PHOTOVOLTAIC POWER SYSTEM ANALYZED BY HOMER

CASE STUDY SABU ISLAND

MR. AKHMAD FATKHUR RIZKI

THIS PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE BACHELOR DEGREE OF ENGINEERING

DEPARTMENT OF ELECTRICAL ENGINEERING

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RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

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CHAPTER 3

DESIGN SYSTEM AND INSTALLATION

3.1 Geography and Administrative Conditions

Sabu Raijua regency located between 10°25'7.12" - 10°49'54.83" South Latitude and between 121°16'10.78" - 122°0'36.26" East Longitude. Sabu island located in the middle of the Sabu Sea and is located between the islands of Sumba and Rote. The regency boundaries are as North, East and West with Sabu Sea and the Indian Ocean in the south. Sabu Island is an area of 460.47 km² with a length beach of 1,026.36 km. The average height of the territories in Sabu Raijua currently on 0 - 100 meters above sea level. The dominant soil types in the area of Sabu Raijua is Alluvial, Grumosol, Litosol, and the Mediterranean with fine to coarse soil texture. In addition, there are also limestone mountains that stretches along the region's districts. [7]

According to topography, surface area of Sabu Raijua mostly composed of limestone hills that are less fertile and average slope of 45 degrees with some towering peaks, but typically no more than about 250 meters [8]. Climatic conditions on the Sabu island influenced its location adjacent to the continent of Australia. Hence this island has characteristics with a long dry season ranged between 7 - 8 months and with low rainfall. In a year just 14 - 69 days of the rainy season, that short rainy season only happens in December to March. [9]

Figure 3.1 Location Map Sabu Island.

Source: Google maps (2015)

Compared to other small islands located in East Nusa Tenggara province, located of Sabu island is quite remote and have the furthest distance to the islands around it, such as to Sumba, Rote and Flores islands. This condition causes the sea freight transportation modes most important role for Sabu Raijua society to connect with other islands in the East Nusa Tenggara province. Sabu Raijua have topographical conditions of the region with mountainous and hilly. Soil surface bare and critical so sensitive to erosion. This topography raises physical isolation, economic isolation and social isolation, especially by the lack of support infrastructure such as roads and bridges in various subdistricts. While transportation to certain islands often rather expensive because low frequency of the means of transportation to several islands, where it is certainly also affect the prices of goods and services in the district. [8]

3.2 Meteorological Conditions and Electricity

Sabu Island meteorological conditions are not so different from the meteorological conditions surrounding islands. The wind blowing around the Sabu island is a season wind that changed direction twice a year with an average speed of 3 - 7 m / sec. The average rainfall around of Sabu island is 123.35 mm with the number of rainy days 9 times. The average monthly temperature of 31.47°C with the maximum and minimum temperature difference of 7.43°C. [7]

3.2.1 Potential Solar Radiation

The data that HOMER necessary to carry out power generation system optimization is the clearness index and daily radiation (kWh / m2 / day) for one year on the Sabu island. Data of Clearness Index and Solar Radiation is a global average solar radiation on a horizontal surface, expressed in kWh / m2, for every day of the year. Clearness Index Average is 0,655 and Average Daily Radiation for Sabu Island is 6,466 kWh / m2 / day. Data source can be obtained by direct measurement or through HOMER assistance that will connect the satellite to NASA through an internet connection by providing the latitude and longitude of the study location [10]. The following image is clearness index data and daily radiation.

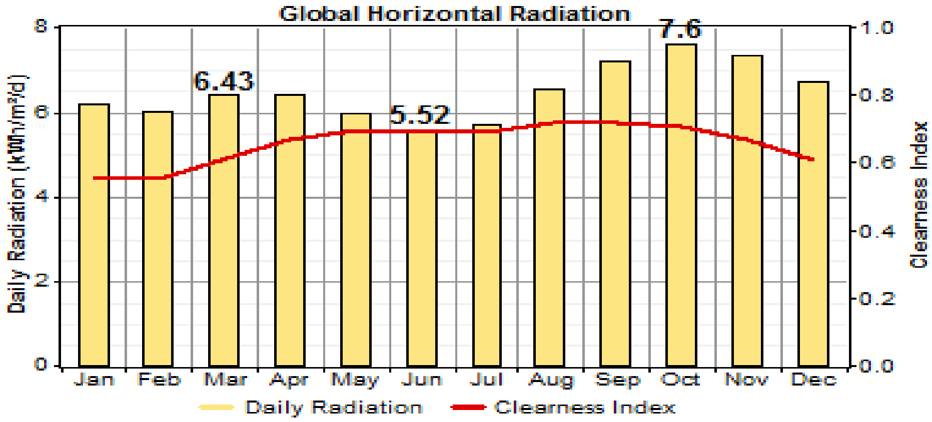

Figure 3.2 Clearness Index and Solar Radiation.

Source: http://eosweb.larc.nasa.gov. (2015)

3.2.2 Electrical Conditions

The demand for electricity on the Sabu island assumed only supplied by Diesel Generator throughout the day with a peak load of 1 MW. If there is a maintenance and repair on one of the machines will be replaced by a spare machine available. Sabu island including remote island, had to use Ferry boats to reach, this led to the supply of fuels including diesel fuel are scarce so the price becomes very expensive. Sabu Island Hybris Power Plant models will be simulated with a daily load curves and deferrable loads. The main load data in the form of daily load data are assumed to be on the Sabu island obtained under the Electricity Supply Business Plan of PT. PLN Persero (State Electricity Company). While the deferrable load data is pump load assumed to be added to the Hybrid Power Plant system.

3.2.2.1 Daily Load

The main load is assumed to be a load for household consumption, which mostly is lighting, TV, and others. The load daily average for Sabu Island is 5.6 MWh / day with peak load of 1 MW occurred at 18:00 p.m. to 19:00 p.m. [11]

The data used is based on data obtained from PT. PLN (State Electricity Company) is daily load data assumed for a full day, the following image is a daily load curve predicted in accordance with the needs of the population on the Sabu island.

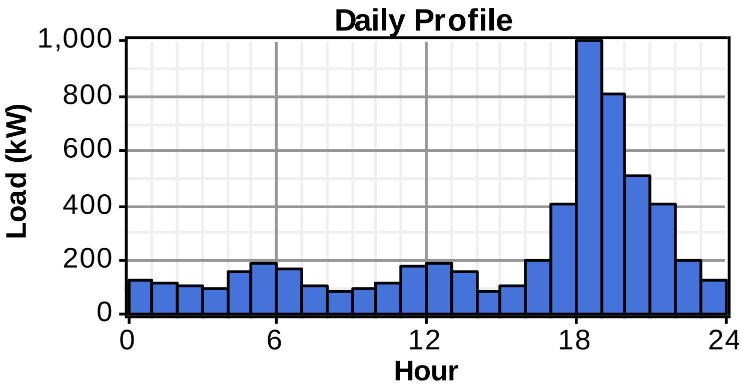

Figure 3.3 Daily Load Curve.

Source: HOMER, NREL

3.2.2.2 Deferrable Load

To meet the water consumption and other purposes, it is assumed that the pump is added as a sidetracked load on Hybrid Power Plant system design. Due to the 88.9% of the households on the Sabu island still use wells as a source of clean water [7]. This load is in the form of a water pump with a peak load of 400 watts operating for 6 hours per day. With the comparison limit of minimum load is 50%, the average pump energy consumed per day to fill the tank of 2.4 kWh / day with a total tank capacity of 4.8 kWh. The following image is a pump load profile as an sidetracked load.

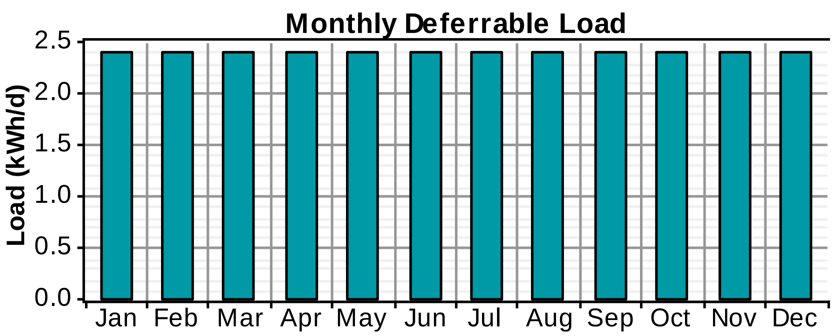

Figure 3.4 Monthly Load Pumps.

Source: HOMER, NREL

3.3 HOMER Software

HOMER software is a software used to optimize the model of small-scale power generation system (micropower), this software makes it easy to evaluate the design of power systems for various types of small-scale power plants either are connected to the power grid or not. The software performs these energy balance calculations for each system configuration that will be considered. Then determine the proper configuration, is able to meet the demand for electricity under defined conditions, the estimated cost of installing and operating the system during the project period. Cost calculation system such as capital costs, replacement, operation and maintenance, fuel, and interest rate. [12]

The software works by three main steps, that are simulation, optimization and sensitivity analysis :

3.3.1 Simulation

Homer can simulate a wide variety of micropower system configurations, comprising any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac-dc converter, an electrolyzer and a hydrogen storage tank. The system can be grid-connected or standalone and can serve ac and dc electric loads and a thermal load.

The software will simulate the operation of Hybrid Power Plant system by making energy balance calculations for 8,760 hours in a year. For each hour, HOMER compares to the electricity needs of the energy system can supply in that hour, and calculate the energy that flows from and to every component of the system. For systems that include batteries or fuel - powered generators, HOMER also decides operating time generator, whether to charge or discharge the battery.

3.3.2 Optimization

After simulated, the next step is to optimize all possible system configurations then sorted based on NPC (Net Present Cost) that can be used to compare system design options. Finding the optimal system configuration may involve; deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use.

3.3.3 Sensitivity Analysis

In a sensitivity analysis, the HOMER user enters a range of values for a single input variable. A variable for which the user has entered multiple values is called a sensitivity variable.

Almost every numerical input variable in HOMER that is not a decision variable can be a sensitivity variable. Examples include the grid power price, the fuel price, the interest rate, or the lifetime of the PV array. When the sensitivity variables are added, HOMER repeats the optimization process for each sensitivity variables that determine. For example, if the wind speed is set as a sensitivity variable, HOMER will simulate system configurations for various wind speeds have been set.

The advantages of this software is easy to use, can simulate, optimize a model then can automatically find the optimum system configuration that can supply the load with the lowest cost (NPC), and can use the parameter sensitivity for better results.

The disadvantage of this software is its main output in the form of economic parameters (NPC, COE) instead of a detailed model of the system, and some renewable energy technologies still can not be simulated by this software.

3.3.4 Calculation of Data

The following equations are used as the basis for the calculation of the energy supplied by renewable energy generation, battery charge and discharge batteries as well as the calculation of the Total Net Present Cost (TNPC). [12]

Power Equation Solar Power Plant.

$$Ppv = \eta w * \eta g * Npvp * Npvs * Vpv * Ipv \quad (3.1)$$

Total Power Equation Renewable Power Plant.

$$P(t) = \sum_{w=1}^{\eta w} Pw + \sum_{s=1}^{\eta s} Ps \quad (3.2)$$

Battery Discharging Equation.

$$Pb(t) = Pb\,(t-1) * (1-\sigma) - \left[\frac{Pbh(t)}{\eta bi} - Pbi(t)\right] \quad (3.3)$$

Battery Charging Equation.

$$Pb(t) = Pb\,(t-1) * (1-\sigma)\left[\frac{Pbh(t) - Pbi(t)}{\eta bi}\right] * \eta bb \quad (3.4)$$

With :

Ipv	is current PV panel
Pb	is the energy of the battery in the time interval
Pbh	is the total energy generated by the PV array
σ	is a factor of its own battery discharge
Pbi	total load on the time interval
ηbb	efficiency battery

3.3.4.1 Total Net Present Cost

Total Net Present Cost (NPC) is the most important economic output for the value of a Hybrid Power Plant system, HOMER will sort the data output of the simulation and optimization based on the lowest value of NPC. Total NPC can be calculated using the following equation :

$$CNPC = \frac{Cann,tot}{CRF(i,Rproj)} \tag{3.5}$$

With :

Cann,tot	is the total annual cost ($ / year)
CRF( )	is a factor of closing capital
i	is the interest rate (%)
Rproj	is the length of time a project
N	is the number of years

While the closure of the capital factor can be obtained by using the following formula :

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \tag{3.6}$$

3.3.4.2 Levelized Cost of Energy

Levelized Cost of Energy (COE) is defined as the average cost per kWh of electricity production in use by the system. To calculate the COE, annual electric energy production costs divided by the total electrical energy use is produced, by the following equation :

$$COE = \frac{Cann,tot - Cboiler\ Etermal}{Eprim,AC + Eprim,DC + Edef + Egrid,sales} \quad (3.7)$$

With :

Cann,tot	is the annual cost of the total system ($ / year)
Cboiler	is margin boiler costs ($ / kWh)
Ethermal	is the total thermal load that fulfilled (kWh / year)
Eprim,AC	is the main AC load that fulfilled (kWh / year)
Eprim,DC	is the main DC load that fulfilled (kWh / year)
Edef	is deferrable loads that fulfilled (kWh / year)
Egrid,sales	is the total sales of the grid (kWh / year)

3.3.4.3 Calculation of Emissions

HOMER uses the following formula to calculate the emissions penalty of Hybrid Power Plant system.

$$Cemisi = \frac{c_{co_2}M_{co_2} + c_{co}M_{co} + c_{UHC}M_{UHC} + c_{PM}M_{PM} + c_{So_2}M_{So_2} + c_{Nox}M_{Nox}}{1000} \quad (3.8)$$

With :

c_{co_2}	CO_2 emissions penalty ($ / ton)
c_{co}	CO emissions penalty ($ / ton)
c_{UHC}	UHC emissions penalty ($ / ton)
c_{PM}	PM emissions penalty ($ / ton)
c_{So_2}	SO_2 emissions penalty ($ / ton)
c_{Nox}	NOx emissions penalty ($ / ton)
M_{co_2}	CO_2 emissions (kg/year)
M_{co}	CO emissions (kg/year)
M_{UHC}	UHC emissions (kg/year)
M_{PM}	PM emissions (kg/year)
M_{So_2}	SO_2 emissions (kg/year)
M_{Nox}	NOx emissions (kg/year)

3.4 Implementation Study Hybrid Power Plant in Sabu Island

This study uses HOMER help with algorithms as shown in the following figure :

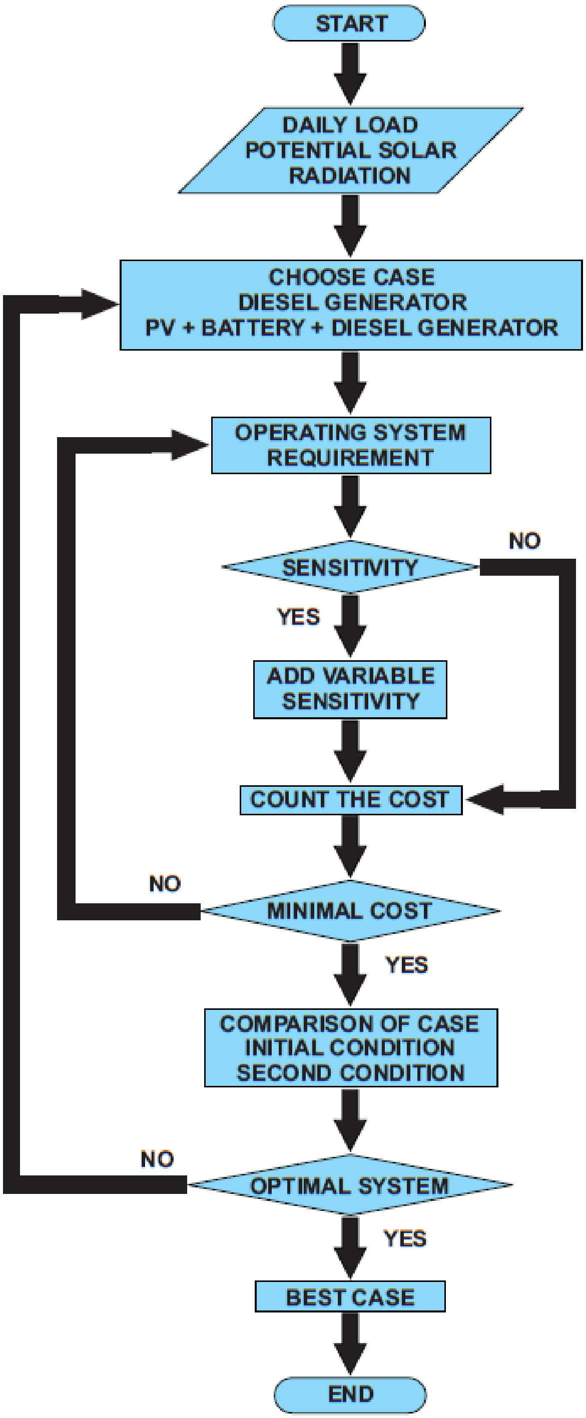

Figure 3.5 Simulation and Optimization Flowchart.

3.4.1 Simulation and Optimization Methods

For design optimization Hybrid Power Plant system is made of two conditions by following the daily load curve, that are :

- The first condition simulation is run to determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.
- The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value and less emissions.

3.4.2 Power Hybrid Models in Sabu Island

Hybrid Power Plant model will be simulated and optimized consists of Solar Panels (Photovoltaic), Diesel Generators, Inverter and Battery. The following image is a model of Hybrid Power Plant which will be simulated and optimized by HOMER.

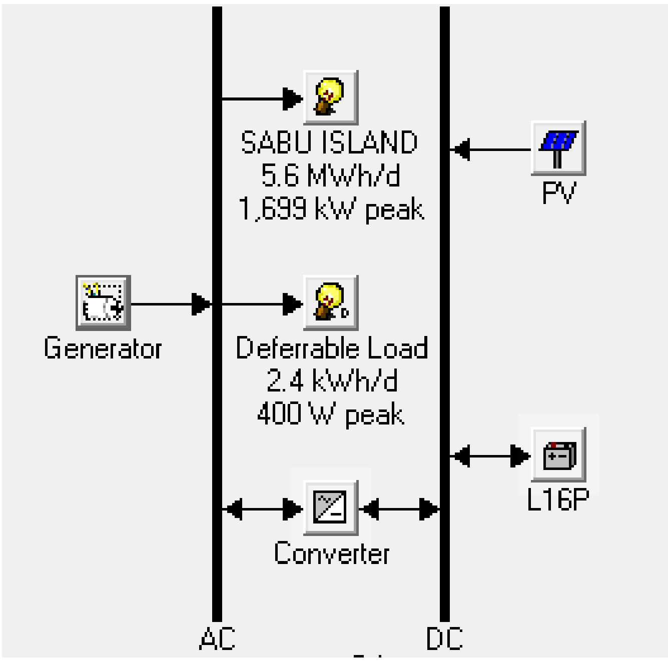

Figure 3.6 Hybrid Power Plant Systems Models.

Source: HOMER, NREL

3.4.2.1 Sizing Each Components of Hybrid System

3.4.2.1.1 Photovoltaics

In order to construct a reliable and long-lasting PV systems an accurate planning is necessary because it implements the economic evaluation during the planning state. Due to the uncertainty of demand prediction and the assumed radiation the energy supply should be basically higher than the energy demand. However, it could sometimes happen that the supply could not meet the demand and the system fails consequently. For this reason, a *quality factor* (*Q*) is commonly used to present how well the supply meets the demand.

Table 3.1: Quality factors of components and different PV systems [28]

Component/System	*Q*
PV module (Crystalline)	0.85…0.95
PV array	0.80…0.90
PV system (Grid-connected)	0.60…0.75
PV system (Stand-alone)	0.10…0.40
Hybrid system (PV/Diesel)	0.40…0.60

The quality factor is defined as the quotient of the real electric output energy measured at the system output (*Eel*), which is normally equivalent to the system load (*Edemand*) and the theoretical output energy (*Eth*), which is defined as the output energy from the same system under ideal conditions, i.e. Standard Test Conditions (STC). With the quality factor formula above and the empirical quality factors of existing systems it is easy to presize the PV array :

$$Ppeak = \frac{E_{el} \cdot I_{STC}}{E_{glob} \cdot Q} \tag{3.9}$$

where:

$Ppeak$ = peak power of the PV array under STC [kW_p]

Eel = real electric output energy of the system [kWh / a]

I_{STC} = incident solar radiation under STC [1 kW / m^2]

Eglob = annual global solar radiation [kWh / m^2a]

Q = quality factor of the system

In the theoretical limiting case, supply and demand values are equivalent and the quality factor is therefore equal to one ($Q = 1$). A measured value of, for example, $Q = 0.75$ means that 75 % of the electric energy, which is converted from incident solar energy, is used whereas 25 % of the electric energy is lost between the solar cell and the system output or it is not used.

3.4.2.1.2 Battery

The battery capacity depends on characteristics of radiation, load, and system reliability as well as intention of the user. From experience, the relation between storage capacity [kWh] and peak power [kW_p] of the PV array is more or less 10:1. In case that the global radiation at the site is nearly constant throughout the year, this value will be lower than 10:1. When having a system where the power consumption is mainly during the night this thumb rule must be corrected to the value higher (up to 20 % more) and vice versa when e.g. a wind generator or a diesel generator is integrated into the system.

$$C_B = 10 \cdot Ppeak \qquad (3.10)$$

where:

C_B = battery capacity [kWh]

Ppeak = peak power of the PV array [kW_p]

3.4.2.1.3 Inverter

The selection of the stand-alone inverter will be determined especially by the AC power to be provided and the selected DC voltage. A stand-alone inverter must be able to power all of the loads that might run at the same time, including any starting surges for pumps and other large motors. When looking at inverter specifications, play close attention to the part load efficiency of the inverter. Related to the over sizing related to the peak current security the stand alone inverter is mostly running in part load about 10 to 30 % of nominal load.

3.4.3 Hybrid Power Plant Components

The Hybrid Power Plant components consists of Photovoltaic Panels, Diesel Generators, Inverters and Batteries. All prices are used in the simulation is obtained from Internet sites were accessed in April 2015.

3.4.3.1 Solar Modules

The capacity of each solar module is 60 Wp. The price for the 1,500 kWp solar module is $ 1,200,000 [13], the replacement cost $ 1,200,000, operating and maintenance costs are assumed to $ 500 per year, the lifetime of solar modules for 25 years.

Specification data MSX-60 module :

Long	: 43.63 inch
Width	: 19.75 inch
Maximum power (Ppp)	: 60 W
Voltage maximum power (Vpp)	: 17.1 V
Current maximum power (Ipp)	: 3.5 A

3.4.3.2 Diesel Generator

Diesel Generators used 1100 kW with operating time for estimated 15,000 hours and minimum load is 30%. For this Diesel Generator investment cost of $ 180,000 [14], the cost of replacing $ 178,000, operating and maintenance costs of $ 0.72 per day is assumed.

3.4.3.3 Inverter

The inverter used is Bidirectional Inverter (Inverter - Rectifier) with inverter efficiency of 90 %, long time operation 10 years. While Rectifier efficiency is 85 % relative to the inverter capacity by 100 %. The investment costs for Bidirectional inverter to 1,500 kW at $ 450,000 [15], the replacement cost of $ 400,000 and the cost of operation and maintenance is assumed at $ 600 per year.

3.4.3.4 Battery

The batteries used are lead acid battery type L16P, investment costs for this battery of $ 1,992,900 [16], the replacement cost of $ 1,990,000 and annual operating and maintenance costs of $ 200 is assumed to lead acid battery characteristics are as follows :

Nominal capacity	: 360 Ah
Nominal voltage	: 6 V
Efficiency	: 85 %
Minimum state of charge	: 30 %
Time use	: 10 years
The maximum charging current	: 18 A

3.4.4 Variable Sensitivity

Sensitivity of fuel prices between 0.6 to 1 $ / liter, the price of fuel is assumed based on Sabu Island in April 2015.

3.4.5 Operating Limits Power Hybrid

- Limitations economy used for all calculations when the hybrid system is simulated real annual interest rate of 8 %, 25 year project period.
- Dispatch strategy used is a charging cycle with the setpoint state of charge of 80%, maximum annual capacity shortage 0%.
- For generator regulation system allowed to operate with some generators and systems are also allowed to operate the generator under load peak.
- The operating system used is a parallel system of Hybrid Power Plant.

After going through the steps - steps above, HOMER will simulate and optimize Hybrid Power Plant predetermined models.

3.5 Summary

Sabu island located in the middle of the Sabu Sea and is located between the islands of Sumba and Rote. Climatic conditions on the Sabu island influenced its location adjacent to the continent of Australia. Hence this island has characteristics with a long dry season ranged between 7 - 8 months and with low rainfall. In a year just 14 - 69 days of the rainy season, that short rainy season only happens in December to March [9]. The wind blowing around the Sabu island is a season wind that changed direction twice a year with an average speed of 3 - 7 m / sec. The average monthly temperature of 31.47°C with the maximum and minimum temperature difference of 7.43°C [7]. Clearness Index Average is 0.655 and Average Daily Radiation for Sabu Island is 6.466 kWh / m2 / day. [10]

The load daily average for Sabu Island is 5.6 MWh / day with peak load of 1 MW occurred at 18:00 p.m. to 19:00 p.m. [11]. The data used is based on data obtained from PT. PLN (State Electricity Company) is daily load data assumed for a full day, to meet the water consumption and other purposes, it is assumed that the pump is added as a sidetracked load on Hybrid Power Plant system design. HOMER software is a software used to optimize the model of small-scale power generation system (micropower), this software makes it easy to evaluate the design of power systems for various types of small-scale power plants either are connected to the power grid or not. [12]

Hybrid Power Plant model will be simulated and optimized consists of Solar Panels (Photovoltaic), Diesel Generators, Inverter and Battery. For design optimization Hybrid Power Plant system is made of two conditions by following the daily load curve, that are :

- The first condition simulation is run to determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.
- The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value and less emissions.

Variable sensitivity of fuel prices between 0.6 to 1 $ / liter, the price of fuel is assumed based on Sabu Island in April 2015. And the operating limits are operating system used is a parallel system of Hybrid Power Plant, limitations economy used for all calculations when the hybrid system is simulated real annual interest rate of 8 %, 25 year project period, dispatch strategy used is a charging cycle with the setpoint state of charge of 80%, maximum annual capacity shortage 0 %, for generator regulation system allowed to operate with some generators and systems are also allowed to operate the generator under load peak.

CHAPTER 4

SIMULATION AND ANALYSIS

4.1 Simulation Results

Simulation and optimization using HOMER produce several different configurations according to the minimum limit of renewable energy contribution.

4.1.1 Initial Condition

4.1.1.1 Peak Power of Photovoltaic

$$
\begin{aligned}
E_{el} &= \text{Primary Load + Deferrable Load} \\
&= 5{,}570 + 2.4 \\
&= 5{,}572.4 \text{ kWh/day}
\end{aligned}
$$

According to the formula 3.9 we get the peak power of PV :

$$
\begin{aligned}
Ppeak &= \frac{E_{el} \cdot I_{STC}}{E_{glob} \cdot Q} \\
&= \frac{5{,}572.4 \times 1}{0.6 \times 6.47} \\
&= 1435.3 \text{ kWp}
\end{aligned}
$$

4.1.1.2 Battery Capacity

$$
\begin{aligned}
C_B &= 10 \cdot \text{Ppeak} \\
&= 10 \times 1435.3 \\
&= 14353 \text{ kWh}
\end{aligned}
$$

The value of PV power rounded to 1,500 kWp and the battery power capacity divided by the nominal capacity of the battery at 2.16 kWh so we get the amount of battery capacity of 6,643 pieces. Diesel Generator capacity used for initial system given the higher value as the peak load on the primary load, amounting to 1.1 MW and capacity inverter used is given a equal value to the value of PV capacity is equal to 1,500 kW.

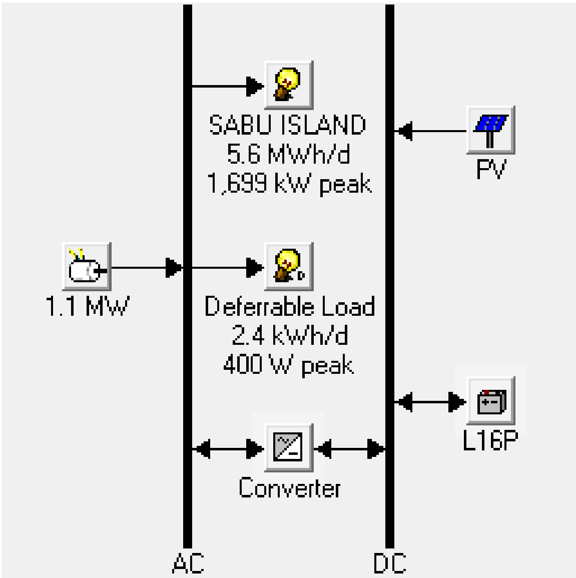

Figure 4.1 Initial Condition Systems Models.

Source: HOMER, NREL

Simulations were performed with the initial condition is as compared to the second condition. This initial condition system consists of 1,100 kW Diesel Generator, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter with the simulation results as follows Table 4.1 below.

Table 4.1 Data Simulation Results on Initial Conditions.

Parameter	Solar + Diesel
NPC ($)	12,358,148
Initial Capital Cost ($)	2,098,200
Operating Cost ($/year)	961,139
COE ($)	0.569
Renewable Energy (%)	59
Fuel Consumption (L/year)	923,254
Hours of Operation (hours/year)	
PV 1500 kW	4,442
Diesel 1100 kW	4,558
Energy Production (kWh/year)	5,092,615
PV 1500 kW	3,004,018
Diesel 1100 kW	2,088,597
Excess Electricity (kW/year)	2,858,037
Excess Electricity (%)	56.1
CO_2 Emissions (kg/year)	2,431,230
SOx Emissions (kg/year)	4,882

4.1.2 Second condition

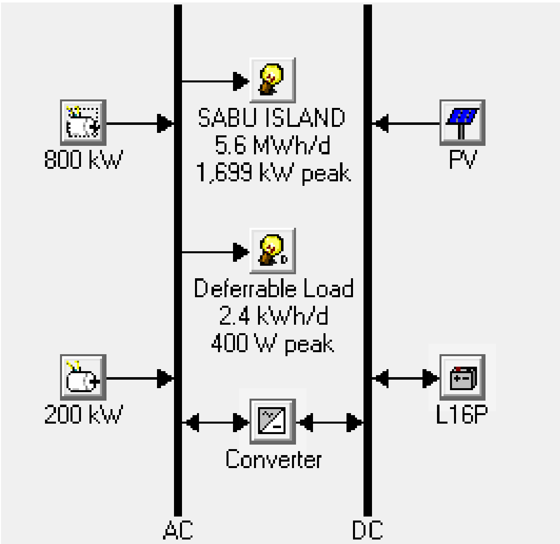

Figure 4.2 Second Condition Systems Models.

Source: HOMER, NREL

Table 4.2 Data Simulation Results on Second Condition.

Parameter	Solar + 2 Diesel
NPC ($)	7,374,541
Initial Capital Cost ($)	2,081,836
Operating Cost ($/year)	495,814
COE ($)	0.34
Renewable Energy (%)	66
Fuel Consumption (L/year)	536,732
Hours of Operation (hours/year)	
PV 1500 kW	4,442
Diesel 800 kW	1,534
Diesel 200 kW	3,748
Energy Production (kWh/year)	4,518,370
PV 1500 kW	3,004,018
Diesel 800 kW	942,151
Diesel 200 kW	572,201
Excess Electricity (kW/year)	2,388,366
Excess Electricity (%)	52.9
CO_2 Emissions (kg/year)	1,413,392
SOx Emissions (kg/year)	2,838

In this case given the limits on the amount of use a maximum of two diesel engines but for the DG can be added the value of different capacity and we assume that the value of PV from the initial condition as the lowest value that will be used. This condition system consists of two Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter with the simulation results as follows Table 4.2 above. The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value.

4.1.3 Comparison of Results All Conditions

Table 4.3 Comparison of Results All Conditions.

Parameter	Solar + Diesel	Solar + 2 Diesel
NPC ($)	12,358,148	7,374,541
Initial Capital Cost ($)	2,098,200	2,081,836
Operating Cost ($/year)	961,139	495,814
COE ($)	0.569	0.34
Renewable Energy (%)	59	66
Fuel Consumption (L/year)	923,254	536,732
Hours of Operation (hours/year)		
PV 1500 kW	4,442	4,442
Diesel 1100 kW	4,558	-
Diesel 800 kW	-	1,534
Diesel 200 kW	-	3,748
Energy Production (kWh/year)	5,092,615	4,518,370
PV 1500 kW	3,004,018	3,004,018
Diesel 1100 kW	2,088,597	-
Diesel 800 kW	-	942,151
Diesel 200 kW	-	572,201
Excess Electricity (kW/year)	2,858,037	2,388,366
Excess Electricity (%)	56.1	52.9
CO_2 Emissions (kg/year)	2,431,230	1,413,392
SOx Emissions (kg/year)	4,882	2,838

4.2 Analysis of Simulation Results

Simulations performed under two conditions, that are the initial condition in which there are only a Diesel Generator with capacity of 1,100 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter while the second condition is using 2 Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter. The simulation results which analyze is the production of electricity, the cost of electricity, fuel consumption by Diesel Generator, the excess electricity that is not absorbed by the load. Here is a full analysis for two conditions of the simulation.

4.2.1 Initial Condition

Analysis of simulation results on the initial conditions are as a comparison or to be used as a benchmark for analyzing optimal system of Hybrid Power Plant simulation results from second conditions.

4.2.1.1 Electricity Production

Production of electricity generated by Diesel Generator capacity of 1,100 kW is 2,088,598 kWh / year or 41 %, a PV capacity of 15,000 kW is 3,004,018 kWh / year or 59 % with total production of electricity generated is 5,092,615 kWh / year.

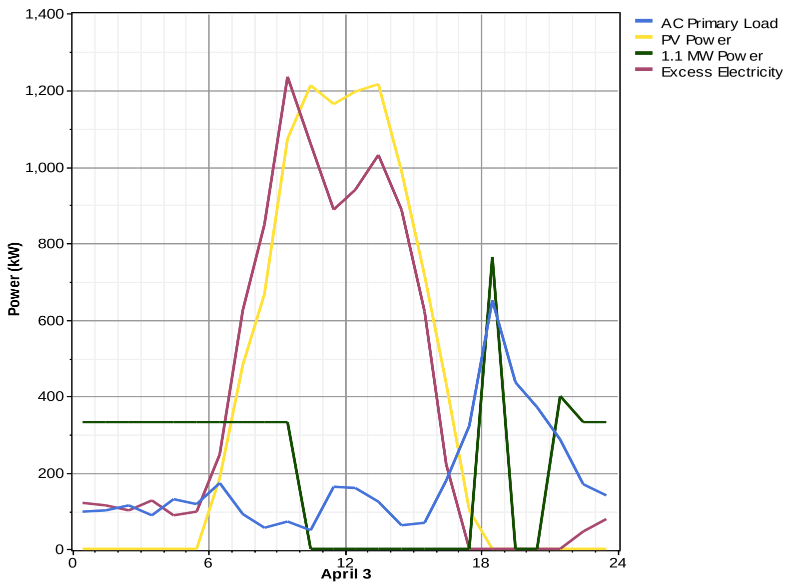

Figure 4.3 Daily Load Conditions, Output Power and Excess Unused Power in Initial Condition.

The picture above is a condition of the supply of electricity on April 3 2015, can be seen Diesel Power 1,100 kW operating almost all day except on 10:30 a.m. to 17:30 p.m. and 19:30 p.m. to 20:30 p.m., can be seen PV operates almost all day when the sunlight.

At this time there is excess electricity. This happens because the excess electrical of Diesel Generator can not be utilized, because there are no batteries for storage of electrical energy in this system.

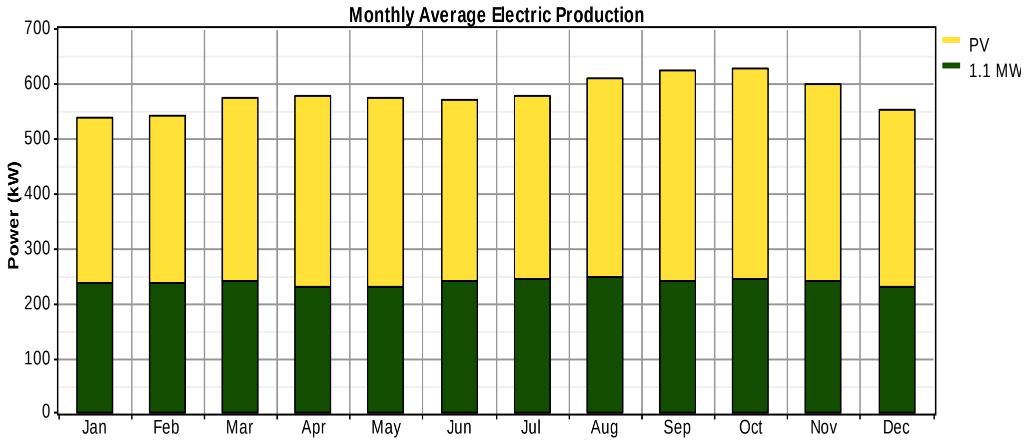

Figure 4.4 Contributions Solar Power Generation - Diesel Generator.

4.2.1.2 Fuel Consumption

Total fuel consumed by the system during the first year is 923,254 liters, that all consumption by Diesel Generator 1,100 kW.

4.2.1.3 Excess Unused Power

Excess electricity contained in this system amounted to 2,858,037 kWh per year, or approximately 56.1 %. Excess electricity is the difference between total production of electrical energy for a year that generated by Diesel Generator and the total load supplied.

4.2.1.4 Costs

Costs obtained from the simulation system of the initial conditions are initial capital invested in this system amount of $ 2,098,200, operating cost amounted to $ 961,139 per year, the net present cost (NPC) amounted to $ 12,358,148 and the cost of electricity (COE) amounted to $ 0.569 per kWh.

4.2.1.5 Environmental Impact (Emission)

When the design is simulated and optimized with value contribution of renewable energy is 59 %, then obtained CO_2 and SOx emission levels are high. The total value of CO_2 emissions produced by system amounted to 2,431,230 kg / years and SOx emissions resulting value of 4,882 kg / years.

4.2.2 Second condition

In the second condition, the simulation system of Hybrid Power Plant produce a configurations, that is PV with 2 Diesel Generator. HOMER simulates Hybrid Power Plant system and sorted by priority based on the lowest NPC. From the simulation results, obtained the order of lowest NPC values is $ 7,374,541.

Criteria established writers to get a optimum Hybrid Power Plant is :

- The NPC values its lowest
- The little environmental impact (low emission)

Based on simulation results and the above criteria, the configuration that qualify as the optimum system consist of PV with a total capacity of 1,500 kWp, 2 unit Diesel Generator capacity of 200 kW and 800 kW, 6,643 pieces of Battery and 1,500 kW of Inverter, more analysis as follows :

4.2.2.1 Electricity Production

Total production of electricity produced by PV and 2 Diesel Generator is 4,518,370 kWh / year with the contribution of PV is 66 % or 3,004,018 kWh / year while the contribution Diesel Generator 200 kW is 13 % or 572,201 kWh / year and capacity 800 kW is 21 % or 942,151 kWh / year.

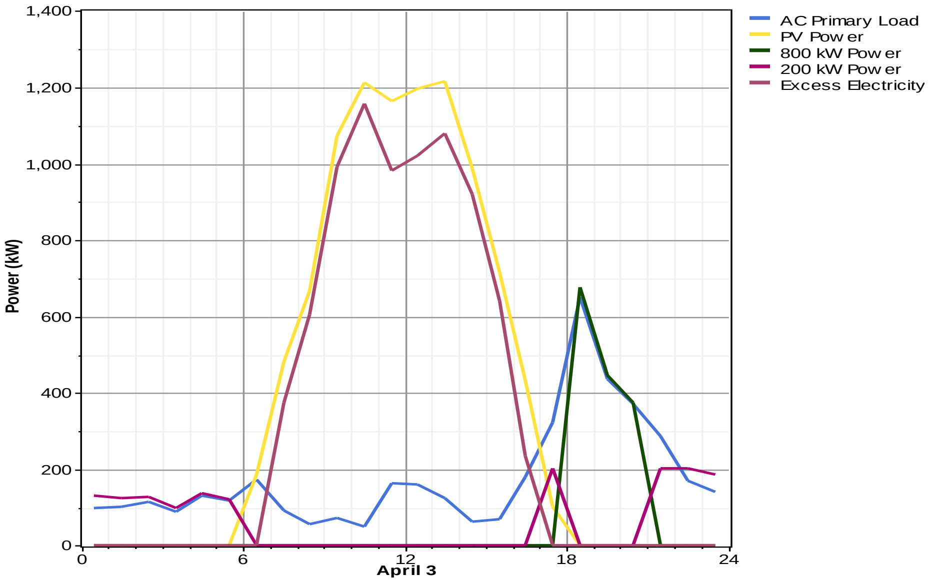

Figure 4.5 Daily Load Conditions, Output Power and Excess Unused Power in Second Condition.

Figure 4.3 is a condition of the supply of electricity on April 3 2015, can be seen Solar Power Plant operates almost all day when the sunlight. All Diesel Generator is not operating at 06:30 a.m. to 16:30 p.m. when electricity production from Solar Power Plants can fill the electricity needs.

Excess electricity is unused in this system is 2,388,366 kWh per year or 52.9 %, this happens because of the electricity produced by the Solar Power Plant for one year excessive to the existing load. In the Figure 4.3 excess electricity occurred at 06:30 a.m. to 17:30 p.m. and at this time 6,643 pieces of batteries used is not sufficient to absorb this excess electricity. In addition to using the battery, excess electricity can also be absorbed by adding this system to the deferrable load.

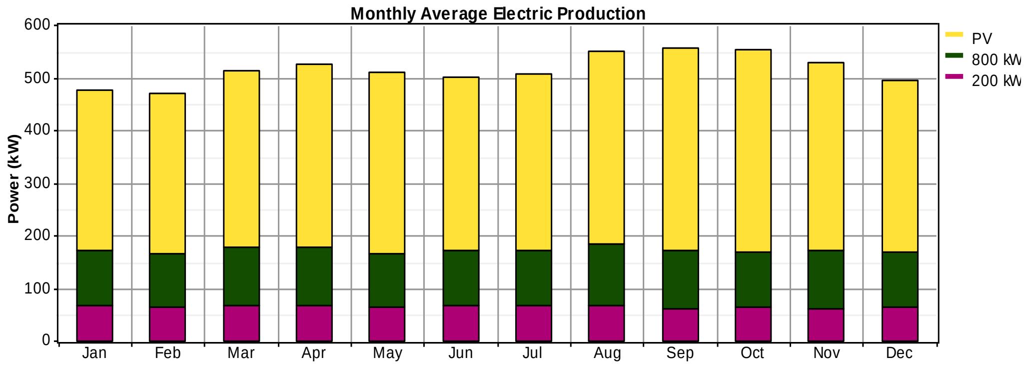

Figure 4.6 Contributions Solar Power Generation - Diesel Generator

In the Figure 4.4 above shows the contribution of each component. Contributions of PV 66 % and the contribution Diesel Generator 200 kW at 13 %, capacity of 800 kW is 21 %.

4.2.2.2 Fuel Consumption

In Figure 4.5 the fuel consumption on the system configuration of Hybrid Power Plant consisting of Solar Power Plant - Diesel Generator amounted to 590,684 liters per year. In this configuration the use of fuel could be saved by 148,952 liters per year, or 20.14 % per year.

4.2.2.3 Excess Unused Power

With a fixed daily load, excess unused power has a value that fluctuates along with the total production of electricity in Hybrid Power Plant. Excess electricity occurred at this system is 52.9 % or 2,388,366 kWh per year with a total production of electrical energy is 4,518,370 kWh per year.

4.2.2.4 Costs

Overall optimal system is Hybrid Power Plant that consisting of PV and 2 Diesel Generator, the costs that obtained from the simulation results are initial capital invested amounted to $ 2,081,836, operating cost amounted to $ 495,814 per year, the net present cost (NPC) is $ 7,374,541, the cost of electricity (COE) is $ 0.34 per kWh. In this system, lower initial investment costs but for 25 years fuel costs can be reduced by 386,522 liters per year, or 41.86 %.

4.2.2.5 Environmental Impact (Emission)

When the hybrid design is simulated and optimized with the value of the contribution of renewable energy of 66 %, then obtained the rate of CO_2 and SOx emissions decreased along with the decrease of fuel consumption in diesel. In the diagram of CO_2 emissions, the highest value occurs when the contribution of ET 0 % with the total value CO_2 is 1,856,939 kg per year. The value of CO_2 emissions is 1,413,392 kg per year and SOx emissions value is 2,838 kg per year.

Overall the optimum conditions by simulating the HOMER software is priced at lowest net present cost (NPC) and the lowest emission values based on the lowest electricity costs (COE) in the same value.

4.3 Summary

Simulation and optimization using HOMER produce several different configurations according to the minimum limit of renewable energy contribution. In Initial Condition the value of PV power rounded to 1,500 kWp and the battery power capacity divided by the nominal capacity of the battery at 2.16 kWh so we get the amount of battery capacity of 6,643 pieces. Diesel Generator capacity used for initial system given the higher value as the peak load on the primary load, amounting to 1.1 MW and capacity inverter used is given a equal value to the value of PV capacity is equal to 1,500 kW.

In this conditions Simulations were performed with the initial condition is as compared to the second condition. In this condition the resulting NPC value is $ 12,358,148 with Initial Capital Cost of $ 2,098,200 and COE of $ 0.569 as well as the contribution of renewable energy from the system by 59 %. Fuel consumption amounted to 923,254 L / year and energy production of 5,092,615 kWh / year. Excess electricity that occurred at 56.1 % and CO_2 emissions by 2,431,230 kg / year. Simulations were performed with the initial condition is as Compared to the second condition.

In Second Condition given the limits on the amount of use a maximum of two diesel engines but for the DG can be added the value of different capacity and we assume that the value of PV from the initial condition as the lowest value that will be used. This condition system consists of two Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter. In this condition the resulting NPC value is $ 7,374,541 with Initial Capital Cost of $ 2,081,836 and COE of $ 0.34 as well as the contribution of renewable energy from the system by 66 %. Fuel consumption amounted to 536,732 L / year and energy production of 4,518,370 kWh / year. Excess electricity that occurred at 52.9 % and CO_2 emissions by 1,413,392 kg / year.

CHAPTER 5

CONCLUSIONS

Utilization of solar energy to generate electricity has grown rapidly along with the aim to reduce the high levels of pollution. In this project is proposed analysis of photovoltaic power system with the operating system using a parallel system to calculate the power requirements of solar power plants and diesel generators as a power generator with integrated large of a load is assumed to be constant in a year. In this study, the amount of power from solar power plants are required to meet the existing load is obtained by calculating the minimum output power to supply the load independently, while the magnitude of the diesel generator is assumed to be equivalent to the existing load.

Having gained much power a minimum of solar power plants using HOMER software, then the calculation is added cost to the system. This serves as a reference in determining the lowest NPC as guidelines for systems with maximum performance. The simulations can show the results of the system to optimize all possible system configurations, such as the size or quantity of each component. The first condition simulation is run to Determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.

In the second condition, the simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC Lowest value and less emissions. Limit the use of diesel generators with a maximum of two, then the second system allows the use of power from diesel generators with different values. It depends on the characteristics of the load values every day in certain hours and power supply all the power supply that adapts to the conditions of solar radiation during the day on solar power and output power capability of the battery and the inverter power supply. HOMER will simulate and analyze how the value of each diesel generator used to obtain optimal system.

Results of each condition compared with taking maximum system generated. At the initial conditions obtained amount of power each component of 1.5 MW in solar power plants and 1.1 MW diesel generators with energy production of 5,092,615 kWh / year. On both conditions was obtained magnitude of each component power of 1.5 MW of solar power plants, as well as kW 800, and 200 kW on diesel generator with energy production of 4,518,370 kWh / year.

Overall in this case study, the optimal Hybrid system is a combination of PV and 2 Diesel Generator. PV contribution towards Hybrid system by 66 % while Diesel Generator by 34 %. This configuration is defined as the most optimal by lowest value of NPC that is equal to $ 7,374,541 and the cost of electricity (COE) for $ 0.34 per kWh. Excess energy during the year amounted to 2,388,366 kWh or 52.9 %.

The environmental impact can be reduced by applying the PV and 2 Diesel Generator system, the CO_2 emissions generated in the system amounted to 1,413,392 kg per year, a decline in the amount of 1,017,838 kg of CO_2 emissions per year, or 41.86 % from the initial conditions in the number of CO_2 emissions by 2,431,230 kg per year. The total consumption of diesel fuel in the PV and 2 Diesel Generator system is 536,732 liters per year, occur in fuel consumption savings of 386,522 liters per year, or 41.86 % of the total consumption of diesel fuel in the initial conditions in the amount of 923,254 liters per year.

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PERSONAL PROFILE

Name	:	AKHMAD FATKHUR RIZKI
ID Number	:	115710401063-9
Place of birth	:	Sidoarjo
Date of birth	:	September 22nd, 1993
Address	:	Jl. Raya Melian 21 RT 02 RW 08 Kejapanan
		Kecamatan Gempol
		Kabupaten Pasuruan
		67155
		East Java
		INDONESIA
Religion	:	Moslem
Email	:	arafarizki@gmail.com
Education	:	SMA Negeri 1 Pandaan (Science)

Project Tittle Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island

Name Mr. Akhmad Fatkhur Rizki

Project Advisor Assistant Professor Boonyang Plangkang, Dr.-Ing.

This project submitted in partial fulfillment of the requirements for the Bachelor Degree in Electrical Engineering.

.... Head of Electrical Engineering Department

(Assistant Professor Surin Ngaemngam, Ph.D.)

Project Examination Committee

.... Chair person

(Associate Professor Krischonme Bhumkittipich, Ph.D.)

.... Committee

(Assistant Professor Somchai Hiranvarodom, Ph.D.)

.... Committee

(Mr. Theerapol Muankhaw)

.... Project advisor

(Assistant Professor Boonyang Plangkang, Dr.-Ing.)

Project Tittle	Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island
Name	Mr. Akhmad Fatkhur Rizki
Program	Electrical Engineering
Project Advisor	Assistant Professor Boonyang Plangkang, Dr.-Ing.
Academic Year	2015

ABSTRACT

Electrical energy is the energy that is needed, in which electrical energy is a primary need in this era of globalization. Meeting the needs of today's society electricity not only rely on the power source of conventional power plants, but many take advantage of the available natural resources, such as water, wind, and sunlight (solar). Solar Power Plant is a power generation system based on renewable energy. Its main purpose to save fuel and reduce emissions mainly CO_2. In this project, photovoltaic power system will be analyze for isolated island that is still little use of renewable energy as a source of electrical energy. It is very suitable to be applied in a country that has many isolated islands such as in Indonesia.

Solar Power Plant system as a whole is a multi-variable system that used the help of the software, in this case HOMER version 2.68. This software optimize based on the value of the lowest NPC. With the Solar Power Plant optimization case study on Sabu Island East Nusa Tenggara province, integrated with Diesel Generator.

Aided simulation and optimization results HOMER software show that overall optimum system to be implemented in the study area above is the integration between Solar Power Plant and Diesel Generator. At the optimum conditions, the optimal Hybrid system is a combination of PV and 2 Diesel Generator. PV contribution towards Hybrid system by 66 % while Diesel Generator by 34 % with Net Present Cost (NPC) of $ 7,374,541, the cost of generating electricity (Cost of Electricity, COE) for $ 0.34 per kWh, fuel consumption by 536,732 liters per year, CO_2 emissions generated by the system at 1,413,392 kg per year or reduced by 41.86%, the excess energy during a year amounted to 2,388,366 kWh.

Keywords : Solar Power Plant, Diesel Generator, HOMER, Simulation, NPC.

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Alhamdulillahirobbil'alamin, Praise is merely to the Almighty Allah SWT for the gracious mercy and blessing that enables me to accomplish this bachelor project entitled: Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island. This bachelor project is presented to fulfill one of the requirements in accomplishing Bachelor degree in Electrical Engineering.

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I realize that this project has not been perfect, both in terms of material and presentation. For that advice and constructive criticism is expected in the completion of this project.

I hope that this project can give benefits and add insight to the reader, especially for the author too.

Pathumthani, June 2015

The Author

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CHAPTER 1

INTRODUCTION

1.1 Photovoltaic System by Homer Energy

Electrical energy is the energy that is needed, in which electrical energy is a primary need in this era of globalization. Almost all human activities related to electricity. Along with the economic growth and the increase in the population of Indonesia, the demand for electricity is also increasing. Meeting the needs of today's society electricity not only rely on the power source of conventional power plants, but many take advantage of the available natural resources, such as water, wind, and sunlight (solar).

The geographical position of Indonesia is located on the equator and the sun shines all year round, it is appropriate to apply the principles and utilize the abundant solar energy and the amount will not be endless. The energy released by the sun to the earth is 20,000 times the energy needed worldwide. As we can see that Indonesia has daily solar radiation average of 4.8 kWh / m2 with the largest energy potential lies Eastern Indonesian region. Based on the map of solar energy in Indonesia, all Indonesian has a good potential for the development of a Solar Power Plant.

East Nusa Tenggara is an area that has great potential for renewable energy, especially solar. In the East Nusa Tenggara Province source of electrical energy virtually all depends on the Diesel Power Plant is about 99.4% in 2009 which is managed by PLN Persero to the level of electrification ratio in 2009 was 22.53%. Sabu Island is an island in East Nusa Tenggara Province, an area of 4.73499 million ha of land spread over 1,192 islands (43 inhabited islands and 1,149 islands are not inhabited). Most of the area is mountainous and hilly, few lowland.

Appropriate government programs in terms of energy saving and for diesel produce a lot of CO_2 emissions, then the supply of electrical energy as possible cultivated utilizing renewable energy sources local (Sabu Island), in this case solar energy. Therefore in need of an analysis to determine optimizing plant design to be optimized and profitable. With advances in technology many ways you can do one of them is using a software. HOMER is a software created to determine optimizing the design of renewable energy, particularly solar energy.

1.2 Objective and Purpose of the Study

The objective and purpose of developing this project are :

1.2.1 Designing a model of Solar Power Plant systems based on natural potentials Sabu Island, East Nusa Tenggara.

1.2.2 Knowing the optimization of the construction and operation of Solar Power Plant and Diesel Generators.

1.2.3 Analyze the results of the simulation, the energy generated by Solar Power, and the percentage contribution of Solar Power.

1.2.4 As a reference in the construction of Solar Power and Diesel Generators.

1.3 Scope of Limitation

The Scope of this project are :

1.3.1 Homer simulation using software version 2.68 Beta.

1.3.2 Load counts is the actual burden borne by the diesel in accordance with the daily load curve Sabu Island. Daily load data is data that is used daily load in 2015.

1.3.3 Load used in this simulation in one year is assumed to be constant.

1.3.4 Discussion of the working principle of Solar Power and Diesel are discussed in general.

1.3.5 Main Power Plant is Diesel, while other Power Plant will be integrated is Solar Power Plant.

1.3.6 Case only be seen in the study area is Sabu Island, East Nusa Tenggara.

1.3.7 All prices of components in April 2015 were obtained from the website of each component.

1.4 Benefits of Project

The Benefits of project are :

1.4.1 Knowing about the design of Solar Power Plant system to be applied in the real condition.

1.4.2 To maximize the utilization of Solar Power Plant system.

1.4.3 To introduce HOMER to the people and knowing about simulate for Solar Power Plant by using HOMER.

CHAPTER 2

BASIC THEORY

2.1 Basic Principles

Hybrid Power Plant is a power generation system that combines several types of power plants, in general between fuel-based power plants with renewable energy-based power plants. Generally the generation systems are widely used for hybrid power plant is a diesel generator, solar power plants, micro-hydro, wind power plants. In this study, hybrid power plant consists of diesel generator and solar power plants. Both types of these plants are operated simultaneously and connected on one rail (busbar) to carry the load .

Contribution of solar power plants at any time is not fixed, given solar power plants is highly dependent on natural conditions. During the day, when the weather is sunny , solar power plants can operate optimally and at night solar power plants not operating at all, but was replaced by a battery that stores electrical energy from solar power during the day. The next generation , diesel generator is instant plant to be fully operational for 24 hours. However, in accordance with the purpose of the operation of diesel power plant, which save fuel and reduce CO_2 emissions , the operation of the diesel is the last variable that follows the change in power supply of solar power plants, so that its contribution was depend on the power supply of the solar power plants. With the integrated operation of the solar power plants on hybrid power plant, then fuel consumption and CO_2 emissions can be reduced.

In principle, a review of the contribution of each power plant in hybrid power plant be reviewed at any time, however a review of the operation of types of power plants, especially diesel generator, may also be reviewed by the cost of fuel oil and other components of operating costs and maintenance costs should be done.

Utilization of the hybrid energy system has several advantages such as [1] :

1. More efficient operation at any time of its generation system.
2. Generation efficiency becomes higher.
3. Easily integrated with any renewable energy system.
4. The availability and continuity of service is very high.
5. Low maintenance level and operators does not need to care and repair.

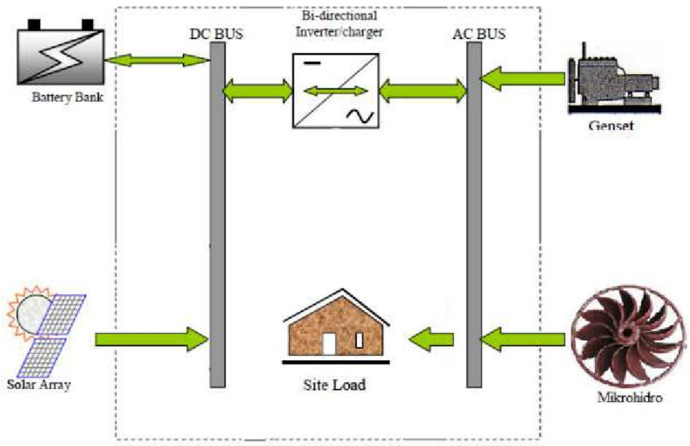

Figure 2.1 Schematic Hybrid Power Plant.

Configuration a hybrid power plant as seen above which includes several main components, that are :

a. *PV Array*, is a combination of several solar panels that are arranged in series and parallel to produce a certain voltage value with a desired power. Total energy generated from the PV array depends on :
   - Total solar panels installed or total watts peak module.
   - The intensity of the sun (*kw / m2 / day*) in place that will be installed.
b. *Diesel Generator*, necessary as a combination of energy to be able to supply power to service the load, especially during peak load or if the conditions of the energy stored in the battery is on the lower level.
c. *Battery Bank* or the battery circuit is part of the hybrid power plant whose function is to store energy derived from solar panels.
d. *Bi-Directional inverter*, is a bi-directional converter that is changing the DC voltage from the battery into AC voltage or vice versa from AC to DC for charging the energy system into a battery.

2.2 Solar Power Plant

Solar Power Plant is a power generation technology that converts photons from the solar energy into electrical energy. This conversion is performed on solar panels comprising photovoltaic cells. These cells are thin layer of pure silicon (Si) or other semiconductor materials are processed in such a way, so that when the material is energized photons will excite the electrons from their atomic bonds into electrons move freely, and ultimately will issue an electric voltage direct current. [2]

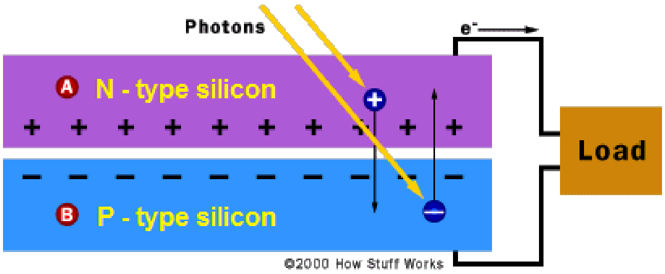

Figure 2.2 Electrical Energy Conversion Process On Solar Panels.

Source : http://www.solarbotics.net/200202_solar_cell_physics.html

By day the solar module receives sunlight which is then converted into electricity through the photovoltaic process. Electricity generated by the module can be directly supplied to the load or stored in batteries before use to load. At night, in which the solar modules do not generate electricity, the load is fully supplied by the battery. Similarly, if the day is cloudy, in which the solar modules generate electricity is lower than when the sun bright. Solar modules with a certain capacity can produce the amount of electricity can vary if placed in different areas.

(a) (b)

Figure 2.3 (a) Decentralized Solar Power Plants. (b) Centralized Solar Power Plants.

Source : (a) http://www.solarpowerplant.co.in/ (b) http://www.anekaciptaselaras.co.id/

Solar power plants use sunlight to generate electricity DC (direct current), which can be converted into AC (alternating current) if necessary. Therefore, although the weather was cloudy, as long as there is a light, then solar power plants can still produce electricity. Solar power plants is essentially a tool that provides power, and can be designed to distribute electricity needs of small to large, either independently, or with the hybrid, either by the method of decentralization (the home of the station) or with a centralized method (electric distributed by cable network).

2.2.1 Main Components of Solar Power Plants

2.2.1.1 Solar Modules

The solar module serves to change the sunlight into electricity direct current, the electric power generated must have a certain voltage corresponding to the required voltage inverter and then the inverter can easily change it into electrical alternating current if necessary. Modular form of solar modules provide ease of electricity to meet the needs of various scale needs. Small needs can be satisfied with a single module or two modules, and large needs can be supplied by even thousands of solar modules are assembled into one.

2.2.1.2 Regulating Device

Regulating device is an electronic device that regulates the flow of electricity from the solar module to the battery and the electric current from the battery to the electrical equipment such as lights, TV or radio. Charge - Discharge controller protects the battery from overcharging and protect from short circuit or excessive current to the input terminal. This device also has several indicators that will provide convenience to Solar Power Plant users by providing information on the condition of the battery so that the user can control the solar power according to the availability of electrical energy consumption contained in the batteries. In addition there are three other indicators that inform the state of charge, the excess charge and charging automatically when the battery is empty.

2.2.1.3 Battery / Accu

Battery function is save electric current generated by the solar module before being used to drive the load. The load can be either lights or electronic equipment and other equipment that require electricity. Battery size spoken is highly dependent on the size of the generator, the size of the solar panel, and load pattern. Battery size that is too big good for the operating efficiency but result in the need for investment is too large, otherwise the battery size is too small can result in the storage of excess power.

2.2.2 Working Principle of Solar Power Plants

By day the solar module receives sunlight which is then converted into electricity through the photovoltaic process. Electricity generated by the module can be directly supplied to the load or stored in batteries before use to load : lights, radio, etc. At night, in which the solar modules do not generate electricity, the load is fully supplied by the battery. Similarly, if the day is cloudy, in which the solar modules generate electricity is lower than when the bright sun. Solar modules with a certain capacity can produce the amount of electricity can vary if placed in different areas. Solar power plants system schematically described as follows :

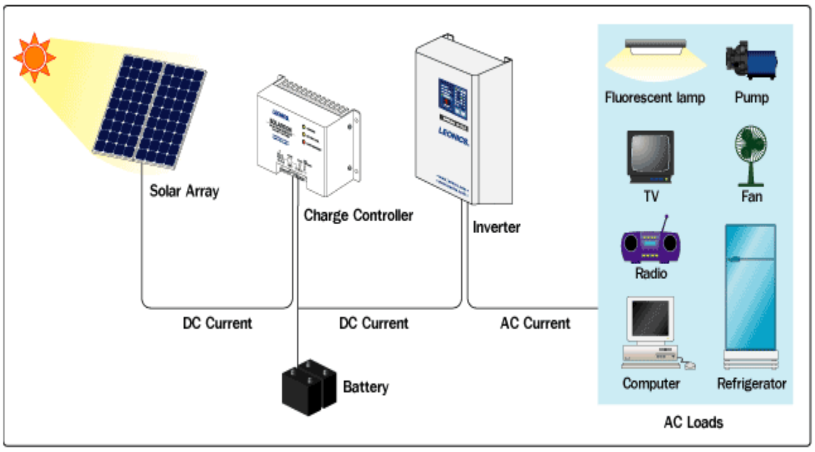

Figure 2.4 Scheme Systems of Solar Power Plants.

Source : http://solarsuryaindonesia.com/info/solar-home-system

2.2.3 Advantages and Disadvantages of Solar Power Plants

The advantages of solar power plants :

- Does not require fuel, since it uses solar energy source that can be obtained anywhere freely throughout the year, so it almost does not require operating costs.
- Does not require the construction of heavy and settled, so it can be installed anywhere and can be moved if needed.

- Can be applied centralization (solar power plants placed in an area and the electricity produced is channeled through the distribution network to places that need) and decentralized (solar power plants system installed at each home, thus not necessary distribution network).
- In the scheme of decentralizatio, disruption in one system will not affect other systems and not much energy is wasted in the distribution network.
- Modular; The resulting electric capacity can be adapted to the needs by assembling the modules in series and parallel.
- Can be operated automatically (unattendable) and using the operator (attendable).
- Environmentally friendly. Not cause noise pollution and smoke pollution.
- There are no moving parts, so it requires almost no maintenance costs, which is required only cleaning module if the dirty and add water batteries (distilled water).
- Life time more than 25 years.

The disadvantages of solar power plants :

- The solar module has a low conversion efficiency compared to other types of plants.
- To work properly, the solar module should be enough to get solar radiation (depending on the season).
- Requires a large area for the installation of solar modules to obtain a high output power.
- The price of solar modules (small scale) are still expensive so the resulting generation cost is also expensive.

2.2.4 Calculation Determination of Total Solar Module

A series of cells in series and parallel is called a module. Usually each module consists of 10-36 units of cells. If the voltage, current and power of a module is not sufficient for load is used, then the modules can be coupled serial, parallel or a combination of both to produce a large voltage and power as needed. A series of modules that are connected in series is called the branch circuit and total modules installed module called by arrangement (array) that consists of a collection of parallel circuit branches.

To obtain a large voltage and power in accordance with the requirements, the photovoltaic cells must be combined in series and parallel, with the following rules [2] :

- To obtain the output voltage that is two times greater than the output voltage of the photovoltaic cell, the two photovoltaic cells must be connected in series.
- To obtain the output current is two times larger than the current output of photovoltaic cells, the two photovoltaic cells must be connected in parallel.
- To obtain the output power is two times greater than the power output of photovoltaic cells with a constant voltage, the two photovoltaic cells must be connected in series and parallel.

2.2.4.1 Determining the Amount Relations Series of Solar Module

Power generator solar modules that have been calculated above should be declared in advance as a provisional calculation results. Generators solar module is a combination of series and parallel relationship solar modules. The next important step is to determine the amount of solar modules to be connected serial and parallel.

The number of series connected modules must be determined by the inverter input voltage, with the following formula [3] :

$$J_S = \frac{V_{INV}}{V_{MF}} \tag{2.1}$$

With :

J_S is number of series solar modules

V_{INV} is inverter input voltage (volts)

V_{MF} is maximum voltage of solar modules (volts)

Numbers J_S must be an integer. When the obtained fractions, then these numbers should be rounded, so obtained [3] :

$$V_{GPV} = J_S * V_{MF} \tag{2.2}$$

With V_{GPV} is a voltage generator solar modules in the Volt.

2.2.4.2 Determining the Amount Relations Parallel Solar Module

A string consists of J_S solar modules in series. To obtain total generator power fotovolatik of P_{GPV}, then the required number of strings, as follows [3] :

$$J_P = \frac{P'_{GPV}}{V_{GPV} * I_{MF}} \tag{2.3}$$

When the obtained fractions, J_P rounded up, the nominal current photovoltaic generator (I_{GPV}) can be calculated later by the following formula :

$$I_{GPV} = J_P * I_{MF} \tag{2.4}$$

Having determined J_S dan J_P, then installed a photovoltaic power generator recalculated using the equation [3] :

$$P_{GPV} = V_{GPV} * I_{GPV} \quad \text{(watt peak)} \tag{2.5}$$

While the amount of the composition of the photovoltaic module (N) installed are :

$$N = J_P * J_S \tag{2.6}$$

With :

J_P	is number of strings of photovoltaic modules
P'_{GPV}	is photovoltaic generator power (watts)
V_{GPV}	is photovoltaic generator voltage (volts)
I_{MF}	is maximum current of photovoltaic modules (ampere)

2.3 Diesel Power Plant

Diesel Power Plant appropriate to be implemented in locations where low fuel spending, water supplies are limited, the oil is very low price compared to coal and all base load is such that can be handled by the engine plant in the small capacity, and can function in a short time. The main usefulness of diesel is a provider of electric power that can serve for the plant, a backup (stand by plant), the peak load and backup for emergency. [4]

Factors that are considered suitable for the diesel option, among others :

- The distance from the load close.
- Inventories areas of land and water.
- The foundation, is not required for the type of mobile diesel power plant.
- Transportation of fuel.
- Noise and environmental difficulties.

2.3.1 Working Principle and Components of Diesel

Main parts of the Diesel is the engine (motor) diesel and a generator. The diesel engine is the internal combustion engine serves to produce mechanical power that is used to rotate the generator rotor. Diesel engines using diesel fuel with high speed, working with the principle of compression combustion and uses two-step rotation in operation, this is used when high-capacity machines.

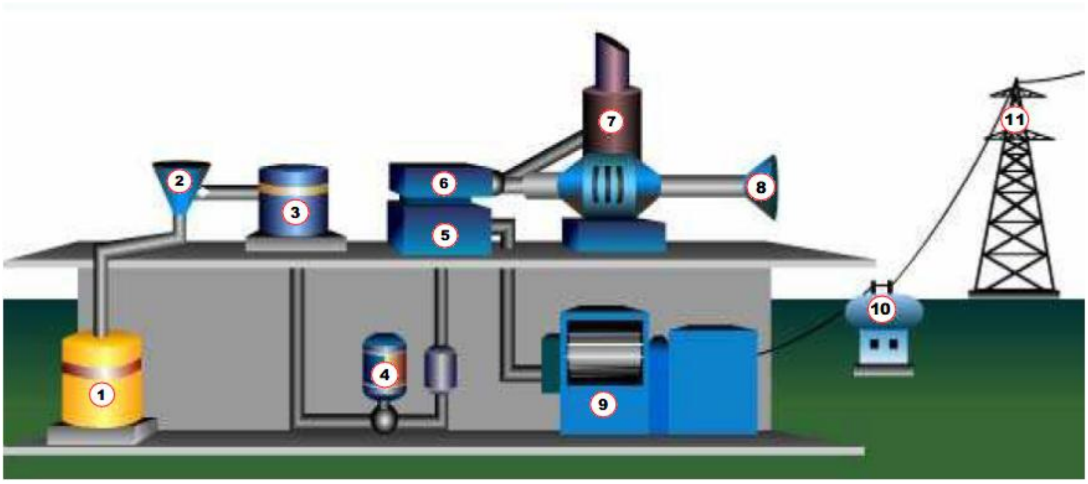

Figure 2.5 Scheme of Diesel Power Plant.

Source : http://www.pln.co.id/InfoUmum/ElectricityEvocation

Component - Component of Diesel (Caption) [5] :

1. *Fuel Tank*
2. *Fuel oil separator*
3. *Daily tank*
4. *Fuel oil booster*

5. *Diesel engine* : Turn on the diesel engine to have the energy to work.
6. *Turbo charger* : To raise the efficiency of the air what mixed with fuel and raising the pressure and temperature.
7. *Air intake filter* : Devices for air flow.
8. *Exhaust gas silincer* : Silencing of residual gas used.
9. *Generator* : Generating electrical energy.
10. *Modifiers main* : The main converters into electric energy.
11. *Transmission line* : The distribution of electrical energy to consumers.

The power generated by diesel engines work specified factors as [4] :

$$P = \frac{P_e * v * i * n}{450000 * a} \tag{2.7}$$

With :

Pe	is effective pressure that works
v	is the volume of a cylinder that can be achieved step
i	is the number of cylinders
n	is rotation per minute or rotational speed machine
a	is 2 to 4 stroke engine types
	worth 1 for machine type 2 step

For type 2 step power output is 2 times the type 4 step, but it kind of step 4 was chosen because of the efficiency of the fuel used is greater. The diesel engine is the internal combustion engine in which the generated power obtained from the combustion of fuel. The power generated will be changed to [4] :

- Power benefits 40 %
- Heat lost to cooling 30 %
- Heat is lost to exhaust 24 %
- Heat lost in the shift, radiation and so on 6 %

2.3.2 Advantages and Disadvantages of Diesel

Diesel as an instant power plant, currently the most widely used as a source of electricity generation. Here are some advantages and disadvantages when using diesel as a source of electricity generation. [6]

2.3.2.1 Advantages when using diesel

- Electrical power is provided in accordance with needs.
- Technically reliable.
- After-sales service is relatively easy to obtain.
- Investment costs ($/kW) is relatively low.

2.3.2.2 Disadvantages when using diesel

- Operating and maintenance costs expensive.
- Requires transportation for supply and storage of fuel.
- Potential air pollution, noise, and odor.
- Requires regular maintenance.
- The operating system is inefficient (wasteful) in low load conditions.

2.4 Hybrid Power Plant

2.4.1 Working Principle of Hybrid Power Plant

Hybrid power plant is a power generation system which combines several types of power generation, in general, between power generation-based fuels with power generation-based renewable energy. A solution to the fuel crisis and the lack of electricity in remote areas, small islands and in urban areas. Generally consists of : solar modules, diesel generator, battery and integrated control equipment. Hybrid power plant goal is to combine the advantages of each plant as well cover the weaknesses of each of the plants to certain conditions, so that the whole system can operate more economically and efficiently. Capable to generating electrical power efficiently in a variety of loading conditions. [6]

In the hybrid system, the diesel generator is a component required to be included in this system to generate power during periods where solar radiation is very low or nonexistent, supply peak load as well as to reduce the size of the array and battery bank. To determine the performance of these hybrid generating system, things to consider include : the use of load characteristics and the characteristics of the power generation in particular with regard to the potential of natural energy that wants to develop following characteristics of the condition of nature itself, like the turn of the day and night, summer and so on.

2.4.2 Operating System of Hybrid Power Plant

The operating system on hybrid power plant divided into three types, namely serial system, switched system, and parallel systems. [6]

2.4.2.1 Serial System of Hybrid Power Plant

2.4.2.1.1 Working Principle of Serial System

All power generating supply DC power into the battery, each component must be equipped with its own charge controller, to ensure reliable operation of this system, generator and inverter must be designed to serve peak load. In this system, a large amount of energy generated is passed through the battery, battery bank cycle to be increased and reduce the efficiency of the system, the electrical power of the generator in DC will converted back to AC before it is supplied to the load, causing significant losses.

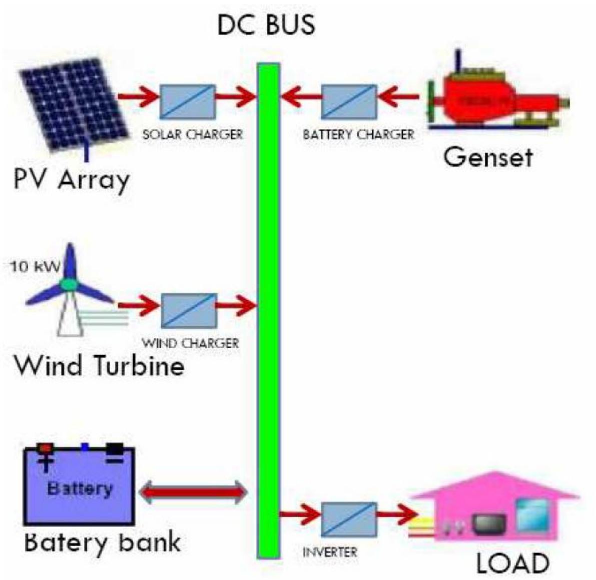

Figure 2.6 Serial System of Hybrid Power Plant.

Source : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

2.4.2.1.2 Advantages of Serial System

This serial system has several advantages, among others :

- Generator can be designed to be loaded optimally, while supplying the load also charge the battery until it reaches the *State of Charge* (SOC) of 70-80%.
- Not required AC switch between energy sources, simplifying the user interface component output, power is supplied to the load is not interrupted when the generator at the start.

2.4.2.1.3 Disadvantages of Serial System

Weakness or loss when using this system are :

- Inverter can not be operated in parallel with the generator, so that the inverter should be designed to supply the peak load.
- Cycles of the battery becomes high, thus reducing battery life, cycle profile requires a large battery bank, to limit the DOD (Depth of Discharge).
- The total efficiency is low, because the generators can not supply the load directly, inverter damage will result in the total loss of power to the load, except the load can be supplied with emergency generators.

2.4.2.2 Switched System of Hybrid Power Plant

2.4.2.2.1 Working Principle of Switched System

On switched system of hybrid power plant, generator and inverter can operate as a source of AC, on systems that do not have a parallel operation, generators and renewable energy sources can charge battery. In this system, the load can be directly supplied by the generator thereby increasing the total efficiency, excess power from the generator can be used to charge the battery, when the load is low, the generator is switched off, the load is supplied from renewable energy along with stored energy.

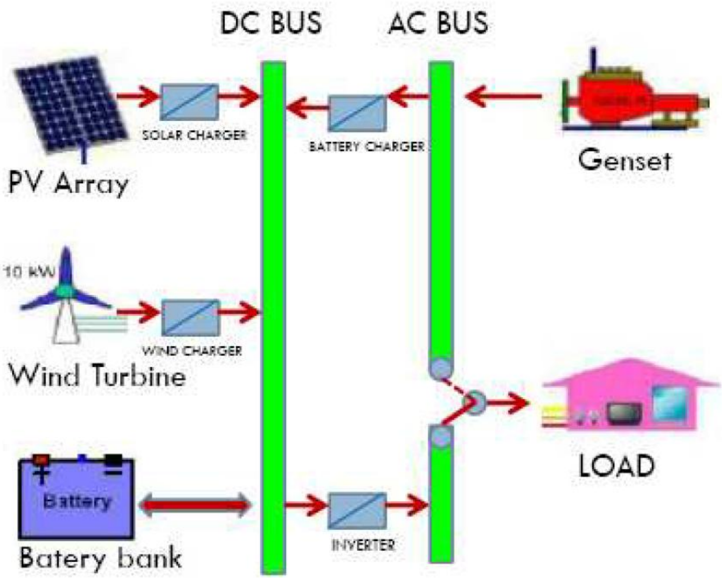

Figure 2.7 Switched System of Hybrid Power Plant.

Sumber : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

2.4.2.2.2 Advantages of Switched System

Advantages that can be obtained when using this system are :

- Inverter can generate a sine wave, a modified box or a box depending on the application.
- Genset can supply the load directly, thereby increasing the total system efficiency and reduce fuel consumption.

2.4.2.2.3 Disadvantages of Switched System

While weakness are :

- Power to the load momentarily interrupted when a transfer of AC power source.
- Generator and inverter designed to be able to supply the peak load, resulting in decreased efficiency at partial load operation.

2.4.2.3 Parallel Systems of Hybrid Power Plant

2.4.2.3.1 Working Principle of Parallel Systems

At hybrid power plant that using this system, the load can be supplied either from the generator and inverter in parallel. *Bi - directional inverter* (BDI) is used to bridge between the battery and the AC source, the BDI can charge the battery of the generator (AC - DC converter) as well as renewable energy sources, can also act as *DCAC converter*, renewable energy source connected to the DC side, the system is divided again into two types of AC Coupling parallel system and DC Coupling parallel system.

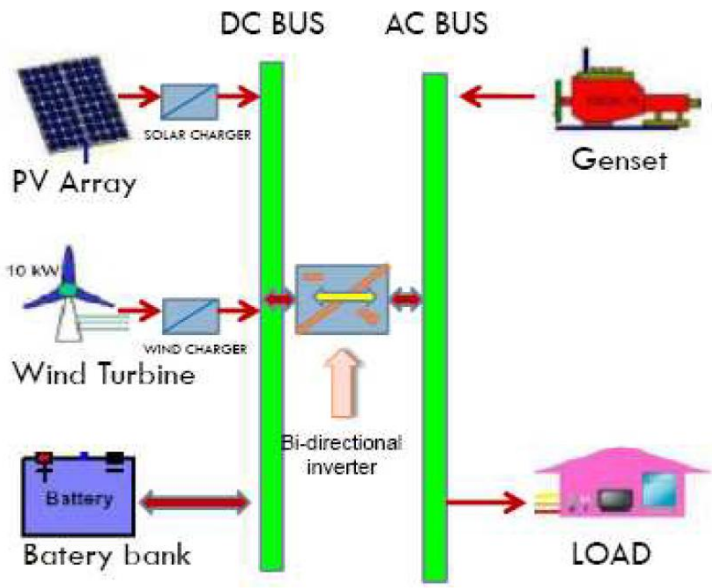

Figure 2.8 Parallel System of Hybrid Power Plant.

Source : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

PHOTOVOLTAIC POWER SYSTEM ANALYZED BY HOMER

CASE STUDY SABU ISLAND

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Project Tittle	Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island
Name	Mr. Akhmad Fatkhur Rizki
Project Advisor	Assistant Professor Boonyang Plangkang, Dr.-Ing.

This project submitted in partial fulfillment of the requirements for the Bachelor Degree in Electrical Engineering.

Surin Ngaemngam .... Head of Electrical Engineering Department

(Assistant Professor Surin Ngaemngam, Ph.D.)

Project Examination Committee

.... Chair person

(Associate Professor Krischonme Bhumkittipich, Ph.D.)

.... Committee

(Assistant Professor Somchai Hiranvarodom, Ph.D.)

Theerapol Muankhaw .... Committee

(Mr. Theerapol Muankhaw)

.... Project advisor

(Assistant Professor Boonyang Plangkang, Dr.-Ing.)

Project Tittle	Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island
Name	Mr. Akhmad Fatkhur Rizki
Program	Electrical Engineering
Project Advisor	Assistant Professor Boonyang Plangkang, Dr.-Ing.
Academic Year	2015

ABSTRACT

Electrical energy is the energy that is needed, in which electrical energy is a primary need in this era of globalization. Meeting the needs of today's society electricity not only rely on the power source of conventional power plants, but many take advantage of the available natural resources, such as water, wind, and sunlight (solar). Solar Power Plant is a power generation system based on renewable energy. Its main purpose to save fuel and reduce emissions mainly CO_2. In this project, photovoltaic power system will be analyze for isolated island that is still little use of renewable energy as a source of electrical energy. It is very suitable to be applied in a country that has many isolated islands such as in Indonesia.

Solar Power Plant system as a whole is a multi-variable system that used the help of the software, in this case HOMER version 2.68. This software optimize based on the value of the lowest NPC. With the Solar Power Plant optimization case study on Sabu Island East Nusa Tenggara province, integrated with Diesel Generator.

Aided simulation and optimization results HOMER software show that overall optimum system to be implemented in the study area above is the integration between Solar Power Plant and Diesel Generator. At the optimum conditions, the optimal Hybrid system is a combination of PV and 2 Diesel Generator. PV contribution towards Hybrid system by 66 % while Diesel Generator by 34 % with Net Present Cost (NPC) of $ 7,374,541, the cost of generating electricity (Cost of Electricity, COE) for $ 0.34 per kWh, fuel consumption by 536,732 liters per year, CO_2 emissions generated by the system at 1,413,392 kg per year or reduced by 41.86%, the excess energy during a year amounted to 2,388,366 kWh.

Keywords : Solar Power Plant, Diesel Generator, HOMER, Simulation, NPC.

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Alhamdulillahirobbil'alamin, Praise is merely to the Almighty Allah SWT for the gracious mercy and blessing that enables me to accomplish this bachelor project entitled: Photovoltaic Power System Analyzed by HOMER Case Study Sabu Island. This bachelor project is presented to fulfill one of the requirements in accomplishing Bachelor degree in Electrical Engineering.

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I realize that this project has not been perfect, both in terms of material and presentation. For that advice and constructive criticism is expected in the completion of this project.

I hope that this project can give benefits and add insight to the reader, especially for the author too.

Pathumthani, June 2015

The Author

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CHAPTER 1

INTRODUCTION

1.1 Photovoltaic System by Homer Energy

Electrical energy is the energy that is needed, in which electrical energy is a primary need in this era of globalization. Almost all human activities related to electricity. Along with the economic growth and the increase in the population of Indonesia, the demand for electricity is also increasing. Meeting the needs of today's society electricity not only rely on the power source of conventional power plants, but many take advantage of the available natural resources, such as water, wind, and sunlight (solar).

The geographical position of Indonesia is located on the equator and the sun shines all year round, it is appropriate to apply the principles and utilize the abundant solar energy and the amount will not be endless. The energy released by the sun to the earth is 20,000 times the energy needed worldwide. As we can see that Indonesia has daily solar radiation average of 4.8 kWh / m2 with the largest energy potential lies Eastern Indonesian region. Based on the map of solar energy in Indonesia, all Indonesian has a good potential for the development of a Solar Power Plant.

East Nusa Tenggara is an area that has great potential for renewable energy, especially solar. In the East Nusa Tenggara Province source of electrical energy virtually all depends on the Diesel Power Plant is about 99.4% in 2009 which is managed by PLN Persero to the level of electrification ratio in 2009 was 22.53%. Sabu Island is an island in East Nusa Tenggara Province, an area of 4.73499 million ha of land spread over 1,192 islands (43 inhabited islands and 1,149 islands are not inhabited). Most of the area is mountainous and hilly, few lowland.

Appropriate government programs in terms of energy saving and for diesel produce a lot of CO_2 emissions, then the supply of electrical energy as possible cultivated utilizing renewable energy sources local (Sabu Island), in this case solar energy. Therefore in need of an analysis to determine optimizing plant design to be optimized and profitable. With advances in technology many ways you can do one of them is using a software. HOMER is a software created to determine optimizing the design of renewable energy, particularly solar energy.

1.2 Objective and Purpose of the Study

The objective and purpose of developing this project are :

1.2.1 Designing a model of Solar Power Plant systems based on natural potentials Sabu Island, East Nusa Tenggara.

1.2.2 Knowing the optimization of the construction and operation of Solar Power Plant and Diesel Generators.

1.2.3 Analyze the results of the simulation, the energy generated by Solar Power, and the percentage contribution of Solar Power.

1.2.4 As a reference in the construction of Solar Power and Diesel Generators.

1.3 Scope of Limitation

The Scope of this project are :

1.3.1 Homer simulation using software version 2.68 Beta.

1.3.2 Load counts is the actual burden borne by the diesel in accordance with the daily load curve Sabu Island. Daily load data is data that is used daily load in 2015.

1.3.3 Load used in this simulation in one year is assumed to be constant.

1.3.4 Discussion of the working principle of Solar Power and Diesel are discussed in general.

1.3.5 Main Power Plant is Diesel, while other Power Plant will be integrated is Solar Power Plant.

1.3.6 Case only be seen in the study area is Sabu Island, East Nusa Tenggara.

1.3.7 All prices of components in April 2015 were obtained from the website of each component.

1.4 Benefits of Project

The Benefits of project are :

1.4.1 Knowing about the design of Solar Power Plant system to be applied in the real condition.

1.4.2 To maximize the utilization of Solar Power Plant system.

1.4.3 To introduce HOMER to the people and knowing about simulate for Solar Power Plant by using HOMER.

CHAPTER 2

BASIC THEORY

2.1 Basic Principles

Hybrid Power Plant is a power generation system that combines several types of power plants, in general between fuel-based power plants with renewable energy-based power plants. Generally the generation systems are widely used for hybrid power plant is a diesel generator, solar power plants, micro-hydro, wind power plants. In this study, hybrid power plant consists of diesel generator and solar power plants. Both types of these plants are operated simultaneously and connected on one rail (busbar) to carry the load .

Contribution of solar power plants at any time is not fixed, given solar power plants is highly dependent on natural conditions. During the day, when the weather is sunny , solar power plants can operate optimally and at night solar power plants not operating at all, but was replaced by a battery that stores electrical energy from solar power during the day. The next generation , diesel generator is instant plant to be fully operational for 24 hours. However, in accordance with the purpose of the operation of diesel power plant, which save fuel and reduce CO_2 emissions , the operation of the diesel is the last variable that follows the change in power supply of solar power plants, so that its contribution was depend on the power supply of the solar power plants. With the integrated operation of the solar power plants on hybrid power plant, then fuel consumption and CO_2 emissions can be reduced.

In principle, a review of the contribution of each power plant in hybrid power plant be reviewed at any time, however a review of the operation of types of power plants, especially diesel generator, may also be reviewed by the cost of fuel oil and other components of operating costs and maintenance costs should be done.

Utilization of the hybrid energy system has several advantages such as [1] :

1. More efficient operation at any time of its generation system.
2. Generation efficiency becomes higher.
3. Easily integrated with any renewable energy system.
4. The availability and continuity of service is very high.
5. Low maintenance level and operators does not need to care and repair.

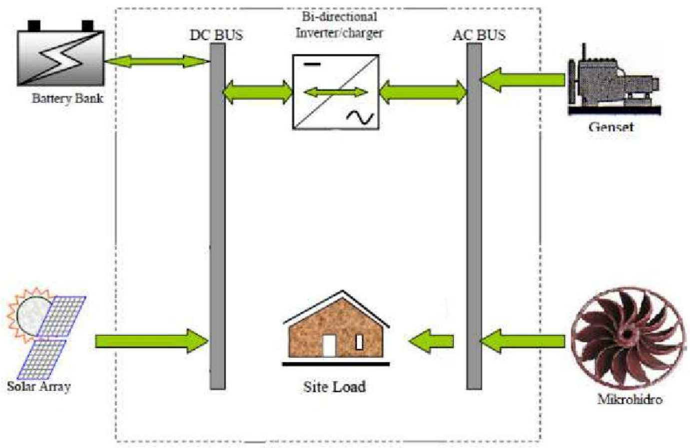

Figure 2.1 Schematic Hybrid Power Plant.

Configuration a hybrid power plant as seen above which includes several main components, that are :

a. *PV Array*, is a combination of several solar panels that are arranged in series and parallel to produce a certain voltage value with a desired power. Total energy generated from the PV array depends on :
   - Total solar panels installed or total watts peak module.
   - The intensity of the sun (*kw / m2 / day*) in place that will be installed.
b. *Diesel Generator*, necessary as a combination of energy to be able to supply power to service the load, especially during peak load or if the conditions of the energy stored in the battery is on the lower level.
c. *Battery Bank* or the battery circuit is part of the hybrid power plant whose function is to store energy derived from solar panels.
d. *Bi-Directional inverter*, is a bi-directional converter that is changing the DC voltage from the battery into AC voltage or vice versa from AC to DC for charging the energy system into a battery.

2.2 Solar Power Plant

Solar Power Plant is a power generation technology that converts photons from the solar energy into electrical energy. This conversion is performed on solar panels comprising photovoltaic cells. These cells are thin layer of pure silicon (Si) or other semiconductor materials are processed in such a way, so that when the material is energized photons will excite the electrons from their atomic bonds into electrons move freely, and ultimately will issue an electric voltage direct current. [2]

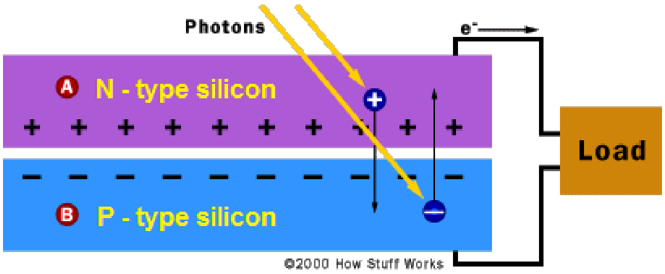

Figure 2.2 Electrical Energy Conversion Process On Solar Panels.

Source : http://www.solarbotics.net/200202_solar_cell_physics.html

By day the solar module receives sunlight which is then converted into electricity through the photovoltaic process. Electricity generated by the module can be directly supplied to the load or stored in batteries before use to load. At night, in which the solar modules do not generate electricity, the load is fully supplied by the battery. Similarly, if the day is cloudy, in which the solar modules generate electricity is lower than when the sun bright. Solar modules with a certain capacity can produce the amount of electricity can vary if placed in different areas.

(a) (b)

Figure 2.3 (a) Decentralized Solar Power Plants. (b) Centralized Solar Power Plants.

Source : (a) http://www.solarpowerplant.co.in/ (b) http://www.anekaciptaselaras.co.id/

Solar power plants use sunlight to generate electricity DC (direct current), which can be converted into AC (alternating current) if necessary. Therefore, although the weather was cloudy, as long as there is a light, then solar power plants can still produce electricity. Solar power plants is essentially a tool that provides power, and can be designed to distribute electricity needs of small to large, either independently, or with the hybrid, either by the method of decentralization (the home of the station) or with a centralized method (electric distributed by cable network).

2.2.1 Main Components of Solar Power Plants

2.2.1.1 Solar Modules

The solar module serves to change the sunlight into electricity direct current, the electric power generated must have a certain voltage corresponding to the required voltage inverter and then the inverter can easily change it into electrical alternating current if necessary. Modular form of solar modules provide ease of electricity to meet the needs of various scale needs. Small needs can be satisfied with a single module or two modules, and large needs can be supplied by even thousands of solar modules are assembled into one.

2.2.1.2 Regulating Device

Regulating device is an electronic device that regulates the flow of electricity from the solar module to the battery and the electric current from the battery to the electrical equipment such as lights, TV or radio. Charge - Discharge controller protects the battery from overcharging and protect from short circuit or excessive current to the input terminal. This device also has several indicators that will provide convenience to Solar Power Plant users by providing information on the condition of the battery so that the user can control the solar power according to the availability of electrical energy consumption contained in the batteries. In addition there are three other indicators that inform the state of charge, the excess charge and charging automatically when the battery is empty.

2.2.1.3 Battery / Accu

Battery function is save electric current generated by the solar module before being used to drive the load. The load can be either lights or electronic equipment and other equipment that require electricity. Battery size spoken is highly dependent on the size of the generator, the size of the solar panel, and load pattern. Battery size that is too big good for the operating efficiency but result in the need for investment is too large, otherwise the battery size is too small can result in the storage of excess power.

2.2.2 Working Principle of Solar Power Plants

By day the solar module receives sunlight which is then converted into electricity through the photovoltaic process. Electricity generated by the module can be directly supplied to the load or stored in batteries before use to load : lights, radio, etc. At night, in which the solar modules do not generate electricity, the load is fully supplied by the battery. Similarly, if the day is cloudy, in which the solar modules generate electricity is lower than when the bright sun. Solar modules with a certain capacity can produce the amount of electricity can vary if placed in different areas. Solar power plants system schematically described as follows :

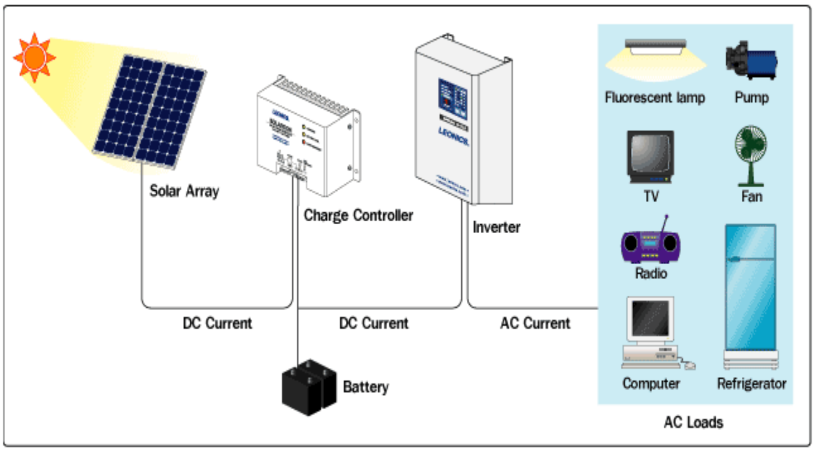

Figure 2.4 Scheme Systems of Solar Power Plants.

Source : http://solarsuryaindonesia.com/info/solar-home-system

2.2.3 Advantages and Disadvantages of Solar Power Plants

The advantages of solar power plants :

- Does not require fuel, since it uses solar energy source that can be obtained anywhere freely throughout the year, so it almost does not require operating costs.
- Does not require the construction of heavy and settled, so it can be installed anywhere and can be moved if needed.

- Can be applied centralization (solar power plants placed in an area and the electricity produced is channeled through the distribution network to places that need) and decentralized (solar power plants system installed at each home, thus not necessary distribution network).
- In the scheme of decentralizatio, disruption in one system will not affect other systems and not much energy is wasted in the distribution network.
- Modular; The resulting electric capacity can be adapted to the needs by assembling the modules in series and parallel.
- Can be operated automatically (unattendable) and using the operator (attendable).
- Environmentally friendly. Not cause noise pollution and smoke pollution.
- There are no moving parts, so it requires almost no maintenance costs, which is required only cleaning module if the dirty and add water batteries (distilled water).
- Life time more than 25 years.

The disadvantages of solar power plants :

- The solar module has a low conversion efficiency compared to other types of plants.
- To work properly, the solar module should be enough to get solar radiation (depending on the season).
- Requires a large area for the installation of solar modules to obtain a high output power.
- The price of solar modules (small scale) are still expensive so the resulting generation cost is also expensive.

2.2.4 Calculation Determination of Total Solar Module

A series of cells in series and parallel is called a module. Usually each module consists of 10-36 units of cells. If the voltage, current and power of a module is not sufficient for load is used, then the modules can be coupled serial, parallel or a combination of both to produce a large voltage and power as needed. A series of modules that are connected in series is called the branch circuit and total modules installed module called by arrangement (array) that consists of a collection of parallel circuit branches.

To obtain a large voltage and power in accordance with the requirements, the photovoltaic cells must be combined in series and parallel, with the following rules [2] :

- To obtain the output voltage that is two times greater than the output voltage of the photovoltaic cell, the two photovoltaic cells must be connected in series.
- To obtain the output current is two times larger than the current output of photovoltaic cells, the two photovoltaic cells must be connected in parallel.
- To obtain the output power is two times greater than the power output of photovoltaic cells with a constant voltage, the two photovoltaic cells must be connected in series and parallel.

2.2.4.1 Determining the Amount Relations Series of Solar Module

Power generator solar modules that have been calculated above should be declared in advance as a provisional calculation results. Generators solar module is a combination of series and parallel relationship solar modules. The next important step is to determine the amount of solar modules to be connected serial and parallel.

The number of series connected modules must be determined by the inverter input voltage, with the following formula [3] :

$$J_S = \frac{V_{INV}}{V_{MF}} \tag{2.1}$$

With :

J_S is number of series solar modules

V_{INV} is inverter input voltage (volts)

V_{MF} is maximum voltage of solar modules (volts)

Numbers J_S must be an integer. When the obtained fractions, then these numbers should be rounded, so obtained [3] :

$$V_{GPV} = J_S * V_{MF} \tag{2.2}$$

With V_{GPV} is a voltage generator solar modules in the Volt.

2.2.4.2 Determining the Amount Relations Parallel Solar Module

A string consists of J_S solar modules in series. To obtain total generator power fotovolatik of P_{GPV}, then the required number of strings, as follows [3] :

$$J_P = \frac{P'_{GPV}}{V_{GPV} * I_{MF}} \tag{2.3}$$

When the obtained fractions, J_P rounded up, the nominal current photovoltaic generator (I_{GPV}) can be calculated later by the following formula :

$$I_{GPV} = J_P * I_{MF} \tag{2.4}$$

Having determined J_S dan J_P, then installed a photovoltaic power generator recalculated using the equation [3] :

$$P_{GPV} = V_{GPV} * I_{GPV} \quad \text{(watt peak)} \tag{2.5}$$

While the amount of the composition of the photovoltaic module (N) installed are :

$$N = J_P * J_S \tag{2.6}$$

With :

J_P	is number of strings of photovoltaic modules
P'_{GPV}	is photovoltaic generator power (watts)
V_{GPV}	is photovoltaic generator voltage (volts)
I_{MF}	is maximum current of photovoltaic modules (ampere)

2.3 Diesel Power Plant

Diesel Power Plant appropriate to be implemented in locations where low fuel spending, water supplies are limited, the oil is very low price compared to coal and all base load is such that can be handled by the engine plant in the small capacity, and can function in a short time. The main usefulness of diesel is a provider of electric power that can serve for the plant, a backup (stand by plant), the peak load and backup for emergency. [4]

Factors that are considered suitable for the diesel option, among others :

- The distance from the load close.
- Inventories areas of land and water.
- The foundation, is not required for the type of mobile diesel power plant.
- Transportation of fuel.
- Noise and environmental difficulties.

2.3.1 Working Principle and Components of Diesel

Main parts of the Diesel is the engine (motor) diesel and a generator. The diesel engine is the internal combustion engine serves to produce mechanical power that is used to rotate the generator rotor. Diesel engines using diesel fuel with high speed, working with the principle of compression combustion and uses two-step rotation in operation, this is used when high-capacity machines.

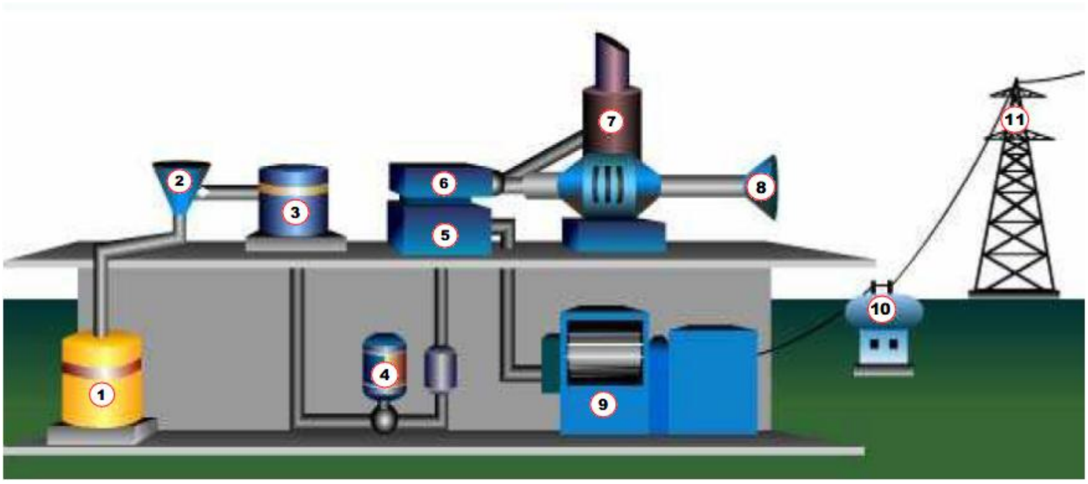

Figure 2.5 Scheme of Diesel Power Plant.

Source : http://www.pln.co.id/InfoUmum/ElectricityEvocation

Component - Component of Diesel (Caption) [5] :

1. *Fuel Tank*
2. *Fuel oil separator*
3. *Daily tank*
4. *Fuel oil booster*

5. *Diesel engine* : Turn on the diesel engine to have the energy to work.
6. *Turbo charger* : To raise the efficiency of the air what mixed with fuel and raising the pressure and temperature.
7. *Air intake filter* : Devices for air flow.
8. *Exhaust gas silincer* : Silencing of residual gas used.
9. *Generator* : Generating electrical energy.
10. *Modifiers main* : The main converters into electric energy.
11. *Transmission line* : The distribution of electrical energy to consumers.

The power generated by diesel engines work specified factors as [4] :

$$P = \frac{P_e * v * i * n}{450000 * a} \tag{2.7}$$

With :

Pe	is effective pressure that works
v	is the volume of a cylinder that can be achieved step
i	is the number of cylinders
n	is rotation per minute or rotational speed machine
a	is 2 to 4 stroke engine types
	worth 1 for machine type 2 step

For type 2 step power output is 2 times the type 4 step, but it kind of step 4 was chosen because of the efficiency of the fuel used is greater. The diesel engine is the internal combustion engine in which the generated power obtained from the combustion of fuel. The power generated will be changed to [4] :

- Power benefits	40 %
- Heat lost to cooling	30 %
- Heat is lost to exhaust	24 %
- Heat lost in the shift, radiation and so on	6 %

2.3.2 Advantages and Disadvantages of Diesel

Diesel as an instant power plant, currently the most widely used as a source of electricity generation. Here are some advantages and disadvantages when using diesel as a source of electricity generation. [6]

2.3.2.1 Advantages when using diesel

- Electrical power is provided in accordance with needs.
- Technically reliable.
- After-sales service is relatively easy to obtain.
- Investment costs ($/kW) is relatively low.

2.3.2.2 Disadvantages when using diesel

- Operating and maintenance costs expensive.
- Requires transportation for supply and storage of fuel.
- Potential air pollution, noise, and odor.
- Requires regular maintenance.
- The operating system is inefficient (wasteful) in low load conditions.

2.4 Hybrid Power Plant

2.4.1 Working Principle of Hybrid Power Plant

Hybrid power plant is a power generation system which combines several types of power generation, in general, between power generation-based fuels with power generation-based renewable energy. A solution to the fuel crisis and the lack of electricity in remote areas, small islands and in urban areas. Generally consists of : solar modules, diesel generator, battery and integrated control equipment. Hybrid power plant goal is to combine the advantages of each plant as well cover the weaknesses of each of the plants to certain conditions, so that the whole system can operate more economically and efficiently. Capable to generating electrical power efficiently in a variety of loading conditions. [6]

In the hybrid system, the diesel generator is a component required to be included in this system to generate power during periods where solar radiation is very low or nonexistent, supply peak load as well as to reduce the size of the array and battery bank. To determine the performance of these hybrid generating system, things to consider include : the use of load characteristics and the characteristics of the power generation in particular with regard to the potential of natural energy that wants to develop following characteristics of the condition of nature itself, like the turn of the day and night, summer and so on.

2.4.2 Operating System of Hybrid Power Plant

The operating system on hybrid power plant divided into three types, namely serial system, switched system, and parallel systems. [6]

2.4.2.1 Serial System of Hybrid Power Plant

2.4.2.1.1 Working Principle of Serial System

All power generating supply DC power into the battery, each component must be equipped with its own charge controller, to ensure reliable operation of this system, generator and inverter must be designed to serve peak load. In this system, a large amount of energy generated is passed through the battery, battery bank cycle to be increased and reduce the efficiency of the system, the electrical power of the generator in DC will converted back to AC before it is supplied to the load, causing significant losses.

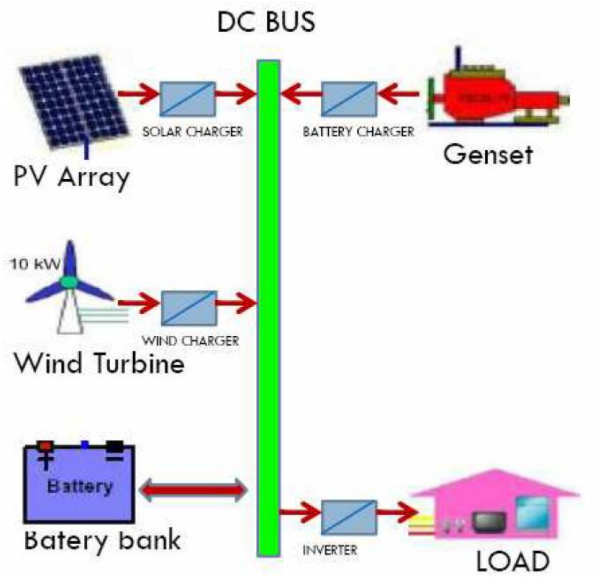

Figure 2.6 Serial System of Hybrid Power Plant.

Source : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

2.4.2.1.2 Advantages of Serial System

This serial system has several advantages, among others :

- Generator can be designed to be loaded optimally, while supplying the load also charge the battery until it reaches the *State of Charge* (SOC) of 70-80%.
- Not required AC switch between energy sources, simplifying the user interface component output, power is supplied to the load is not interrupted when the generator at the start.

2.4.2.1.3 Disadvantages of Serial System

Weakness or loss when using this system are :

- Inverter can not be operated in parallel with the generator, so that the inverter should be designed to supply the peak load.
- Cycles of the battery becomes high, thus reducing battery life, cycle profile requires a large battery bank, to limit the DOD (Depth of Discharge).
- The total efficiency is low, because the generators can not supply the load directly, inverter damage will result in the total loss of power to the load, except the load can be supplied with emergency generators.

2.4.2.2 Switched System of Hybrid Power Plant

2.4.2.2.1 Working Principle of Switched System

On switched system of hybrid power plant, generator and inverter can operate as a source of AC, on systems that do not have a parallel operation, generators and renewable energy sources can charge battery. In this system, the load can be directly supplied by the generator thereby increasing the total efficiency, excess power from the generator can be used to charge the battery, when the load is low, the generator is switched off, the load is supplied from renewable energy along with stored energy.

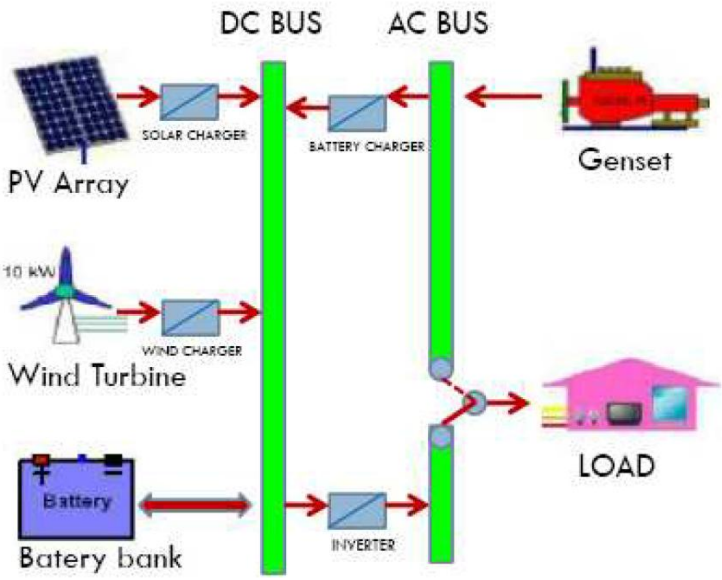

Figure 2.7 Switched System of Hybrid Power Plant.

Sumber : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

2.4.2.2.2 Advantages of Switched System

Advantages that can be obtained when using this system are :

- Inverter can generate a sine wave, a modified box or a box depending on the application.
- Genset can supply the load directly, thereby increasing the total system efficiency and reduce fuel consumption.

2.4.2.2.3 Disadvantages of Switched System

While weakness are :

- Power to the load momentarily interrupted when a transfer of AC power source.
- Generator and inverter designed to be able to supply the peak load, resulting in decreased efficiency at partial load operation.

2.4.2.3 Parallel Systems of Hybrid Power Plant

2.4.2.3.1 Working Principle of Parallel Systems

At hybrid power plant that using this system, the load can be supplied either from the generator and inverter in parallel. *Bi - directional inverter* (BDI) is used to bridge between the battery and the AC source, the BDI can charge the battery of the generator (AC - DC converter) as well as renewable energy sources, can also act as *DCAC converter*, renewable energy source connected to the DC side, the system is divided again into two types of AC Coupling parallel system and DC Coupling parallel system.

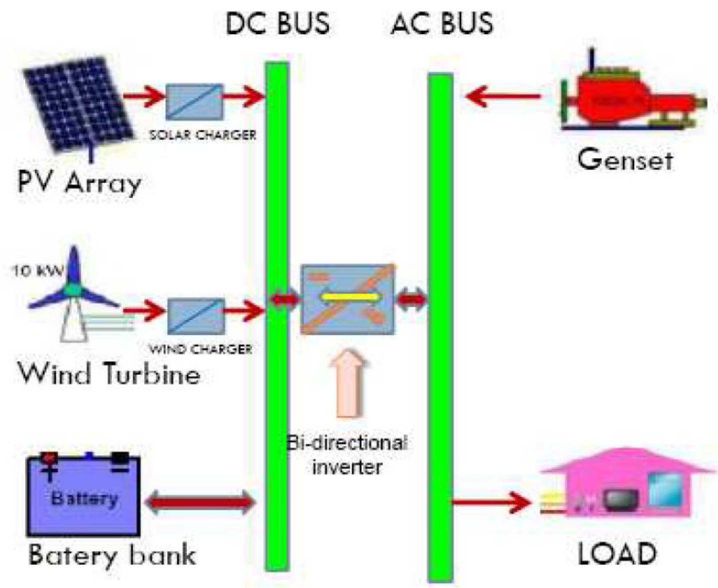

Figure 2.8 Parallel System of Hybrid Power Plant.

Source : Rosyid, A., (2008) PLTH Wini. Balai Besar Teknologi Energi – BPPT. Tangerang

CHAPTER 3

DESIGN SYSTEM AND INSTALLATION

3.1 Geography and Administrative Conditions

Sabu Raijua regency located between 10°25'7.12" - 10°49'54.83" South Latitude and between 121°16'10.78" - 122°0'36.26" East Longitude. Sabu island located in the middle of the Sabu Sea and is located between the islands of Sumba and Rote. The regency boundaries are as North, East and West with Sabu Sea and the Indian Ocean in the south. Sabu Island is an area of 460.47 km² with a length beach of 1,026.36 km. The average height of the territories in Sabu Raijua currently on 0 - 100 meters above sea level. The dominant soil types in the area of Sabu Raijua is Alluvial, Grumosol, Litosol, and the Mediterranean with fine to coarse soil texture. In addition, there are also limestone mountains that stretches along the region's districts. [7]

According to topography, surface area of Sabu Raijua mostly composed of limestone hills that are less fertile and average slope of 45 degrees with some towering peaks, but typically no more than about 250 meters [8]. Climatic conditions on the Sabu island influenced its location adjacent to the continent of Australia. Hence this island has characteristics with a long dry season ranged between 7 - 8 months and with low rainfall. In a year just 14 - 69 days of the rainy season, that short rainy season only happens in December to March. [9]

Figure 3.1 Location Map Sabu Island.

Source: Google maps (2015)

Compared to other small islands located in East Nusa Tenggara province, located of Sabu island is quite remote and have the furthest distance to the islands around it, such as to Sumba, Rote and Flores islands. This condition causes the sea freight transportation modes most important role for Sabu Raijua society to connect with other islands in the East Nusa Tenggara province. Sabu Raijua have topographical conditions of the region with mountainous and hilly. Soil surface bare and critical so sensitive to erosion. This topography raises physical isolation, economic isolation and social isolation, especially by the lack of support infrastructure such as roads and bridges in various subdistricts. While transportation to certain islands often rather expensive because low frequency of the means of transportation to several islands, where it is certainly also affect the prices of goods and services in the district. [8]

3.2 Meteorological Conditions and Electricity

Sabu Island meteorological conditions are not so different from the meteorological conditions surrounding islands. The wind blowing around the Sabu island is a season wind that changed direction twice a year with an average speed of 3 - 7 m / sec. The average rainfall around of Sabu island is 123.35 mm with the number of rainy days 9 times. The average monthly temperature of 31.47°C with the maximum and minimum temperature difference of 7.43°C. [7]

3.2.1 Potential Solar Radiation

The data that HOMER necessary to carry out power generation system optimization is the clearness index and daily radiation (kWh / m2 / day) for one year on the Sabu island. Data of Clearness Index and Solar Radiation is a global average solar radiation on a horizontal surface, expressed in kWh / m2, for every day of the year. Clearness Index Average is 0,655 and Average Daily Radiation for Sabu Island is 6,466 kWh / m2 / day. Data source can be obtained by direct measurement or through HOMER assistance that will connect the satellite to NASA through an internet connection by providing the latitude and longitude of the study location [10]. The following image is clearness index data and daily radiation.

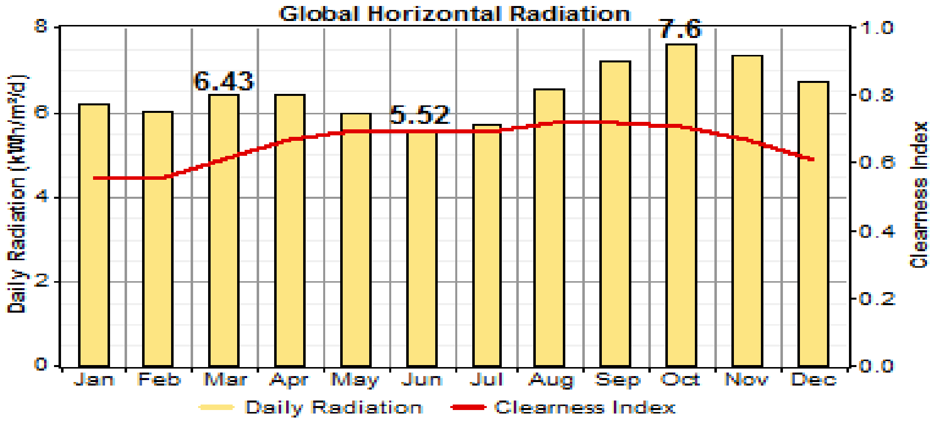

Figure 3.2 Clearness Index and Solar Radiation.

Source: http://eosweb.larc.nasa.gov. (2015)

3.2.2 Electrical Conditions

The demand for electricity on the Sabu island assumed only supplied by Diesel Generator throughout the day with a peak load of 1 MW. If there is a maintenance and repair on one of the machines will be replaced by a spare machine available. Sabu island including remote island, had to use Ferry boats to reach, this led to the supply of fuels including diesel fuel are scarce so the price becomes very expensive. Sabu Island Hybris Power Plant models will be simulated with a daily load curves and deferrable loads. The main load data in the form of daily load data are assumed to be on the Sabu island obtained under the Electricity Supply Business Plan of PT. PLN Persero (State Electricity Company). While the deferrable load data is pump load assumed to be added to the Hybrid Power Plant system.

3.2.2.1 Daily Load

The main load is assumed to be a load for household consumption, which mostly is lighting, TV, and others. The load daily average for Sabu Island is 5.6 MWh / day with peak load of 1 MW occurred at 18:00 p.m. to 19:00 p.m. [11]

The data used is based on data obtained from PT. PLN (State Electricity Company) is daily load data assumed for a full day, the following image is a daily load curve predicted in accordance with the needs of the population on the Sabu island.

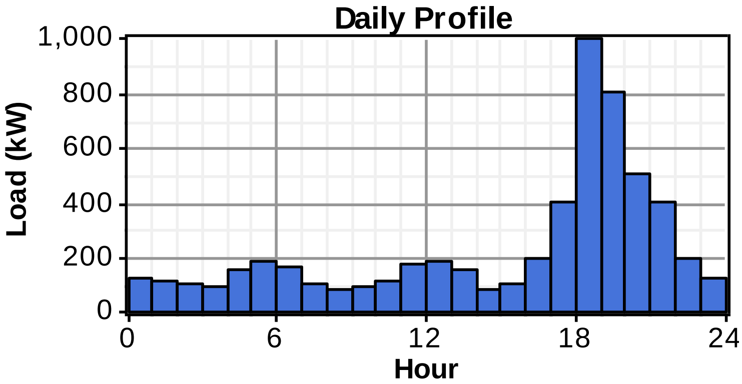

Figure 3.3 Daily Load Curve.

Source: HOMER, NREL

3.2.2.2 Deferrable Load

To meet the water consumption and other purposes, it is assumed that the pump is added as a sidetracked load on Hybrid Power Plant system design. Due to the 88.9% of the households on the Sabu island still use wells as a source of clean water [7]. This load is in the form of a water pump with a peak load of 400 watts operating for 6 hours per day. With the comparison limit of minimum load is 50%, the average pump energy consumed per day to fill the tank of 2.4 kWh / day with a total tank capacity of 4.8 kWh. The following image is a pump load profile as an sidetracked load.

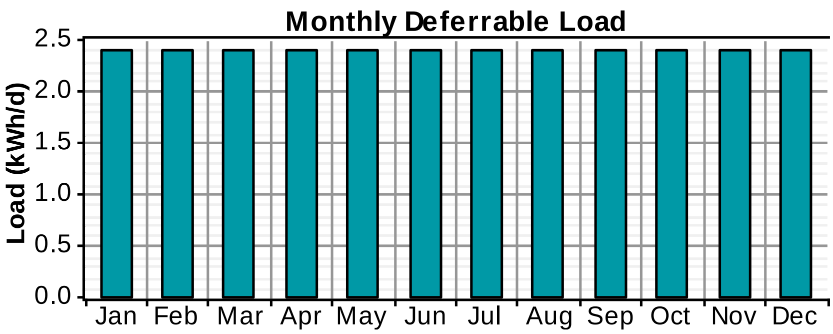

Figure 3.4 Monthly Load Pumps.

Source: HOMER, NREL

3.3 HOMER Software

HOMER software is a software used to optimize the model of small-scale power generation system (micropower), this software makes it easy to evaluate the design of power systems for various types of small-scale power plants either are connected to the power grid or not. The software performs these energy balance calculations for each system configuration that will be considered. Then determine the proper configuration, is able to meet the demand for electricity under defined conditions, the estimated cost of installing and operating the system during the project period. Cost calculation system such as capital costs, replacement, operation and maintenance, fuel, and interest rate. [12]

The software works by three main steps, that are simulation, optimization and sensitivity analysis :

3.3.1 Simulation

Homer can simulate a wide variety of micropower system configurations, comprising any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac-dc converter, an electrolyzer and a hydrogen storage tank. The system can be grid-connected or standalone and can serve ac and dc electric loads and a thermal load.

The software will simulate the operation of Hybrid Power Plant system by making energy balance calculations for 8,760 hours in a year. For each hour, HOMER compares to the electricity needs of the energy system can supply in that hour, and calculate the energy that flows from and to every component of the system. For systems that include batteries or fuel - powered generators, HOMER also decides operating time generator, whether to charge or discharge the battery.

3.3.2 Optimization

After simulated, the next step is to optimize all possible system configurations then sorted based on NPC (Net Present Cost) that can be used to compare system design options. Finding the optimal system configuration may involve; deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use.

3.3.3 Sensitivity Analysis

In a sensitivity analysis, the HOMER user enters a range of values for a single input variable. A variable for which the user has entered multiple values is called a sensitivity variable.

Almost every numerical input variable in HOMER that is not a decision variable can be a sensitivity variable. Examples include the grid power price, the fuel price, the interest rate, or the lifetime of the PV array. When the sensitivity variables are added, HOMER repeats the optimization process for each sensitivity variables that determine. For example, if the wind speed is set as a sensitivity variable, HOMER will simulate system configurations for various wind speeds have been set.

The advantages of this software is easy to use, can simulate, optimize a model then can automatically find the optimum system configuration that can supply the load with the lowest cost (NPC), and can use the parameter sensitivity for better results.

The disadvantage of this software is its main output in the form of economic parameters (NPC, COE) instead of a detailed model of the system, and some renewable energy technologies still can not be simulated by this software.

3.3.4 Calculation of Data

The following equations are used as the basis for the calculation of the energy supplied by renewable energy generation, battery charge and discharge batteries as well as the calculation of the Total Net Present Cost (TNPC). [12]

Power Equation Solar Power Plant.

$$Ppv = \eta w * \eta g * Npvp * Npvs * Vpv * Ipv \quad (3.1)$$

Total Power Equation Renewable Power Plant.

$$P(t) = \sum_{w=1}^{\eta w} Pw + \sum_{s=1}^{\eta s} Ps \quad (3.2)$$

Battery Discharging Equation.

$$Pb(t) = Pb\,(t-1) * (1 - \sigma) - \left[\frac{Pbh(t)}{\eta bi} - Pbi(t)\right] \quad (3.3)$$

Battery Charging Equation.

$$Pb(t) = Pb\,(t-1) * (1 - \sigma)\left[\frac{Pbh(t) - Pbi(t)}{\eta bi}\right] * \eta bb \quad (3.4)$$

With :

Ipv	is current PV panel
Pb	is the energy of the battery in the time interval
Pbh	is the total energy generated by the PV array
σ	is a factor of its own battery discharge
Pbi	total load on the time interval
ηbb	efficiency battery

3.3.4.1 Total Net Present Cost

Total Net Present Cost (NPC) is the most important economic output for the value of a Hybrid Power Plant system, HOMER will sort the data output of the simulation and optimization based on the lowest value of NPC. Total NPC can be calculated using the following equation :

$$CNPC = \frac{Cann,tot}{CRF(i,Rproj)} \quad (3.5)$$

With :

Cann,tot	is the total annual cost ($ / year)
CRF( )	is a factor of closing capital
i	is the interest rate (%)
Rproj	is the length of time a project
N	is the number of years

While the closure of the capital factor can be obtained by using the following formula :

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \quad (3.6)$$

3.3.4.2 Levelized Cost of Energy

Levelized Cost of Energy (COE) is defined as the average cost per kWh of electricity production in use by the system. To calculate the COE, annual electric energy production costs divided by the total electrical energy use is produced, by the following equation :

$$COE = \frac{Cann,tot - Cboiler\ Etermal}{Eprim,AC + Eprim,DC + Edef + Egrid,sales} \quad (3.7)$$

With :

Cann,tot	is the annual cost of the total system ($ / year)
Cboiler	is margin boiler costs ($ / kWh)
Ethermal	is the total thermal load that fulfilled (kWh / year)
Eprim,AC	is the main AC load that fulfilled (kWh / year)
Eprim,DC	is the main DC load that fulfilled (kWh / year)
Edef	is deferrable loads that fulfilled (kWh / year)
Egrid,sales	is the total sales of the grid (kWh / year)

3.3.4.3 Calculation of Emissions

HOMER uses the following formula to calculate the emissions penalty of Hybrid Power Plant system.

$$Cemisi = \frac{c_{co_2}M_{co_2} + c_{co}M_{co} + c_{UHC}M_{UHC} + c_{PM}M_{PM} + c_{So_2}M_{So_2} + c_{Nox}M_{Nox}}{1000} \quad (3.8)$$

With :

c_{co_2}	CO_2 emissions penalty ($ / ton)
c_{co}	CO emissions penalty ($ / ton)
c_{UHC}	UHC emissions penalty ($ / ton)
c_{PM}	PM emissions penalty ($ / ton)
c_{So_2}	SO_2 emissions penalty ($ / ton)
c_{Nox}	NOx emissions penalty ($ / ton)
M_{co_2}	CO_2 emissions (kg/year)
M_{co}	CO emissions (kg/year)
M_{UHC}	UHC emissions (kg/year)
M_{PM}	PM emissions (kg/year)
M_{So_2}	SO_2 emissions (kg/year)
M_{Nox}	NOx emissions (kg/year)

3.4 Implementation Study Hybrid Power Plant in Sabu Island

This study uses HOMER help with algorithms as shown in the following figure :

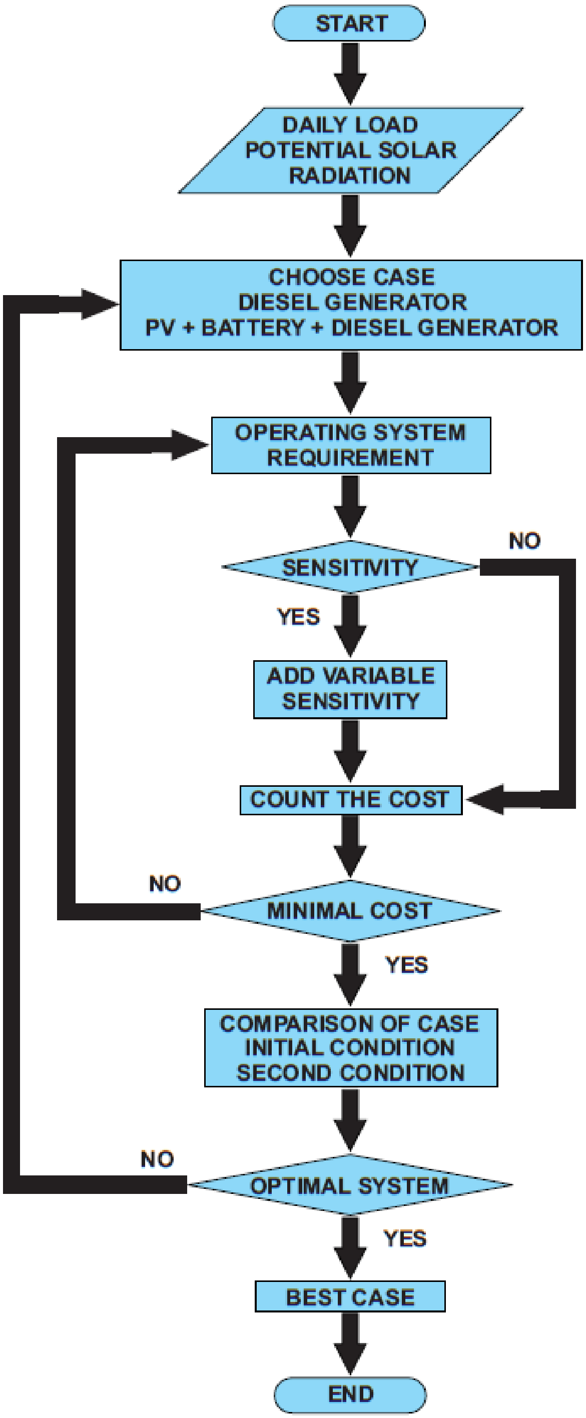

Figure 3.5 Simulation and Optimization Flowchart.

3.4.1 Simulation and Optimization Methods

For design optimization Hybrid Power Plant system is made of two conditions by following the daily load curve, that are :

- The first condition simulation is run to determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.
- The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value and less emissions.

3.4.2 Power Hybrid Models in Sabu Island

Hybrid Power Plant model will be simulated and optimized consists of Solar Panels (Photovoltaic), Diesel Generators, Inverter and Battery. The following image is a model of Hybrid Power Plant which will be simulated and optimized by HOMER.

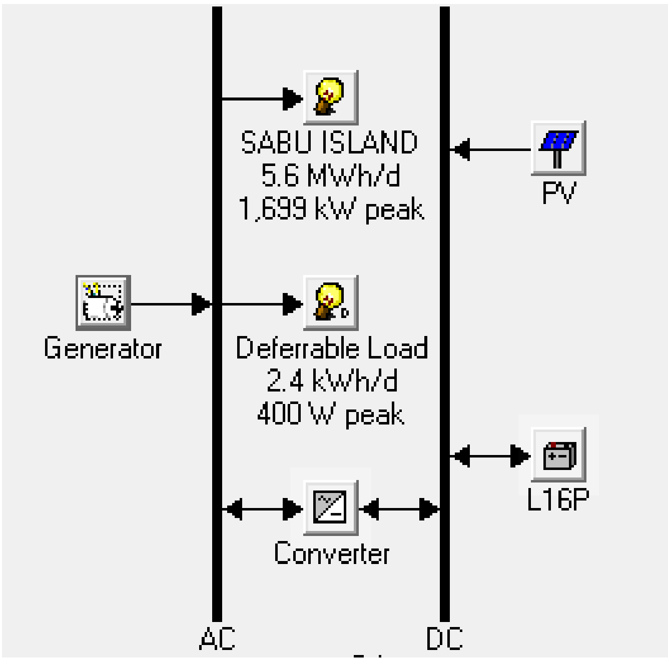

Figure 3.6 Hybrid Power Plant Systems Models.

Source: HOMER, NREL

3.4.2.1 Sizing Each Components of Hybrid System

3.4.2.1.1 Photovoltaics

In order to construct a reliable and long-lasting PV systems an accurate planning is necessary because it implements the economic evaluation during the planning state. Due to the uncertainty of demand prediction and the assumed radiation the energy supply should be basically higher than the energy demand. However, it could sometimes happen that the supply could not meet the demand and the system fails consequently. For this reason, a *quality factor* (*Q*) is commonly used to present how well the supply meets the demand.

Table 3.1: Quality factors of components and different PV systems [28]

Component/System	*Q*
PV module (Crystalline)	0.85…0.95
PV array	0.80…0.90
PV system (Grid-connected)	0.60…0.75
PV system (Stand-alone)	0.10…0.40
Hybrid system (PV/Diesel)	0.40…0.60

The quality factor is defined as the quotient of the real electric output energy measured at the system output (*Eel*), which is normally equivalent to the system load (*Edemand*) and the theoretical output energy (*Eth*), which is defined as the output energy from the same system under ideal conditions, i.e. Standard Test Conditions (STC). With the quality factor formula above and the empirical quality factors of existing systems it is easy to presize the PV array :

$$Ppeak = \frac{E_{el} \cdot I_{STC}}{E_{glob} \cdot Q} \tag{3.9}$$

where:

$Ppeak$ = peak power of the PV array under STC [kW_p]

Eel = real electric output energy of the system [kWh / a]

I_{STC} = incident solar radiation under STC [1 kW / m^2]

Eglob = annual global solar radiation [kWh / m^2a]

Q = quality factor of the system

In the theoretical limiting case, supply and demand values are equivalent and the quality factor is therefore equal to one (Q = 1). A measured value of, for example, Q = 0.75 means that 75 % of the electric energy, which is converted from incident solar energy, is used whereas 25 % of the electric energy is lost between the solar cell and the system output or it is not used.

3.4.2.1.2 Battery

The battery capacity depends on characteristics of radiation, load, and system reliability as well as intention of the user. From experience, the relation between storage capacity [kWh] and peak power [kW_p] of the PV array is more or less 10:1. In case that the global radiation at the site is nearly constant throughout the year, this value will be lower than 10:1. When having a system where the power consumption is mainly during the night this thumb rule must be corrected to the value higher (up to 20 % more) and vice versa when e.g. a wind generator or a diesel generator is integrated into the system.

$$C_B = 10 \cdot Ppeak \tag{3.10}$$

where:

C_B = battery capacity [kWh]

Ppeak = peak power of the PV array [kW_p]

3.4.2.1.3 Inverter

The selection of the stand-alone inverter will be determined especially by the AC power to be provided and the selected DC voltage. A stand-alone inverter must be able to power all of the loads that might run at the same time, including any starting surges for pumps and other large motors. When looking at inverter specifications, play close attention to the part load efficiency of the inverter. Related to the over sizing related to the peak current security the stand alone inverter is mostly running in part load about 10 to 30 % of nominal load.

3.4.3 Hybrid Power Plant Components

The Hybrid Power Plant components consists of Photovoltaic Panels, Diesel Generators, Inverters and Batteries. All prices are used in the simulation is obtained from Internet sites were accessed in April 2015.

3.4.3.1 Solar Modules

The capacity of each solar module is 60 Wp. The price for the 1,500 kWp solar module is $ 1,200,000 [13], the replacement cost $ 1,200,000, operating and maintenance costs are assumed to $ 500 per year, the lifetime of solar modules for 25 years.

Specification data MSX-60 module :

Long	: 43.63 inch
Width	: 19.75 inch
Maximum power (Ppp)	: 60 W
Voltage maximum power (Vpp)	: 17.1 V
Current maximum power (Ipp)	: 3.5 A

3.4.3.2 Diesel Generator

Diesel Generators used 1100 kW with operating time for estimated 15,000 hours and minimum load is 30%. For this Diesel Generator investment cost of $ 180,000 [14], the cost of replacing $ 178,000, operating and maintenance costs of $ 0.72 per day is assumed.

3.4.3.3 Inverter

The inverter used is Bidirectional Inverter (Inverter - Rectifier) with inverter efficiency of 90 %, long time operation 10 years. While Rectifier efficiency is 85 % relative to the inverter capacity by 100 %. The investment costs for Bidirectional inverter to 1,500 kW at $ 450,000 [15], the replacement cost of $ 400,000 and the cost of operation and maintenance is assumed at $ 600 per year.

3.4.3.4 Battery

The batteries used are lead acid battery type L16P, investment costs for this battery of $ 1,992,900 [16], the replacement cost of $ 1,990,000 and annual operating and maintenance costs of $ 200 is assumed to lead acid battery characteristics are as follows :

Nominal capacity	: 360 Ah
Nominal voltage	: 6 V
Efficiency	: 85 %
Minimum state of charge	: 30 %
Time use	: 10 years
The maximum charging current	: 18 A

3.4.4 Variable Sensitivity

Sensitivity of fuel prices between 0.6 to 1 $ / liter, the price of fuel is assumed based on Sabu Island in April 2015.

3.4.5 Operating Limits Power Hybrid

- Limitations economy used for all calculations when the hybrid system is simulated real annual interest rate of 8 %, 25 year project period.
- Dispatch strategy used is a charging cycle with the setpoint state of charge of 80%, maximum annual capacity shortage 0%.
- For generator regulation system allowed to operate with some generators and systems are also allowed to operate the generator under load peak.
- The operating system used is a parallel system of Hybrid Power Plant.

After going through the steps - steps above, HOMER will simulate and optimize Hybrid Power Plant predetermined models.

3.5 Summary

Sabu island located in the middle of the Sabu Sea and is located between the islands of Sumba and Rote. Climatic conditions on the Sabu island influenced its location adjacent to the continent of Australia. Hence this island has characteristics with a long dry season ranged between 7 - 8 months and with low rainfall. In a year just 14 - 69 days of the rainy season, that short rainy season only happens in December to March [9]. The wind blowing around the Sabu island is a season wind that changed direction twice a year with an average speed of 3 - 7 m / sec. The average monthly temperature of 31.47°C with the maximum and minimum temperature difference of 7.43°C [7]. Clearness Index Average is 0.655 and Average Daily Radiation for Sabu Island is 6.466 kWh / m2 / day. [10]

The load daily average for Sabu Island is 5.6 MWh / day with peak load of 1 MW occurred at 18:00 p.m. to 19:00 p.m. [11]. The data used is based on data obtained from PT. PLN (State Electricity Company) is daily load data assumed for a full day, to meet the water consumption and other purposes, it is assumed that the pump is added as a sidetracked load on Hybrid Power Plant system design. HOMER software is a software used to optimize the model of small-scale power generation system (micropower), this software makes it easy to evaluate the design of power systems for various types of small-scale power plants either are connected to the power grid or not. [12]

Hybrid Power Plant model will be simulated and optimized consists of Solar Panels (Photovoltaic), Diesel Generators, Inverter and Battery. For design optimization Hybrid Power Plant system is made of two conditions by following the daily load curve, that are :

- The first condition simulation is run to determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.
- The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value and less emissions.

Variable sensitivity of fuel prices between 0.6 to 1 $ / liter, the price of fuel is assumed based on Sabu Island in April 2015. And the operating limits are operating system used is a parallel system of Hybrid Power Plant, limitations economy used for all calculations when the hybrid system is simulated real annual interest rate of 8 %, 25 year project period, dispatch strategy used is a charging cycle with the setpoint state of charge of 80%, maximum annual capacity shortage 0 %, for generator regulation system allowed to operate with some generators and systems are also allowed to operate the generator under load peak.

CHAPTER 4
SIMULATION AND ANALYSIS

4.1 Simulation Results

Simulation and optimization using HOMER produce several different configurations according to the minimum limit of renewable energy contribution.

4.1.1 Initial Condition

4.1.1.1 Peak Power of Photovoltaic

$$E_{el} = \text{Primary Load} + \text{Deferrable Load}$$
$$= 5{,}570 + 2.4$$
$$= 5{,}572.4 \text{ kWh/day}$$

According to the formula 3.9 we get the peak power of PV :

$$P_{peak} = \frac{E_{el} \cdot I_{STC}}{E_{glob} \cdot Q}$$
$$= \frac{5{,}572.4 \times 1}{0.6 \times 6.47}$$
$$= 1435.3 \text{ kWp}$$

4.1.1.2 Battery Capacity

$$C_B = 10 \cdot P_{peak}$$
$$= 10 \times 1435.3$$
$$= 14353 \text{ kWh}$$

The value of PV power rounded to 1,500 kWp and the battery power capacity divided by the nominal capacity of the battery at 2.16 kWh so we get the amount of battery capacity of 6,643 pieces. Diesel Generator capacity used for initial system given the higher value as the peak load on the primary load, amounting to 1.1 MW and capacity inverter used is given a equal value to the value of PV capacity is equal to 1,500 kW.

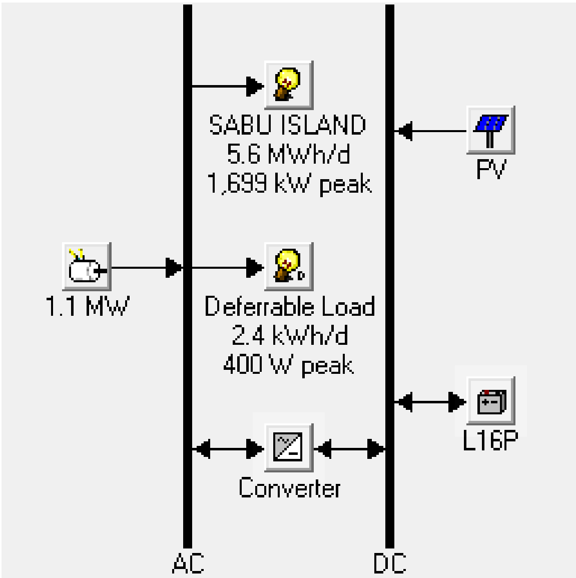

Figure 4.1 Initial Condition Systems Models.

Source: HOMER, NREL

Simulations were performed with the initial condition is as compared to the second condition. This initial condition system consists of 1,100 kW Diesel Generator, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter with the simulation results as follows Table 4.1 below.

Table 4.1 Data Simulation Results on Initial Conditions.

Parameter	Solar + Diesel
NPC ($)	12,358,148
Initial Capital Cost ($)	2,098,200
Operating Cost ($/year)	961,139
COE ($)	0.569
Renewable Energy (%)	59
Fuel Consumption (L/year)	923,254
Hours of Operation (hours/year)	
PV 1500 kW	4,442
Diesel 1100 kW	4,558
Energy Production (kWh/year)	5,092,615
PV 1500 kW	3,004,018
Diesel 1100 kW	2,088,597
Excess Electricity (kW/year)	2,858,037
Excess Electricity (%)	56.1
CO_2 Emissions (kg/year)	2,431,230
SOx Emissions (kg/year)	4,882

4.1.2 Second condition

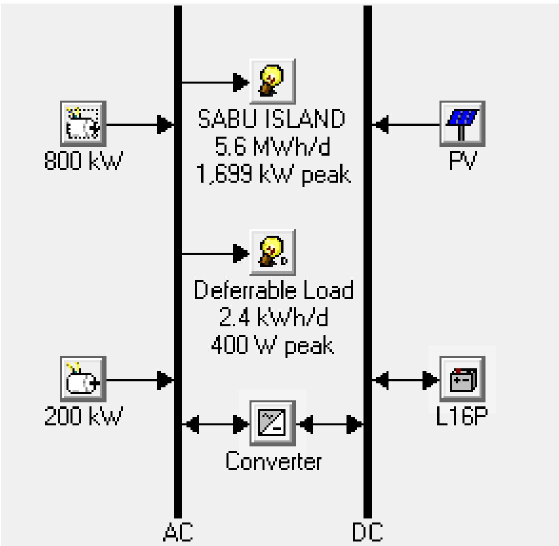

Figure 4.2 Second Condition Systems Models.

Source: HOMER, NREL

Table 4.2 Data Simulation Results on Second Condition.

Parameter	Solar + 2 Diesel
NPC ($)	7,374,541
Initial Capital Cost ($)	2,081,836
Operating Cost ($/year)	495,814
COE ($)	0.34
Renewable Energy (%)	66
Fuel Consumption (L/year)	536,732
Hours of Operation (hours/year)	
PV 1500 kW	4,442
Diesel 800 kW	1,534
Diesel 200 kW	3,748
Energy Production (kWh/year)	4,518,370
PV 1500 kW	3,004,018
Diesel 800 kW	942,151
Diesel 200 kW	572,201
Excess Electricity (kW/year)	2,388,366
Excess Electricity (%)	52.9
CO_2 Emissions (kg/year)	1,413,392
SOx Emissions (kg/year)	2,838

In this case given the limits on the amount of use a maximum of two diesel engines but for the DG can be added the value of different capacity and we assume that the value of PV from the initial condition as the lowest value that will be used. This condition system consists of two Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter with the simulation results as follows Table 4.2 above. The second condition simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC lowest value.

4.1.3 Comparison of Results All Conditions

Table 4.3 Comparison of Results All Conditions.

Parameter	Solar + Diesel	Solar + 2 Diesel
NPC ($)	12,358,148	7,374,541
Initial Capital Cost ($)	2,098,200	2,081,836
Operating Cost ($/year)	961,139	495,814
COE ($)	0.569	0.34
Renewable Energy (%)	59	66
Fuel Consumption (L/year)	923,254	536,732
Hours of Operation (hours/year)		
PV 1500 kW	4,442	4,442
Diesel 1100 kW	4,558	-
Diesel 800 kW	-	1,534
Diesel 200 kW	-	3,748
Energy Production (kWh/year)	5,092,615	4,518,370
PV 1500 kW	3,004,018	3,004,018
Diesel 1100 kW	2,088,597	-
Diesel 800 kW	-	942,151
Diesel 200 kW	-	572,201
Excess Electricity (kW/year)	2,858,037	2,388,366
Excess Electricity (%)	56.1	52.9
CO_2 Emissions (kg/year)	2,431,230	1,413,392
SOx Emissions (kg/year)	4,882	2,838

4.2 Analysis of Simulation Results

Simulations performed under two conditions, that are the initial condition in which there are only a Diesel Generator with capacity of 1,100 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter while the second condition is using 2 Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter. The simulation results which analyze is the production of electricity, the cost of electricity, fuel consumption by Diesel Generator, the excess electricity that is not absorbed by the load. Here is a full analysis for two conditions of the simulation.

4.2.1 Initial Condition

Analysis of simulation results on the initial conditions are as a comparison or to be used as a benchmark for analyzing optimal system of Hybrid Power Plant simulation results from second conditions.

4.2.1.1 Electricity Production

Production of electricity generated by Diesel Generator capacity of 1,100 kW is 2,088,598 kWh / year or 41 %, a PV capacity of 15,000 kW is 3,004,018 kWh / year or 59 % with total production of electricity generated is 5,092,615 kWh / year.

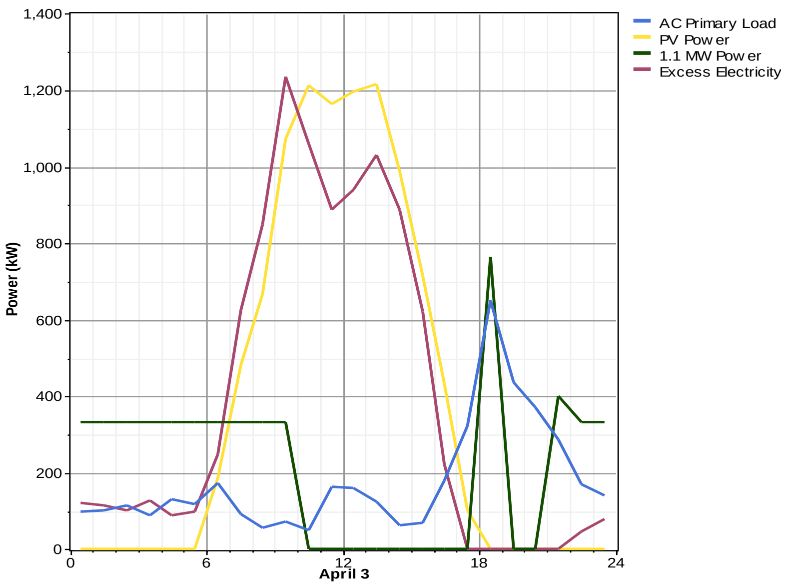

Figure 4.3 Daily Load Conditions, Output Power and Excess Unused Power in Initial Condition.

The picture above is a condition of the supply of electricity on April 3 2015, can be seen Diesel Power 1,100 kW operating almost all day except on 10:30 a.m. to 17:30 p.m. and 19:30 p.m. to 20:30 p.m., can be seen PV operates almost all day when the sunlight.

At this time there is excess electricity. This happens because the excess electrical of Diesel Generator can not be utilized, because there are no batteries for storage of electrical energy in this system.

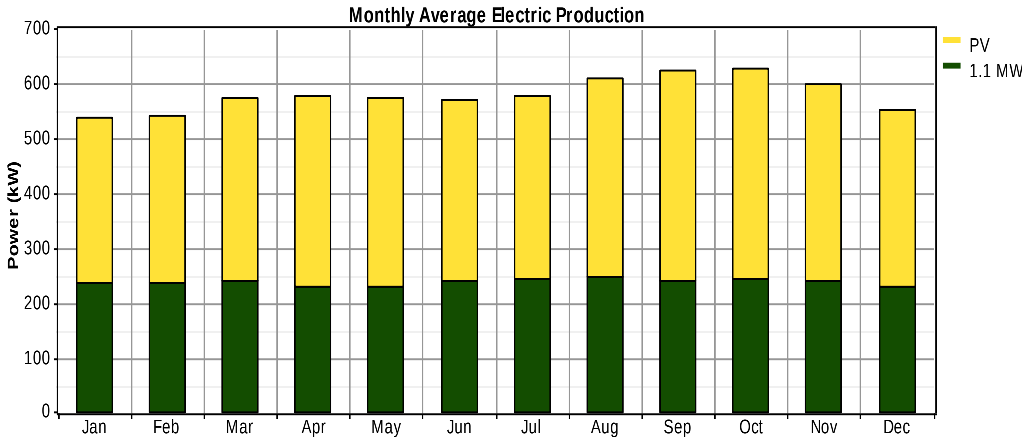

Figure 4.4 Contributions Solar Power Generation - Diesel Generator.

4.2.1.2 Fuel Consumption

Total fuel consumed by the system during the first year is 923,254 liters, that all consumption by Diesel Generator 1,100 kW.

4.2.1.3 Excess Unused Power

Excess electricity contained in this system amounted to 2,858,037 kWh per year, or approximately 56.1 %. Excess electricity is the difference between total production of electrical energy for a year that generated by Diesel Generator and the total load supplied.

4.2.1.4 Costs

Costs obtained from the simulation system of the initial conditions are initial capital invested in this system amount of $ 2,098,200, operating cost amounted to $ 961,139 per year, the net present cost (NPC) amounted to $ 12,358,148 and the cost of electricity (COE) amounted to $ 0.569 per kWh.

4.2.1.5 Environmental Impact (Emission)

When the design is simulated and optimized with value contribution of renewable energy is 59 %, then obtained CO_2 and SOx emission levels are high. The total value of CO_2 emissions produced by system amounted to 2,431,230 kg / years and SOx emissions resulting value of 4,882 kg / years.

4.2.2 Second condition

In the second condition, the simulation system of Hybrid Power Plant produce a configurations, that is PV with 2 Diesel Generator. HOMER simulates Hybrid Power Plant system and sorted by priority based on the lowest NPC. From the simulation results, obtained the order of lowest NPC values is $ 7,374,541.

Criteria established writers to get a optimum Hybrid Power Plant is :

- The NPC values its lowest
- The little environmental impact (low emission)

Based on simulation results and the above criteria, the configuration that qualify as the optimum system consist of PV with a total capacity of 1,500 kWp, 2 unit Diesel Generator capacity of 200 kW and 800 kW, 6,643 pieces of Battery and 1,500 kW of Inverter, more analysis as follows :

4.2.2.1 Electricity Production

Total production of electricity produced by PV and 2 Diesel Generator is 4,518,370 kWh / year with the contribution of PV is 66 % or 3,004,018 kWh / year while the contribution Diesel Generator 200 kW is 13 % or 572,201 kWh / year and capacity 800 kW is 21 % or 942,151 kWh / year.

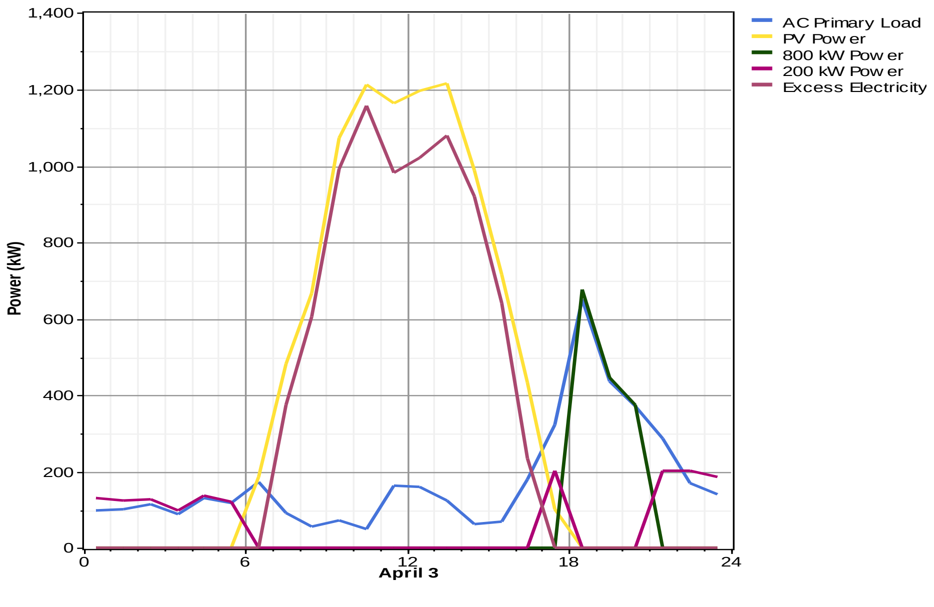

Figure 4.5 Daily Load Conditions, Output Power and Excess Unused Power in Second Condition.

Figure 4.3 is a condition of the supply of electricity on April 3 2015, can be seen Solar Power Plant operates almost all day when the sunlight. All Diesel Generator is not operating at 06:30 a.m. to 16:30 p.m. when electricity production from Solar Power Plants can fill the electricity needs.

Excess electricity is unused in this system is 2,388,366 kWh per year or 52.9 %, this happens because of the electricity produced by the Solar Power Plant for one year excessive to the existing load. In the Figure 4.3 excess electricity occurred at 06:30 a.m. to 17:30 p.m. and at this time 6,643 pieces of batteries used is not sufficient to absorb this excess electricity. In addition to using the battery, excess electricity can also be absorbed by adding this system to the deferrable load.

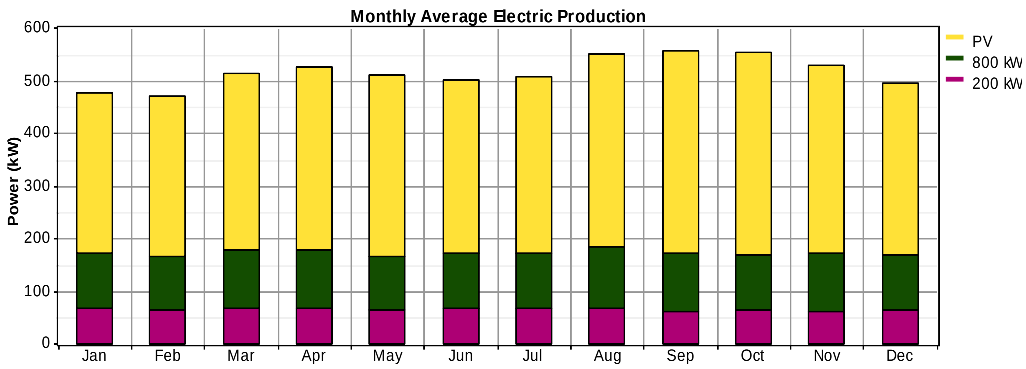

Figure 4.6 Contributions Solar Power Generation - Diesel Generator

In the Figure 4.4 above shows the contribution of each component. Contributions of PV 66 % and the contribution Diesel Generator 200 kW at 13 %, capacity of 800 kW is 21 %.

4.2.2.2 Fuel Consumption

In Figure 4.5 the fuel consumption on the system configuration of Hybrid Power Plant consisting of Solar Power Plant - Diesel Generator amounted to 590,684 liters per year. In this configuration the use of fuel could be saved by 148,952 liters per year, or 20.14 % per year.

4.2.2.3 Excess Unused Power

With a fixed daily load, excess unused power has a value that fluctuates along with the total production of electricity in Hybrid Power Plant. Excess electricity occurred at this system is 52.9 % or 2,388,366 kWh per year with a total production of electrical energy is 4,518,370 kWh per year.

4.2.2.4 Costs

Overall optimal system is Hybrid Power Plant that consisting of PV and 2 Diesel Generator, the costs that obtained from the simulation results are initial capital invested amounted to \$ 2,081,836, operating cost amounted to \$ 495,814 per year, the net present cost (NPC) is \$ 7,374,541, the cost of electricity (COE) is \$ 0.34 per kWh. In this system, lower initial investment costs but for 25 years fuel costs can be reduced by 386,522 liters per year, or 41.86 %.

4.2.2.5 Environmental Impact (Emission)

When the hybrid design is simulated and optimized with the value of the contribution of renewable energy of 66 %, then obtained the rate of CO_2 and SOx emissions decreased along with the decrease of fuel consumption in diesel. In the diagram of CO_2 emissions, the highest value occurs when the contribution of ET 0 % with the total value CO_2 is 1,856,939 kg per year. The value of CO_2 emissions is 1,413,392 kg per year and SOx emissions value is 2,838 kg per year.

Overall the optimum conditions by simulating the HOMER software is priced at lowest net present cost (NPC) and the lowest emission values based on the lowest electricity costs (COE) in the same value.

4.3 Summary

Simulation and optimization using HOMER produce several different configurations according to the minimum limit of renewable energy contribution. In Initial Condition the value of PV power rounded to 1,500 kWp and the battery power capacity divided by the nominal capacity of the battery at 2.16 kWh so we get the amount of battery capacity of 6,643 pieces. Diesel Generator capacity used for initial system given the higher value as the peak load on the primary load, amounting to 1.1 MW and capacity inverter used is given a equal value to the value of PV capacity is equal to 1,500 kW.

In this conditions Simulations were performed with the initial condition is as compared to the second condition. In this condition the resulting NPC value is $ 12,358,148 with Initial Capital Cost of $ 2,098,200 and COE of $ 0.569 as well as the contribution of renewable energy from the system by 59 %. Fuel consumption amounted to 923,254 L / year and energy production of 5,092,615 kWh / year. Excess electricity that occurred at 56.1 % and CO_2 emissions by 2,431,230 kg / year. Simulations were performed with the initial condition is as Compared to the second condition.

In Second Condition given the limits on the amount of use a maximum of two diesel engines but for the DG can be added the value of different capacity and we assume that the value of PV from the initial condition as the lowest value that will be used. This condition system consists of two Diesel Generator with capacity of 800 kW and 200 kW, 1,500 kW of PV, 6,643 pieces of Battery and 1,500 kW of Inverter. In this condition the resulting NPC value is $ 7,374,541 with Initial Capital Cost of $ 2,081,836 and COE of $ 0.34 as well as the contribution of renewable energy from the system by 66 %. Fuel consumption amounted to 536,732 L / year and energy production of 4,518,370 kWh / year. Excess electricity that occurred at 52.9 % and CO_2 emissions by 1,413,392 kg / year.

CHAPTER 5

CONCLUSIONS

Utilization of solar energy to generate electricity has grown rapidly along with the aim to reduce the high levels of pollution. In this project is proposed analysis of photovoltaic power system with the operating system using a parallel system to calculate the power requirements of solar power plants and diesel generators as a power generator with integrated large of a load is assumed to be constant in a year. In this study, the amount of power from solar power plants are required to meet the existing load is obtained by calculating the minimum output power to supply the load independently, while the magnitude of the diesel generator is assumed to be equivalent to the existing load.

Having gained much power a minimum of solar power plants using HOMER software, then the calculation is added cost to the system. This serves as a reference in determining the lowest NPC as guidelines for systems with maximum performance. The simulations can show the results of the system to optimize all possible system configurations, such as the size or quantity of each component. The first condition simulation is run to Determine the initial conditions of the load supply system in Sabu island using the minimum value of the each component.

In the second condition, the simulation is run by change the value of the capacity and number of each Solar and Diesel Generator accordance with NPC Lowest value and less emissions. Limit the use of diesel generators with a maximum of two, then the second system allows the use of power from diesel generators with different values. It depends on the characteristics of the load values every day in certain hours and power supply all the power supply that adapts to the conditions of solar radiation during the day on solar power and output power capability of the battery and the inverter power supply. HOMER will simulate and analyze how the value of each diesel generator used to obtain optimal system.

Results of each condition compared with taking maximum system generated. At the initial conditions obtained amount of power each component of 1.5 MW in solar power plants and 1.1 MW diesel generators with energy production of 5,092,615 kWh / year. On both conditions was obtained magnitude of each component power of 1.5 MW of solar power plants, as well as kW 800, and 200 kW on diesel generator with energy production of 4,518,370 kWh / year.

Overall in this case study, the optimal Hybrid system is a combination of PV and 2 Diesel Generator. PV contribution towards Hybrid system by 66 % while Diesel Generator by 34 %. This configuration is defined as the most optimal by lowest value of NPC that is equal to $ 7,374,541 and the cost of electricity (COE) for $ 0.34 per kWh. Excess energy during the year amounted to 2,388,366 kWh or 52.9 %.

The environmental impact can be reduced by applying the PV and 2 Diesel Generator system, the CO_2 emissions generated in the system amounted to 1,413,392 kg per year, a decline in the amount of 1,017,838 kg of CO_2 emissions per year, or 41.86 % from the initial conditions in the number of CO_2 emissions by 2,431,230 kg per year. The total consumption of diesel fuel in the PV and 2 Diesel Generator system is 536,732 liters per year, occur in fuel consumption savings of 386,522 liters per year, or 41.86 % of the total consumption of diesel fuel in the initial conditions in the amount of 923,254 liters per year.

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PERSONAL PROFILE

Name	:	AKHMAD FATKHUR RIZKI
ID Number	:	115710401063-9
Place of birth	:	Sidoarjo
Date of birth	:	September 22nd, 1993
Address	:	Jl. Raya Melian 21 RT 02 RW 08 Kejapanan
		Kecamatan Gempol
		Kabupaten Pasuruan
		67155
		East Java
		INDONESIA
Religion	:	Moslem
Email	:	arafarizki@gmail.com
Education	:	SMA Negeri 1 Pandaan (Science)