Modeling and Simulation of Hybrid Generator of Photovoltaic, Genset and Battery

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Abstract—Electrical power system generating from renewable energy sources especially solar and conventional power plants such as the generator is designed as an educational model for the public to understand how the hybrid system can generate electrical power as a unified system. This paper is aimed to investigate the hybrid system performance between photovoltaic, genset and battery as well as the system units, so that they could work as an integrated system in generating the electric power. This is a descriptive paper with simulation approach. Simulation parameters were obtained through data documentation of the photovoltaic, genset, battery and Solar radiation intensity, they were input into a Simulink/Matlab simulation program. The simulation model parameters created were adjusted with the unit component characteristics of the existing generator in the Laboratory. The results obtained from the simulation indicates that if the photovoltaic and battery power can still serve the load, the genset will be "off" or vice versa. The power magnitude generated by photovoltaic is 110.17 Watts at 0.88 kW/m² solar radiation, whereas the power magnitude of the genset is 98.08 Watts on the lap of 350 rad/sec. At 31.78 and 55.79 hours and 67.70 hours until 70.04 hours of 72 hours simulated, the power supply decrease occurs from the generator. This can be overcome by using a larger battery capacity.

I. INTRODUCTION

Management and operation of renewable energy hybrid system showed that the generation project which is managed by many people fail because of lack of basic public pengetahuan electrical system based on renewable energy. That requires a model of training to the community on the optimization of the power generated electricity generation from renewable energy sources especially solar and conventional power plants as genset to produce electrical power as a unified system. This research is the development of a research conducted by Aryuanto et al (2011), in which the hybrid generating system consisting of wind energy, solar and battery.

The power plant is a hybrid system that combines multiple generator system generating units that have different energy sources (Nayar et al., 1998; Kunafi., 2010). In this study a hybrid system which is designed photovoltaic and genset are equipped with media storage (batteries). PV modules in the system design, there are several factors to be considered (Weldemarian., 2010), namely: technical specifications, the size of individual components, safety considerations and economic aspects of a system. Diesel generators (genset) is power generation using diesel engines as prime mover. Prime mover is an equipment that has the function of generating mechanical energy required to rotate the generator rotor. Generator set is generally used as a backup generator for a variety of applications such as mobile workshop, in emergency and rescue operations, backup generators in industry, farms and households (Jan, 2006). In this study, the control system will be designed hybrid between a photovoltaic generator, genset and the battery so that it can generate power optimally. On the control system, it will set the pattern of distribution of the output power and power from the photovoltaic genset. Mode setting operation is performed without disconnecting the power supply to the load (Samii, 2008).

This research aims to create a simulation of hybrid renewable energy systems, particularly photovoltaic, genset and battery as well as the units system. It is able to work as an integrated system to produce electrical power so that the performance of renewable energy hybrid systems can be measured.

II. PV-MODULE

A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. Since a typical PV cell produces less than 2W at 0.5V approximately (Huan-Liang Tsai, 2008), the cells must be connected in series-parallel configuration on a module to produce enough high power. The equivalent circuit for the solar module arranged in NP parallel and NS series is shown in Fig. (1). The terminal equation for the current and voltage of becomes as follows

\[ I = N_p I_{ph} - N_p I_S \left[ \exp \left( \frac{q V \left( \frac{1}{N_p} + \frac{R_s}{R_p} \right)}{kT_c A} \right) - 1 \right] - \frac{N_p V}{N_S} R_s \]

(1)

where \( I_{ph} \) is a light-generated current or photocurrent, \( I_s \) is the cell saturation of dark current, \( q \) (= 1.6 x10⁻¹⁹ C) is an electron charge, \( k \) (= 1.38 x10⁻²³ J/K) is a Boltzmann’s constant, \( T_c \) is the cell’s working temperature, \( A \) is an ideal factor, \( R_{sh} \) is a shunt resistance, and \( R_s \) is a series resistance.
The photocurrent mainly depends on the solar insolation and cell’s working temperature, which is described as

\[ I_{ph} = \left[ I_{sc} + K_i \left( T_c - T_{ref} \right) \right] \lambda \]  \hspace{1cm} (2)

where \( I_{sc} \) is the cell’s short-circuit current at a 25°C and 1kW/m², \( K_i \) is the cell’s short-circuit current temperature coefficient, \( T_{ref} \) is the cell’s reference temperature, and \( \lambda \) is the solar insolation in kW/m². On the other hand, the cell’s saturation current varies with the cell temperature, which is described as

\[ I_s = I_{rs} \left( \frac{T_c}{T_{ref}} \right)^3 \exp \left[ \frac{qE_g}{kA} \left( \frac{1}{T_{ref}} - \frac{1}{T_c} \right) \right] \]  \hspace{1cm} (3)

where \( I_{rs} \) is the cell’s reverse saturation current at a reference temperature and a solar radiation, \( E_g \) is the bang-gap energy of the semiconductor used in the cell (Silicon = 1.11 eV). The ideal factor \( A \) is dependent on PV technology (Si-mono = 1.2).

On the other hand, the \( V_{oc} \) parameter is obtained by assuming the output current is zero. Given the PV open-circuit voltage \( V_{oc} \) at reference temperature and ignoring the shunt-leakage current, the reverse saturation

\[ I_{rs} = \left[ \exp \left( \frac{qE_g}{kA} \right) - 1 \right] \]  \hspace{1cm} (4)

III. DIESEL MODEL ENGINE

Definition and identification of mathematical models of diesel engines are based on the analysis of phenomena in the physical and partial models. The fundamental differential equation of engine behavior is based on the well-know torque equation (Jan Leucher, 2006).

\[ M_E = M_D + M_R + M_L \]  \hspace{1cm} (5)

where \( M_E \) is the driving torque of the engine, \( M_D \) is the dynamic torque, \( M_R \) and \( M_L \) are resistant and load torques. The dynamic torque \( M_D \) is expressed by equation (6). \( J \) is the framework moment of inertia.

\[ M_D = J \frac{da}{dt} = J \dot{\omega} \]  \hspace{1cm} (6)

Simplified expressions \( M_E \) for and \( M_R \) in the form of 1st order polynomials are used

\[ M_R = f(d, \omega) = f(\omega) = r_0 + r_1 \omega \]  \hspace{1cm} (7)

\[ M_R = f(d, \omega) = f(\dot{\omega}) = m_0 + m_1 d \]  \hspace{1cm} (8)

where the driving torque \( M_E \) is increasing by \( d \) and slightly changed by angular velocity \( \omega \) and \( M_R \). Parameter \( d \) is a quantum of fuel injection. The resistant torque \( M_R \) is a function of angular velocity \( \omega \) and the effect of \( d \) can be neglected.

Load torque \( M_L \) can be expressed as a function of load power \( P_L \) or load current \( I_L \) for output voltage.

\[ M_L = f(P_L) = f(I_L) = a_0 + a_1 I_L \]  \hspace{1cm} (9)

IV. PERMANENT MAGNET DC GENERATOR MODEL

Basically a DC machine can function as a motor or generator. Permanent magnet DC generator models can be seen in Fig. (2).

Induction voltage (emf) to be raised on the coils of a generator. The normal voltage value is calculated based on the following equations: (Chee-Mun Ong, 1997).

\[ E_a(t) = k_q \omega(t) = k_q \omega(t) \]  \hspace{1cm} (10)

\[ k_q \omega(t) = R_a I_{ag}(t) + L_a \frac{d I_{ag}(t)}{dt} + V_a(t) \]  \hspace{1cm} (11)

\[ R_a I_{ag}(t) = L_a \frac{d I_{ag}(t)}{dt} = k_q \omega(t) - V_a(t) \]  \hspace{1cm} (12)

\[ \frac{d I_{ag}(t)}{dt} = \frac{1}{L_a} [k_q \omega(t) - V_a(t) - R_a I_{ag}(t)] \]  \hspace{1cm} (13)

\[ V_a(t) = k_q \omega(t) - R_a I_{ag}(t) \]  \hspace{1cm} (14)

\[ T_{em}(t) = \frac{k_q \omega(t) \cdot I_{ag}(t)}{\omega(t)} \]  \hspace{1cm} (15)

V. LEAD-ACID BATTERY MODEL

Equivalent circuit of the battery can be shown in Fig. (3), which consists of a voltage source in series with a resistance (Aryuangto et al).

Voltage at the battery terminals (\( V_{dc} \)) is expressed in the equation:

\[ V_{dc} = V_0 - R_i I_b(t) \]  \hspace{1cm} (16)

Power is supplied from the battery can be expressed as:

\[ P_{bb}(t) = V_{dc} I_b(t) \]  \hspace{1cm} (17)
The energy is stored in the battery after the load draws power from the battery can also be expressed as:

\[ e_{bb} = e_{bb\text{init}}(t) - \int P_{bb}(t)dt \]  

(18)

where \( V_{dc} \) is the DC voltage on the DC bus, \( V_o \) is the voltage of the battery bank, \( R_s \) is the resistance of the battery bank, \( i_b(t) \) is the current flowing out of the battery to the load, \( e_{bb}(t) \) is the energy delivered to the load when the battery is used up, \( e_{bb}(t) = e_{sto}(t) \) (energy storage) when the battery is being charged, \( e_{bb\text{init}}(t) \) is the initial energy battery, \( P_{bb}(t) \) is the battery power is sent to the load.

VI. METHODS

A. Research Design

Hybrid system that will be designed using the principle of the one-way and parallel, where the load will be supplied by one of the plant and at certain times the load supplied by two generators. When the weather is sunny (during the day), then the maximum power generated solar (photovoltaic power greater than the power load) so as to supply the load and the rest is stored in the battery (the charge). Conversely, if the weather is cloudy or at night (photovoltaic power is smaller than the load), the battery can supply loads up to limit operation (discharge process). As the battery is not able to supply the load completely, then the genset must operate to maintain continuity of service so that the load current beterei will work in parallel with the genset. After a while working parallel, disconnected the battery to the load, so that the generator charge the battery at the same time working alone. Furthermore, if the weather is sunny again, then the genset will disconnect (off) with the load so that the solar re-supply load. Algorithm battery charge and discharge processes and algorithms On-Off process of each genset can be seen in Figure 4 and 5.

B. Data Collection Method

Data needed to research the primary data and secondary data. Primary data is data on photovoltaic modules, a data genset and da tabattery in the Electrical Energy Engineering Laboratory Department of Electrical Engineering, Hasanuddin University. While secondary data can be obtained through library is a collection of material, articles, books, statements of work, or papers related to the research conducted.

![Graph](image_url)

**Figure 4. Algorithm battery charge and discharge processes.**

**Figure 5. Algorithm On-Off process genset.**

C. Data Analysis Methods

Data analysis method used is the method of simulation to see the characteristic of a hybrid power plant. Sofware this simulation with Matlab Simulink. In the simulation using Matlab Simulink software can be used to facilitate in understanding how the hybrid system works because it looks as visualization.

VII. RESULTS

Figure 6 is a hybrid simulation model of photovoltaic, generator and batteries. The results with a temperature of 25 °C and solar radiation of 1 kW/m² which is on the surface of the photovoltaic will produce a short circuit current \( I_{sc} \) amounted at 6.92 A and a maximum power \( P_{pv} \) of 126.1 Watts on the open circuit voltage \( V_{oc} \) of 22.53. While at the same temperature with solar radiation of 0.88 kW/m² will produce a short circuit current \( I_{sc} \) of 6.09 A at maximum power \( P_{pv} \) of 110.17 Watt on the open circuit voltage \( V_{oc} \) of 22.53 V.

Based on the simulation results on genset, if genset is given round of 350 rad/sec will produce a voltage \( V_{dg} \) of 11.82 V, current \( I_{dg} \) 8.3 A and power \( P_{dg} \) of 98.08 Watt. While on round 150 rad/sec will produce a voltage \( V_{dg} \) of 4.378 V, current \( I_{dg} \) of 8.3 A and \( P_{dg} \) power of 36.34 Watt.

In Figure 7 (using a battery with a capacity of 40 Ah) shows that at 31.78 to the load power is greater than the power source. Thus the source of power of 8.406 Watt shortage. This also happens when the clock shows the time to 55.79, where the source of supply shortages of 8.016 Watt. At 67.70 hours until 70.04 hours to also be in short supply with a maximum value of 14.79 Watt. Unlike the case in the figure 8 where the simulation is using a battery with a capacity of 80 Ah. In this figure shows that for 72 hours there is no shortage of power supply and battery power source.
Figure 6. Matlab Simulink simulation model Hybrid System.

Figure 7. Power load profile, source, losses, battery voltage, battery current and the battery energy capacity of 40 Ah.
Figure 8. Power load profile, source, losses, battery voltage, battery current and the battery energy capacity of 80 Ah.

VIII. DISCUSSION

Results of this study showed that the greater the solar radiation on photovoltaic modules, the greater the power generated. On genset, the greater the round of the prime mover, the greater the voltage is raised so as to generate greater power anyway.

Based on the results of the hybrid simulation has been performed, at the time of photovoltaic power raised, then the genset will stop operating (off). When there is a transition of supply from the photovoltaic genset to be a shortfall of power generation sources, but this will be examined by the battery because the current battery has been able to cater for a while to load. So it is seen that the genset will stop operating if the battery and photovoltaic able to serve load. Power losses will occur if the genset operates but smaller load power demand but also not able to be addressed by batteries and photovoltaic. Power loss will also occur when generating photovoltaic maximum power during the day but demand for smaller loads and the battery is fully charged.

In the process of charging / discharging the battery, which occurs when the charging process is indicated by the increase in the value of current battery energy and battery negative. Vice versa, if a process is shown by the reduced energy discharging the battery and the positive battery current value. At the time of filling (charging) battery, the voltage is higher than normal voltage. Vice versa during discharging (discharging) battery voltage is lower than normal voltage.

IX. CONCLUSIONS AND RECOMMENDATION

From the research that has been presented, some conclusions can be formulated as follows: the generated power photovoltaic solar energy generation in accordance with the magnitude of the intensity of solar radiation received, a large voltage generated by the genset is influenced by the speed of the shaft of the prime mover, genset will operate when the photovoltaic and battery is no longer able to supply the power demand of the load, there is a shortage of power supply source to the load on the clock to 31.78 and 55.79 when using a battery with a capacity of 40 Ah. This will be resolved when using a battery with a capacity of 80 Ah.
In designing a hybrid generator between a photovoltaic, genset and battery storage capacity to be aware of the battery to the load so that continuity of care will be achieved. In designing the prototype between photovoltaic, genset and battery in Energy Engineering Laboratory Department of Electrical Engineering Unhas should use a battery with a capacity above 80 Ah.

REFERENCES


