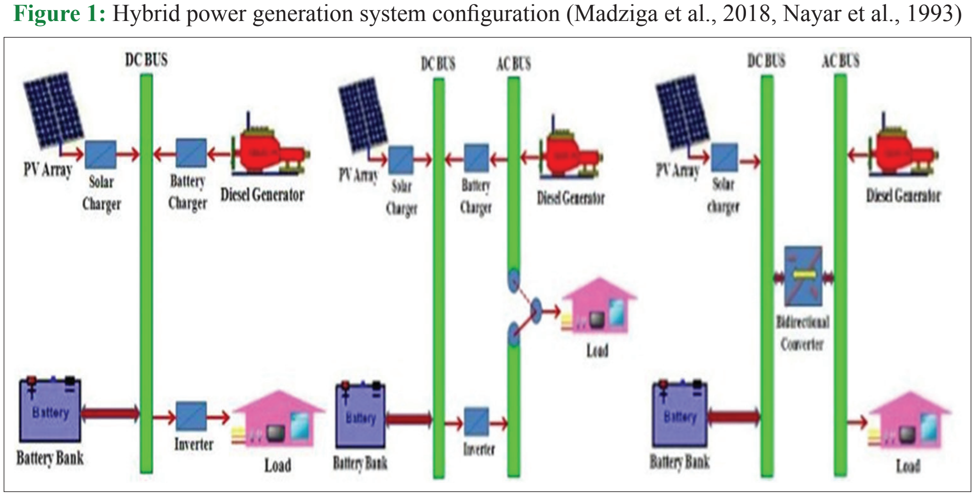
2.1. Renewable Energy Resource

This research designs and simulates hybrid power plants suitable for community settlements in Brumbun Beach where they have not enjoyed the utilization of electrical energy due to remote locations of urban and hilly road access that are difficult to carry out network expansion. From the design and simulation of planned generator system to get optimal result with configuration of hybrid power plant system between diesel generator, PV panel, and wind turbine. Power plants with centralized system configuration have many advantages over dispersed systems. The most optimal system configuration of power plant design simulated by HOMER software is the use of 10 kW diesel generator, 8 kW capacity PV panel, 6 kW wind turbine, 24 V busbar with 8000 Ah capacity and 5 kW inverter capacity. Based on the technical review, the operation of the generator for 1 year is 341 h or 0.9 h/day, resulting in less fuel use and longer diesel generator life. While based on economic reviews, the value of net present cost (NPC) of US $ 44,680, the value of cost of energy (COE) of US $ 0.268 $/kWh, and CO_2 gas emissions of 1,077 kg/year.

2.1.1. Solar radiation

The characteristics and potential of solar energy in selected locations are analyzed based on global solar radiation with monthly averages as well as monthly brightness (Olatomiwa, 2015). Global Horizontal Irradiance (GHI) is the total solar radiation that occurs on the horizontal surface (HOMER Manual Book, 2017). Figure 1 shows the minimum value of solar radiation in January at 4,850 kWh/m^2/day with a brightness index of 0.448 and in

Figure 1: Hybrid power generation system configuration (Madziga et al., 2018, Nayar et al., 1993)



September is a maximum value of 6.220 kWh/m^2/day with a brightness index of 0.613, while the average annual solar radiation is 5,37 kWh/m^2/day.

2.1.2. Wind speed

Electric energy can be generated from wind gusts to wind turbines, so wind speed parameters are required in mechanical design of wind turbines. The wind speed data is equipped with a high anemometer where wind speed is measured (HOMER Manual Book, 2017). Figure 2 shows the largest wind velocity (6.1 m/s) obtained in August and minimum wind speed (2.95 m/s) in December, while the mean annual wind velocity at Brumbun Beach is 4.43 m/s.

2.1.3. Load profile

Load profile is a characteristic of the use of electrical energy for 24 h on the consumer of electrical energy. Some facilities, facilities, and infrastructure that require electrical energy, among others: residential residents, places of worship, schools, and shops. Figure 3 shows the peak load profile at 17.00 - 19.00 WIB of 30.480 kW.

Figure 2: Renewable energy potential data at Brumbun beach (NASA, 2016)

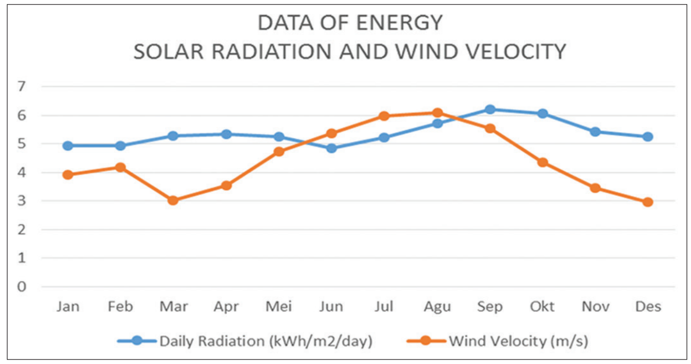
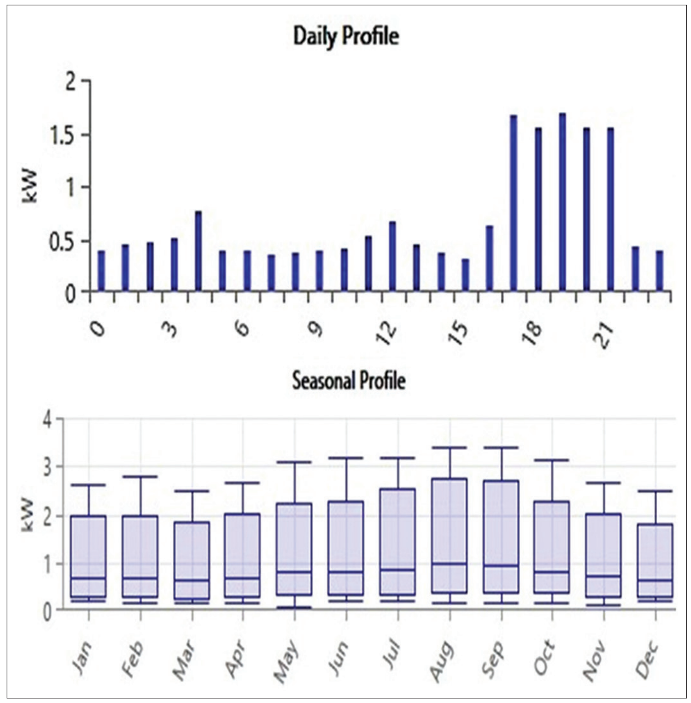


Figure 3: Load profile data



2.2. System Configuration

The isolated problem of power grids in remote areas and islands with small population communities can be solved by implementing the construction of Stand-Alone or off-grid hybrid power plants, apart from costly and costly network expansion as well as to minimize fossil fuels in energy generation electricity on diesel generators. The components used in the design of power plant system configuration in this study are as follows:

2.2.1. Diesel generator or genset

A diesel generator is a power plant that is used to supply electrical loads on a small power capacity and to increase electrical power during peak loads. Optimization of diesel generator use is done in isolated area and not yet reached by power grid. For selection of capacity of diesel generator/generator to be used by using equation 1 (Alayan, 2016; Okwu et al., 2017).

$$P_{diesel} = \frac{E_{diesel}(t)}{\eta_{diesel}} \times 130\% \quad (1)$$

Where:
Estimated capacity increase of 30%
P_{diesel}: Output power of diesel generator (KW)
E_{diesel}: Electric load to be met per hour (kWh)
η_{diesel}: Diesel efficiency (assuming=0.9).

2.2.2. Solar panels

Commonly known as photovoltaic panels (PV) are modern equipment capable of generating electrical energy by converting photon energy from sunlight into electrical energy (Quaschning, 2016). Based on the manufacture technology (Handbook for Solar Photovoltaic (PV) Systems, 2017) solar cells are divided into 3 kinds, namely: (a). Monocrystalline Solar Cell; (b). Polycrystalline Solar Cell; and (c). Thin Film Solar Cell (TSFC). In this study the solar panel used is Monocrystalline type because it has the highest efficiency level with 24.1% (GSES, 2016). Modeling Solar panels in HOMER software model the arrangement of PV as a device that produces DC electricity in proportion to the incidence of solar radiation globally present, regardless of the temperature and the affected voltage (Lambert et al., 2006), to determine the capacity of the PV integrated with the battery, solar charge controller, and inverter by using equation 2 (Alayan, 2016; Okwu et al., 2017).

$$P_{PV} = \frac{E_{load} \times I_0 \times k}{H_0 \times \eta_b \times \eta_{inv} \times \eta_m \times \eta_{bcu}} \quad (2)$$

Where:
P_{Pv}: Solar panel power capacity (kWp)
E_{load}: Electric load to be supplied
I_0: Standard radiation
k: Coefficient
H_0: Average radiation
η_b: Battery efficiency
η_{inv}: Inverter efficiency

η_m: Maching efficiency
η_{buc}: Efficiency of unit control batteries

Or to determine the amount of energy produced E_{el} *PV* panel used, can be determined using equation 3 (Alayan, 2016; Okwu et al., 2017)

$$E_{el} = \frac{P_{max-out} \times H_0 \times \eta_b \times \eta_{inv} \times \eta_m \times \eta_{bcu}}{k \times I_0} \quad (3)$$

As for determining the number of *PV* panels (N_{PV}) used can be determined using equation 4 (Alayan 2016, Okwu et al., 2017).

$$N_{PV} = \frac{P_{PV}}{P_{max-out}} \quad (4)$$

Where:
N_{PV}: Number of *PV* panels
P_{PV}: The energy from PV panels (kWh)
$P_{max-out}$: The load energy that the generator must meet (kWh).

2.2.3. Wind turbine

Wind turbine is a device used to convert wind energy into kinetic energy connected to the generator to generate electrical energy. The voltage generated by the wind turbine can be either DC or AC voltage seseuai with the type of generator used. With HOMER software can be determined the use of the optimum amount of wind turbines in serving the load. Determination of output power from wind turbine in software HOMER can be done with four stages (Lambert et al., 2006), namely: (a). It determines the average wind speed for the hour at the anemometer height by referring to the wind resource data, (b). It calculates the corresponding wind speed at the turbine's hub using the logarithmic law or the power law, (c). It refers to the turbine's power curve to calculate its power output at that wind speed assuming standard air density, (d). It multiplies that power output value by the air density ratio, which is the ratio of actual water density to the standard water density. To determine the capacity of wind turbine generator (P_{WG}) using equation 5 and to determine the energy generated using equation 6 (Balachander et al., 2012)

$$P_{WG} = \frac{1}{2} \times \rho \times A_r \times C_P \times V_W^3 \quad (5)$$

$$= \frac{1}{2} \times \rho \times \pi \times C_P \times V_W^3$$

$$E_{WG}(t) = P_{WG} \times t \quad (6)$$

Dimana:
P_{WG}: Output power of wind turbine generator
E_{WG}: Energy produced wind turbine
ρ: Air density
A_r: The area of the rotor
C_p: Power coefficient
V_W: Wind velocity
t: Time

2.2.4. Battery

Battery is an equipment used to store unidirectional DC (DC) charge. To improve the efficiency of the system by reducing shortage factor, energy storage is required. The required battery capacity (Ah) can be determined using equation 6 (Ishaq and Ibrahim, 2013)

$$C_{bat}(\text{Ah}) = \frac{E_{load} \times Day\ of\ Automous}{DOD_{max} \times \eta_{bat} \times V_{bat-nom}} \quad (7)$$

Dimana:
C_{bat}: Batteray capacity (Ah)
E_{load}: Electric load to be supplied (kWh)
Day of Autonomous:
DOD_{max}: Deep of discharge
η_{bat}: Battery Efficiency
$V_{bat-nom}$: Battery nominal voltase

And to determine number of battery (N_{bat}) used equation 7.

$$N_{bat} = \frac{C_{bat}}{V_{bat-nom}} \quad (8)$$

2.2.5. Bidirectional converter

Bidirectional Converter is a tool used to convert DC-voltage power sources from 12, 24, 48 Volts generated from electrical sources such as solar panels, wind turbines and batteries, into AC-inverter power sources that can be used to power equipment electronics as per specification (120 or 240 V AC, 50 or 60 Hz) or equivalent to PLN electricity voltage and vice versa (rectifier) (Purwadi et al., 2012). The efficiency of a converter is better when the output load approaches the rated work of the converter, and vice versa. In equation 8 is shown to determine the working capacity of the inverter (Purwadi et al., 2012).

$$P_{inv} = \frac{P_{peak\,load} \times 1{,}15}{\eta_{inv}} \quad (9)$$

Dimana:
$P_{peak\,load}$: Peak load daily
P_{inv}: Inverter produced the power
η_{inv}: Inverter efficiency

2.3. Cost Optimization

The economic evaluation of the entire hybrid system is achieved by optimizing the total life cycle cost of the system configurations. The NPC (or life-cycle cost) of a component is the present value of all the costs of installing and operating that components over the project lifetime, minus the present value of all revenues that it earns over the project lifetime. To determine the value of NPC is shown in equation 9 (HOMER Manual Book, 2017).

$$C_{NPC} = \frac{C_{ann\,tot}}{CRF\ (i\,N)} \quad (10)$$

Dimana:
C_{NPC}: Overall cost over lifetime
$C_{ann\,tot}$: Total annualized cost
CRF: Capital recovery factor
I: Interest rate
R_{proj}: Project period.

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows) (HOMER Manual Book, 2017).

HOMER defines the COE as the average cost per kWh of useful electrical energy produced by the system (HOMER Manual Book, 2017). To determine the value of COE, HOMER compares the value of the total annual cost (NPC) with the actual electrical load of the serve by the hybrid system (kWh/year). To determine the value of COE is shown in equation 10 (Laksmhi et al., 2012)

$$COE = \frac{C_{ann\,tot}}{E_{load,AC} + E_{load,DC} + E_{def} + E_{gridsales}} \quad (11)$$

Where:
COE: Cost of energy
$E_{load,AC}$: The load is served AC voltage
$E_{load,DC}$: The load is served DC voltage
E_{def}: Deferable load
$E_{grid\ sales}$: Total sales of power grids.

3. DISCUSSION

In this research, the design and simulation of hybrid power plant configuration is solved using HOMER software. HOMER is a simulation tool developed by NREL that is used for the design, simulation, and evaluation of hybrid power generation systems (Lambert et al., 2006). HOMER simulates to obtain an optimized off-grid and grid-connected power grid system (Sopian et al., 2005, Purwadi et al., 2012, Olatomiwa, 2015), which consists of a combination of solar panels, wind turbines, microhydro, biomass, diesel generators, micro turbines, fuel-cells, battery, and hydrogen storage, also serves AC and DC power loads, as well as thermal loads. The optimization algorithm and HOMER software sensitivity analysis facilitate the evaluation of various possible system configurations (HOMER Manual Book, 2017). Many references suggest the use of HOMER software to make the design of optimal hybrid power generation systems (Magarappanavar and Koti, 2016; Sopian et al., 2005; Lambert et al., 2006; NASA, 2016; Handbook for Solar Photovoltaic (PV) Systems, 2016).

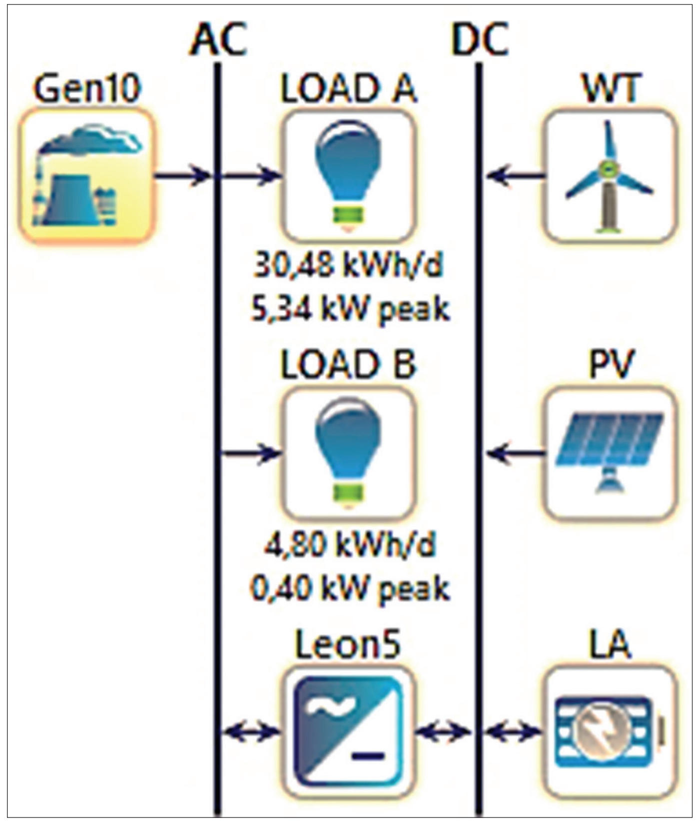
In this research the hybrid power plant design uses a parallel configuration with the advantages shown in Figure 4. Consists of 100 Wp photovoltaic panel, 1kW wind turbine generator, 5 kW converter, 10 kW diesel generator, and GEL Deep Cycle battery. To optimize the power output of the wind turbine and the resulting power is fluctuating, it must be connected to the DC generator. Diesel generator operates at peak load and as back-up voltage source when power capacity of PV panel output, wind turbine, battery in minimum condition. With a decent hybrid system diesel generator configuration can be active maximum for 1 h/day to keep the diesel generator is always in good condition also keep the voltage stability. Table 1 is shown in detail rather than hybrid power plant components to be planned.

Sizing of Design Hybrid Power Generation:

1. Load demand
   Total energy usage=30,480 kWh/day
2. Capacity of diesel generator

$$P_{diesel}(t) = \frac{5,34 + 0,4}{0,9} \times 130\% = 8,29\,\text{kW}$$

Figure 4: Hybrid Power Plant Configuration Purposed



Source: Author’s Computation using HOMER, 2017)

Table 1: Component data input

Panel PV	
Technology	Monocrystal
Capital cost	$7,800
Replacement	$7,800
Lifetime	15 years
Derating faktor	80%
Wind turbin generator	
Technology	Low speed
Capital cost	$ 3,000
Replacement	$ 3,000
O & M cost	$ 100
Lifetime	15 years
Converter	
Capital cost	$ 2,000
Replacement cost	$ 2,000
Efficiency	95%
Lifetime	15 years
Diesel generator	
Capital Cost	$ 5,575
Replacement	$ 5,575
O & M cost	$ 0.7
Lifetime	15.000 h
Battery	
Technology	GEL Deep Cycle
Capital cost	$ 4,000
Replacement cost	$ 4,000
O & M cost	$ 10
Battery busbar voltage	24 Volt
Lifetime	10 years

Source: Author’s computation using HOMER, 2017

And in the HOMER software provided generator capacity is close to 8.29 kW is a generator with a capacity of 10 kW.

3. Solar energy potential

$$E_{el} = \frac{(1)\times(4{,}850)\times 0{,}85\times 0{,}95\times 1\times 0{,}95}{1{,}1\times(1)}$$

E_{el} = 3,213 kWh (Energy produced 1 h)

4. Solar panel capacity

$$P_{peak} = \frac{(27)\times 1\times 1{,}1}{4.850\times 0{,}85\times 0{,}95\times 1\times 0{,}95}$$

P_{peak}=7,96 kW≈8 kW

5. Power output of wind turbine

$$P_{WT} = \frac{1}{2}\ .1{,}225\ .\ 1{,}07\ .2{,}293\ .0{,}59 = 4{,}64\,\text{kW}$$

6. Number of power turbine

$$N_{WT} = \frac{30480}{4640} = 6{,}57 \approx 7\,\text{unit}$$

7. Battery capacity

$$C_{bat} = \frac{30.480\ \text{Wh}\times 3}{0{,}75\times 0{,}80\times 24\,\text{Volt}} = 6.350\,\text{Ah}$$

8. Number of battery

$$N_{bat} = \frac{6.350\,\text{Ah}}{100\,\text{Ah}} \approx 64\,\text{unit}$$

9. Power capacity of inverter

$$P_{inv} = \frac{P_{peak\ load}\ .125\%}{\eta_{inv}} = \frac{(3{,}220+0{,}40).1{,}25}{0{,}96}$$

P_{inv}=4,72 kW≈5 kW

To maintain the safety and stability of the inverter should be considered with a size 25-30% greater than the total load.

The inverter that should be installed with a minimum specification is 5 kW.

4. RESULT

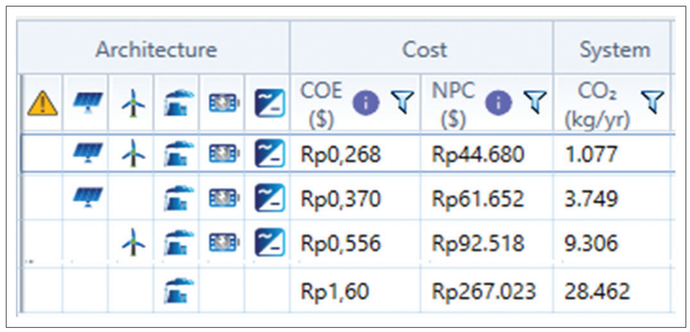
To get optimal system configuration of Hybrid Power Generation (PLTH) in Brumbun Beach by modeling electrical condition and availability of renewable energy potency, so there are 4 models of system design configuration which will be simulated using Software HOMER, that is: (1). Disel Diesel Generator Configuration; (2). Diesel Generator + Panel + PV + Battery Configuration; (3). Diesel Generator Configuration + Wind Turbine + Battery; and (4). Diesel Generator + PV Panel + Wind Turbine + Battery Configuration. The feasibility of a power plant is reviewed on the technical and economic side. Based on the design and simulation using HOMER software obtained comparison of several output parameters (NPC, COE, and CO_2) of the four system configuration of PLH shown in Figure 5.

Figure 6 shows a bar chart of the NPC value value or the total total cost of each planned system configuration. The largest NPC value in Diesel configuration as the main supply in the fulfillment of electrical loads with a value of US $ 267,023 and the lowest value is the configuration of a hybrid power plant (Diesel - PV - WT). The total NPC value includes all costs used during the project, consisting of component procurement costs, replacement costs, operations and maintenance costs (O & M), fuel costs, emission fine costs (if any), and interest rates.

Figure 7 shows a bar chart of the COE value or the price of electricity per kWh of each planned system configuration. The largest electricity price in Diesel configuration as the main supply in the fulfillment of electrical loads with a value of US $ 1.60/kWh and the lowest value is the configuration of a hybrid power plant (Diesel - PV - WT).

Figure 8 illustrates that the selling price of electricity in the hybrid configuration system (Diesel - WT) is 0.556 $/kWh or 34% cheaper than the Diesel configuration system as the main supply.

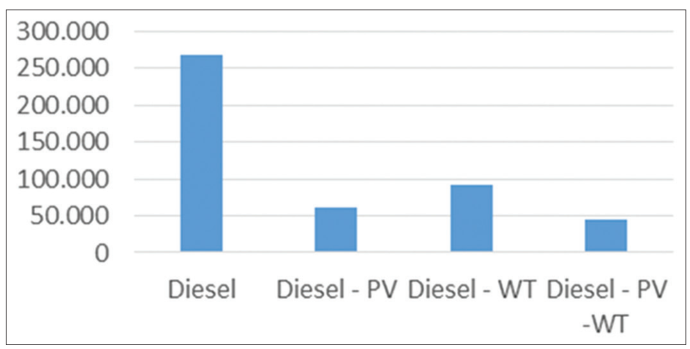
Figure 5: Net present cost, cost of energy, and CO_2 system values based on HOMER software



Architecture	Cost		System
	COE ($)	NPC ($)	CO_2 (kg/yr)
	Rp0,268	Rp44.680	1.077
	Rp0,370	Rp61.652	3.749
	Rp0,556	Rp92.518	9.306
	Rp1,60	Rp267.023	28.462

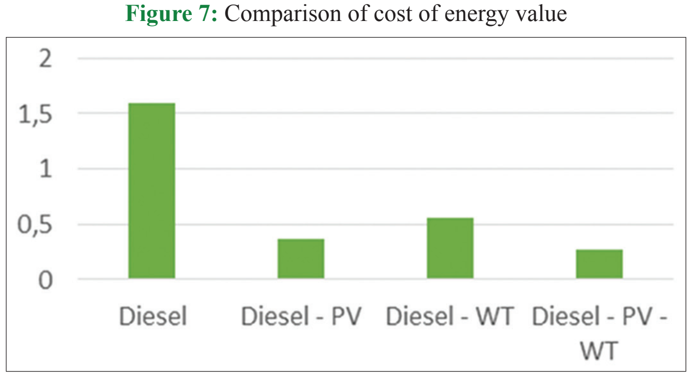
Source: Author's computation using HOMER, 2017

Figure 6: Comparison of net present cost value



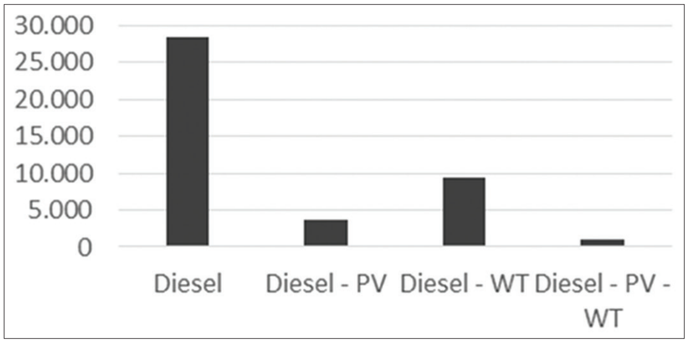
Source: Author's computation using HOMER, 2017

Figure 7: Comparison of cost of energy value



Source: Author's computation using HOMER, 2017

Figure 8: Comparison of CO_2 emission



Source: Author's computation using HOMER, 2017

Table 2: Tariff of electricity power of four PLTH configuration systems

Configurations	COE (Rp/kWh)
Diesel	1.600
Diesel–PV	0.370
Diesel–WT	0.556
Diesel–PV–WT	0.268

Source: Author's computation using HOMER, 2017. COE: Cost of energy

The hybrid configuration system (Diesel - PV) is 0.370 $/kWh or 67% cheaper than the hybrid configuration system (Diesel - WT). Among the four planned configuration systems, the selling price of the hybrid configuration system (Diesel - PV - WT) is 0.268 $/kWh. Table 2 shows the Electricity Tariff (TDL) of several Hybrid Power Generation configuration systems when changed according to the electricity tariff in the State of Indonesia.

Figure 8 shows the gas emission stem diagram (CO_2) produced by each planned system configuration. The largest gas emission value in Diesel configuration as the main supply in the fulfillment of electrical load is 28,462 kg/year and the lowest value is hybrid power plant configuration (Diesel - PV - WT). For 1 year the generator continues to operate, but every configuration system with the addition of a generator from renewable energy occurs a reduction in operating time.

5. CONCLUSIONS

This research designs and simulates hybrid power plants suitable for community settlements in Brumbun Beach where they have not enjoyed the utilization of electrical energy due to remote locations of urban and hilly road access that are difficult to carry out network expansion. From the design and simulation of planned generator system to get optimal result with configuration of hybrid power plant system between diesel generator, PV panel, and wind turbine. Power plants with centralized system configuration have many advantages over dispersed systems. The most optimal system configuration of power plant design simulated by HOMER software is the use of 10 kW diesel generator, 8 kW capacity PV panel, 6 kW wind turbine, 24 V busbar with 8000 Ah capacity and 5 kW inverter capacity. Based on the technical review, the operation of the generator for 1 year is 341 h or 0.9 h/day, resulting in less fuel use and longer diesel generator life. While based on economic reviews, the value of NPC of US $ 44,680, the value of COE of US $ 0.268 $/kWh, and CO2 gas emissions of 1,077 kg/year.

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