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Renewable Energy Sources Optimization: A Micro-Grid Model Design

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Abstract

This paper analyzes the possibility to develop the simple micro-grid model in optimizing the utilization of local renewable energy for on-grid area. The proposed micro-grid model integrates the power plants driven by renewable energy sources employing micro hydro (MHP) and photovoltaic system (PV) which is connected to grid system. This model is analyzed using HOMER and MATLAB software. Based on the load profiles and the availability of water resources, the HOMER simulates the proposed micro-grid model with three options of MHP capacity. The simulation results show that the micro-grid model with the largest capacity MHP produced the lowest energy cost, greatest reduction of CO_2 emission, and largest fraction of renewable energy. However, these result required the expensive initial capital cost. In addition, the PV power generation was always recommended with a minimum capacity. Hence, MATLAB results show the performances of the power plants with renewable energy sources were used maximally.

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Keywords: Micro-grid; Micro Hydro; Photovoltaic; Cost of Energy; Carbon Emission.

1. Introduction

Nowadays, the Optimizing utilization of renewable energy sources reducing the usage of endangered fossil energy is a brilliant idea. In Indonesia, the usage of fossil energy including coal, gas and oil are believed as the primary energy source of the power plant. According to Indonesia National Electricity Company in 2011[1], the total energy production of power plants are 142,739.06 GWh, distributed based on the primary energy sources: *coal* 54,950.57 GWh (41.5%); oil 41,846.27 GWh (31.6%); *natural gas*

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32,138.47 GWh (24.3%); *hydro* 10,315.55 GWh (7.8%) and *geothermal* 3,487.39 GWh (2.6%). This condition would have the impact on the increase of carbon emissions as a result of the use of power plants driven by fossil energy. However, the Indonesia government is serious to reduce the percentage of electric energy production from fossil energy and increase the proportion of the electric energy from renewable energy sources. Through a national energy policy, electricity laws and regulations, the Indonesian government encourages the number of activities to produce the electricity of renewable energy sources.

The electricity supply of power plants using renewable energy sources in standalone installed is hard to grow due to unreliable and costly. It relates to the fluctuation of renewable energy availability (e.g., solar, micro hydro, wind, etc.) and its amount depends on the place, time, climate and weather. In the meantime, the area employing the network utilities (on-grid area), the energy cost of power plants using renewable energy sources in stand-alone is more expensive rather than the electricity selling price of the grid system. This condition is caused by the government subsidy of electricity selling price in the grid system. In addition, the electrical load in the rural areas has a lower load factor (10-40%) [2], consequently, the use of the stand-alone power plant will decrease its capacity factor and increase the energy cost.

The effective effort maintaining the power supply reliability of renewable energy sources related to the combination of multiple power plants in different energy sources, namely is hybrid power systems [3]-[5]. The hybrid system consist of the power plant using renewable energy sources, such as photovoltaic (PV), micro hydro (MHP), wind, biomass, and others, employing battery storage or conventional diesel generator, that can be connected to the grid system or stand alone configuration are identified as the micro-grid [3], [6]. The use of the micro-grid in the off-grid area, a combination of power plants using renewable energy sources is also complemented by the diesel generator. Meanwhile, in the on-grid area, the combination would be complemented by the electricity supply of the grid system.

The research in the field of micro-grid/hybrid power generation system across the world using feasibility studies, computer modeling, control strategy and experimental work has been intensively conducted. The system configuration, control strategy and numerous micro-grid applications in several locations of the world have been reviewed in the preview study [3]. The usage possibility of micro-grid employing the power plants combination of renewable energy sources using the micro turbine was discussed in the studies [7]-[9]. Previous studies [4], [5] also have discussed the feasibility study and optimization of the model micro-grid/hybrid using HOMER which is suitable for isolated rural areas. The study have conducted in [7] operating the combination of biomass, PV, wind system and diesel generator, and the combination of PV/wind/MHP and diesel generator is analyzed [8].

This paper analyzes the possibility to develop the simple micro-grid model optimizing the utilization of local renewable energy for on-grid area. The optimization is conducted using HOMER software related to the size and type of energy conversion technologies used by local renewable energy sources (MHP and PV). Meanwhile, the considerable variable is the cost of electricity (COE), the initial capital and the carbon emission reduction. In addition, the micro-grid model constructed is analyzed using SIMULINK-MATLAB software to observe its performance.

This paper is organized in five sections. The fisrt section is introduction, the next section (2) describes the study location and system configuration of the proposed micro-grid models. Micro-grid model development using Homer and MATLAB software is discussed in section 3 of this paper. Section 4 presents results and discussion in this study. Finally, the conclusions are discussed in section 5 of this paper.

2. Study Location and System Configuration

The current study is conducted in the Engineering Faculty campus, Andalas University (UNAND). The campus locates at 0^0 54.843' S and 100^0 27.877' E, with an altitude of 330 m above sea level and the average total rainfall per month 325 mm. This campus has six main buildings, including one faculty

building and five department buildings. Currently, the entire electricity need of the campus is supplied by the utility grid through a distribution transformer. Approximately 1 km from the location, a micro hydro energy source is available and potentially to be developed. In addition, solar energy is always available to be utilized supporting the campus electricity supply.

Simple micro-grid model proposed in this study is adjusted to the availability of renewable energy sources locally. The system configuration of the proposed micro-grid models as shown in Fig. 1. The figure shown that micro-grid is built by power plants with renewable energy sources (MHP and PV), and combined with the grid system. In this configuration, the energy of the MHP and the PV power genaration are used optimally. Along with that, the grid system plays the role as a backup power source. The grid system will supply power when micro-grid is unable to meet the needs of load, and will absorb excess power the power surplus condition.

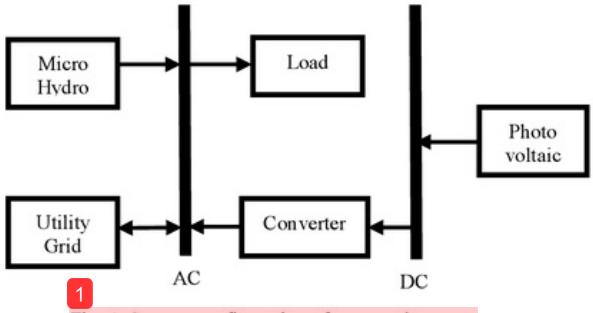


Fig. 1. System configuration of proposed system.

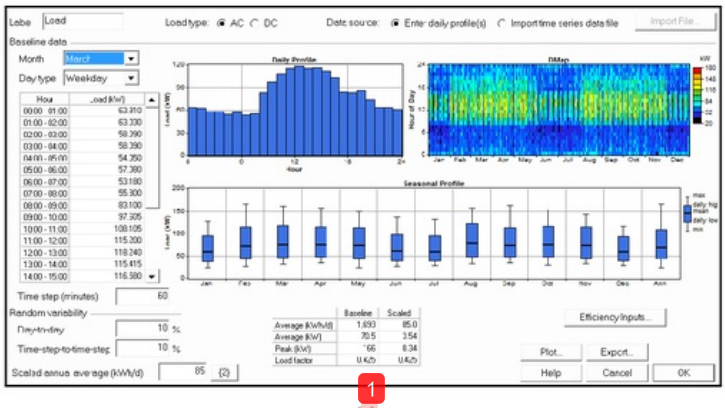
2.1. Electric Load Profile

Electrical load characteristics depend on the activities performed and equipment used. There are numerous campus activities including tutorials, exams, laboratory practice, research, final project and administrative activities. The types of equipment used include the lighting, air conditioning, water pump, computer, laboratory, and workshop. The measurement of the electrical load is done directly using the power analyzer equipment per one hour during 24 hours. The weekly profile, measurements were made for 2 days in weekday and 2 days in weekend, hence its average results are entered into HOMER. The monthly profile is grouped in the semester break and semester day. The semester breaks are December, January, June, and July. Whereas, The semester day are February, March, April, May, August, September, October, and November.

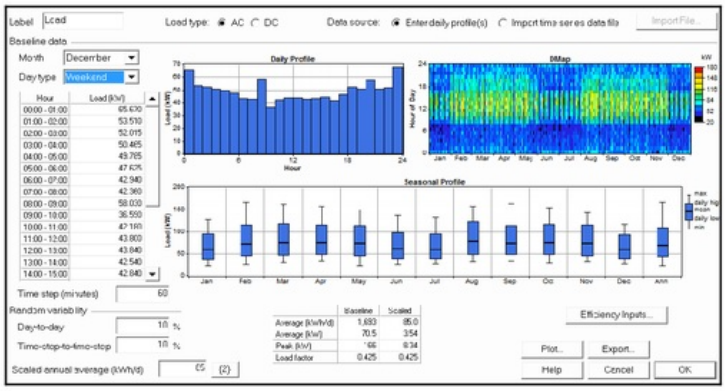
The assumption of random variability from day to day and time step to time step have similar values that is by 10%, load profiles for the proposed system can be displayed by HOMER (Fig. 2). Again, Fig. 2a shown that, the electrical load varies at weekdays in semester class between 53.80 kW and 118.24 kW. The weekend in break semester varies between 41.425 kW and 69.45 kW as seen Fig. 2b. Overall, the power of the average electrical load of the campus is 70.50 kW, with a load factor of 0.425 and energy per day of 1693 kWh/d.

2.2. Solar Energy Sources

Solar radiation data and Cleanness Index data are retrieved online from HOMER Energy Website, which is data set: NASA SSE World [5], [14]. By entering data latitude and longitude of the study location ($0^0$54' S and $100^0$27' E) and the time zone of location (GMT +07) to the HOMER software, the solar radiation and cleanness index data will be obtained, as shown in Fig. 3.



(a)



(b)

Fig. 2. Electric load profile: (a) Weekday profile in semester day; (b) Weekend profile in semester break

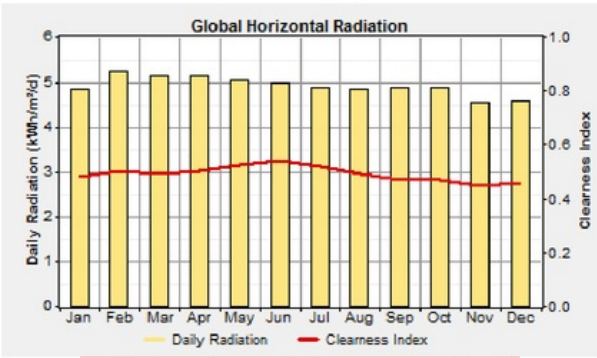


Fig. 3. Solar radiation and cleanness index of the site

2.3. Water Resources

Beside Andalas University campus flows Limau Manis river with watershed as indicated by Fig. 4. The stream flow of Limau Manis River was obtained from the processed data of the rainfall and weather

since 1996-2012 on the location of Gunung Nago climatology station [18] by Energy Research Centre, Andalas University. These results were also cross-checked with direct measurement of instantaneous stream flow in 2008. Fig. 5 shows the stream flow average of Limau Manis River every month during one year.

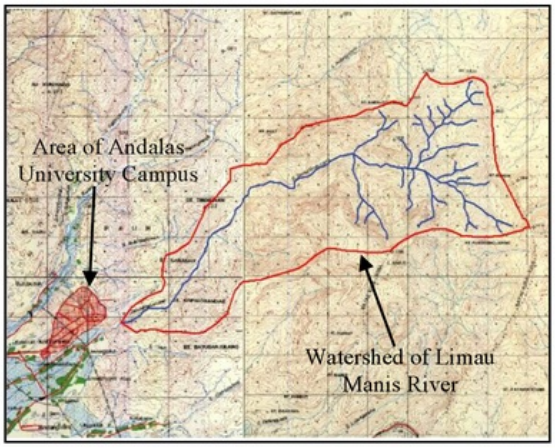


Fig. 4. The watershed of Limau Manis river [source map: Reptak Japtop TNI-AD Jakarta, Edited by E. Ekaputra]

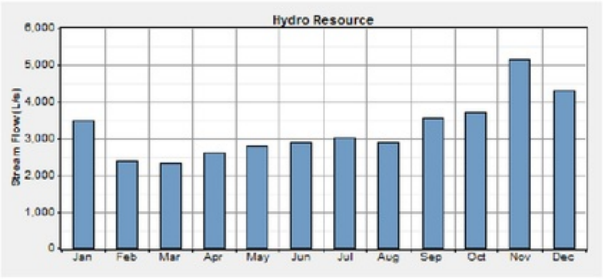


Fig. 5. The Stream flow of Limau Manis river

2.4. Grid System

The proposed micro-grid of this study is the type of partial feeder micro-grid [6], which is part of the Unand's feeder. Unand's feeder is one of the feeders in Pauh Limo's substation, wich is simplified as shown in Fig. 6 [19]. Besides supplying the load in the study area, this feeder also supply the load of the other faculties, administration building, and housing next to the university. Meanwhile, Pauh Limo's substation is connected to West Sumatera's Grid System.

3. Modelling of Micro-Grid

3.1 Micro-grid Model Using HOMER Software

Fig. 7 shows the proposed micro-grid model using HOMER software. This model was developed from the system configuration in Fig. 1 that is equipped with a battery system.

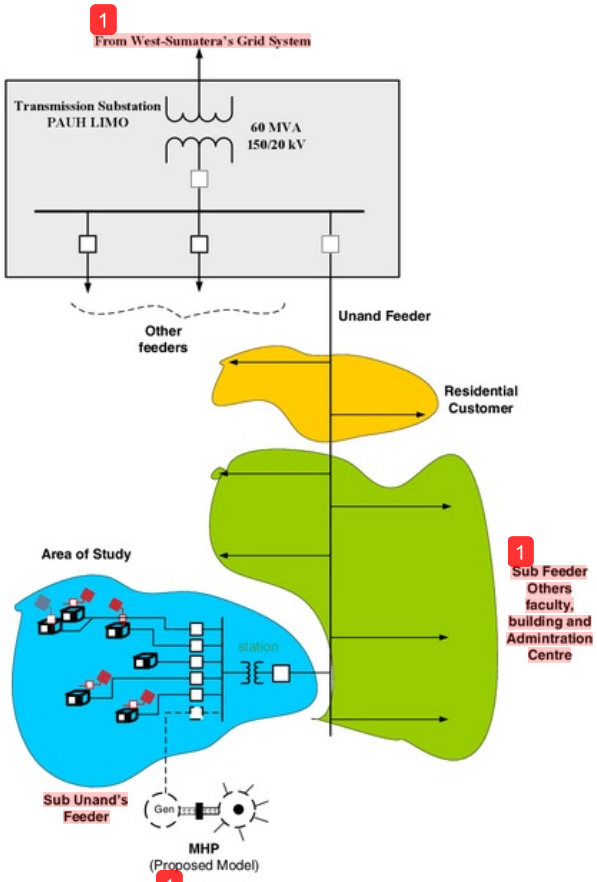


Fig. 6. Grid system and study area

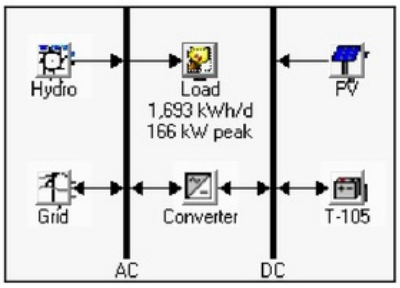


Fig. 7. Modelling of proposed micro-grid using HOMER

3.1.1 Micro Hydro Power Plant Model

Micro Hydro Power Plant (MHP) model was proposed using the stream flow of Limau Manis River to generate electricity. Based on Fig. 5, the minimum of stream flow was 2340 L/s, occurred in March. Taking into account the residual flow of 1000 L/s, the stream flow can be used for power generation 1340 L/s or 1.34 m^3/s. The nominal power of MHP can be calculated using the following equation [15]:

$$P_{MHP} = g.\eta_{MHP}.h.Q_{design} \quad (1)$$

where: P_{MHP} is nominal power output of MHP [kW], g is acceleration due to gravity [m/s^2], η_{MHP} is MHP efficiency, h is gross head [m], and Q_{design} is design flow [m^3/s].

The consideration of the profile loads (Fig. 2) and the availability of water resources (Fig. 5), three design flow options for MHP model are simulated as 0.9, 0.6, and 0.3 m^3/s. Meanwhile, the gross head for all options was 23 m. The capital cost per kW of MHP in Indonesia for power of 50-150 kW with medium head was USD 3500 – 3000 [5], [16]. The efficiency and lifetime of the power plant were assumed to be 75% and 25 years respectively. The replacement cost as the identification of the replacing cost for energy equipment (such as: turbines, generators, control equipment and installations) was 25% of the capital cost.

3.1.2. PV Power Generation Model

HOMER estimates the power output of the PV power generation using the following equation [15]:

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_s} \quad (2)$$

Where: f_{PV} is the derating factor of PV, Y_{PV} is rated capacity of PV (kW), I_T is the solar radiation (kW/m^2), and I_s is 1 kW/m^2 (the standard amount radiation).

PV modules are paired in a combination of series and parallel. The capital cost per kW is USD 3,500 including the cost of purchasing solar panels, mounting panels, control systems, wiring and installation [10], [11]. Based on the specification, the age of solar module is determined for 25 years [10], [11].

3.1.3 Battery and Converter Model

The battery is required to improve the system performance of micro-grid. This device is used in responding short-time disturbances and variations of irradiation solar. Number and capacity of batteries per string is adjusted to the capacity and output voltage of PV generation. In this model, a 6 V-225 Ah battery has been considered. The capital cost and the replacement cost per battery are identified as the similar number that is USD 200.

The converter works as a coupling between the DC and AC system, and can flow the electrical power in two directions (bidirectional). On the other hand, the converter can work both as an inverter and rectifier depending on the direction of power flow. In this model, the converter of 7.5 kW is used, and suitable with PV capacity. The capital cost and the replacement per kW converter put in the similar number that is USD 350.

3.1.4 Utility Grid Model

Currently, selling price of electricity from the grid system to the campus is IDR 824/kWh or USD 0.0824/kWh [17]. Meanwhile, sellback price for excess power from power plants with renewable energy sources to grid system are decided by the government in Sumatra Island is IDR 787/kWh or around USD 0.0787/kWh [17].

The operation of thermal power plants as a supply source of the grid system produces gas emissions, such as CO_2, N_2O, SO_2, NOx, CH4, and others. Among these emissions, CO_2 emission contributes significantly to global warming [13]. Accordingly, the current study focuses only to CO_2 emissions. Emission coefficients of the grid system are calculated based on the emission coefficient and the electrical

energy produced by each power plant. The emission coefficient and energy production in each type of power plants are shown in Table 1 [13], [20]. Meanwhile, the emission coefficient of the West-Sumatera Grid System in 2012 can be calculated by the following equation:

$$\text{Emission Coefficien t of Grid} = \frac{\sum_{i=1}^{n} EC_i x\, kWh_i}{\sum_{1=1}^{n} kWh_i} \quad (3)$$

where
EC_i = Emission coefficient of the power plants to-i (kg/kWh)
kWh_i = Production of power plants to-i (kWh)
The calculation of Emission Coefficient for the West-Sumatra's Grid System is shown in Table 1.

Table 1. Emission CO_2 Coefficient of Power Plants and West-Sumatera Grid System

Type of Power Plants	Capacity (MW)	Production (MWh)	Emission CO_2 Coefisient (kg/kWh)
Coal	178	1.126.746,50	1,140
Gas	53	161.103,52	1,091
Diesel	40	270.160,30	0,786
Hydro	252	1.029.392,30	0,000
Grid System		2.587.402,62	0,6464

3.2 *Micro-grid Model Using SIMULINK-MATLAB*

The performance analysis of the micro-grid using SIMULINK-MATLAB modeling is required. The modelling of proposed micro-grid using SIMULINK-MATLAB is shown in Fig. 8. This model is constructed by MHP, Grid, PV power generation, and load block. The PV power generation block consist of PV modules, converter, transformer and filter. This model implemented the configuration of option 2. PV modules were paired in a combination of series and parallel. MHP block used a 110 kW induction machine provided by MATLAB software. The power distribution from the substation to the micro-grid is modeled by block grid. This simulation will was be observed the effect of changing the load on the power contribution of the MHP, Grid System, and PV power generation.

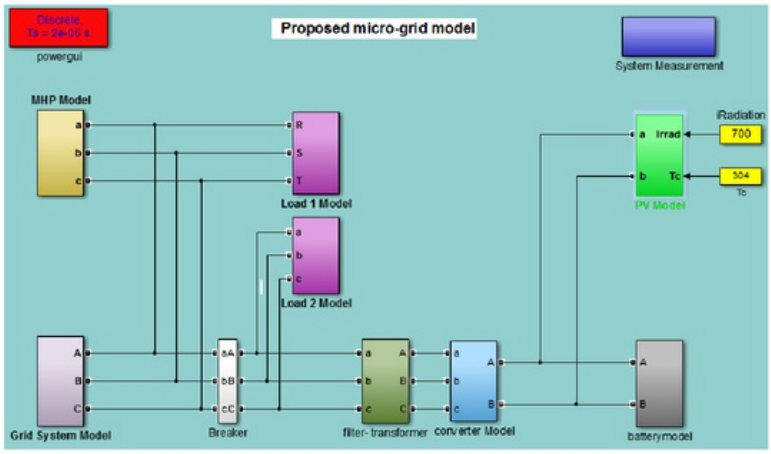


Fig. 8. Proposed micro-grid model using SIMULINK-MATLAB

4. Results and Discussion

4.1 Optimization Results Using HOMER

The optimization results of the proposed micro-grid in three options flow design for MHP (0.9, 0.6, and 0.3 m^3/s) using the HOMER are shown by Fig. 9. The optimatization results in eight items as the most cost effective configuration for each option were solved. In addition, the PV capacity was always recommended with a minimum capacity of 5 kW. Based on Fig. 9, the configuration chosen for each option were the combination containing all local renewable energy sources (PV and MHP) to develop the proposed micro-grid model. The battery system was also required to improve the system performance of proposed micro-grid.

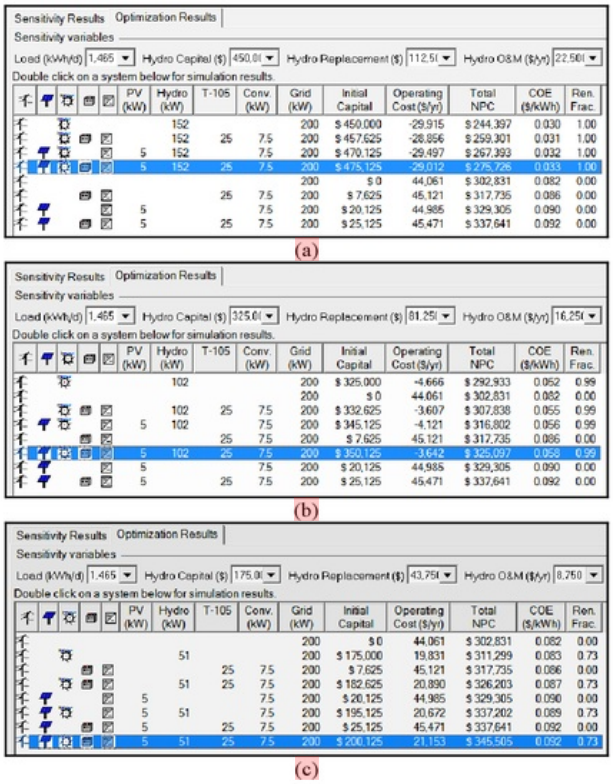


Fig. 9. The optimization results for the proposed micro-grid using HOMER: (a) option 1; (b) option 2 ; (c) option 3

Table 2 shows a comparison of output for all design options. In terms of cost, option 1 required the high initial capital costs. On the contrary it provided the low energy cost comparing to the tariff of the electricity grid (USD 0.0824/kWh), the energy costs for option 1 and 2 are cheaper, rather than option 3. As shown in Table 2, the operating cost of option 1 and option 2 is negative, due to the sale of electric energy from the excess power to the grid system. The sales proceed of excess power will cover the operating costs of the system. In addition, the levelized cost of MHP for option 1 and option 2 was still lower than the tariff of electricity grid.

The fraction of renewable sources correlated to the amount of CO_2 emissions was generated by the micro-grid and the number of the emissions reduction on the environment. As shown in Table 2, CO_2

emissions generated micro-grid for option 1 and 2 is negative. It means a micro-grid reducing the CO_2 emissions on grid system as a result of the delivery of electrical energy to the grid from renewable energy sources. If unavailable micro-grid, the amount of CO_2 emissions as a result of the use of electrical energy from the grid system is 534,727 kWh x 0.6464 kg/kWh = 345,647.53 kg. Meanwhile, the total amount of CO_2 reduction on the environment is determined by the total amount of renewable energy production and CO_2 emission coefficient of the grid system, as shown in Table 2.

Table 2. Comparison of results for all design options

Variable	Unit	Option 1	Option 2	Option 3
Capacity				
PV Array	kW	5	5	5
MHP	kW	152	102	51
Grid System	kW	200	200	200
Cost				
Initial Capital Cost	USD	475.125	350.125	200.125
Total Operating Cost	USD/kWh	-29.012	-3.642	21.153
COE	USD/kWh	0.033	0.058	0.092
Levelized Cost				
MHPP	USD/kWh	0.0733	0.0794	0.0855
PV Array	USD/kWh	0.405	0.405	0.405
Energy Production				
PV Array	kWh/year	7,158 (1%)	7,158(1%)	7,158 (1%)
MHP	kWh/year	1,200,744(99%)	800,454(98%)	400,227(72%)
id Purchase	kWh/year (%)	11(0%)	11,528(1%)	147,528(27%)
Energy Cosumsion				
Load	kWh/year (%)	534,727(44%)	534,727(65%)	534,727(97%)
Grid Sales	kWh/year (%)	672,455(56%)	282,184(35%)	14,112(3%)
Emission & Renewable Energy				
Emission CO_2	kg/yr	-424.984	-171.055	84.319
Reduction Emission CO_2	kg/yr	780,322	528,051	229.323
Renewable Fraction	%	100.00	98.60	73.10

In option 1, all electricity needs were supplied by the renewable energy sources; MHP 99% and PV 1%. Approximately 56% of the energy produced by the micro-grid system is sold to the grid system in sellback price which is higher than the levelized cost of MHP. This condition will significantly impact on decrease the energy cost of micro-grid. For option 3, the composition of the largest electric energy provider still MHP (72%), but there is the purchase from the grid system by 27%, as shown in Fig. 10. In addition, the levelized cost of MHP and PV power generation in this option is higher than the tariff of electricity grid. This condition will cause energy costs for this option is higher than the tariff of electricity grid.

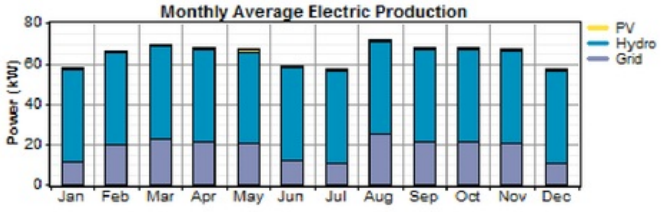


Fig. 10. Energy Production for Option 3

4.2 Results of Perfomances Simulation

Fig. 11 shows the simulation performance results of proposed micro-grid using SIMULINK-MATLAB. Before t = 0, the MHP has been supplying power to the load and grid system. At t = 0, the PV power generation connected to the grid. As seen in this figure, the MHP and PV power generation have shared to supply the power of load and grid system. At t = 0.4 s, the load was increased. MHP and PV maintain its power at a relatively constant value, while the grid system will increase power supply for micro-grid in order anticipating the increasing load. In this condition MHP, PV, and Grid system will share supply the power to the load. At t = 0.7 s, the load was down. Hence, the grid system will be separated from the load supply of micro-grid, because the supply of MHP and PV meet the needs of the load. Briefly, electricity supply from renewable energy sources for the proposed micro-grid were optimized, while the power of grid system were varied according to the load requirements.

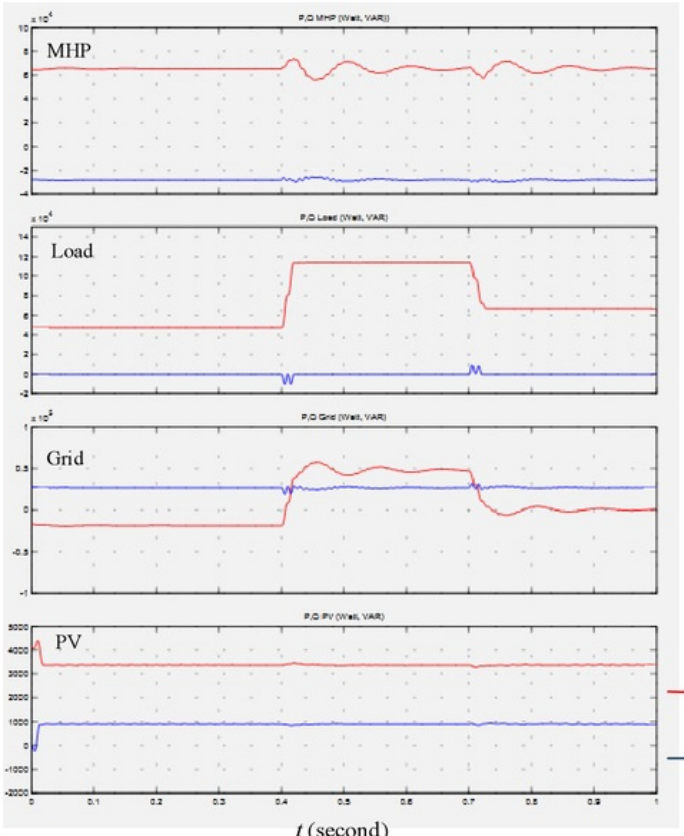


Fig. 11. the effect of changing the load on the power distribution

5. Conclusions

This paper has analyzed the possibility to develop the simple micro-grid model in optimizing the utilization of local renewable energy for on-grid area. Based on the profile loads and the availability of water resources, three design options of MHP model are considered, that are: 152 kW, 102 kW, and 51

kW. The micro-grid model with MHP design in approaching the peak load capacity (152 kW) produced the lowest energy cost, greatest reduction of CO_2 emission, largest fraction of renewable energy. On the contrary, this condition required the expensive initial capital cost. Meanwhile, for a micro-grid model with MHP design in approaching the base load capacity (51 kW) required low initial capital costs, however it tends to have the high energy cost, low reduction of CO_2 emission and small fraction of renewable energy. These three options of micro-grid, the PV capacity was always recommended with a minimum capacity, since the levelized cost of PV is more expensive than the electricity tariff of grid. However in the future, considering the electric load growth and the downward trend in the levelized cost of PV, the development of PV units on the proposed micro-grid is very promised. The micro-grid performance has been observed using MATLAB-SIMULIK simulation.The simulation results, the electric power generated by the power plants with renewable energy sources were optimally used. Finally, this study needs to be continued with the development of control strategy for the micro-grid in optimizing the utilization of local renewable energy.

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