Hybrid Energy System Design of Micro Hydro-PV-biogas Based Micro-grid

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Abstract. Hybrid renewable energy system is an arrangement of one or more sources of renewable energy and also conventional energy. This paper describes a simulation results of hybrid renewable power system based on the available potential in an educational institution in Indonesia. HOMER software was used to simulate and analyse both in terms of optimization and economic terms. This software was developed through 3 main principles; simulation, optimization, and sensitivity analysis. Generally, the presented results show that the software can demonstrate a feasible hybrid power system as well to be realized. The entire demand in case study area can be supplied by the system configuration and can be met by ¾ of electricity production. So, there are ¼ of generated energy became an excess electricity.

1. Introduction

The interest in alternative environmentally friendly energy sources has been increasing since the last few years. Renewable energy is an energy source that is currently considered because of its high potential. The use of renewable energy resources can fully withstand the depletion of petroleum and other nonrenewable energy sources, as well as the production of environmentally unfriendly substances resulting from fossil fuels burning [1]. Renewable energy systems such as photovoltaic, biogas, micro-hydro, and hybrid systems from them incrementally can provide cost effective electricity generation in a certain area. Renewable energy systems are also expected to have a positive impact on the environment, economic, social, and political problem of the world today.

Hybrid renewable energy systems (HRES) is composed by one single renewable energy source and one or more conventional energy sources or even without conventional energy sources connected to the grid or stand-alone [2]. The exact placement of each HRES component is the primary key in terms of economic feasibility of the system. Therefore, the maximum benefit from the use of HRES itself largely depends on the used methodology in designing the hybrid energy system optimally [3].

There are many simulation programs used by researchers on designing HRES such as the used of computer simulations. The simulation will compare the effectiveness and cost of energy production with
a variety of system configurations. From all the existing software, Hybrid Optimization Model for Electric Renewable (HOMER) becomes widely used software for hybrid system optimization. This software has been used for operating strategy of a complex optimization in economically easy and accurate because it can generate the lowest Total Net Present Cost (TNPC) of the optimization [4].

In 2014 this software was used to design the electrical supply needs in hotel construction in Kish Island, Iran. This software indicates a proper system to be applied with the lowest Net Present Cost (NPC) [5]. In addition, this software can also estimate the amount of emissions gas resulting from the generation system. It will help to make decision in building a hybrid power generation system, especially in un-electrified areas, or stand-alone generation system connected to grid. Based on description above, the authors conducted a study to design HRES model which is optimally in an educational institution. The using software will then simulate and analyze the performance of the system both in terms of optimization as well as economic terms.

2. Theoretical Study

2.1. Renewable Energy Sources
Based on the balance sheet and predicted energy shortages and environmental problems, renewable energy resources management have attracted much attention in many literature. To solve this problem, some of environmentally friendly fuels intended to replace conventional fuels. Generally, it is because renewable energy source provides high electrical efficiency and low environmental impact [6].

To solve this world's energy problems, the use of renewable energy becomes the very widespread in various sectors. There is a number of technologies which still not so well known and accepted by the public [7]. The country currently expected to participate the dissemination of the renewable energy sources use at local plants with different forms of distribution. By using this renewable energy, the building structures of the plant do not require much land and material use, also can reduce network transmission losses and the impasse on the network [8].

2.1.1. Solar Radiation Resources. Solar energy is the energy radiated by the sun and used in a way to tap the light photons to excite electrons (Fathima & Palanisamy, 2015). At present, solar energy is widely used, and was raised on a large scale by various energy investment company.

Daily averages of the world solar radiation based on horizontal surfaces can be obtained from the NASA Surface Meteorology and NASA solar energy website. Annual average global solar radiation per day is 6 kWh/m²/day. The low global radiation relatively seen between July to September because this period is quite cloudy and rain heavily. Beside that, the clearness Index monthly average is about 0.612. Clearness Index is defined as the solar radiation fraction in upper atmosphere that reach specific location on earth as a solar radiation existence information provider on the earth's surface [9].

By entering latitude, longitude, and time zone data of the research location, solar radiation and clearness index data can be obtained [10]. If the data is entered correctly, the feasibility of the photovoltaic installation panels will be determined as a renewable solution for the load based on the average radiation per hour. It is required 5-6 hours of the average radiation per year to get a best photovoltaic panels data [11].

2.1.2. Bioenergy. Bioenergy is an energy source and renewable fuel that can be applied in many different circumstances. Bioenergy is defined as well as a combustible gases mixture produced from the anaerobic fermentation of biomass by bacteria that require several days to form. In the wild, biological material fermentation process occurs in a very less oxygen area like a swamp or a marsh [12].

The remainder of agricultural products is a good resource for bioenergy. For example, woods and remnants of the harvest can be processed by thermal conversion to produce energy, vegetable oils and animal fats to produce biodiesel, or starch crops to produce ethanol. Moreover, bioenergy can be produced also from animal manures. Livestock manure left on the ground will rot and go through natural fertilization that will produce biogas [7]. Biogas can also be produced from human activity such as
domestic landfills or sewage fermented. Anaerobic process in it currently produced less industry waste compared to aerobic fermentation [12].

2.1.3. **Hydropower.** Hydro power plant has become one of the largest energy sources used in electricity generation. In 2012, about 16% of world energy consumption generated from hydropower. Hydropower has a number of benefits compared to other energy sources. One of the reasons for hydropower renewable energy sources: water. By using water as a source of energy, hydro power generation can be quickly and easily vary the output power [13].

2.2. **Hybrid Renewable Energy System**

Renewable energy sources have widely considered as one of the alternative energy sources that are very promising compared to conventional fossil fuels [14]. The earth has enough generating resources to cover the increasing electrical load. However, there are several generation sources that its utilization depend on the season. Therefore, to achieve the transition from renewable energy generation to generation fueled will require a combination of several energy alternatives. Alternative sources of energy such as micro-hydro, geothermal, biomass/biogas, wind, solar, hydrogen, nuclear and etc. have to work with different configurations simultaneously in fulfilling demand areas (Fathima & Palanisamy, 2015). A unit resulted from the combination is called a hybrid renewable energy systems (HRES).

HRES known as a multiple natural resource system consists of several renewable energy. HRES has a great potential to provide reliability and better quality of electricity supply. Hybrid systems can be developed either as stand-alone systems or grid-connected systems as long as the purpose of the grid is available. All of it depends on the load demand and the operational strategy needs by users or providers. A stand-alone renewable energy system is unconnected system to the grid that are intended for unelectrified areas by any distribution system. This stand-alone renewable energy system requires a sufficient storage capacity to handle a wide variety of the carried energy resources. This system is also known as a micro-grid system because it has both of energy generation sources and provided load [15].

Micro-grid is a small-scale energy network consists of distributed generators, energy storage and load [16]. Micro-grid emerging as the main solution to manage smart grids with high penetration of renewable energy, non-linear, and unbalanced load [17]. Micro-grid planning with consideration of renewable energy sources in a region requires the provision of a number of factors such as, renewable energy sources can best be utilized, a large generating capacity, the total system cost, the amount of emissions that can be saved, excessive energy, etc. [18].

2.2.1. **Hybrid Optimization Model for Electric Renewable (HOMER).** HOMER is a simulation tool developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the renewable energy based micro-grid planning and design. The software was first developed in 1993 as an internal use by the Department of Energy to understand the sales between the different energy productions. Several years after his original design, NREL make an available version for public freely to serve the growing of system design community who are interested in renewable energy [19].

The major device usage is as designing software for hybrid systems that facilitate the planning of electric power systems for stand-alone-application. The presented input in designing an optimal hybrid system involves, electrical load (year load datas), renewable energy sources, detail and cost of technical components, constraints, control, types of distribution/delivery strategies, and so forth [20]. The software is designed to cope uncertainty on some key parameters in micro-grid planning such as load growth and future fuel prices.

2.2.2. **System Components**

- Microhydro Turbine: Hydropower system is based on the waterflows potential energy to drive turbines in generating electricity. Hydropower system is dependent on waterflows and water droplets. Head turbines commonly called hydraulic head is an effective part of the turbine works [21].
• Biogas Generator: Biogas is a renewable fuel and energy source that can be applied in many different settings. Biogas is also defined as a mixture of flammable gas derived from anaerobic fermentation of biomass by bacteria and can take several days to form [12]. Biogas can be obtained from all kinds of garbage/dirt and can be used to generate electricity with biogas generator [22].

• Photovoltaic Array (PV): Photovoltaic (PV) system changes solar radiation energy directly into electricity. PV is composed by several PV cells, usually in the form of layers or pieces of thin semiconductor material that generates small current when sunlight reaches it. Some cells can be collected into several modules that can be connected in one or more arrangement [23]. An available PV module on public market can be classified into two general types based on their technology, there are crystalline silicon and thin film. Crystalline silicon itself is divided into two types, namely, polycrystalline and monocrystalline. Monocrystalline modules have a slightly higher efficiency compared to polycrystalline modules [24]. New advances in technology have introduced the production of PV cells coated titanium oxide which greatly improves the output efficiency [25]. Prices of solar panel itself is highly dependent on many factors, including, retailers, solar panel size, arrangement technology, and panel brand [9]. Temperature and gleam affect the two main factors of output power from PV cells. Temperature dependent on the voltage, where the voltage will drop when the temperature rises. Meanwhile, the light will affect the current generated. Light flow generation is directly proportional to the photon flux. Therefore, the short circuit current of the solar cell is directly proportional to radiance and input from the PV array such as, the light, the surrounding temperature, and voltage of the buck converter. On the other hand, the output of the PV array is temperature and current PV cells. Solar power generated from the PV is multiplication of converter voltage and PV current. The integration of solar power will generate PV energy produced per day [26].

• Storage: Most major losses from renewable energy sources is that renewable energy can not be stored for future use. So, tapping energy from the maximum renewable sources is needed while its limited availability is there. Moreover, these renewable energy sources can not be always certainly aligned and focused and also depends on the climate at local site [25]. This makes it irregular and unreliable. Due to an intermittent renewable energy sources, the storage facility is a necessity to provide uninterrupted power supply [22]. Electrical energy storage media appears in answering the needs of the supply energy balance and demand. If there is no accumulation system, energy is generated and used simultaneously. Several factors must be considered in assessing the suitable energy storage system including the required power specification, energy, weight, size, efficiency, charge and discharge speed, life average, and so forth [22].

3. Research Methods
For easily understanding the undertaken steps of this study, the research procedure can be seen in Fig. 1. This study begins by identifying the load on the case study area. By identifying the load profile, hybrid system configuration design can be specified to meet the needs of the load based on available potential. Next, determine the components of the configuration to be designed.

After determining its schematic, the next step is to determine the resources data. After that, the hourly load data per day can be entered in this software. In the process of the data inputting, there are several parameters such as scale variability, which is type of daily load for a year can be set. In addition to these parameters, there are also requirements of operating systems such as economics, optimizations, constraints and system control. Once these parameters are met, the next step is to enter sensitivity analysis parameter of the system configuration in the form of capital cost, replacement cost, and also the operation and maintenance cost. The last step is to perform calculations resulted optimization and sensitivity analysis based on the parameters that have been determined.
Optimization will produce various configurations of hybrid system. However, only one configuration will be determined by the sensitivity analysis. That hybrid system configuration is being proposed recommendation system. If the calculation is not running, the software will display an error recommendation or evaluation. Generally simulation error occurs because of inappropriate or unmet parameter. Hence the review of the parameter sensitivity analysis of the configuration of the system is needed, because the capital cost, replacement cost, and also the operation and maintenance cost is very considered to determine the best configuration.

Figure 1. Research Flowchart
4. Findings and Discussions

4.1. Design and Modelling System in Case Studi Area

In this case study, a renewable energy system is analyzed using software developed by NREL in the United States. The software is capable to create the design, optimization and sensitivity analysis of the renewable energy design. The software works by some of the parameters input included technical options, cost of components and energy resources. By entering the load profile, this software will simulate the entire configuration that allows then sort it by lowest NPC.

Design of hybrid energy system modeling in this study is intended to meet the electrical energy demand in Baitturahman Boarding School, Ciparay, Kab. Bandung. Baitturahman Boarding School is a private school located about 40 km from Bandung. The area of the boarding school is about 35,000 m2 and is located at position 7° 4.9' south latitude and 107° 41.1' west longitude.

Examination of load profile identifies the energy consumption situation on the object of the study. Loads size are relatively the same every day without any significant changes due to the activities of the students which is quite limited. Overall there are 14 buildings located in the school area with different characteristics load consists of school buildings, student dormitories, teachers' houses, masjid, the main hall, and computer lab. The supplied load generally include lighting, air conditioners, water pumps, washing machines, refrigerators, computers and other office equipment.

![Figure 2. Schematic Design of Hybrid Renewable Energy System](image)

This hybrid system modeling consists of several components of the generation with the use of available renewable energy potential, which consists of hydro turbines, photovoltaic modules, biogas generator, converter, and is also supported by a battery as energy storage media. Hybrid renewable energy system planning is assembled from micro hydro parallles with biogas that produces AC power, then parallels also with PV and battery with the DC power that is connected to a converter. Detail modelling shown in Fig. 2.

4.2. Optimization Results

Based on the calculations results made by software, overall there are 36 hybrid power configuration with only one sensitivity analysis results. Several configurations are offered from the simulation results and sorted by lowest NPC. The best option from this analysis is aimed to hybrid system configuration of micro-hydro, biogas and PV systems equipped with koverter. In this configuration, there is no option for batteries as a storage media. It shows that configuration of the available resources can fulfill all the
load needs, and then the absence of the battery showed that the AC and DC electricity from renewable energy generation is directly supplied to the load without storage mechanism.

4.3. Sensitivity Analysis Results
NPC of the system amounted to $73,208 or Rp 960,488,960.00 with $0.0727/kWh of Cost of Electricity (CoE) and $309.14 per year of Operating and Maintenance Cost (O/M). Based on the sensitivity analysis, the demand increasing will affect the operating costs, total NPC and the CoE. So do its resources. The greater potential resources are used, the fewer components are used. This will reduce the total number of NPC on the system.

4.4. Economy Analysis Results
The sharing percentage of overall system component costs contributed 87.7% to the capital cost, 3.5% to replacement cost and 8.8% to the O/M. In this best configuration system replacement cost is only used for converter systems only. Because micro turbines, biogas generators, and solar panels have an estimated lifespan more than the lifetime project, each of it is about 25, 28 and 33 years old. In component costs relation, 46.6% of all costs met by micro-hydro system, 26.1% by biogas, 17.0% by PV and 10.3% of the entire cost is used for converter system.

The best configuration shows that Cost of Electricity reached about $0.072/kWh or approximately Rp 944.64/kWh. This rate is way below the basic electricity tariff in Indonesia which is in the price of $0.105 or Rp 1410.12/kWh (PLN, August 2016). Based on the rate, the cost of electricity bills per month in the study area has decreased significantly. The cost of electric bills at boarding school originally reached about $7,244,491.5/month. Whereas, in this hybrid system the cost of electricity that needs to be payed is about Rp4,853,088/month. That is, the system is able to suppress and conserve electricity budget of Rp2,391,403.5 per month. It shows that the utilization of renewable energy as an alternative energy configuration in the case study area can reduce the cost of electricity from the grid. Therefore, the best configuration is feasible to be implemented in order to meet the needs of the electrical load on the object of study.

4.5. Electrical Analysis Results
Based on the best configuration from the sensitivity analysis, the generated electricity reached 69.67 MWh per year. Microhydro become the largest supplier in this case, which generate 39.7 MWh per year or 55.33% of total electricity production. Micro-hydro is expected to be an alternate grid that supplies the load demand continuously. On the other hand, biogas scheduling is considered to supply the load demand at peak periods, from around 17:00 pm until 21:00 pm. Biogas electricity contributes about 23.9 MWh per year, equivalent to 33.37% of the total system electricity production. PV become a complementary supplier that produces 8.1 MWh per year which is equivalent to 11.29% of total system electricity production. While total primary burden to be met at 61.65 MWh per year. Therefore, overall load demands can be met by the system. Fig. 3. shows the monthly average of the electricity production of the system configuration.

![Figure 3. Monthly Average of Electricity Production](image-url)

In the case of this study there is 16.86 MWh excess electricity per year, or 21.5% of total electricity resulted by system with 100% renewable energy penetration.
5. Conclusions and Recommendation

5.1. Conclusions
The renewable energy potential to meet the electricity supply for the boarding school has been analyzed. The best system in this case study had been determined by the software through utilization determination to find the technological possibilities of renewable energy. The optimization results show that a hybrid renewable energy system in this case, micro turbine capacity should be designed equals to PV. Meanwhile, biogas generator used is ½ of the micro turbine or PV capacity. The system should be equipped by converter system with a capacity equals to PV.

Recommendation systems are referred to indicate that entire electricity demand in the area of the case study can be supplied with the winner system configuration. With a maximum fraction of renewable energy, the load demand can be met by 3/4 of electricity production. Then there is ¼ generated energy into excess electricity.

The proposed system based on the sensitivity analysis influenced operating costs, capital costs, and so CoE. The greater potential resources that are used, the less necessary components, so the total NPC will be reduced significantly. From an economic perspective, this simulation can reduce the CoE up to 1/3 of the basic electricity tariff in Indonesia currently. It shows that the system can be realized, as it has significant benefits to the electricity and financial aspects.

5.2. Recommendation
The author is aware that the research is far from perfect, therefore, further studies are needed and expected to enhance this research. Recommendations for further research are as follows:

- Audit electricity used yearly from the grid so financial profit from the utilization of renewable energy sources available on site Baiturrahman Boarding School can be analyzed.
- Analyze the environmental impacts or emissions produced from the resulting system configuration.
- Connect the system to the grid with the aim of selling an excess electricity in order to be wasted.

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