Comparative Study of Electricity Generation Fueled by Gasoline, Liquefied Petroleum Gas and Biogas from Municipal Solid Waste

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Article Info	ABSTRACT
	This paper presents a comparative study in terms of power quality and fuel consumption in electricity generation using three kinds of fuel: gasoline, liquefied petroleum gas (LPG) and biogas from anaerobic digestion of municipal solid waste. The electrical parameters measured and compared are voltage, current, frequency, active power, apparent power, reactive power, power factor, displacement power factor, current harmonics, voltage harmonics, transient, sags and swell. From the experiment, resistive loads (100 W bulb and 2 x 100 W bulbs) and resistive-inductive load (125 W water pump) were used as loads of generator set. It can be seen that in general, the power quality among those three fuels shows almost the similar performance. The problem on using combustible gases, either LPG or biogas, significantly appears at the frequency with greatly difference to the standard (i.e. 50 Hz).

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1. INTRODUCTION

Energy supply systems are facing significant changes in many countries around the world. There are many intensive researches and publications on different types of renewable energy sources in order to prepare the migration from conventional energy conversion source using fossil fuels to the renewable sources which are environmental friendly. In the path on this migration, combining energy sources between conventional and the renewable ones is one of the solutions that has been taken, because there many considerations to produce high power level of electricity such as efficiency, costs, expertise, regulation and culture. Combination of two different energy sources described in [1] regarding the simulation result of a hybrid system between solar system using photovoltaics and wind energy. Another paper [2] described the use of fuel cell to produce the energy powered air diffused aeration system. There are still many examples that can be found related to the hybridization. Furthermore, migration from gasoline to gaseous fuel as the experimental study can be found in [3].

In developing countries, such as in Indonesia, still many people using gasoline-fuel generator set. This phenomenon appears since the unreliability supply of electricity in many areas, then people have to be ready for the blackout, or even some areas are very lack of electricity. Another problem is rising since the price of gasoline increases which cause the price of electricity becomes high.

On the other hand, the use of gas for generating electricity brings a high attention nowadays since it produces lower emission in the conversion process. Liquefied petroleum gas (LPG) is combustible gas that

could be used as fuel in the electricity generation system. The LPG is a mixture of propane and butane in liquid form with a pressure of 2-20 bars. Propane (C_3H_8) is the main constituent of LPG as it is a single, relatively simple compound, so engines could have a clean combustion process. It can be stored at atmospheric pressure and avoid evaporative losses.The LPG nowadays exists abundantly and inexpensively in the developing countries such as in Indonesia.

Another combustible gas namely biogas canbe produced from anaerobic digestion.Many previous researches on biogas-powered electricity generation presented in [4-7]. Qualitative and quantitative analysis on biogas generation system using an induction motor-based generator set is presented in [8]. General qualitative analysis of biogas from landfill was briefly presented in [10] without technical data. Furthermore, some analysis of biogas process through modeling, numerical or simulations are presented in [9, 10, 11, 12]. In this presented paper, the biogas from anaerobic digestion of municipal solid waste (MSW) is taken into account, from which the pollutant (solid waste) could harm the environment once they are casted out without further treatment.

The main advantage of using combustible gases as fuel compared to gasoline is a cleaner gas emission after combustion, while the output power seemed similar. Therefore, using organic solid waste as source of electrical generation system by converting them into biogas will bring two benefits: renewable energy source and environmental friendly technology.

This paper purposes to convey the experimental study results by comparing the quality electrical parameters among gasoline, LPG and biogas from MSW. The comparison is based on the power quality analysisand fuel consumption in electricity generation using three kinds of fuel: gasoline, liquefied petroleumgas (LPG) and biogas from anaerobic digestion of municipal solid waste.

2. RESEARCH METHOD
3.1. Materials and Method to Produce the Biogas from MSW
For the experiment, there were three sources of fuel for generator set: gasoline, LPG and biogas. Gasoline and LPG could be easily bought at the local market. For the biogas, an anaerobic digester was built to produce the gas from MSW. Detail of biogas production process can be seen in the previous research in [13] and the potency of biogas from MSW to generate electricity has been investigated in [14].

The waste fed in digester were taken based on grab sampling method from a nearby traditional market in Pontianak city with a composition of ± 80 % vegetable waste and ± 20% fruit wastes. The total waste weight was 160 kg and mixed manually during the feeding. The feeding was carried out for two weeks. The starter using in this research was an inoculum from cow rumen and mixed with the wastes just before the digester was closed. Chemical analysis of initial waste and bioreactors slurry was performed using standard methods.

There are different types of reactors used for energy recovery from solid wastes, including batch reactors, one stage and two stage reactors [7]. In this research, a single stage fed-batch anaerobic digester was used with total volume of 9m^3 contained about 14 tons solid waste. It was operated at ambient temperature in the mesophilic range (27 – 31°C), yet the temperature and moisture were monitored daily using thermo-hygrometer. A gas collector was provided for collection and determination of the amount of biogas. The content of methane concentration produced in the reactor was monitored weekly.

3.2. Experimental Set-up for Electricity Generation
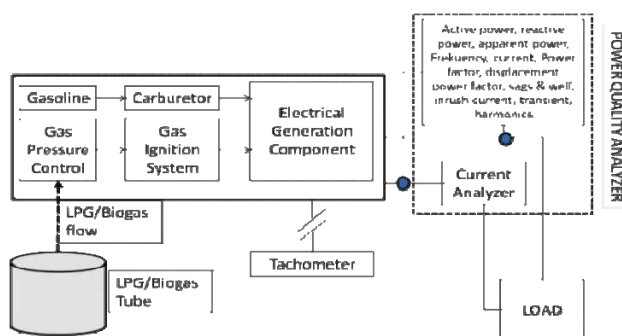

Figure 1. Experiment design of electricity generation fueled by gasoline, LPG and Biogas

The experimental set-up for energy conversion scenario from gasoline, LPG and biogas along with the electrical measurements using Power Quality Analyzer (PQA) [13] is presented in Figure 1. One of the advantages of using PQA is the integration of some power quality parametersinto equipment so thatthe datacan beanalyzed easily.

3.3. Electrical Parameters Measurement and Analysis Method

Three of the measurement parameters considered are voltage, current and frequency. For Indonesian standard voltage is 220 VAC, the permissible supply voltage varies between (+5%) and (-10%) of the standard according to the standard used by State Electricity Company (*Perusahaan Listrik Negara*, PLN) of Indonesia. Meanwhile, based on ANSI C84.1the voltage is constrained to be varied in the range (-10%) and (+ 4%) of the standard in normal condition while in an emergency conditionthe variation is allowed between (-13%) and (+6%) of the standard. Further more, in the experiment, fuel consumption and rotor speed of generator were also measured.

Three kinds of power are also measured: active power, apparent power and reactive power. The Active Power (Watt) is that portion of electrical power which is the real power including the heat losses. Utility charges are based on Watts. Apparent Power (VA) is the product of the root mean square (RMS) voltage and current which are related to the effective load seen by the transformer and current carrying conductors [13]. Meanwhile, the reactive power (VAR) is the reactive component of the apparent power, caused by a phase shift between AC current and voltage in inductors (coils) and capacitors. VAR is present in a distribution system as a result of inductive loads, such as motors, reactors, and transformers. It can also caused by installation in electrical network. The use of capacitor banks is generally used to compensate reactive power in order to get a better power factor (PF), lower current and lower voltage drop.

Furthermore, PF and displacement power factor (DPF) were also measured. PF is the ratio of real or active power to apparent power. Inductive loads cause current to lag behind voltage, while capacitive loads cause current to lead voltage. Also the presence of harmonic current decreases the PF. The PF uses the total RMS value, thus including all harmonics, for its calculation. If PF value is between 0 and 1, it means not all supplied power is consumed since the present of reactive power. If PF equals to 1, the device is consuming all supplied power sincethere is no reactive power. The device is generating power, current and voltage in phase if PF is -1, while if PF is between -1 to 0 then device is generating power, current leads or lags [13]. DPF is the cosine of the phase angle between the fundamental current and the fundamental voltage. Inductive loads cause current to lag behind voltage, while capacitive loads cause current to lead voltage. Low DPF means that corrective measures have to be taken such as installing capacitors to correct the phase shift between the voltage and the current. If DPF is between 0 and 1, it means current leads or lags, device consuming power. If DPF equals to 1, the device is consuming, current and voltage in phase. The device is generating power, current and voltage in phase if DPF is -1, while if DPF is between -1 to 0 then device is generating power, current leads or lags. If PF and DPF differ greatly (> 10%), this indicates the presence of harmonics [13].

Harmonic is a sinusoidal component of an AC voltage that is a multiple of the fundamental frequency. The measurement of power harmonic was also done in the experiment. Harmonic distortion means periodic distortion of the sine wave. The waveform becomes distorted when higher frequency components are added to the pure sine wave. Meanwhile, Total Harmonic Distortion (THD) is the amount of harmonics in a signal as a percentage of the total RMS value (THD-R) or a percentage of the fundamental (THD-F). It is a measure of the degree to which a waveform deviates from a purely sinusoidal form. 0% indicates that there is no distortion. For lighting loads, if the current THD is less than 20 %, the harmonic distortion is still acceptable. For the motor, in general the THD of the voltage should not exceed 5 %. Negative sequence harmonics (5th, 11th, 17th, etc.) will cause most heating because they try to run the motor slower than fundamental since they create reverse rotating magnetics fields within the motor. Positive sequence harmonics (7th, 13th, 19th, etc.) also cause heating because they try to run the motor faster than fundamental.

Furthermore, transient measured in the experiment is a very short and sharp increase or decrease in the voltage (or current) on a waveform. The last parameters measured were Sag and Swell. A Sag is a temporary voltage decrease caused by, for instance, large equipment starting up or shutting down. The duration is usually from one cycle to a few seconds. A Swell is a temporary voltage increase where the duration is usually from one cycle to a few seconds.

3. RESULTS AND ANALYSIS

3.1. Experiment using 100 Watt Bulb

Table 1 shows the measurement resultsusing PQA of the electrical generation with three kinds of fuel for 100 W bulb (as mentioned in the lamp specification), i.e. gasoline, LPG and biogas. Generator fueled by 200 ml gasoline operated in 23 minutes 26 seconds (8.53 ml/min) at 3,200 rpm. The working voltage of 223.8 V still appropriate according to PLN and ANSIC84.1 standards, where the frequency was 53.1Hz. The harmonic distortion is still acceptable since the difference value between PF and DPF less than 10%. It can also be seen that 7VAR reactive poweris visible, whichmeans that there is fewer inductive load of the lightelements, but because of the value is quite small, then it give no significant influence to the PF.

In Table 1, generator with 100W bulb consumes 3g/minof LPG with rotor speed 3,459rpm. The working voltage is 229.8 volts which is still within PLN standard, frequency is 53.7Hz, and current equals to 0.398 Ampere. The PF and DPF are equivalent to 1 which theharmonicdistortionvalue is acceptable. The reactive power 8 VAR shows less inductive load of the lamp elements.

Biogas driven generator with 100W Bulb load consumes 1.5 g/min of biogas with 2,830 rpm spin the generator rotor. The electrical parameters of PQA data is listed in Table 1. Its working voltage is 229.8 V which is still in accordance with the PLN standard with frequency of 46 Hz and current 0.4 Amperes. Active power (91 W) and apparent power (92 VA) show approximately equalvalues, therefore the PF is1. Meanwhile, the DPF indicates the value of 1 and shows that the harmonic distortion is still acceptable. This little harmonic distortion actually appears since for reactive load PF =1 and the DPF (91/92 = 0,9891) where they show a little difference value which explains why there is a little harmonics. The reactive power is 2 VAR, whichmeans that there is less inductive loadof the lampelements.

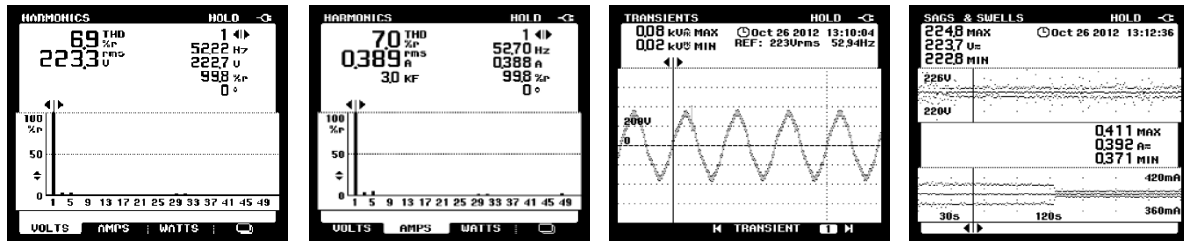Table 1. Measurement Result of Electricity Generation with load 100 W Bulb

No	Electrical Parameters	Gasoline	LPG	Biogas
1.	Voltage (V)	223.8	229.8	229.8
2.	Frequency (Hz)	52.8	54	46
3.	Current (A)	0.390	0.398	0.400
4.	Active Power (W)	87	91	91
5.	Apparent Power (VA)	87	91	92
6.	Reactive Power (VAR)	7	8	2
7.	PF	1	1	1
8.	DPF	1	1	1

Figure 2 shows other electrical parameters measured in the experiment such as harmonics, transient and Sags & Swells with 100 W bulb load (resistive load). The voltage harmonics for the three scenarios using three kinds of fuel in generating electricity show good results although we can see a small positive harmonics (5th, 29th on using gasoline or LPG and 5th, 11th, 29th on using Biogas). Three fuels can be surely safe for lighting loads. Their THDs are lower than 20% which are still acceptable. Figure 2 shows that no significant transient (sharp increase or decrease voltage) on using the three fuels once the generator set was loaded. From the Sags & Swells measurement, it can be seen that generally there are no Sag and Swell. The Sag in Figure 2(c) was happen appeared not because of the generation system performance, but it is caused by the shutting down the generator after running about 100 seconds, while the Sag does not appear before it in the normal operation.
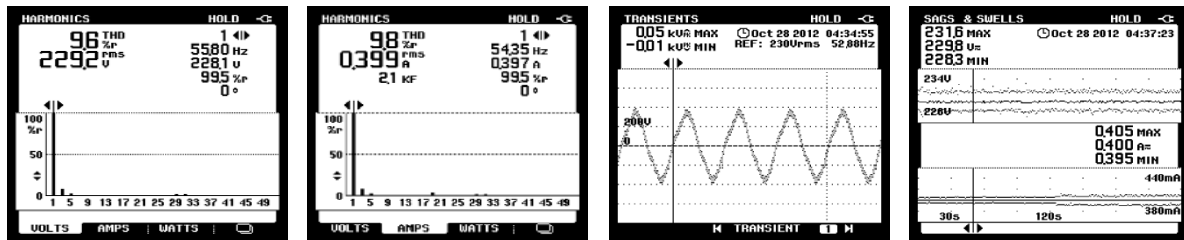
3.2. Experiment using 200 Watt Bulb

Generatorset fueled by200ml gasoline with 200W Bulb can operatefor 22 minutes 56 seconds (8.72 ml/minute) at 3,203 rpm generator rotor rotation. The electrical parameters of PQA data is presented in Table 2. Its working voltage still fulfills the PLN and ANSIC84.1 standards with frequency of53Hz. Active power and apparent power show the same value, hence the PF is1, while the DPF equals to 1 and this shows that the harmonic distortion is still acceptable. The reactive power 12 VAR means there is less inductive load of the lamp elements.
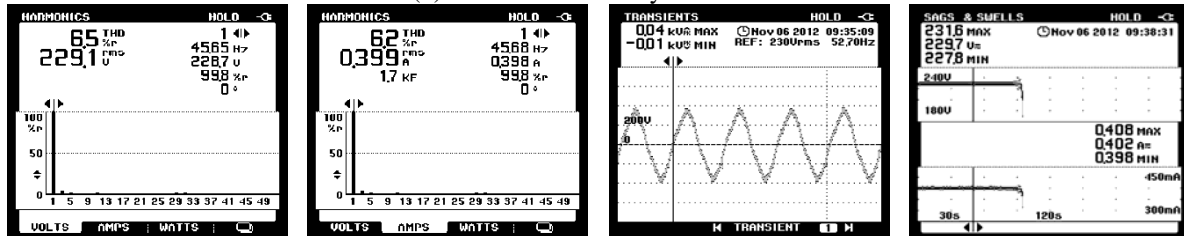
LPG generator setloaded with2 x 100W bulbs consumes 3.33 g/minof LPG with the generator rotor speed 2,370 rpm. The electrical parameters of PQA data is presented in Table 2. The working voltage is slightly less than PLN standard, still fulfill the emergency standard, with quite low frequency. The active power and apparent power shows the same values and the PF and PDF equal to1 (based on the PQA precision, although there is a little different value which can cause a hermonic distortion). Therefore, the harmonic distortion is still acceptable. The reactive power18 VAR means less inductive load of the l amp elements.

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(a) Generator fueled by Gasoline

(b) Generator fueled by LPG

(c) Generator fueled by Biogas

Figure 2. Power Quality of Generator with 100 W Bulb load: Power Harmonics, Transient, Sags & Swells

The experiment using biogas from MSW with 200 W bulb load consumes 2 g/min of biogas where the generator rotor speed is lower than the previous ones (i.e. 2,366 rpm). Table 2 shows that the working voltage fulfilling the PLN and ANSI C 84.1 standard with quite low frequency (i.e. 39.3 Hz). In Table 2, active and apparent powers show the similar value, therefore the PF and DPF equal to 1. Because of the precision of the PQA meter, ther could be a little difference value between Active and apparent power. It can be seen in the Figure 3 that shows a litlle distortion. However, since the difference between PF and DPF is not moe than 10%, the harmonic distortion is still acceptable. It is almost similar to the previous results using other fuels, the reactive power is appear (i.e. 6 VAR) caused by the inductive load in the lamp elements.

Table 2. Measurement Result of Electricity Generation with load 2 x 100 W Bulbs

| No	Electrical Parameters	Gasoline	LPG	Biogas
1.	Voltage (V)	223.5	233.7	229
2.	Frequency (Hz)	53	41.5	39.3
3.	Current (A)	0.791	0.803	0.830
4.	Active Power (W)	176	183	187
5.	Apparent Power (VA)	177	183	188
6.	Reactive Power (VAR)	12	18	6
7.	PF	1	1	1
8.	DPF	1	1	1

Figure 3 shows the measurement of harmonics, transient and Sags & Swells with 2 x 100 W bulb load (resistive load). The voltage harmonics for the three scenarios using three kinds of fuel in generating electricity reveals good results although there arequite small positive harmonics (5th on using gasoline, 5th, 29th on using LPG or Biogas). A quite small negative harmonics (7th) is occuredwhen using LPG. Three fuels can be surely safe for lighting loads. Their THDs are lower than 20% which are still acceptable for

lighting loads. There is no either significant sharp increase or decrease in voltage as transient on using the three fuels once the generator set is loaded. From the Sags & Swells measurement, it can be seen that generally there are no Sag and Swell. The Sag is happen on using biogas caused by the shutting down the generator after running about 40 seconds, while the Sag does not appear before it.

3.3. Experiment using 125 Watt Water Pump

The operation of generator set using 200 ml gasoline with the resistive-inductive load (i.e. 125 Watt water pump can operate for 22 minutes 19 seconds (9.6 ml gasoline/minute) with the generator rotor speed 3,190 rpm. The electrical parameters data of PQA is presented in Table 3 The working voltage fulfill the PLN and ANSIC84.1 standards, with frequency 52.8Hz. Active power and apparent powershow a different value therefore the PF and PDF are lower than 1. This is caused by the value of inductive load decrease the value of PF. However, there is no harmonic distortion since the difference between PF and PDF lower than 10%. The reactive power is 42 VAR, which means there is alarge inductive load of the motor winding in the pump.

Further more, the LPG consumption in the generator operation was 3.33 gram/minute with 2,301 rpm rotor speed. Table 3 shows that the working voltage fulfilled PLN and ANSIC84.1 standards, with quite low frequency. The active power and apparent power shows arather large difference, consequently the PF and DPF are less than 1 without harmonic distortion. It can be seen that there is 290 VAR reactive power, which means that there are quite large inductive load sof winding elements on the pumpmotor.
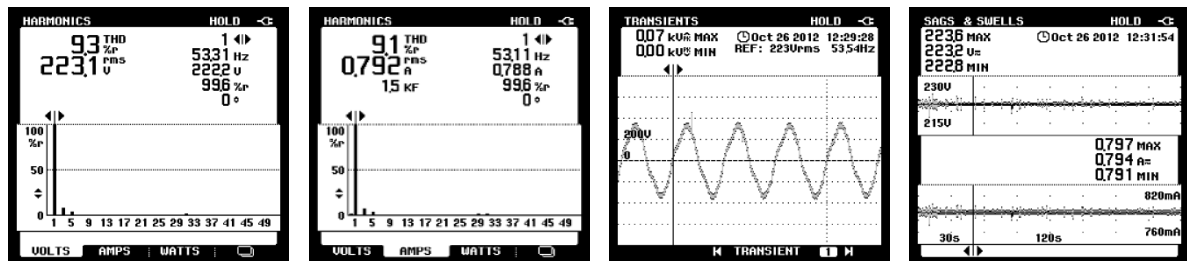
(a) Generator fueled by Gasoline
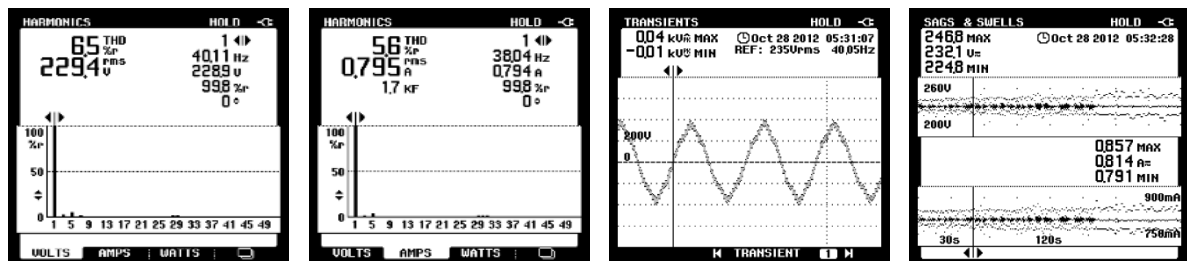
(b) Generator fueled by LPG
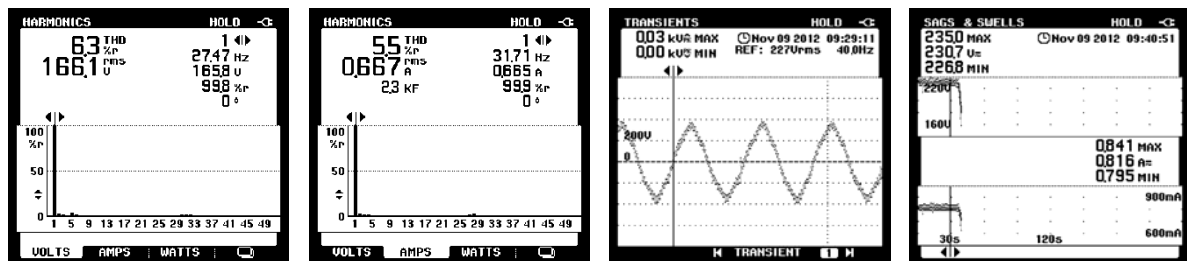
(c) Generator fueled by Biogas

Figure 3. Power Quality of Generator with 2x 100 W bulbs load: Power Harmonics, Transient, Sags & Swells

The consumption of biogas for the electricity generation with 125 W water pump as load 3 gram/minute with 1,364 rpm of rotor speed. In Table 3, the working voltage was still in the PLN and ANSI C

84.1 standard with quite low frequency. Active and apparent power show a big difference, therefore the PF and DPF are quite less than 1 without harmonic distortion. It is caused by the large inductive load in the pump motor. The reactive power value shows the high inductive load in the wire turn in the motor.

Table 3. Measurement Result of Electricity Generation with load 125 W Water Pump

No	Electrical Parameters	Gasoline	LPG	Biogas
1.	Voltage (V)	221.2	221.4	224
2.	Frequency (Hz)	53.0	38.1	37.7
3.	Current (A)	0.778	1.779	1.117
4.	Active Power (W)	148	257	162
5.	Apparent Power (VA)	174	384	249
6.	Reactive Power (VAR)	92	290	179
7.	PF	0.86	0.66	0.65
8.	DPF	0.87	0.67	0.67

4. CONCLUSION

The power quality and energy consumption of electrical generation using gasoline, LPG and biogas from MSW has been compared in this paper. The performance of voltage using these three fuels generally still fulfilled the PLN, ANSI C 84.1 and emergency standard. The problem appeared in frequency especially for both LPG and Biogas which was still quite low compare to the requirement (i.e. 50 Hz). The feature of active, apparent and reactive powers for three fuels under resistive load (100 W and 200 W bulbs) and resistive-inductive load (125 W water pump) expressed the similar phenomena which influenced the PF and DPF. Furthermore, energy consumption in using combustible gas either LPG or biogas was less expensive and less emissions than using gasoline. Future work will address the frequency control especially for generator set application which can be applied modularly.

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Seno Darmawan Panjaitan was born in Pontianak, Indonesia on July 16, 1975. He received Bachelor degree (S.T.) in Electrical Engineering from Tanjungpura University (Indonesia) in 1997 andMaster degree (M.T.) in Electrical Engineering from Bandung Institute of Technology (Indonesia) in 2001. He received his doctoral degree (Dr.-Ing.) on electrical and computer engineering from Technishce Universitaet Kaiserslautern (Germany) in 2007. He is now working as an Associated Professor in Department of Electrical Engineering, Tanjungpura University, in Automatic Control Engineering research group. His research focuses on automatic control and industrial informatics, green control technology, energy optimization, and mechatronics. He is now an IEEE member and also joining IEEE Industrial Electronics society, IEEE Industry Applications society, IEEE Power & Energy society, and IEEE Robotics and Automation Society.

Yandri was born at Singkawang, Indonesia on March 29, 1969. He received Undergraduate Degree (S.T.) on Electrical Engineering from Tanjungpura University (Indonesia) in 1994 and Master Degree (M.T.) on Electrical Engineering from Bandung Institute of Technology (Indonesia) in 2005 with the major in Electrical Power Engineering. He once worked in the Electrical Section, IKPP Corporation (Indonesia), a company which manufactures pulp and paper (from 1995 to 1999). He has been working as a lecturer in the Department of Electrical Engineering, Engineering Faculty, Tanjungpura University for 14 years (since 1999). He is interested in Electric Machines and Power Plant. The researches that have been done focussing on Induction Motor and Renewable Energy.

Sukandar received Bachelor degree (S.Si.) in Chemistry Department in 1998 and Master degree (M.T.) inCivil and Environmental Engineering Department in 2001 from Bandung Institute of Technology (Indonesia). He received his doctoral degree (Dr. Eng.) in Environmental science and technology, Okayama University, Japan 2006. He is now working as a senior lecturer in Department of Civil and Environmental Engineering, Bandung Institute of Technology, in Air and Waste Management group. His research focuses on solid, poissoned and hazardous solid waste.

Berlian Sitorus was born in Barus, Indonesia on October 10, 1974. He received Bachelor degree (S.Si) in Chemistry from Bandung Institute of Technology (Indonesia) in 1998, Master degree (M.Si) in Chemistry from Bandung Institute of Technology (Indonesia) in 2001, and Master (M.Sc) in Environmental Sanitation from University of Ghent (Belgium) in 2006. Now she works as lecturer and researcher at Chemistry Department, Tanjungpura University (Indonesia). Her research focuses on environment such as waste/wastewater treatment and their conversion into valuable products. She is now a member of Indonesian Chemical Society