Experimental Testbed and Performance Evaluation for Rooftop Solar PV System and Generator Set

Dena Hendriana[a] , Erikson Ferry Sinaga[a]
[a]Swiss German University
Indonesia
dena.hendriana@sgu.ac.id

Arko Djajadi KT[ab*]
[b]Higher Colleges of Technology
UAE
*atodokromo@hct.ac.ae

***Abstract*—Adoption of renewable energy sources into daily energy consumption has become both trends and necessity worldwide to cultivate environmentally friendly attitude of living. On top of that, Indonesia was once a member of oil exporting countries, but recently the county has been forced to become a net oil importer due to increasing internal demands. So fossil fuel and electricity are getting pricier. The use of rooftop solar photovoltaics system with a backup system such as a generator set (genset) provides a viable alternative solution. Such a solution is quite popular in Indonesia due to their wide availability and abundance of solar radiation. The underlying questions are: how efficient is such approach, and how can the efficiency be improved. In this paper, first the electric power and energy production of an installed rooftop solar photovoltaics system is studied and possible losses in the system are estimated by comparing daily measurements and PVGIS modelled energy productions. The study reveals that the current system is estimated to have 29% loss that is attributable to the inefficiency in the PV panel, cabling and inverter.**

Tests on the genset were performed to verify the quality of the AC electricity output and to produce the fuel consumption characteristic of the genset. It was achieved by attaching electric loads to the genset output while inputting a fixed amount of gasoline volume, and recording the running time of the genset for each load. Each test was done for a different electric load. Knowing the running time of the genset, total electrical energy output of the genset could be calculated and its energy efficiency could be calculated. The resultant efficiency curve for the genset used in this study yielded a maximum of 15% of usable electric energy out of 100% of supplied fuel energy. It demonstrated the quite big loss in converting fuel energy to electric energy. Genset producing electricity ideally should be loaded high enough of around 80% of its ideal capacity to further minimize losses.

These findings from experimental setup are useful to consider and where to focus for the next study to gain improved efficiency when combining multi-sources in the context of renewable energy and smart grid. These findings will be applicable in most parts of the world.

Keywords: Photovoltaics; Solar PV; genset; testbed; measurement

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I. Introduction

Indonesia has been forced to become a net oil importer, so fossil fuel and electricity are getting more pricy. Global oil price fluctuates erratically. Therefore, not only must the use of electricity be more efficient, but also must alternative solutions be invented, tested and adopted. Most households in Indonesia use PLN, a name of government's power grid company, as the main source of electrical energy supply. However, the monthly electricity bill keeps increasing steadily due to higher and higher kWh prices. People start to look for alternative sources of electricity simply to reduce their electricity bills or to be less dependent from PLN. To pursue for that, worldwide people start to utilize and convert some natural resources into electrical energy. Available resources such as sunlight, wind, running water, biomass, etc can readily be converted to usable electrical energy and consumed locally [1,2,4,5,6,7,11,13,15]. Other electrical energy sources such as genset and storage such as battery have been used to fulfill the need for electricity [1,2,4,11,13].

In another case, many telecommunication stations (BTS) are located away from the city, and the network of electricity from PLN does not reach the sites. In this situation, they need to use genset with a combination of solar panel and battery to power the BTS to cover their continuous operation. Configuration and strategy on utilizing these combinations of power sources have been studied in several references [1,2,4,12,13]. Usually, the use of genset is quite expensive due to the price of the fuel and the difficulty of fuel transport to the site for a continuous operation. Therefore, their strategy is to minimize the use of genset and maximize locally generated energy from available resources.

Below is a brief review of natural resources that offer potential as a source of energy for electrical energy, especially in Indonesia. Sunlight is an abundant source of energy due to country's location around and along the equator. The sunlight is available everywhere, however, its intensity varies between seasons due to weather variations during daylight. Clouds, atmospheric haze, temperature and rains affect the intensity of earth surface radiation [17,19]. The intensity of sunlight depends on the time of the day, with lower intensity dominates in the morning and evening time, and with significantly higher intensity in between during clear sky day. The solar intensity depends on the season, with lower intensity dominates during raining season and with higher intensity shines during dry season. This variation of radiation intensity undoubtedly will reduce the amount of solar energy reaching the earth surface that can be converted into electricity by the PV panels.

Wind is another source of energy. In general, wind energy in Indonesia is not as high as in northern America or northern Europe. However, it has been surveyed that in some part of Indonesia wind energy has a good potential to be converted to electricity [6,8]. Wind speed and its direction is changing from time to time within the day. To calculate its potential energy, a wind speed graph as a function of time for the whole day of the year is needed. This wind speed graph shows an average for the whole month or even the whole year. With this graph, potential kinetic energy from the wind per unit area can be calculated and estimated for daily, monthly or yearly.

On the other hand, the technology to convert wind to electric energy needs to be adapted to the typical wind speed in Indonesia. Most of wind turbines in the market are rated for high wind speed such as 10 m/s or higher, and this technology is not applicable in Indonesia due to lower wind speed, such as 4-6 m/s. Development of wind turbines optimized for lower wind speed is needed for the application in Indonesia [6,8,9].

Water has been used most extensively to produce electricity. Energy from running water is available in the areas close to rivers or lakes. The conversion of water's potential energy to electric energy can be done in those areas after securing the required license and permit to do so. Blocking a large river flow will create large water area which might displace housing and existing objects in the area.

The other common source of electric energy is a generator set or genset for short. This equipment is available with reasonable price. However, generator sets need gasoline or diesel fuel to run and generate electricity. As the price and transport of the fuel is not cheap, this will increase the operating cost. Test and measurement need be done on a generator set to obtain its electric generation and fuel consumption characteristics, and to find how much the cost to generate electricity per kWh.

Battery is a common apparatus to store electric energy. High capacity battery is still quite expensive and can only store a limited quantity of electric energy. However, its application is essential to enable a continuous electricity delivery to users using some forms of renewable energy sources [4,13]. Optimization of required battery capacity needs to be done to minimize the cost of investment.

II. Literature Reviews

A. *Solar Panel*

The invention of solar cell was started in early 1900s when engineers observed the effect of some material being stroked by sunlight and generated some amount of electric current [3,4]. Significant developments of solar panel occurred around 1970 by many universities and companies. The current technology for solar cell, published by National Renewable Energy Laboratory (NREL) from USA, is shown in the following graph [18].

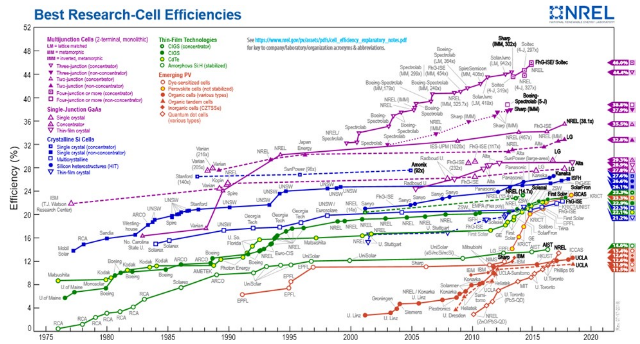


Fig 1. Timeline and development of solar cell efficiencies (source: NREL)

Based on the graph, there are 5 major types of solar cell developments. The first type is multi junction cells. The solar cell efficiency of this type is quite high, 46%, and it is still growing [3,16,18,21]. The challenge for this type of solar cell is that the manufacturing cost is still expensive. The second type is single junction Gallium arsenide (GaAs). Its efficiency is 29%, which is quite high but the cost of this solar cell is very expensive. The most common solar cell is the third type, Crystalline silicon cell. Its highest efficiency is 27%. Poly-Crystalline and Mono-Crystalline solar cells are the main solar panel in the market due to their better price. The price is lower because the manufacturing process for this type of solar cell is easier than other types and with cheaper raw material. Now, researchers are looking for cheaper solar cell and emerging solar cell is made of organic material which is quite popular in universities [22]. However, its efficiency is only 12% and there are still a lot of work to be done to improve it.

Market share for different solar cell types is shown in Figure 2. From this graph, the most popular solar cell in 2010 is Multi-Si or Poly-Crystalline Silicon base solar cell which is holding for around 53% and the second most popular is Mono-Si or Mono-Crystalline Silicon base solar cell which is accounting for around 33% of the market share [16,23]. Both products control 86% of the market share.

B. *Photovoltaic Geographical Information System (PVGIS)*

PVGIS is a free online solar photovoltaic energy calculator for stand alone or connected to the grid. It calculates the annual, monthly and daily output power and potential electricity generation of solar photovoltaic panels with defined modules tilt and orientation. The area covered by the PVGIS calculator is almost the whole world from America, Europe, Africa and Asia including Indonesia.

PVGIS is utilizing maps representing yearly average of daily total of global irradiation on a horizontal and inclined surface [17]. The data is derived by data enhancement of the HelioClim-1 database [26] which is containing 20-years average, period 1985-2004, see Figure 7. PVGIS contains several calculations:

- Computation of clear-sky global irradiation on a horizontal surface.

- Sky obstruction by local terrain features (hills or mountains) calculated from the digital elevation model.
- Interpolation of the clear-sky index and computation of global irradiation on a horizontal surface.

C. Generator Set

A gasoline generator set is a combination of gasoline internal combustion engine with an electric generator to generate electrical power. Generator sets, or called gensets, are usually used in locations without any connection to power grid, or for emergency power-supply when the grid fails, or for grid support and for exporting to the power grid.

Proper sizing of genset is critical to avoid a shortage of power or over supply of power. Sizing depends on electric demand and complexity comes when the demand is not constant and sometimes unpredictable. Figure 8 shows different kinds of gensets. As a general practice, diesel engines are used up to 50 MW. For higher demand, an open cycle gas turbine is more efficient at full load than an array of diesel engines. The gas turbine is far more compact at comparable capital costs. For regular part-loading, diesel arrays are sometimes preferred to open cycle gas turbines, due to better efficiencies. In a typical household, electric demand is not constant, depending to the condition of the family activity. Generator size of 3000 watt should be sufficient for most of households and we consider this size in this research.

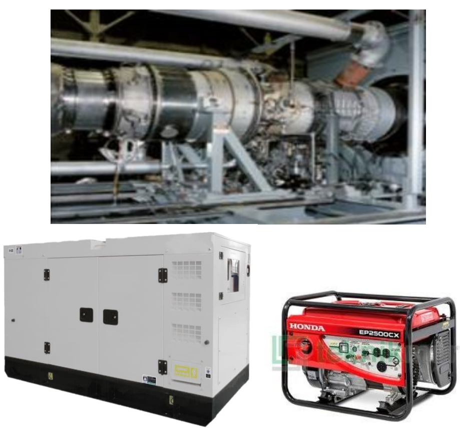


Fig 2. Different kinds of gensets: 12.5 MW gas turbine, 12.5 kW diesel, 2.2 kW gasoline gensets.

III. SOLAR PANEL SYSTEM INSTALLATION AND TEST

In this project, a 2000-watt-peak of solar panel PV system is used as a testbed to evaluate the overall efficieny of the installed system, in comparison to the theoretical analysis from a simulation sofware tool. The installed PV system consists of 10 pieces of 200-watt solar panels, a cabling system and an On-Grid inverter, as is shown in Figure 9. The location is in Tangerang, Banten, (latitude, longitude: -6.248, 106.606.)

Fig 3. Installation of a rooftop solar panel PV system on site for the test.

The installed system is equiped with a online monitoring system that sends data to the clouds and can be accessed in the internet by the web address www.ginlongmonitoring.com. The monitoring system records the power and energy generated every 5 minutes. From the power generation, the total produced energy is accumuled, recorded, aggregated and displayed by day, by month and by year for ease of monitoring.

Typical graphs of power generation in a day are shown in figure 10 for the recorded data on the 10th and 12th of September 2018. They confirm that power generation starts around 07:00 in the morning and ends around 17:30 in the evening of local time, when the sun rays are shining on the PV panels . Daily power curve is climbing gradually in the morning and dropping down fast in the evening. This could be because of the positioning of solar PV panels at a fixed angle on the rooftop which are facing more to the west and so the sun has more visibility to the panels in the afternoon time until sunset.

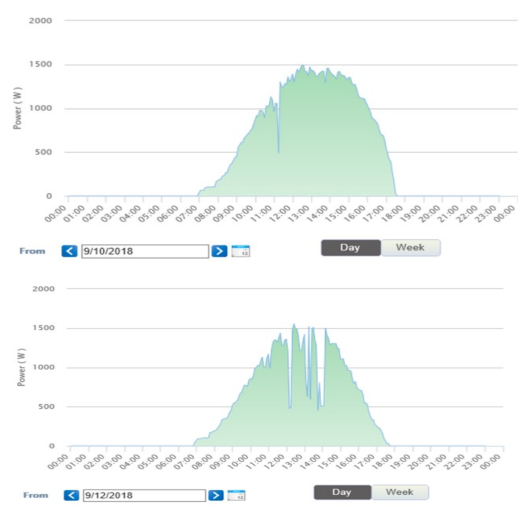


Fig 4. Typical graph of power generation in a day.

The graphs show that during the day time, there were power drops especially for the 12th September data. These power drops were mainly due to clouds or rains that blocked the sun rays resulting in lower electric power generation. Typically the denser the clouds the lower the power generated will be. The longer the time of the clouds blocks along the path of sun rays reaching the PV panels, the longer the time of power drops will be, as can be observed from the graph.

Both graphs show that electric power of the 2000-watt installed capacity can only reach a maximum of around 1500 watt. A quick check to the power generation on any other days, the electric power has never reached 2000 watt, confirming that he maximum power generated was only around 1500 watt. This 80% performance is attributed most likely to the marketed watt-peak as claimed by the vendor of PV panels, whose watt-peak value can only be achieved in idealised testing condition. Further investigatation of why the solar panel system never reaches the designed maximum power needs to be planned in a separate study by collecting and using a database based on a large amount of installed PV in many different places in order to compare the claimed watt-peak capacity against the actual power produced. Other factors such as the tilt angle, orientation, shadowing are worth a closer look at.

Daily electric energy generation for June and July 2018 are shown in Figure 11. The amount of electric energy in kWh per day was not constant, depending on the clouds and weather. A heavy rainy and cloudy day on 25 June only produced 1.2 kWh while a very clear day on 1 June produced 9.4 kWh. This evidently indicates that effect of the weather to electric generation is quite significant.

Fig 5. Daily electric energy generation for June and July 2018.

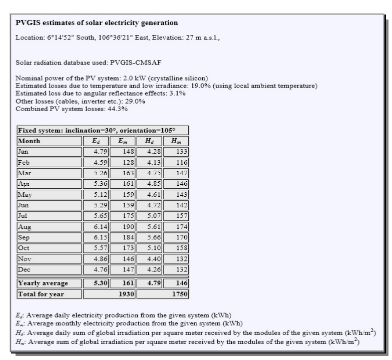
The monitoring system shows that the total electric energy generation on the month of June 2018 was 160 kWh and on July 2018 was 170 kWh. If all days in June were as clear as 1st June day, then the maximum monthly energy generation would be 9.4 kWh x 30 = 282 kWh. And if all days in June were as cloudy as 25th June day, the minimum monthly energy generation would be only 1.2 kWh x 30 = 36 kWh. As an estimation, the effect of weather on electric energy generation in June gave the energy output of 160/282 x 100% = 57% from maximum monthly energy. The extreme weather whenever all the days in June were as cloudy as 25th June day would give monthly energy output of 36/282 x 100% = 13% from maximum potential produced energy on that day. The range here is 13% to 57%.

Similar study can be done for recorded data on July 2018. Note that data on 16th July was not good because of an internet connection problem. The clearest day in July was 15th July day and it produced 8.1 kWh. Dividing this value by the maximum achievable power of 1.5 kW gives the number of equivalent peak hour with clear sky of of 8.1/1.5 h = 5.4 h for that specific day. Obviously, other days have relatively lower values than 5.4 h. The actual daylight with observale output power is 10 hours / day from the graphs in Figure 10, with a typical half circle shape and not a square shape of power distribution through out the day.

To gain insight about the experimental results based on an actual installed PV system above, the effect of weather to electric energy generation is calculated and simulated in the PVGIS website as briefly reviewed before. In this analysis, we are going to use PVGIS to estimate cable and other system loss in the installed PV panel system by approximating the energy generation in the month of June 2018. After several iterations, we have the following inputs to the PVGIS

- PV technology: Crystalline Silicone
- Installed peak PV power: 2 kWp
- Estimated system losses: 29% (after several iterations to match June energy generation)
- Mounting position: Building integrated (installed on building roof)
- Slope: 30 degree (based on building design)
- Azimuth: 105 derajat (based on building orientation on the map)

The result of PVGIS calculation is shown in the following figure.



PVGIS estimates of solar electricity generation

Location: 6°14'52" South, 106°36'21" East, Elevation: 27 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 2.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 19.0% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 3.1%
Other losses (cables, inverter etc.): 29.0%
Combined PV system losses: 44.3%

Fixed system: inclination=30°, orientation=105°				
Month	E_d	E_m	H_d	H_m
Jan	4.79	148	4.28	133
Feb	4.59	128	4.13	116
Mar	5.26	163	4.75	147
Apr	5.36	161	4.85	146
May	5.12	159	4.61	143
Jun	5.29	159	4.72	142
Jul	5.65	175	5.07	157
Aug	6.14	190	5.61	174
Sep	6.15	184	5.66	170
Oct	5.57	173	5.10	158
Nov	4.86	146	4.40	132
Dec	4.76	147	4.26	132
Yearly average	**5.30**	**161**	**4.79**	**146**
Total for year		**1930**		**1750**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Fig 6. PVGIS calculation result for the project location.

With the cable loss of 29%, the june electric energy production is 159 kWh, which is close to recorded june electric energy production of 160 kWh. Note that July recorded energy production of 170 kWh has 1 day missing data of 16th July and if that missing day is filled with estimated average of 5 kWh, then the total July production will be 175 kWh and this is the same as calculated July production by PVGIS. Looking at the yearly average from January to December from the PVGIS of 161 kWh, this value is very close to the value from June 2018 of 160 kWh.

This cable loss can be the reason why the solar panel full capacity of 2000 watt is never reached. Subtracting the effect of cable loss to the maximum power, we have 2000 watt x (1.0 – 0.29) = 1420 watt, which is close to maximum value in the daily power graph. The loss can be recovered partially with more efficient inverters, better cabling and improvement of PV efficiency for future installations. Meanwhile the loss of 15.3% are still attributable to the less or ucontrollable enviromental factors as has been included in the simulation. This sum up the results obtained from the testbed of solar PV system under study.

IV. Generator Set Characteristic Study

The generator set or genset used in this project has spesifications as follows: Output voltage 220 Volt, Output Frequency 50 Hz, Maximum Output Power 3000 Watt, Rated Output Power 2800 watt, Power Factor 1.0, Starter system electric or manual, Weight 55 kg. The reason for choosing this product is because many households have 2200 VA PLN power connection and it is less than 3000 watt. Ideally, this genset will be used as an electric power back-up in a hybrid renewable energy system for a household which is equipped with other sources such as solar panel, wind turbine and microhydro system.

Two types of tests are performed to verify the main quality of the electricity output. First test is to look into the voltage waveforms of the generated electricity to see the shape and frequency of voltage and compare it to a prefect sinusoidal function of 50 Hz. Second test is to obtain a fuel consumption characteristic of the generator, to calculate efficiency curve of the generator and to estimate the price per kWh on the maximum efficiency for this generator. The voltage waveform generated by this genset can be seen in the Figure 13.

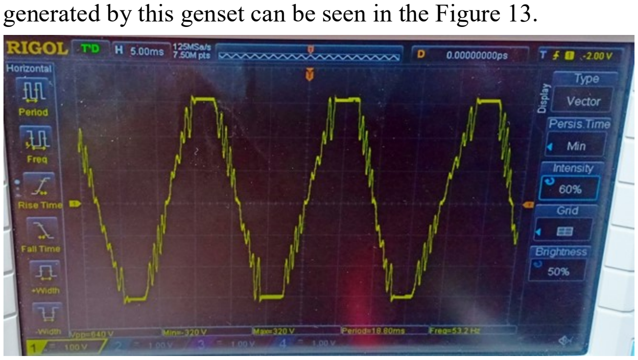


Fig 7. Voltage waveform of the electricity generated by the genset using Rigol DS1074 Digital Oscilloscope.

The graph shows that electrical voltage waveform is not a sinusoidal function but rather a rigid linear function up and down with linear cut-off in maximum and minimum peak at 320 Volt. The wave contains harmonic waves. Frequency of this wave is 53.2 Hz. To calculate the rms value of this wave, we remove the harmonic waves resulting in a simplified function of the wave as shown in the Figure 14. Wave function is compared to the perfect sinusoidal function.

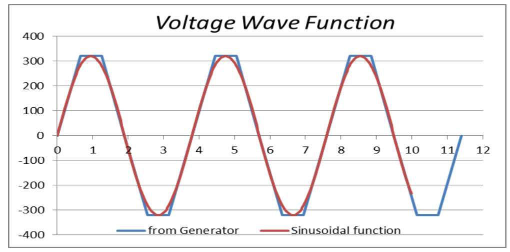


Fig 8. Simplified model of voltage waveform function from genset vs. a sinusoidal function.

The formula to calculate the rms value is

$$f_{\mathrm{rms}} = \lim_{T\to\infty} \sqrt{\frac{1}{T}\int_0^T [f(t)]^2\,dt}.$$

Utilizing the formula above, we can get V_rms = 0.7375 V_max = 0.7375 x 320 V = 236 Volt. Note that the constant in front of V_max for sinusoildal function is 1/√2 = 0.7071. The voltage function from generator has slightly larger constant in front of V_max. Based on this, the deviation from output voltage specification is (236-220) = 16 Volt, and its error is 16/220 ~ 7%. And the frequency deviation is (53.2-50) Hz = 3.2 Hz and its error is 3.2/50 ~ 6%.

Second test is to find generator fuel consumption characteristic and to estimate its efficiency. The test is done by applying different resistive load for the same amount of gasoline, which is 200 ml in this case, and we let the generator runs until it runs out of fuel. In each run, we measure how many seconds the generator runs, how much energy is generated, what are the output voltage and current. To improve test accuracy, each of the case is performed 5 times. Configuration of the test is shown in the following figure.

Fig 9. Test equipment consists of genset, resistive load lamp, electric voltage, current and energy meter and stop-watch.

The following table is the summary of test results. For each run, 200 mL gasoline is used and gasoline energy density is 34.2 mega joule per liter. Therefore, energy content in 200 mL gasoline is 0.2 x 34.2 MJ = 6.84 MJ. Genset running time is measured by the stop-watch.

No	Gasoline Volume (mL)	Gasoline Energy Content (MJ)	Resistive Load (kW)	Generated Electricity					Genset Running Time (second)	Genset Life Time per Liter Gasoline (minute/Liter)	Gasoline Consumption Rate (Liter/hour)
				V-rms (Volt)	I-rms (Amp.)	Total Electric Energy (MJ)	Total Electric Energy (kWh)	Genset Energy Efficiency			
1	200	6.84	0	231.2	0	0.000	0	0.0%	1,035	86.3	0.696
2	200	6.84	0	222.7	0	0.000	0	0.0%	985	82.1	0.731
3	200	6.84	0	223.5	0	0.000	0	0.0%	1,010	84.2	0.713
4	200	6.84	0	222.5	0	0.000	0	0.0%	1,035	86.3	0.696
5	200	6.84	0	224	0	0.000	0	0.0%	1,065	88.8	0.676
average	**200**	**6.84**	**0**	**224.8**	**0.0**	**0.000**	**0.0**	**0.0%**	**1026**	**85.5**	**0.702**
6	200	6.84	0.522	223.2	2.34	0.435	0.1209	6.4%	855	71.3	0.842
7	200	6.84	0.513	224	2.29	0.472	0.131	6.9%	880	73.3	0.818
8	200	6.84	0.521	222.9	2.336	0.442	0.1227	6.5%	870	72.5	0.828
9	200	6.84	0.517	222.1	2.328	0.444	0.1234	6.5%	875	72.9	0.823
10	200	6.84	0.523	223.4	2.343	0.414	0.115	6.1%	840	70.0	0.857
average	**200**	**6.84**	**0.519**	**223.1**	**2.327**	**0.441**	**0.123**	**6.5%**	**864**	**72.0**	**0.833**
11	200	6.84	1.022	223.2	4.578	0.765	0.2125	11.2%	750	62.5	0.960
12	200	6.84	1.015	222.5	4.563	0.693	0.1925	10.1%	685	57.1	1.051
13	200	6.84	1.024	223.9	4.575	0.721	0.2003	10.5%	711	59.3	1.013
14	200	6.84	1.026	223.6	4.59	0.715	0.1986	10.5%	702	58.5	1.026
15	200	6.84	1.022	223.1	4.58	0.702	0.195	10.3%	690	57.5	1.043
average	**200**	**6.84**	**1.022**	**223.3**	**4.577**	**0.719**	**0.200**	**10.5%**	**708**	**59.0**	**1.018**
16	200	6.84	1.941	222.8	8.712	1.084	0.3011	15.8%	565	47.1	1.274
17	200	6.84	1.930	221.5	8.715	0.998	0.2773	14.6%	527	43.9	1.366
18	200	6.84	1.940	222	8.74	1.005	0.2791	14.7%	536	44.7	1.343
19	200	6.84	1.926	221.3	8.705	1.014	0.2816	14.8%	540	45.0	1.333
20	200	6.84	1.933	221.7	8.717	1.004	0.2788	14.7%	533	44.4	1.351
average	**200**	**6.84**	**1.934**	**221.9**	**8.718**	**1.021**	**0.284**	**14.9%**	**540**	**45.0**	**1.333**

Fig 10. Test results for different resistive load value.

A resistive load is the same as the generator output power. Electric voltage, current and total energy are measured by the electric power meter. Genset efficiency is defined as a ratio of generated electric energy to the supplied gasoline energy content. Genset life time per liter gasoline is calculated from genset running time in minute divided by gasoline volume in liter. Gasoline consumption rate is calculated from gasoline volume in liter divided by genset running time in hour.

Using results from average data, genset energy efficiency is plotted in the Figure 17. Four data points can be approximated by a quadratic function to represent genset energy efficiency curve.

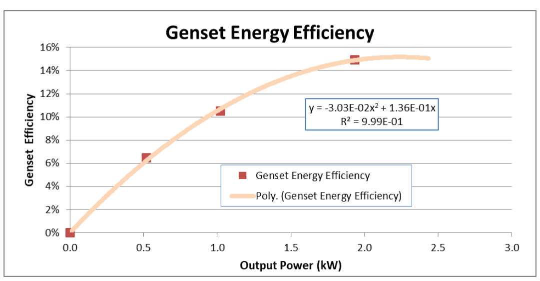


Fig 11. Genset energy efficiency curve as a function of output power.

From the graph, efficiency of genset is zero at zero output power, or in idle condition. The maximum genset energy efficiency is around 15% when output power is around 2.1 kW and the curve starts to drop. Another study [14] on gensets showed maximum efficiency of 16%. This makes sense because when we try to test the genset using 2.5 kW resistive load, genset is running unstable and stop. This indicates that its efficiency declines when the output power is too high. Therefore this quadratic curve seems to be representative characteristic for this genset being evaluated.

Genset energy efficiency is calculated using the following relationship.

$$\text{Genset energy efficiency} = \frac{\textit{Output power}}{\textit{Gasoline consumption rate} \times \textit{gasoline energy content}}$$

From this relationship, the gasoline consumption rate curve is defined from genset energy efficiency curve for given output power.

$$\text{Gasoline consumption rate} = \frac{\textit{Output power}}{\textit{Genset energy efficiency} \times \textit{gasoline energy content}}$$

Output power in kJ/s, gasoline energy content in kJ/liter and genset energy efficiency with no dimension. Applying the trend relation from Figure 17 with output power as independent variable x,

$$\text{Gasoline consumption rate} = \frac{x \times 3600}{(0.136\,x - 0.0303\,x^2) \times 34{,}200}$$

The constant 3600 is the convertion from second to hour. The gasoline consumption rate is drawn in the following figure. Based on this relation, fuel consumption increases at high output power area.

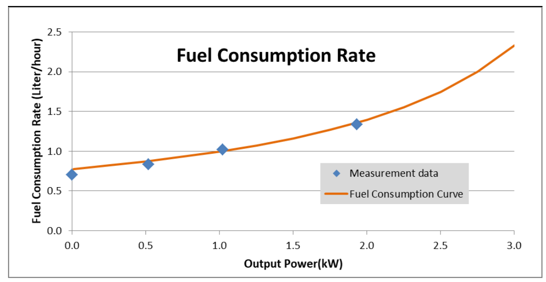


Fig 12. Genset fuel consumption rate curve as a function of output power.

Software renewable energy analysis HOMER (Hybrid Optimization of Multiple Electric Renewables) is using fuel consumption rate curve to be a linear function [10,14]. The curve comparison between the quadratic efficiency curve assumption and linear fuel consumption rate curve assumption are shown in the following figures.

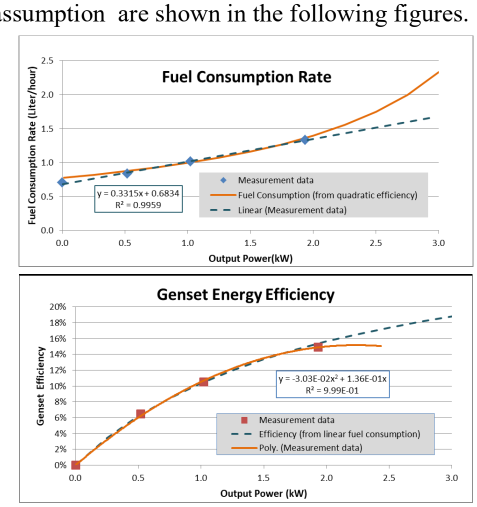


Fig 13. Genset fuel consumption rate curve and energy efficiency curves comparions: linear efficiency curve (upper) vs. quadratic fuel consumption curve (lower).

Both curves are close in the range of 0 – 2 kW output power, however, the curves are significantly different in high output power area. Different genset machines behave differently close to their maksimum rated output power. The machine used in this test behaved unstable at high output power and therefore the curves associated with quadratic energy efficiency curve seems to be closer to the machine real behavior.

Looking into idle condition, the genset is consuming 0.702 liter/hour to idle. This is the cost for making electricity available using a genset. This fuel consumption rate is equivalent to an internal power of

Internal Power at Idle = fuel consumption rate * fuel energy content = (0.702 L/hr) x (34,200 kJ/L) x (1 hr/ 3600 s)

= 6.67 kW

Notice that this internal power at idle is more than twice of the genset rated output power.

We are going to calculate generated electric energy based on fuel price at the highest energy efficiency condition at output power 2.1 kW. Based on the curve, the fuel consumption rate at this condition is 1.45 liter/hour. In this test, gasoline Pertalite is used with unit price Rp. 7800 per liter. The price of electric energy per kWh is

Price of electric energy = fuel consumption rate / output power x gasoline price = 1.45 L/h / 2.1 kW X Rp.7800/L

= Rp. 5385 / kWh

This price is quite expensive compared to PLN price which is around Rp. 1500/kWh.

Notice that maximum genset energy efficiency is only 15%. It is quite low compared to other electric generators, such as PLTU with coal fuel where its efficiency could reach around 25-50% and hydro electric generator with its efficiency could reach 90-95%. Larger capacity genset and different brand of genset could have higher energy efficiency.

CONCLUSION

Based on the study on solar panel system and generator set, we can conclude the following

- Maximum power output of the solar panel system is only 75% from the total installed solar panel capacity of 2000 watt.
- Using PVGIS, we can estimate the loss of the solar PV system by matching inputs using actual energy production for the month June 2018. The cable and inverter loss is estimated to be around 29%, which is quite high.
- Cable loss could be the reason why daily maximum power produced to be much less than the capacity power specified. Verification can be done by replacing the cable with a better cable.
- Maximum energy efficiency of the generator set is only 15%.
- Fuel consumption rate at idle for this generator set is 0.702 L/hr, which can be interpreted as internal power of 6.67 kW.
- Although the rated value of the generator set is 2800 watt and its capacity is 3000 watt, the real maximum output power is only 2100 watt (around 70% of its maximum capacity). If the load is larger, the generator becomes unstable.
- Price to generate electric energy using this generator set is around Rp.5385/kWh. This calculation is based on fuel consumption and price only.
- Generator set is therefore expensive to operate with low efficiency. The usage should be minimized only in emergency situation.

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