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OPTIMIZATION OF RENEWABLE ENERGY GENERATION TO INCREASE THE ELECTRIFICATION RATIO IN BORME DISTRICT - PAPUA PROVINCE

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ABSTRACT

The Government of Indonesia through the Ministry of energy and Mineral resources, at the beginning of the year 2016 introduced a program called "Bright Indonesia”. The goal of the program is to accelerate Electrification Rate (ER) with a priority on the six provinces in eastern Indonesia Province includes Papua province. Papua is still showing low ER (45.93%) among the other provinces. Micro-Hydro power plant (PLTMH) and Centralized solar power plant (PLTS Centered) with a capacity of 22 Kwp hybrid power generation systems and models designed to simulate and determine the most optimal system to provide electrical energy for electrical load on a settlement. Hybrid Optimization Model for Electric Renewables (HOMER) serves to design the system and to facilitate the comparison of micropower technology power plants. Details of the electric energy of the system is produced from the PLTMH dominate the electrical energy needed by the load of 440.298 kWh/yr., PLTS amounting to 76.518 kWh/yr, diesel power plant of 13.708 kWh/yr., with successive presentations of 83%, 14%, 3%. The penetration of renewable energy of this system is of 97.4%, derived from PLTMH and PLTS respectively amounted to 80.1% and 17.3%.

Keywords: optimization, renewable energy, electrification ratio of borme district.

1. INTRODUCTION

Renewable energy sources have a great potential when used to generate electrical energy, which can be used in areas that are isolated by using hybrid power generation systems..

The Electrification ratio is very low in Papua, which is 45.93% with dominated by oil-fueled power generators/diesel power (96%) as well as the demand for power increasing needs (8% per annum) is the main problem in the Papua province [1]. The establishment of a Special Autonomy Law of the year 2002 and the encourage of the utilization of renewable energy in the year 2007 by the Government of Papua Region is one of the act of the Provinces in terms of supporting compliance-based electric potential energy. penetration of non fuel oil plant in Papua Province supported by Government policy through the Ministry of energy resources has increased with the number of renewable energy power generation development in mini and microscale-especially in a hard to reach area.

Borme district, a mountainous District, Papua Province, is a district bordering the country of Papua New Guinea (PNG) new 2 years more can enjoy the facilities of electric Micro Hydro power plant (PLTMH) and power generation Centralized solar power (PLTS Centered) with a capacity of 22 Kwp. Based on the data of radiation of sunlight, water and discharge of rivers in Borme District, generating hybrid system model designed to simulate and determine the most optimal system for supplying electrical energy to the electrical load on the settlement residents [2].

HOMER (Hybrid Optimization Model for Electric Renewables), which can simulate the operating system from a system based on the calculation of each energy to 8,760 hours in a year. HOMER compares electrical and thermal loads in one hour to energy that can be supplied by the system at that Time [3]. If the system meets the burden throughout the year, HOMER predicts the cost of the life cycle of the system, calculating the cost of capital, replacement, operation and maintenance, fuel and interest. Energy flow perhour can be seen on each component, as well as annual fees and performance summary.

After simulating all possible system configurations, HOMER displays a list of the feasibility of the system, which is sorted by lifecycle cost. The system with the lowest costs were at the top of the list so that it can easily be found and also a list of other system feasibility can be searched so that it is optimal to meet the needs of the load [12] and maximize the potential of sunlight radiation for PLTS to river flow and PLTMH in achieving a Ratio of Electrification (RE).

In this issue the proposed Hybrid Optimization Model for Electric Renewables (HOMER) to be able to resolve the problems of Optimization based on the most optimum formulation.

2. METHODOLOGY

2.1 Energy self-sufficient village

The Self-sufficient energy village (DME) is one of the programs for the fulfilment of its own energy needs. This program was first initiated by the President of the Republic of Indonesia in 2007. Criteria of Self-sufficient energy village (DME) is a village that is able to meet the minimum 60% of its total energy needs (electricity and

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fuel) with the empowering potential of local resources as well as the growth of the productive activities to improve the economy of the village as the impact of the availability of local energy. It is expected with the Self-sufficient energy village (DME), the energy dependence in the community against the use of non renewable sources of energy and energy use of subsidies from the Government can be minimized [1], [7].

2.2 Solar power generation (PLTS)

PLTS is a plant which convert the energy of photons of solar into electrical energy. This conversion occurs in the solar panels which consist of solar cells. PLTS utilize sunlight to generate Direct Current (DC) electricity, which can be converted to electricity Alternating Current (AC) when needed. The components of the PLTS that are required depending on the functional and operational needs of the system, and its main components such as photovoltaic modules, inverters, batteries, battery systems and controllers.

The solar cell is physically very similar to a p-n diode. When the light on the surface of the solar cell, a few photons of light are absorbed by atoms of semiconductors to liberate electrons from the Atomic bonds so that it becomes non-moving electrons. The existence of the displacement of these electrons is what causes the onset of electric current. [4]

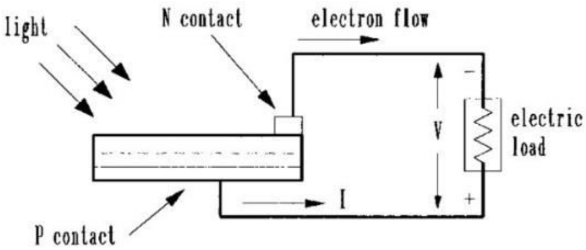

Figure-1. The effect of the solar cells convert the energy of the photons flow.

Two of the most important parameters that are widely used to describe the performance of solar cells, namely the Open-circuit Voltage (Voc) which occurs at a point where the flow is zero, so that the output power is zero and Short-circuit Current (Isc) which occur at a point where the voltage is zero, so that the output power is zero (Santiari, 2011). Voltage and current output that is produced when the solar cells obtain the radiation which is a characteristic that are presented in the form of the I-V curve and P-V with Maximum Power Point (MPP).This curve shows that at a time when the current and voltage are on point, then the MPP will produce maximum output power (PMPP).MPP voltage (VMPP), smaller than the Voc and the current moment MPP (IMPP) is lower than the Isc current [5].

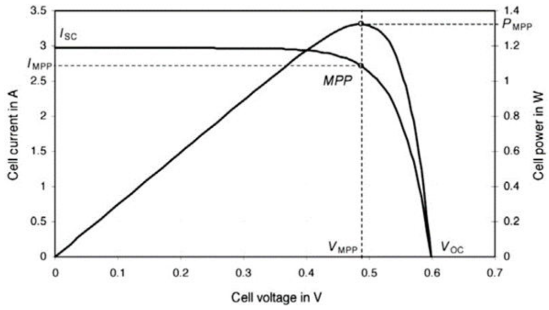

Figure-2. Curve characteristics of I-V and P-V solar cells with MPP.

2.2.1 The energy output of the solar module

The energy output of the solar module is formulated as [6]:

$$E_{nom} = \sum_{i=1}^{m} G_{iref} \; x \; \eta_{STC} \; x \; A_{Ac} \tag{1}$$

Where :

G_{iref} = Solar Radiation (W/m^2)
I = Data that were used (Hour)
m = The amount of data used
η_{STC} = Efiensi solar module testing standards
A_{Ac} = Surface area solar module (m^2)

The efficiency of the solar cell is a comparison between the maximum power capable in PV panel does with multiplication between the value of the isilasi daily Sun and the cross-sectional area of the PV module. The equation used to determine effesiensi modules are as follows:

$$\eta_{STC} = \frac{P_m}{E \; x \; Ac} \tag{2}$$

Dimana:

η_{STC} = Solar module efficiency (%)
Pm = Solar panel peak power
Ac = Wide panel (m^2)
E = Solar radiation at STC (1000 W/m^2)

2.2.2 Solar energy technology

In hybrid systems, PLTS are shared equally with the other plant system in supplying electricity. System components generally consist of series of solar cells that form the solar module (PV Panel) and some of the supporting components such as batteries, inverter, control system and others which is called balance of system (BOS). PV technology applications are: PLTS rural or urban (on the grid or off grid), Solar Home System (SHS) solar street pumping, solar lighting, BST solar, solar refrigerator. In solar thermal systems, solar connector absorbs solar radiation and convert it into heat energy used to heat the fluid medium such as water or air which can be used directly or indirectly for different applications such as: water heater, agricultural drying (solar dryer), distillation or desalination, cooking (solar cooker), solar cooling (solar cooling), power generation (solar thermal power plant). In addition, the solar thermal technology is also potentially to be utilized as a source of additional heaters for process industry production processes that require thermal energy [8].

The obstacles faced in the implementation of the PLTS in Indonesia is the high cost of investment, other major photovoltaic modules i.e. PLTS are still imported from other countries and the efficiency of the photovoltaic module only amounted to 16% that causes the price of PLTS per kW is still high [9].

2.2.3 Analysis of the potential solar energy

Planning a potential solar energy calculated using the most efficient modules, namely Silicone monocrystal module (16 - 25%) is higher than Policrystal with an efficiency of 14 - 16% and Amorphous silicon with the lowest efficiency 9 - 10.4% and the cheapest. The intensity of solar radiation received by the solar panels to power the output panel, the lower intensity means the lower the power generated.

Solar panel orientation is very important to achieve maximum energy. For solar panels at the site of the northern hemisphere at the Equator then the panel is oriented to the South and vice versa. The angle of slope of the panel will cause the maximum power if its angle equal to the latitude of the location. In the simulation study, assumed to be the maximum power is obtained by meeting the above requirements.

The formula of PLTS power calculation as follows:

a. Counting PV area

$$PV_{area} = \frac{E_L}{G_{av}\ x\ \eta_{PV}\ x\ TCF\ x\ \eta_{out}} \quad (3)$$

Where:
E_L = Energy Consumption (kWh/day)
G_{av} = Average daily sun radiation (kWh/m^2/day)
η_{PV} = Solar panel efficiency
TCF = Temperature correction factor
η_{out} = Inverter efficiency

b. Counting the power generated by PLTS Wp (Watt Peak)

$$P_{Wp} = Area\ Array\ x\ PSI\ x\ \eta_{PV} \quad (4)$$

Where:
PSI = Peak Solar Insolation (1000 W/m^2)

c. Counting the amount of PLTS panel (Unit)

$$\text{Amount of solar panel} = \frac{P_{Wp}}{P_{MPP}} \quad (5)$$

Where:
P_{MPP} = Maximum power of solar panel output (W)

2.3 Micro-hydro power plant (PLTMH)

Micro-hydro Power Plant (PLTMH) is also a generator that can convert small-scale moving water energy into small-scale electrical energy by using a water turbine connected to an electric generator.

A water power Center consist of water dams, reservoirs, waterways (conduits), water channels, and the central power with all its equipments. Job description of a PLTMH include the flow of the River, the river flows will be accommodated at a reservoir which is complete with intake gate (the doors of the uptake of water) that goes into conducting channels. The water will flow in the pipe rapidly (Penstock) that after going through the valve entrance (Inlet Valve) water will continue to flow towards the turbine wheel (Runner), runner will be rotating the shaft of water turbine, which in turn will drive an electrical generator [10].

2.3.1 The principles of electrical power plant with micro-hydro power plant

Electric power plant with PLTMH is the process of converting the mechanical energy produced by water power into electric energy. Height of fall of water effectively (Hnet) from the highest level to the lowest is utilized to rotate the turbine that will spin the generator. As shown in equation (6), (7) and (8).

a. Effective height of the fall of water equation can be calculated below

$$H_{net} = H_{gross} - (h_{f\ sb} + h_{f\ forebay}) \quad (6)$$

Where :
Hnet = Effective height of fall of water (m)
Hgross = Maximum measured of Height of the fall of water (m)
$H_{f\ sb}$ = Head fraction calculated on sedimentary tub (m)
$H_{f\ forebay}$ = forebay Head fraction calculated on Stilled tub (m)

b. General equation for water discharge is as follows:

$$Q = A.v \quad (7)$$

Where:
Q = Water Discharge (m^3/second)
A = Cross-sectional area line (m^2)
v = Average speed of water flow (m/second)

c. General equation of power generated in all water power plants:

$$P = g\ H\ Q\ \eta t\ \eta g\ \eta tr \quad (8)$$

Dengan:
P = Power produced (Watt)
g = Gravity (9.81 m/second^2)

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H = maximum height of the fall of the water (meters)
Q = Water Discharge (m^3/second)
ηt = Efficiency of the turbine
ηg = Efficiency of generator
ηtr = Mechanical Efficiency of the transmission

Based on the above equation, then effort get the maximum power depends on effort to obtain high and maximum height of the fall of the water and maximum water discharge.

2.3.2 Components of Microhydro power plants

a. Civil works components

The components of civil works involved building works such as:

- Dodge building
- Spillway
- Sattling basin
- Headrace
- Forebay, and
- Penstock

b. Components of mechanical and electrical works

The components of this work include mechanical and electrical equipment such as a water turbine. The selection of water turbine can be calculated considering the parameters that affect specific turbine operating system, among others, the effective height of fall of water (Hnet) and magnitude of water discharge (Q) which will be utilized.

The equation of specific speed of water turbine is:

$$n_s = n \frac{\sqrt{P}}{H_{net}{}^{5/4}} \qquad (9)$$

With :
n_s = The specific speed of a water turbine (rpm)
n = Turning speed of water turbine (rpm)
P = Power raised (kW)
H_{net} = Effective High fall of water (m)

Minimum runner diameter of a water turbine can be determined by the following equation:

$$D_{runner} = \sqrt{\frac{Q}{2{,}2\sqrt{H_{net}}}} \qquad (10)$$

With :
D_{runner} = Minimum runner diameter (mm)
Q = Calculated water discharge (m^3/detik)

2.4 Homer

HOMER ® stands for the Hybrid Optimisation Model for Electric Renewables, one popular tool for PLTH system design using renewable energy. HOMER ® simulate and optimize system power plant either stand-alone or grid-connected which can consist of a combination of wind turbines, micro hydro, biomass, photovolaic, generator (diesel/petrol), microturbine, fuel-cell, battery, and hydrogen storage, serving the load power.

HOMER (Hybrid Optimization Model for Electric Renewables) [11], is the software optimization model of micro power system. Some of the functions of HOMER are:

- Looking for a combination of system components with the lowest cost in accordance with the load.
- Simulates thousands of system configuration possibilities.
- Optimization of overall costs in accordance with the age of the system and analysis of sensitivity from some input.

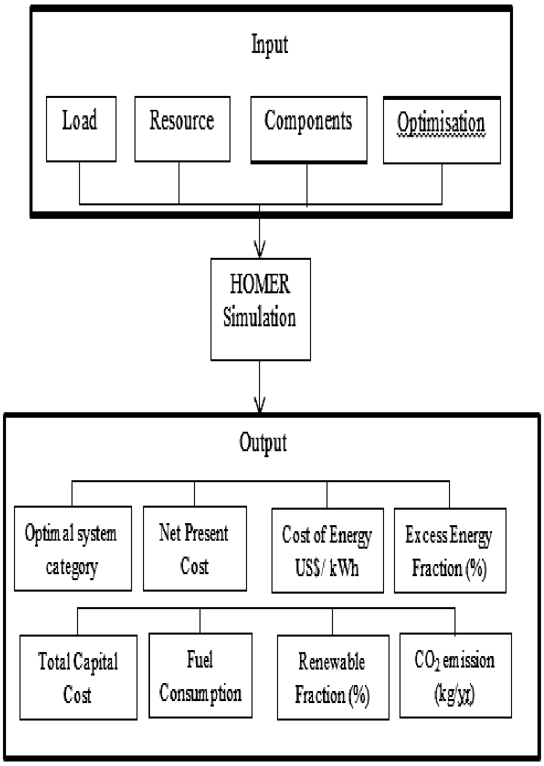

Figure-3. Architecture simulation and optimization of homer.

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3. RESULT AND DISCUSSIONS

3.1 Borme district electrical condition

Electricity in Borme district is supplied by two genset with a capacity of 30 kVA and 10 kVA, PLTMH 40 kVA and Centered PLTS 22 KWp by the number of customers of 1087 households, which are managed individually. graphs below can explain the image of the electrification ratio (RE) in 13 villages in Borme district.

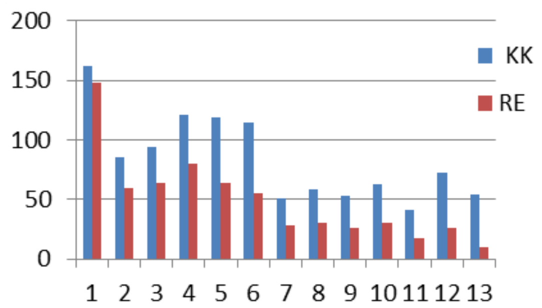

Figure-4. Distribution of electrification ratio in 13 villages.

Because of the lack of electricity infrastructure, most areas in the village of Borme District is still under 50% RE. This is because of the difficult geographic area. As in the picture below that shows a percentage of the number of families who have been provided with electricity (RE) and the number of families that is non RE.

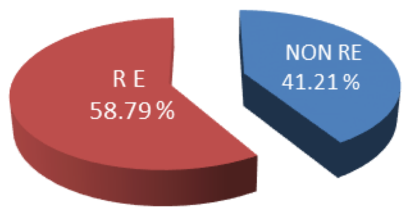

Figure-5. Percentage of number of families with RE and non RE.

By comparing the number of families who have been provided with (RE) and the number of families who have not been provided with electricity (Non RE) as in the picture above, then, we can see the percentage of families who've been RE of 58.79% and the percentage of families who are Non RE of 41.21%, show that the overall rate of RE in Borme district is still below the national average of RE amounting to 88.30%.The main reason RE is lowest in Papua is a vast territory with landlocked situation and mountains as well as a low population density. But again, it is the geographic and demographic constraints make electric power do not spread well in Papua.

3.2 Borme district renewable energy potential

The intensity of solar radiation in HOMER is achieved by specifying the latitude and longitude of an area. these latitude and longitude are used to produce the intensity of solar radiation each day based on the monthly average. Borme district which is located on 4 ° 3945 ' LS and 140 ° 4361 ' BT then the intensity of the solar radiation can be seen in Table-1 with the average of 5,098 KWh/m2/day. This value approaches the value of 5.14 KWh/m2/day, the difference is 0041 KWh/m2/day or 0.798%.

Table-1. Solar radiation of Borme district.

Month	**Daily radiation** (KWh/m2/d)	**Average temperature** (^{o}C)	**Average speed** (m/s)
Januari	4.990	25.74	4.68
Februari	5.000	25.76	4.81
Maret	5.150	25.81	4.23
April	4.870	25.8	4.09
Mei	4.550	25.52	4.75
Juni	4.330	24.93	4.67
Juli	4.600	24.46	4.9
Agustus	5.230	24.82	4.87
September	5.860	25.8	4.69
Oktober	6.010	26.66	4.05
November	5.550	26.59	3.85
Desember	5.040	25.89	4.31
Average	5.098	25.65	4.49

Source: NASA 2015

At the location of the research contain potential electric power that can be utilized to PLTMH based on measurement as follows:

Table-2. Results of PLTMH potential measurement.

No	**Parameter**	**Value**
1	Average flow speed (m/s)	0.2
2	Average depths (m)	0.82
3	Cross sectional area (m2)	0.78
4	Width of cross sectional river (m)	7.6
5	Water discharge (m3)	0.58
6	Head (m)	15,5

3.3 Result of the simulation

The configuration of the modeled system consists of PLTMH, PLTD and PLTS with energy storage

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(batteries). The model of the system is presented in Figure-6, where the system is composed of 2 buses, namely Bus AC and DC Bus. PLTMH and Diesel Power connected on AC Bus while the PLTS and battery connected to the DC Bus. The results of these simulations provide some configuration that can supply the load continuously in a year. The results are presented in Table-3 below. The resulting system configuration is based on the economic matters of the system that is the NPC. The results of the simulation puts system that has the smallest NPC is considered optimal to meet the needs of the load.

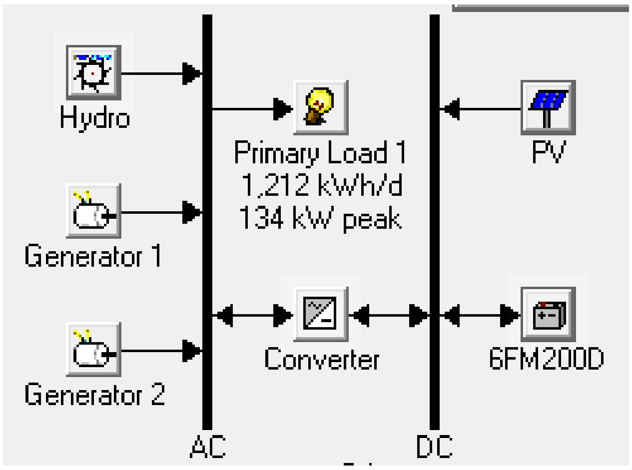

Figure-6. System simulation model on a HOMER.

The results of the simulation based on table 3 provide an optimal system is the system with configuration of PLTMH at 40 kW, 1 x 10 kW PLTD, PLTS amounting to 52 kW, and 268 batteries. This configuration provides the smallest NPC on the configuration of the other systems i.e. $981.662. However, the goal will be reached in this study that is designing a system to determine the optimal PV capacity to meet the load, because of PLTMH and PLTD is already exist.

Based on the results of simulation on table 3, optimal for PV capacity load is of 58 kW, so the new optimal system can be developed is the system with configuration of PLTMH 40 kW, PLTD 1 x 30 kW and 1 x 10 kW, PLTS amounting to 58 Kw, the battery is as much as 272 and converter at 75 kW.

Table-3. System simulation results.

No	PLTS (kW)	PLTMH (kW)	PLTD (kVA)	Converter (kW)	Baterai (Unit)	Initial Cost ($)	NPC ($)	COE ($)
1	52	40	1 x 10	75	268	429,751	981,662	0.199
2	58	40	1 x 30 1 x 10	75	272	445,547	1,200,265	0.238
3	58	40	1 x 30	80	272	446,797	1,228,600	0.244
4		40	1 x 30 1 x 10	65	256	301,459	1,341,701	0.269

Based on the Figure-8 in September - November the power generated by PLTM is high due to higher water flowing debit. So the opposite happen in May, the power generated by PLTM is the lowest, due to low water flow. Electric energy produced by the PLTM becomes the main supply to load because it

3.4 Analisis dan Pembahasan

Electrical energy generated by this system in a year is 530.523 kWh. Details of the electric energy of the system is presented in Figure 7. Based on the Figure 7, electric energy generated from the PLTMH dominate the electrical energy needed by the load. PLTMH generates electric energy amounted to 440.298 kWh/yr., PLTS amounting to 76.518 kWh/yr, PLTD of 13.708 kWh/yr., with successive presentations of 83%, 14%, 3%. The penetration of renewable energy of this system is of 97.4%, derived from PLTMH and PLTS respectively amounted to 80.1% and 17.3%.

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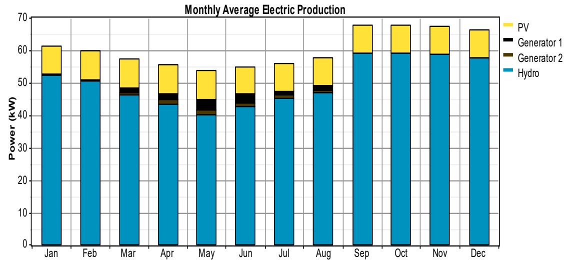

Figure-7. Average energy resulted per month.

3.4.1 Electrical energy of PLTMH

PLTMH installed has a nominal capacity of 40 kW, with a design flow rate 4 m3/s, generating electric energy amounted to 440.298 kWh/year. The average energy that can be generated is 40.3 kW and the maximum power that can be raised is 49.1 kW. Figure 8 shows the monthly average power generated by PLTMH in a year. has a low generation rates i.e. of $27/kWh and can operate all year round.

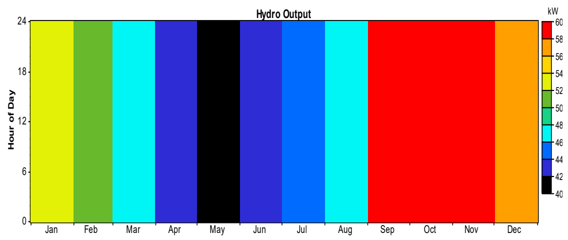

Figure-8. The profile of monthly energy of PLMTH.

3.4.2 PLTS electrical energy

PLTS in this system can generate energy of 76.518 kWh/yr or 14% of the total annual production of energy. Average energy that can be raised is 210 kWh/hr, on average 8.7 kW output and a maximum of 55.5 kW. Figure 9 shows the average monthly production of PLTS, average power generated is highest in March is proportional to the radiation of the Sun, because the sun radiation on the month is also the highest of the other months. While the lowest was in June. This PLTS has a capacity factor amounted to 15.1% at a price of the generator at 0.190$/kWh. Electric energy produced by this PLTS contribute 14% to meet the requirements of the load.

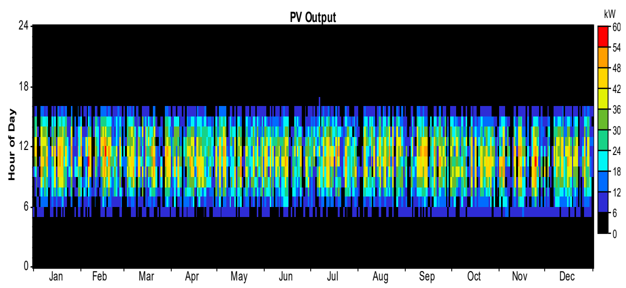

Figure-9. The profile of monthly energy of PLTS.

3.4.3 PLTD electrical energy

PLTD used in the system is composed of 2 with a capacity of 30 kW and 10 kW. The profile of energy generated from PLTD 30 kW are presented in Figure 10 and Figure 11 is the energy profile of PLTD at 10 kW. PLTD 30 kW a year evokes the energy of 9.004 kWh and operate for 481 minutes. Fuel consumption is 0.735 L/kWh and cost of generation is $1.61/kWh. Meanwhile, PLTD 10 kW in a year generate energy of 4.704 kWh and operate for 667 hours. Fuel consumption is 0.365 L /kWh and cost of generation is $662/kWh. Both of these images give an idea that PLTD was largely operated in March - August.

This is due to on certain months, the energy from PLTMH and PLTS cannot cover the needs of load. The average energy is generated by PLTD is18.7 kw and 7.05 kW with capacity factor each 3.43% and 5.37% for PLTD 30 kW and 10 kW.

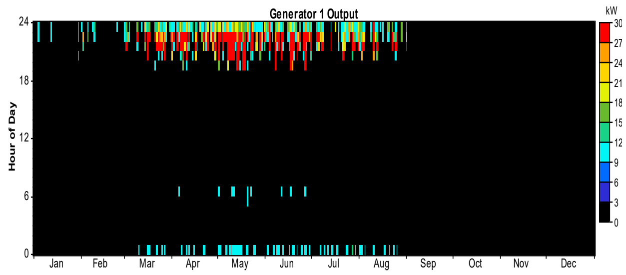

Figure-10. Energy profile PLTD 30 kW.

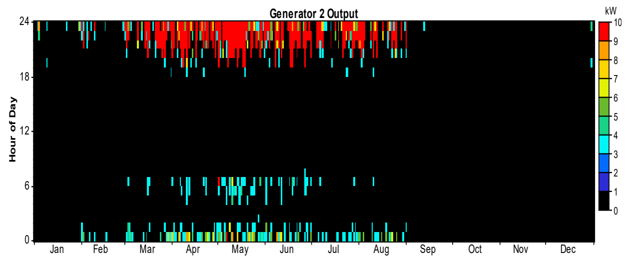

Figure-11. Energy profile PLTD 10 kW.

3.5 The profile of load and electrical energy by the generator

The load of the system and its resources are raised and the SOC of the battery. Based on the figure 12, load is supplied by PLTM with power produced at 40 kW. PLTS generates electricity that starts at 07.00 to 16.00 with maximum power generated is of 31,109 kW which occurred at 10.00 at the same time the battery do the filling up to 17.00 discharging process then happens until 22.00. Thus, lack the power needed by the load is supplied by the stored energy from the battery for 5 hours, this can be seen with the output of the inverter with a peak power of 75 kW. While both PLTD supply load at 22.00 up until 02.00 o'clock along with reduced load.

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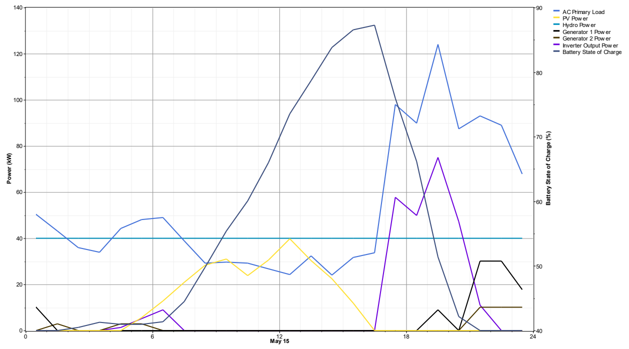

Figure-12. The profile of load and electrical energy.

4. CONCLUSIONS

Based on the results of the optimization of renewable energy to renewable power generation, the amount of electric energy produced by the system simulation model of homer is able to meet the needs of electrical energy in achieving the electrification ratio (RE) and towards the energy independent village (DME) in Borme District. The results of the Simulations provide an optimal system with a PV capacity of 58 kW with configuration PLTMH, with 40 kW, PLTD 1 x 30 kW and 1 x 10 kW, PLTS amounting to 58 Kw, 272 batteries and converter of 75 kW. This configuration gives the value of NPC for $1, 200.265. Electric energy generated by this system in a year is 530.523 kWh. Details of the electric energy of the system is produced from the PLTMH dominate the electrical energy needed by the load of 440.298 kWh/year, PLTS amounting to 76.518 kWh/yr, PLTD of 13.708 kWh/yr., with successive presentations of 83%, 14%, 3%. The penetration of renewable energy of this system is of 97.4%, from PLTMH and PLTS respectively amounted to 80.1% and 17.3%.

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