Design of Stand-Alone Hybrid Power Generation System at Brumbun Beach Tulungagung East Java

A N Rahmat*, M N Hidayat, F Ronilaya, A Setiawan
Electrical Engineering Department, State Polytechnic Of Malang, Malang, Indonesia

*Angg4nr@gmail.com

Abstract. Indonesian government insists to optimize the use of renewable energy resources in electricity generation. One of the efforts is launching Independent Energy Village plan. This program aims to fulfill the need of electricity for isolated or remote villages in Indonesia. In order to support the penetration of renewable energy resources in electricity generation, a hybrid power generation system is developed. The simulation in this research is based on the availability of renewable energy resources in Brumbun beach, Tulungagung, East Java. Initially, the electricity was supplied through stand-alone electricity generations which are installed at each house. Hence, the use of electricity between 5 p.m. – 9 p.m. requires high operational costs. Based on the problem above, this research is conducted to design a stand-alone hybrid electricity generation system, which may consist of diesel, wind, and photovoltaic. The design is done by using HOMER software to optimize the use of electricity from renewable resources and to reduce the operation of diesel generation. The combination of renewable energy resources in electricity generation resulted in NPC of $44,680, COE of $0.268, and CO2 emissions of 0.038 % much lower than the use of diesel generator only.

1. Introduction
Increased consumption of electrical energy needs is followed by an increase in population and electrical energy needs. Currently, electricity energy has become a primary requirement. since Indonesia, electricity development projects are still focused on urban and industrial areas because the distribution of power grids in remote areas get less attention so that the electricity supply is not reliable. Independent Energy of Village is one of the government's programs to meet the needs of electric energy by optimizing available renewable energy to be able to reduce people's dependence on the use of non-renewable energy sources [1].

Many countries have developed hybrid power generations and their numbers are increasing now [2]. The use of hybrid power generations can reduce the use of expensive fossil fuels and can replace them with clean and environmentally friendly electrical energy. Which in turn, it will improve the quality of the lives of people in remote areas [3].

2. System Description
A hybrid power generation system consists of two or more renewable energy sources that are operated together to obtain an efficient and optimal system [3]. The combination of different energy sources provides the balance and stability of a power plant [3]. The advantages of hybrid power generation system [2][4-6], among others: (1) improving the reliability of the system in supplying the load, (2)
reducing the emission gas from the use of fossil fuels, (3) providing a 24-hour power supply, (4) extend the life of the system, and (5) improve the effectiveness and efficiency of the use of electrical energy optimally. Hybrid power generation system configuration [2][5][6], among others: (1) series hybrid system, (2) hybrid switch system, and (3) parallel hybrid system. The advantages of parallel hybrid configuration [6], among others: (1) more optimal load fulfillment, (2) operational efficiency and maintenance of diesel generator, and (3) the other component size is more minimalist thus reducing investment cost.

2.1. Renewable Energy Sources

Various types of renewable energy sources that can be converted into electrical energy, such as wind, solar, water and geothermal. Renewable energy is energy that is in nature free to be utilized. Indonesia is an archipelago country and passed by the equator so that the source of renewable energy is very abundant. Wind is an easily accessible source of renewable energy in coastal areas. Brumbun Beach (8°18’ LS, 110°094’ BT) is located in Ngrejo Village, Tangunggunung District, Tulungagung District, East Java Province. It can be accessed by passing through damaged and impassable roads, the last distance between power lines and residential areas is around 5 km. The data of solar intensity and wind velocity is obtained through hybrid power plant optimization software, by filling in the latitude and longitude coordinates of the location to be studied.

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 [7]. Global Horizontal Irradiance (GHI) is the total solar radiation incident on a horizontal surface [8]. At the Brumbun site, it is known that the minimum value of solar radiation in January at 4.850 kWh/m²/day with a brightness index of 0.448 and in September is a maximum value of 6.220 kWh/m²/day with a brightness index of 0.613, while the average annual solar radiation is 5.37 kWh/m²/day.

Wind speed parameters are needed in designing wind turbines. The data of wind resources is equipped with a high anemometer in which wind speed is measured [8]. At Brumbun beach area, the recorded maximum wind velocity is in August, i.e.: 6.1 m/s and the minimum wind speed is in December, i.e.: 2.95 m/s, while the average wind speed per year is 4.43 m/s.

Electric energy consumptive behavior for 24 hours on the consumer of electrical energy. Some facilities that require electrical energy, among others: homes, mosques, schools, and shops. The peak load profile occurring at 7 pm for 3.62 kW.

2.2. System Configuration

The configuration of stand-alone or off-grid hybrid power plants is particularly suitable for areas far from the grid’s reach, such as remote areas or small populated islands, apart from costly network expansion as well as to minimize electricity generation from non-renewable sources. Here are the components used in the design of power generation systems in this study.

Genset is a power plant to meet the electrical load with a small capacity and to increase electrical power when the peak load. The use of generators is suitable for isolated areas and not yet covered by the power grid. A diesel generator is a model based on its Fuel Consumption (FG) pattern, which is proportional to its output power [12]:

$$F_G = B_G \times P_{G\text{-rated}} + A_G \times P_{G\text{-out}}$$

Photovoltaic is a power generation technology that converts photon from solar radiation into electrical energy [13][14]. In this research, the PV panels used were monocrystalline type because it has the highest efficiency with 24.1% [16]. HOMER modeled the composition of PV as a device that produces dc electricity proportional to the incidence of global solar radiation present, regardless of the temperature and the affected voltage [7]. The equation for determining the output power is [8]:

$$P_{PV} = G \times A$$
\[ PPV = f_{PV} \cdot Y_{PV} \cdot \frac{I_T}{I_s} \] (2)

Where, \( f_{PV} \) is the derating factor of PV, \( Y_{PV} \) is the capacity value of the PV module (kW), \( I_T \) is GHI (kW/m\(^2\)), whereas \( I_s \) is 1 kW/m\(^2\).

Electrical energy is generated from wind blows that rotate turbine connected to the generator. By using this software can be determined the use of the optimum amount of wind turbines. Four steps determining the output power of wind turbine [7], are: 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. The equation determines the output power of the wind turbine [8]:

\[ P_{WT} = \frac{1}{2} \rho A v^3 C_{pmax} \] (3)

Where \( P_{WT} \) is the wind turbine output power (kW), \( \rho \) is the real air density (kg/m\(^3\)), \( v \) is the wind velocity (m/s) while \( C_{pmax} \) is the wind velocity coefficient typically is 0.59. The battery is an equipment used to store direct DC electric charge. To improve the efficiency of the system by reducing shortage factor, energy storage is required [10]. The battery storage capacity is given as [13]:

\[ C_{Wh} = \frac{(E_L \times AD)}{(\eta_{inv} \times \eta_{batt} \times DOD)} \] (4)

Where \( E_L \) is the average energy needed every day (kWh/day), the AD is the battery Autonomy Day, DOD is the depth of discharge, while \( \eta_{inv} \) and \( \eta_{batt} \) represent each inverter and battery efficiently. The bidirectional converter is a device used to convert DC power source generated from a power source into an AC power source (inverter) and otherwise (rectifier). When the output load is closer to the converter’s loaded workload the efficiency is better and otherwise. The efficiency of the converter is better when the output load is close to the workload shown in the converter. The inverter efficiency equation is:

\[ \eta_{inv} = Chatt + [(100\% - \eta_{inv})]C_{batt} \] (5)

### 2.3. Cost Optimization

Economic evaluation of the entire hybrid system is achieved by optimizing the total life-cycle cost of the system configurations [17]. The Net Present Cost (NPC) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime [8].

\[ C_{NPC} = \frac{Cann tot}{CRF \times (1/\tau)} \] (6)

HOMER defines the level of Cost of Energy (COE) as the average cost per kWh of the useful electrical energy produced by the system [8]. To determine the value of COE, HOMER compares the value of the total annual cost (NPC) to the actual electrical load by the hybrid system (kWh/year).
Figure 1. The proposed hybrid configuration

The equation of COE is:

$$COE = \frac{Cam tot}{Eload serve}$$  (7)

3. Method

In this research, simulation and design of hybrid power plant system are done using HOMER software. It is a simulation tool developed by NREL that is used to design a hybrid power plant system [7]. It simulates and optimizes off-grid and grid-connected power generation systems [4][9][11], which can consist of a combination of wind turbines, photovoltaic, micro-hydro, biomass, generators (diesel/gasoline), microturbine, fuel-cell, battery, and hydrogen storage, also serving both electrical and thermal loads. Its algorithm can optimization and sensitivity analysis facilitates the evaluation of various possible system configurations [8]. To make the design of optimum hybrid power plant systems many references suggest using this software [3-5][7][12-14].

The stand-alone hybrid power plant design in this study uses a parallel configuration as shown in Figure 1. Selection of wind turbine with output DC voltage due to the voltage generated by fluctuating conditions. A diesel generator will be used as back-up voltage source if PV panels and wind turbines cannot supply batteries and at that time the battery is empty. A diesel generator is also switched on maximum for 1 hr per day during peak load to keep diesel generator always in good condition also keep stable voltage.

| Table 1. The input window of hybrid system components |
|-----------------------------------------------|
| Quantity | PV | WT | Converter | Genset | Battery |
| Size (kW) | 8 | 6 | 5 | 10 | 20 |
| Capital ($) | 7800 | 3000 | 2000 | 5750 | 4000 |
| Replacement ($) | 7800 | 3000 | 2000 | 5750 | 4000 |
| O&M ($/yr) | 100 | 100 | | | |
| Lifetime (year) | 25 | 25 | 10 | 15000 hour | 10 |

The sizing of a hybrid system as shown in Figure 1 is as follows:
- Determine power consumption demand. Total Appliance use = 35,28 kWh/day
- Output Power of PV = $P_{PV} = 0.8 \times 4.5 \times 37/1 = 17.2$ kWh
- Output Power of WT = $P_{WT} = \frac{1}{2} \times 1.225 \times 1.072 \times 29 \times 3.059 = 4.64$ kWh
- Inverter sizing. Total load of equipment = 3620 W. To maintain the security and stability of the inverter should be considered to be 25-30% larger than the total load. The inverter that should be installed with a minimum specification is 5 kW.
- Battery storage capacity $CWh = (21.620x3)/(0.85x0.6x12) = 3532$ Ah. So the capacity of batteries to be installed voltage of 24 V with 4000 Ah with 32 hr autonomy.
4. Result and discussion

The parameters used in determining the optimal power system configuration using HOMER software are the smallest values of Net Present Cost (NPC), Cost Of Energy (COE), and CO₂ emissions gas from some of the power plant configurations offered. The optimization analysis is divided into four kinds of system configuration: Diesel Generator, Diesel Generator and PV also battery, Diesel Generator and wind turbine (WT) also the battery, and Diesel Generator PV and WT are also batteries.

![Figure 2. Simulation results of the hybrid configuration system](image)

**Case 1:** Diesel System Generation. From Figure 2 it is shown that the use of power generators only from diesel generators has a COE value of $1.60 of NPC value of $ 67,023 and CO₂ emissions of 28,462 kg/yr. The absence of Battery causes utilization-focused only on diesel. This condition is a current problem in the residents of Brumbun Beach, where to meet the need for electricity must generate diesel generators with operational tariffs and very expensive maintenance also energy utilization that has not been 24 hours.

**Case 2:** Diesel – PV System Generation. From Figure 2 it is shown that the use of diesel generator, PV and battery storage power generators has a more optimum value than an only diesel generator. With a COE value of $ 0.370 the NPC value of $ 61,562 and CO₂ emissions levels of 3,749 kg/ yr. With the PV is able to reduce the use of diesel generators to supply the utility voltage during the day. Battery life is required to maintain the stability of this generating system with 32 hr autonomous clock.

**Case 3:** Diesel – WT System Generation. Figure 2 shows that the use of diesel generator, WT and battery storage media, has a COE value of $ 0.566.00, an NPC value of $ 92,518.00, and a CO₂ emissions level of 9,306 kg/yr. With the WT is able to reduce the use of diesel generator but for the stability of battery filling is very little, because the topography of the coast Brumbun makes little wind gusts. To maximize the electricity generated from wind turbines, a low-speed turbine type is required. Batteries are required to maintain the stability of this generating system with 16 hours less autonomous clock than case 2. The length of autonomous batteries is due to the fluctuating levels of renewable energy sources.

**Case 4:** Diesel – PV – WT System Generation. From Figure 2 it is shown that the use of diesel generator, WT, PV and battery storage power generators have the smallest value of COE of $ 0.268 the smallest NPC value of $ 44,460 and CO₂ emissions of 1.077 kg/yr. With the combination of two sources of renewable energy PV and wind turbine capable of providing optimal.

5. Conclusion

The aim of this research is to design and simulate the design of hybrid power generation in community settlement at Brumbun Beach. From the design and simulation of the proposed power generation system, optimal results are obtained. Power generation with centralized system configurations has many advantages over-dispersed systems. The results obtained from the design and simulation of hybrid power plants using HOMER software have the value of Cost Of Energy (COE) for 0.268 $, Net Present Cost (NPC) value of 44,460 $, and with CO₂ emissions of 1.077 kg/yr. The hybrid power generation designed is capable of supplying power for 24 hours at a cost per kWh.
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