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REAL-TIME PERFORMANCE MODEL OF HYBRID POWER GENERATION (LANDFILL GAS, PHOTOVOLTAIC SYSTEM, DIESEL GENERATOR)

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Abstract. *The landfill gas, photovoltaic system and diesel generator based hybrid power generation is not commonly equipped with a smart monitoring system for biogas gas content, temperature, and voltage/current output. In order to obtain the optimal operation, it is important to utilize sensors for the real-time smart system monitoring. In this research, the sensor utilities are methane gas sensor of MQ4, voltage sensor of ZMPT101B and non-invasive current sensor of SCT013, temperature sensor of LM35 that need to be calibrated. The calibration test results and characteristics of each sensor indicate 1.91% of error, linear input-output with error of 1.499V and 0.0022A average error and operation range of 30-120°C with error of 0.519°C in MQ4, ZMPT101B and SCT013, LM35 sensors, respectively. For real-time interface, the hardware data acquisition is based on ATmega2560 Rev3 microcontroller and the software acquisition data is based on Visual Studio.net. The observation model of real-time performance of hybrid power generation yields an increased concentration of CH_4 during daytime from 08:00 to 17:00 due to the sunlight exposure on landfill. The load supply is measured depending on the activities of Integrated Service Unit of landfill, particularly the Waste Weighing Unit between 08:00 and 16:00 with the obtained voltage/current about 230V/4A. In addition, the diesel generator operates only available for 8 hours during daytime.*
Keywords: Real-time monitoring, Hybrid power generation, Sensors, Calibration test, VStudio.net

1. **Introduction.** Fulfillment of the need for electricity, especially the one generated from conventional electricity generators (fuel oil-, gas-, and coal-fueled ones) directly contributes to increasing emission of greenhouse gasses (GHGs), namely CO_2, CH_4 to the atmosphere, which results in an increase in the earth's temperature and in turn impedes the balance process as a result of disruption to the carbon cycle in the atmosphere [1]. Methane (CH_4) gas is one of the constituents of greenhouse gasses with the strength of 21 times more powerful than carbon dioxide (CO_2). Therefore, mitigating methane gas from the existing landfills provides important benefits, especially through conversion of the resulting methane into carbon dioxide by burning the gas, and the formation of CH_4 itself can be considered as an added value of a landfill through the use of converting methane gas into electricity [2].

One way to diversify the conversion of urban waste into electricity is to combine several energy sources commonly known as the hybrid power system (HPS), which is the combination of several energy sources in order to produce greater energy output. Beside the HPS technology development is environmentally friendly in nature, the technology

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can also be operated in areas where electricity networks are still unavailable by the utilization of hybrid power sources, such as photovoltaic (PV)/diesel generator/battery, PV/wind/battery, and PV/wind/diesel generator/battery [3].

A series of previous researches have been carried out regarding the hybrid power utilization such as the research on the potential contribution of the waste to energy facility to meet electricity needs in the three main cities in the Eastern province of Saudi Arabia by waste to energy development including waste combustion, waste recycling, and fuels from refused derived fuel (RDF) with bio-metanation [4]. The researchers designed hybrid microgrid systems hybrid PV and wind turbines to determine the most suitable size for low-budget target power supplies in rural areas outside Yanbu City, Saudi Arabia [5]. The limitation of some of these studies is the absence of a model that integrates two or more local energy sources in a real-time manner using economical materials and generating low emissions.

Despite major advancements in research on renewable energy, no one conducted research on the real-time performance model of hybrid power generation for the tropical climate in regions that are underdeveloped and traversed by the equator. The location has an advantage with greater methane content as a landfill gas for energy production. In this research, the landfill waste is geographically located in the equator line which is potential for a fairly enormous level of exposure to sunlight. The observation made over six weeks' periods shows that the average solar irradiation in landfill gas location is around 6.43kWh/m^2 [6]. Continuous research is conducted by calculating methane emissions and carbon dioxide emissions using the method issued by the Intergovermental Panel on Climate Change (IPCC) [7,8]. The previous results show that the composition of organic waste contributes to significant volume of 44.47% with methane emissions of almost 500 thousand tons/year and carbon dioxide emissions of about 135 thousand tons/year. Overall, the composition of urban waste produced amounts to more than 1 million tons/year of methane emissions. The conversion of gas mitigation might generate a total electricity energy of more than 28GWh per year from methane gas emissions.

The potential of waste volumes in Bontang Lestari Landfill of Bontang City which is supported by the abundance characteristic of sunlight can be used to produce electricity by combining different types of energy sources in the form of hybrid power generation. The potential landfill gas, photovoltaic system and diesel generator based hybrid power generation with real-time technology application can be used as an alternative energy sources to meet electricity demand. The proposed real-time hybrid generation model can be used as supported local energy sources in economical, sustainable, and eco-friendly manners. Therefore, the assessment of real-time performance of the landfill gas, photovoltaic system and diesel generator model based hybrid power generation model is provided in the following sections.

2. **Case Study.** Sanitary landfill gas produces the anaerobic waste decomposition process which is soil-buried by the activity of microorganisms [9]. One of the innovations of sanitary landfill developed by Bontang City is the installation of pipeline facilities to deliver methane gas from the soil containing piles of garbage to the ground top for gas utilization. Figure 1 presents the distribution facility of methane gas and the sampling point field survey of Bontang City Landfill. In this case, the methane gas is distributed to the Bontang Lestari Landfill Unit office and several existing houses in the area around the landfill site. The methane gas is used in some parts as a fuel for cooking and has also been converted to electrical energy to meet the local electricity demand. Through the method of NGPA 2261 of methane gas test parameters [10], it is obtained the average discharge of methane gas composition of 60.57% and methane gas debit of 3.57ml/sec. Meanwhile, the data acquisition system utilized in this research is the computer data that undergoes a sampling process of converting from analog value into a digital numeric value

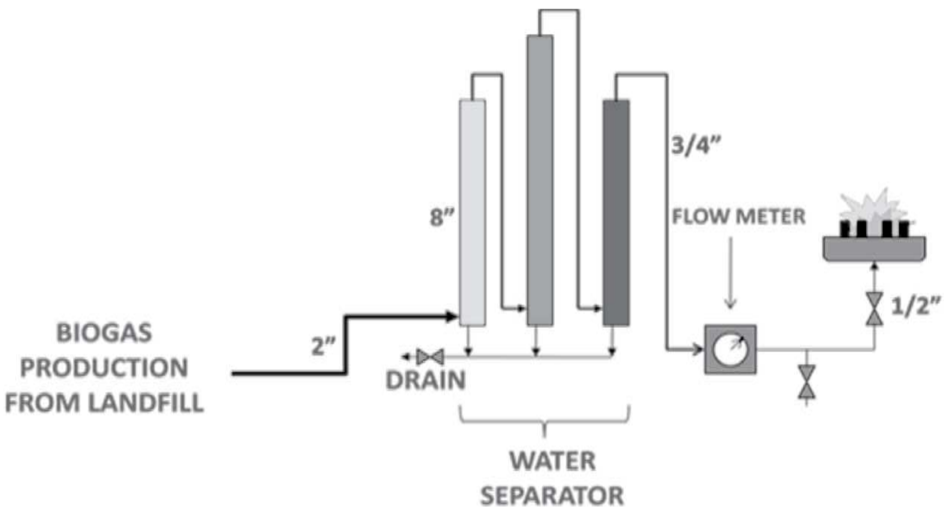

FIGURE 1. Biogas distribution facilities and field

[11]. The components of the data acquisition system are sensors which need to be initially calibrated to convert electrical signals to digital values. In this research, the application of data acquisition system is controlled by a software program called Visual Studio.net to establish the big scale data acquisition system.

3. **Methodology.** The research methodology is presented with aims to explain the various procedures and experimental setup and to evaluate the system model of real-time performance of the landfill gas, photovoltaic system and diesel generator based hybrid power generation. Firstly, it is necessary to perform fully the calibration of the existing sensors. In this case, it is important to analyze the data logger test results that indicate the real-time performance of the proposed hybrid power generation system. Finally, the real-time data from each data logger is considered for simulation procedures with Visual Studio.net software.

3.1. **Model and implementation of real-time systems.** Figure 2 shows the design scheme of real-time system of landfill gas, photovoltaic system and diesel generator based hybrid power generation with capacity of 1kW. The operational scenario is performed for daytime mode where electrical energy generated by the proposed hybrid power generation system is only used in the Integrated Service Unit of Bontang Lestari Landfill. Most energy utilization goes to the Waste Weighting Bridge Unit when the trucks contain municipal waste across the bridge and the weight of garbage on trucks is recorded during operational hours. The remained gas production is stored in Biogas Balloon Tube for another energy utilization. Meanwhile, the photovoltaic system energy output is stored in the battery system to supply the normal load, such as lights and computers from 18:00 to 17:00. During the peak load condition where energy deficiencies from the battery system occur, the diesel generator of 1.3kW takes the role as the back-up power supply to the local load, while the excess energy is used to charge the battery system.

3.2. **Sensors and calibration tools.** Sensors have the function to convert physical quantities into electrical signals that can be measured automatically and then sent to a computer or microprocessor for data processing. However, the sensors should be calibrated in the system before the utilization in order to achieve the best accuracy since there is no perfect sensor. Also, it is commonly found that two sensors with the same types and producers may produce slightly different readings [12].

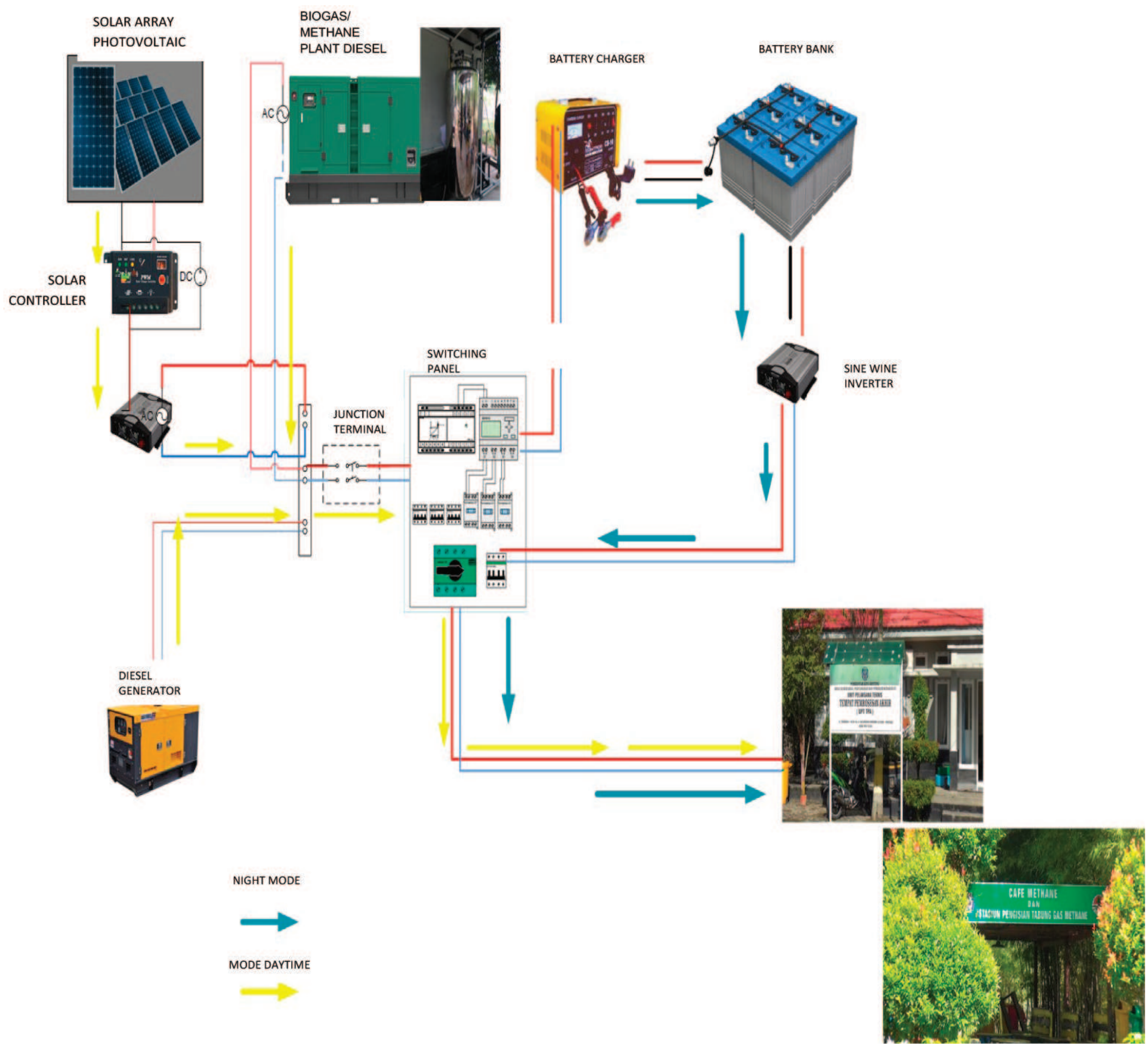

FIGURE 2. Real-time model of hybrid power generation

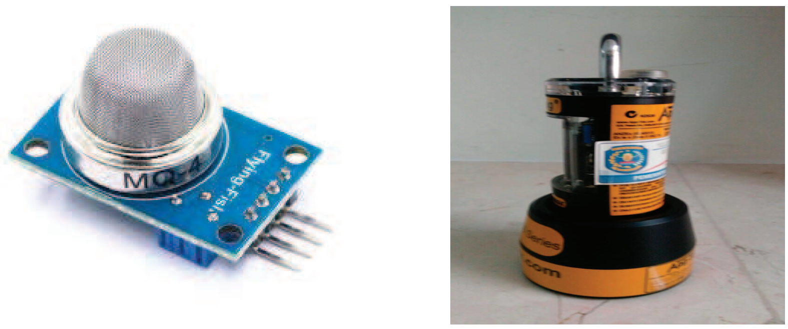

FIGURE 3. MQ4 methane sensor and calibration tool

3.2.1. *MQ4 methane gas sensor.* Biogas methane gas sensor as shown in Figure 3 is a gas sensor which has a high sensitivity to combustible gases (gases which are easy to burn), particularly methane gas, as well as other gases, such as propane and butane gases. The MQ4 sensor has a SnO_2 material that is sensitive to changes in the combustible gas with the output of analog signals [13]. Changes in methane gas detection result in resistance changes to MQ4 sensors. This material has a low conductivity when in the open air that does not contain combustible gas and has a higher conductivity when there is a change in the concentration. The concentration of gas content that the MQ4 sensor can reach is 300-10000ppm [14].

3.2.2. *ZMPT101B voltage sensor.* Sensor of ZMPT101B with ultra-micro voltage transformer which has a small size, high accuracy, good consistency for voltage and power measurement is shown in Figure 4. The sensor is an AC voltage sensor module that equipped an isolation transformer with 1:1 voltage ratio. The sensor manufacturer does not provide a resolution equation so the sensor must be manually calibrated. The calibration process is conducted by comparing the readings from analog bit signal as the output of voltage sensor with the RMS voltage reading using digital multimeter. This comparison result is then used to create the bit-to-RMS conversion equation.

3.2.3. *SCT013 current sensor.* The SCT013 current sensor test in Figure 5 is conducted by providing a load of 100W-400W, with the measured minimum-maximum current limit between 0-100A. The current output will be displayed in value via the LCD monitor. The sensor works by an induction coil that detects the magnetic field changes that occur around the current carrying conductor. By measuring the amount of current generated by the coil, the amount of current through the conductor can be calculated.

3.2.4. *LM35 temperature sensor.* Temperature sensor LM35 is an electronic component that has high accuracy and functions to change the temperature into a unit of electricity in the form of voltage and is able to measure up to 100 degrees Celsius. Figure 6 is the scheme of the basic circuit of LM35-DZ temperature. This circuit is very simple and

Figure 4. Voltage sensor of ZMPT101B and calibration tool

Figure 5. Current sensor of SCT013 and calibration tool

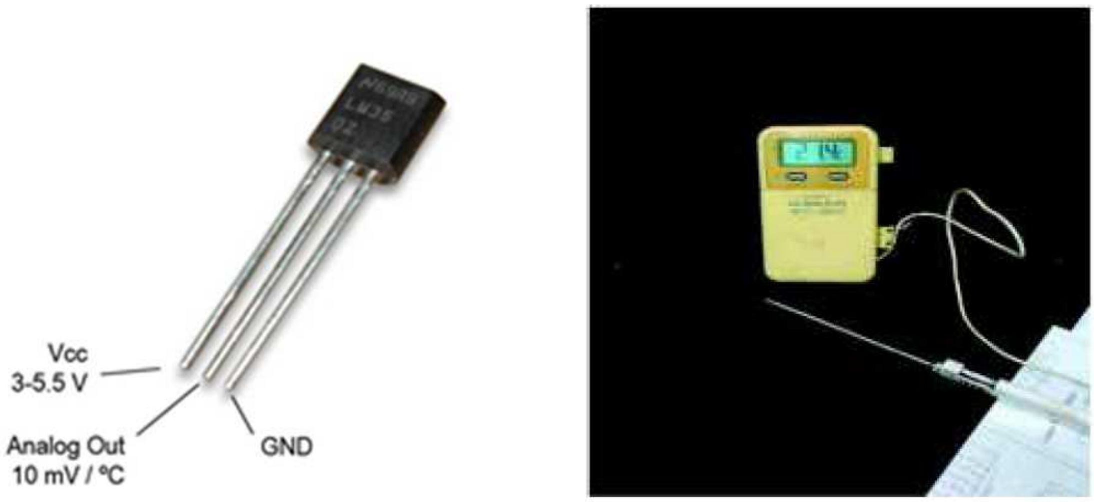

FIGURE 6. Temperature sensor of LM35 and calibration tool

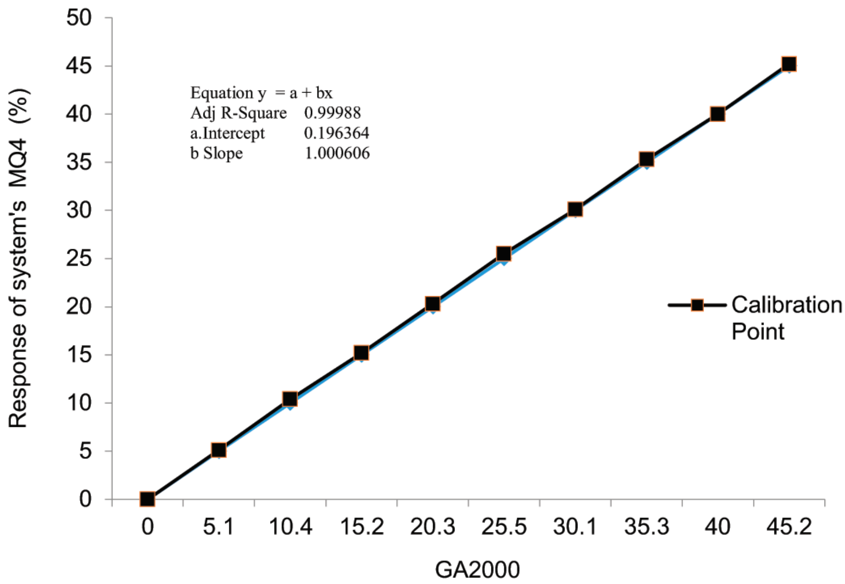

FIGURE 7. MQ4 methane gas sensor calibration test result

practical. Vout is a linear-scaled voltage sensor output towards the measured temperature of 10 millivolts per 1 degree celsius. Thus, if Vout = 530mV, the measured temperature will be 53 degrees Celsius. Otherwise, if Vout = 320mV, the measured temperature will be 32 degrees Celsius. This output voltage can be directly fed as the input to a signal conditioning circuit, such as operational amplifier circuit and filter circuit, or other circuits, such as voltage comparator circuit and analog to digital converter circuit.

3.3. **Design of data acquisition system.** The electronic data acquisition is designed based on the performance of ATmega 2560 Rev3 microcontroller. In this case, the data processing is through the computer software called Visual Studio.net which consists of 3 modes, i.e., real-time mode, off-line mode, and display mode of the landfill gas, photovoltaic system and diesel generator based hybrid power generation model.

4. Experimental Results.

4.1. **Results of sensors calibration test.** The experimental results of sensors calibration test are presented in Figures 7-10. In Figure 7, the calibration results of MQ4 methane sensor yields the minimum-maximum deviations between 1.34% and 2.28%. However, the

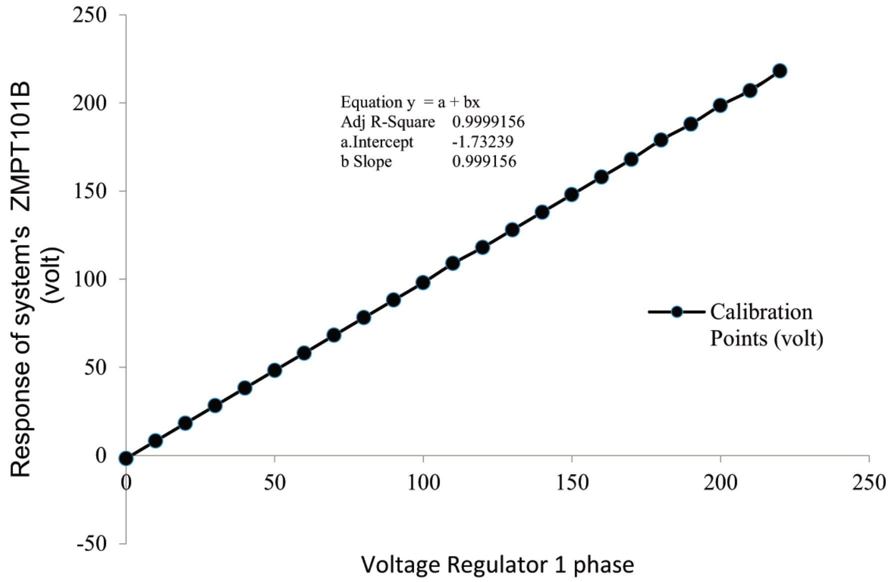

Figure 8. ZMPT101B voltage sensor calibration test result

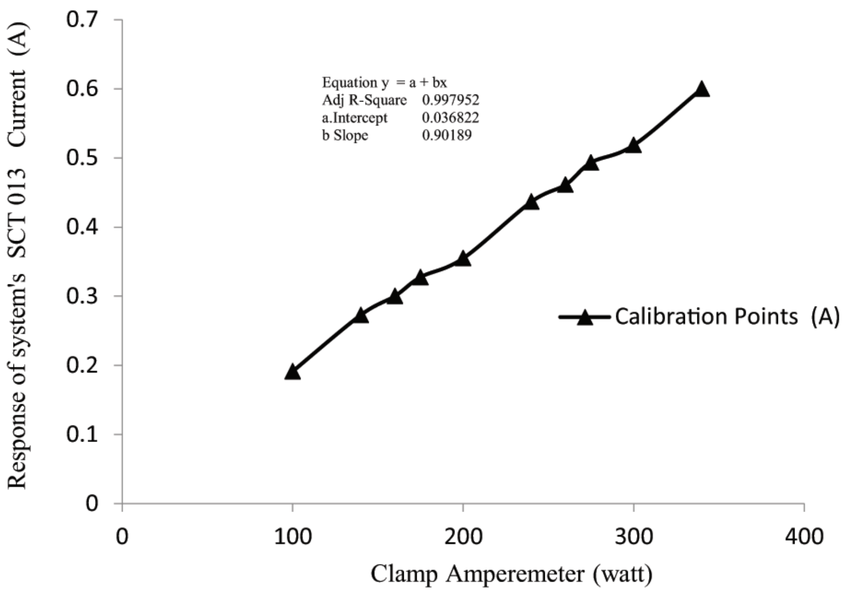

Figure 9. SCT013 current sensor calibration test result

experimental results show that the sensor of methane gas data acquisition has error value of 1.91% and this value is obtained by summing all error values of each test and divided by the number of tests (15 times).

Meanwhile, the calibration results of voltage and current sensors are shown in Figures 8 and 9, respectively. The voltage data acquisition system of ZMPT101B voltage sensor in Figure 8 has an error of 1.499V and this value is obtained by summing all error values of each test and divided by the number of tests (28 times). In comparison, the results in calibration test of SCT013 current sensor show that the current data acquisition system has an error of 0.0022A with this value was obtained by summing up all error values of each test and divided by the number of tests (10 times).

The temperature sensor of LM35 in Figure 10 shows the linear output voltage with a change of 10mV for each increase or decrease in temperature per 1°C. It means that the data acquisition of LM35 temperature sensor in the proposed real-time design is

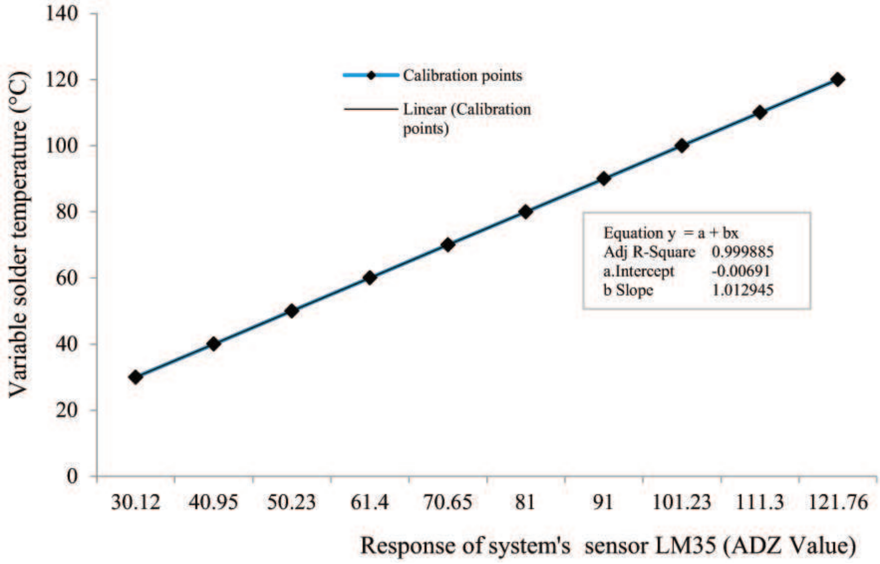

FIGURE 10. LM35 temperature sensor calibration test result

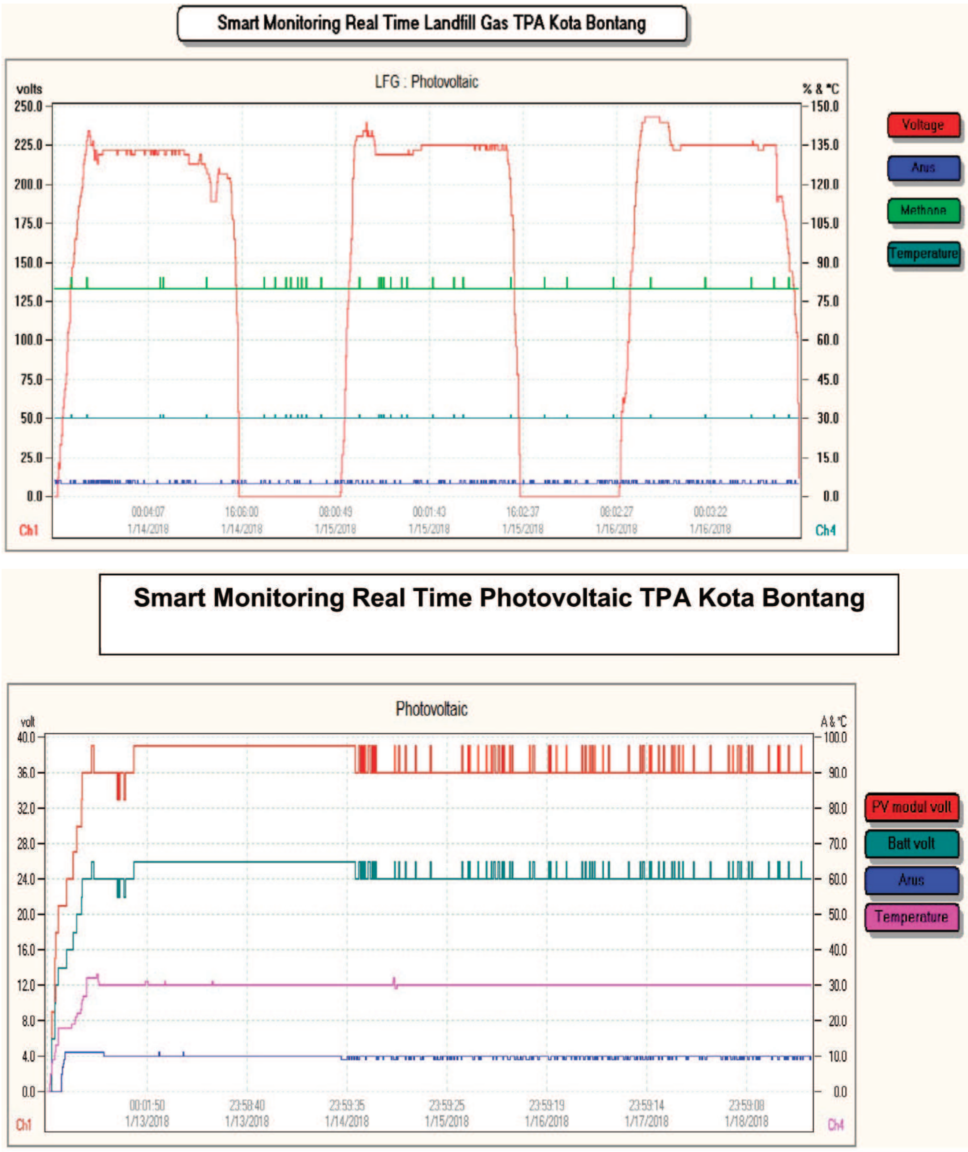

FIGURE 11. (color online) Profile of real-time monitoring system

accurate in temperature readings. The LM35 temperature sensor output data is basically the analog-data conversion via microcontroller execution.

4.2. **Real-time monitoring system.** Through the graphical user interface (GUI) system and utilization of the existing buttons on the GUI view, the operators will easily monitor the amount methane gas flows, as well as the voltage, current and temperature data in real time. An example of real-time monitoring output is shown in Figure 11 for measurement and monitoring the quality of landfill gas starting from 08:00 to 16:00 between 14 January 2018 and 16 January 2018. In this case, the software interface of Visual Studio.net displays and performs the real-time data monitoring and recording. All data measurement is stored in the data logger in the TRD extension files. There is high number of 10,000 rows data recorded and saved at once time data processing.

These data are commonly used to perform the network testing. It is shown in Figure 11; the increased concentration of methane gas occurs during daytime from 08:00 to 17:00 due to the significant sunlight exposure on the landfill surface. During this period, the monitoring output of voltage and current which are suitably utilized for Waste Weighing Unit in the landfill location reaches 230V and 4A, respectively. The remained period where the sunlight goes down and methane activity reduces, the diesel generator which is capable for 8-hour operation takes over the power supply to the facility loads. In addition, the temperature measurement in the surrounding area is averagely about 30°C.

5. **Conclusion.** The real-time monitoring system of landfill gas, photovoltaic system and diesel generator based hybrid power generation has been designed. Based on the calibration test results, sensors may respond accurately which are indicated by the low average error. The average errors of MQ4, ZMPT101B, SCT013 and LM35 sensors are 1.91%, 1,499V, 0.0022A and 0.519°C, respectively. The increased concentration of methane gas occurs during daytime from 08:00 to 17:00 after significant exposure of sunlight on landfill surface. Within the same period, the output voltage/current of 230V/4A is suitably enough to be utilized in the Waste Weighing Unit operation. The remained period where the methane gas activity decreases, the power supply is handled by the diesel generator which is available for the maximum 8 hours' operation. Finally, the efficiency performance of hybrid power generation system can be improved by connecting high capacity of battery systems as the back-up energy storage.

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