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Experimental Study of Power Characteristic for Photovoltaic and Wind Turbine

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ABSTRACT

Photovoltaic (PV) and wind turbine are renewable and clean since they does not produce unwanted green-house gases. The aim of this paper is to study the characteristic of output power from PV system and wind turbine. The experimental study was conducted at the Laboratory of Thermodynamics and Heat Transfer. PV system was modeled by using basic circuit current equations with varying iiradiation of 400, 600, 800, and 1000 W/m^2, constant cell temperature of 25 ^{o}C, maximum power point tracking (MPPT), and DC-DC boost converter of 12/25 V. The characteristic of PV model indicated that the maximum current is 1.84 A and maximum voltage is 28 V where the power is 41 W. The efficiency of PV reached highest at radiation intensity of 1000 W/m^2 is 8.8%. The wind turbine produced voltage of 31 V and current 1.3 A at wind speed of 6 m/s. The power coefficient of wind turbine at wind speed of 6 m/s is 0.23. The experimental results showed good agreement for PV system and wind turbine.

Keywords: *Power characteristic, Photovoltaic, Wind Turbine.*

1. INTRODUCTION

Because of global warming, environmental issue, and reducing fossil energy resources, the use of environmental friendly energy resources, such as solar and wind energy, becomes even more urgent and attractive. Harvesting energy from the solar and the wind can be done by using photovoltaic (PV) and wind turbine, respectively. The beneficial of the PV is static, quiet, free of moving parts, and low cost of operation and maintenance [1]. The most important aspect of PV is generating electricity from solar energy and mainly made from silicon cells. Although each cell produces a relatively low voltage (approximately 0.7 V under open circuit condition), the can be modulated by connecting them into modules in series or parallel. In a typical module, it can consist of 36 cells and produce an open circuit voltage of about 20 V [2]. PV modules are the fundamental power conversion unit of the PV generator and the characteristics of PV modules strongly depend on the irradiation and the cell temperature.

Many countries of the world are solving problems in the fossil fuel depletion and environmental issues by harvesting wind energy. Wind energy is one of the available non-conventional sources, which is clean and infinite resource. Previous study has shown that the variable wind speed has a number of advantages over fixed wind speed to maximize the performance, to develop the low amount of mechanical stress, and to improve the efficiency [3]. The wind turbine converts wind energy into mechanical energy and produces electricity based on the electromagnetic principle. The mechanical power from turbines was used to move past stationary magnets spools of thread known as the stator [4].

Wind energy delivery systems are among the most interesting, low cost, and environmentally friendly power supply for remote communities. To overcome the wind speed fluctuation, the power system for standalone needs the battery storage. The battery stores energy generated from the wind speed higher than required load and delivers to the load when wind speed lower. The advantages of wind turbine system include free, no green-house gases, and small land needed. Meanwhile the disadvantages of wind turbine are variation of the wind strength, noisy, and disfigure the countryside [5]. Furthermore, a permanent magnet synchronous generator (PMSG) can significantly improve the reliability of energy generating at the variable wind speed. PMSG has several advantages over other types of generators used in wind power, such as; the simple structure, the ability of the low speed operation, a self-excitation power leading to a high power factor and a high efficiency [6].

Research group designed using MATLAB Software Hybrid photovoltaic-wind turbine combined system as a small-scale alternative source of electrical energy. The PV and WT are selected as main energy sources, while the battery is used as back-up energy source. Two individual DC-DC boost converters are used to control the power flow to the load. A simple and cost effective control with DC-DC converter is used for maximum power point tracking (MPPT) and hence maximum power is extracted from the o turbine and the photo voltaic array. The modeling of hybrid system is developed in MATLAB- SIMULINK. The power fluctuation of the hybrid system is less dependent on the environmental conditions as compared to the power generated of individual PV and WT systems. This power fluctuation has been suppressed using a battery [7].

Another study present describes based simulation design and experimental calculations of PV and wind turbine system studied characteristics the of power both of PV/wind turbine dc load 50 w and steady state, transient regime in PV model. The maximum power point had been tested in PV cell with different load resistance. Regarding the wind energy conversion system, a wide range of speed are used variable speed 3-6 m/s synchronous generator (PMSG)with rectifier dc load 50 w studied the output of wind power, current, voltage Characteristic of wind in different load resistances [8].

Fuzzy controller for standalone "Hybrid Energy System" in mobile industry implemented to achieve energy management of the complete hybrid system. The results demonstrated that the designed control is capable to determining the operation mode of each subsystem presented on hybrid energy system. To accomplish the different control objectives (i.e., power regulation or maximum power conversion) in both (wind and solar subsystems). The researcher assumed that the main generation role would be carried out by the renewable energy, i.e., wind and solar subsystem respectively, while the traditional generation play a complementary role [9].

The paper is organized as follows: Section 1 introduce a brief introduction to Photovoltaic (PV) and wind turbine systems (WT), Section 2 descripts the case studies and hardware implementation of the PV/WT systems, Section 3 shows the technical results and discussion of the PV/WT systems, and finally Section 4 Highlights the conclusions.

2. CASE STUDIES

The renewable energy defines as the energy produced by natural resources such as solar, wind, wave, biomass, and water falls. Renewable energy resources (RERs) appear to be the one of the most efficient and effective solutions. So, the renewable energy resources nowadays are becoming increasingly more utilized for energy generation. In addition, due to the advancement in power electronics industry, the environmental and economic challenges being faced by the world. Among these RERs are the Photovoltaics (PVs) and Wind Turbines (WTs) [10].

Ongoing concerns about climate change have made renewable energy sources an important component of the world energy consumption portfolio. Renewable energy technologies could reduce carbon dioxide emissions by replacing fossil fuels in the power generation industry and the transportation sector. Due to negative and irreversible externalities in conventional energy production, it is necessary to develop and promote renewable energy supply technologies. In addition, the results estimate that 103 trillion dollars will be saved during the years 2010-2050 by reducing fossil fuels consumption [11]. Figure 1 presented some applications for RERs. These applications commonly used for home lighting, hospitals, oil refineries and industrial machines.

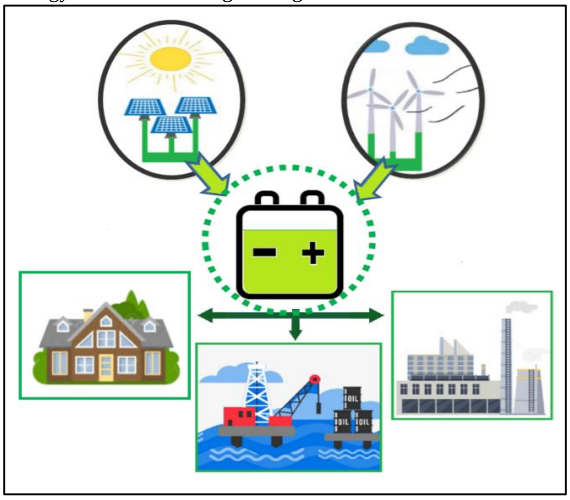

Figure .1 Some applications for Renewable Energy Resources.

2.1 Photovoltaic System (PV)

PV arrays convert sunlight to electricity. Systems are made up of modules assembled into arrays that can be mounted on or near a building. The PV equipment (Figure .2) used for this study were PV model 60 W, MPP tracking, DC-DC converter 12/25 V, 2 battery 24 V, and resistance load of 50 W. PV system displayed also module ND-060 W, maximum power (P_{max}) of 60 W, open circuit voltage (V_{oc}) of 22 V, and short circuit current (I_{sc}) of 3.9 A. Meanwhile, the voltage at maximum power point is 17.4 V and the current at maximum power point is 3.45 A. The over current protection is 7.5 A. The power characteristic from PV system was studied at different radiation, namely 400 W/m^2, 600 W/m^2, 800 W/m^2, and 1000 W/m^2. Meanwhile the power characteristic of the wind turbine was investigated at various variable speeds of 3 m/s, 4 m/s, 5 m/s, and 6 m/s.

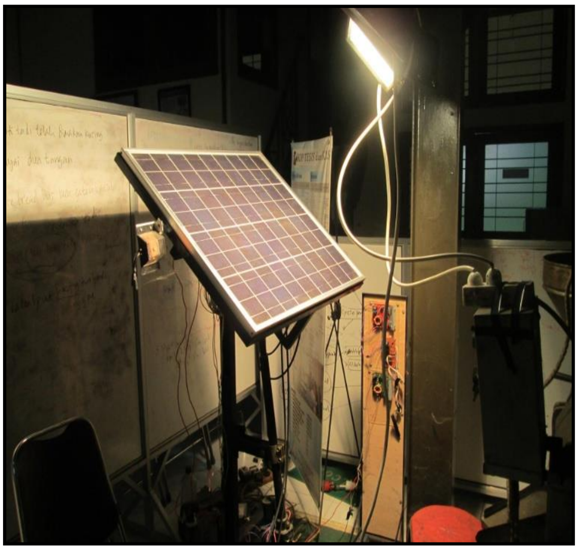

Figure .2 PV system used in this study.

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2.2 Wind Turbine System (WT)

Wind turbines use rotating propeller-like blades to harness the energy in the wind and drive a turbine that generates electricity. The equipment of wind turbine (Figure .) consisted of wind model 300 W, resistance load of 50 W, and 2 fans to model of wind moving. The wind system has the specifications of Ouyad angel 300 W, rated power of 300 W, rated voltage of 24 V, and rotor diameter of 1.44 m. The startup wind speed is 2 m/s and the wind speed rated is 9 m/s. In addition, the cut-out wind speed is 12 m/s.

Figure .3 Wind turbine system used in this study**.**

3. RESULT AND DISCUSSION

This section presents the results, discussion, and the personal insights that the researchers have gathered through the experimental investigations for both cases of PV and WT techniques.

3.1 Experimental Result of Photovoltaic System

The output power of a solar panel is a function of temperature, irradiation, and position of the panel. The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation that is perpendicular to the module surface. Measuring the radiation in nine positions of solar cells was determined by using photometer device. The experiment was done by using the parallel PV module 60 W, DC-DC converter 12/25 V, MPPT, and two batteries of 24 V. The PV module was tested with variable radiation of 400, 600, 800, and 1000 W/m^2 at a constant temperature of 25^{o}C to get the maximum power point, V_{MPP} (voltage at maximum power point), I_{MPP} (current at maximum power point), and the best efficiency of PV system with fixed load of 50 W. The PV module followed the mathematical equations:

Input power = area of PV x irradiation (1)

Output power = Voltage (V) x Current (I) (2)

Efficiency $(\eta) = \frac{\text{output power}}{\text{input power}} \text{x}100$ (3)

Table.1 Experiment results of PV System

Area of PV (m^2)	**Power of PV** (w)	**Radiation Intensity** (W/m^2)	**Voltage** (V)	**Current** (I)	**Power** (V x I)	**Efficiency** %	**Voltage in battery** (V)
0,4352	174,08	400	18.2	0.34	6,19	3.56	24.7
0,4352	261,12	600	22.9	0.42	9,62	3.68	25.4
0,4352	348,16	800	23.3	1.10	25.63	7.36	25.6
0,4352	435,2	1000	31.8	1.20	38.16	8.77	25.2

The experimental results of PV system are shown in Table 1. At irradiation of 400 W/m^2, the current-voltage (I-V) characteristic from the basic description of the PV shows that the voltage reached 18.20 V and the current was 0.34 A. The power generated at this irradiation was 6.19 W with the efficiency of 3.56%. The increase of irradiation displayed an increase of both voltage and current. At irradiation of 1000 W/m^2, the voltage was 31.8 V, the current was 1.2 A, and the efficiency was 8.77%. Therefore, the relationship between the irradiation intensity and the characteristics of PV, namely I, V, P, and efficiency is increasing when the radiation increase until 1000 W/m^2. Here we observed also that the output voltage at the load using DC-DC converter 12/25 V and maximum power point tracking (MPPT) in varying radiation of 400, 600, 800, and 1000 W/m^2 was almost constant, i.e. 24.7 V, 25.4 V, 25.6 V, and 25.2 V, respectively as shown in Table 1. The average voltage is close to the desired voltage of 26 V for a duty cycle of 40%. When the inductor is charging, the switch is on, and there is no current across the capacitor or diode because the output stage is isolated. When the switch is off the inductor discharges energy and there is current through the diode and capacitor.

3.2 Experimental Results of Wind Turbine System

Firstly, the wind speed was determined by using an anemometer device. The measuring position of wind speed is shown in Figure 4. The wind speed for calculating the performance of the wind turbine was determined from their average. Meanwhile the experiment result of wind turbine is shown in Table 2.

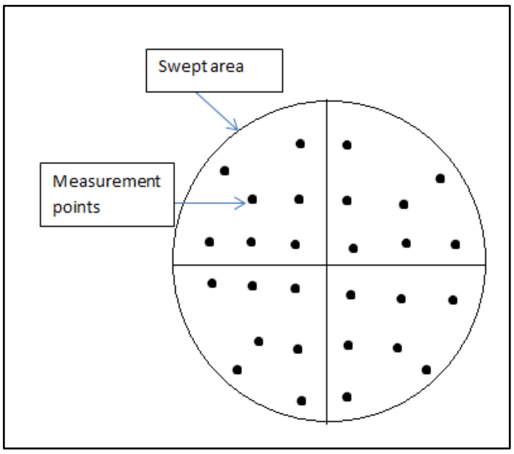

Figure 4. Measuring position of wind speed.

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Table.2 Experiment result of wind turbine.

Area	Air density	Power of wind	Wind Speed	Voltage	Current	Power	C_p
(m^2)	(kg/m^3)	(W)	(m/s)	(V)	(I)	(V x I)	
1.77	1.23	29.39	3.0	2.5	0.05	0.13	0.004
1.77	1.23	69.67	4.0	8.8	0.20	1.76	0.025
1.77	1.23	136.07	5.0	40.3	0.72	29.02	0.213
1.77	1.23	235.13	6.0	54.0	1.02	55.08	0.234

For the following experiment results, the wind turbine was started with an initial wind velocity of 3 m/s at a resistance load of 50 W. The output voltage of a permanent magnet DC generator strongly depended on the shaft RPM and the load. The diode bridge rectifier controlled the output voltage. In low wind speed conditions, the voltage might be lowered to prevent the DC load from reverse biasing of the diode rectifier under high wind speed conditions.

As the increase of wind speed, the voltage tremendously increased while the current gradually increased. The reasonable power characteristic was observed at a wind speed upon 5 m/s. At wind speed lower than 5 m/s, the power coefficient is very low (< 0.2) leading to drawback for applied in reality. The voltage of 54 V, current of 1.02 A, and C_p of 0.23 were obtained from the wind turbine with wind speed of 6 m/s. For higher wind speed than 5 m/s, the power was sharply increasing while the power coefficient was almost constant as shown in Figure 5.

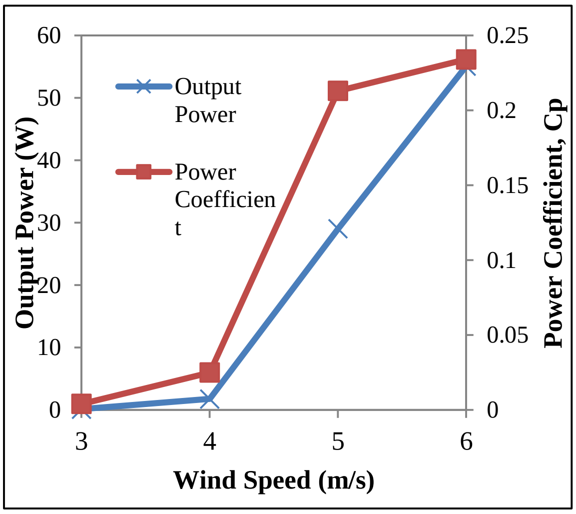

Figure 5. Output power and power coefficient of wind turbine.

3.3 The Power characteristic of PV and WT

Apparently, the PV cell and wind turbine produced different pairs of current and voltage at various load. The power characteristic of PV and wind turbine at various load is shown in Figure 6. It shows that at load of 20 ohm produces respective maximum power of 40.7 W and 59.1 W for PV and WT.

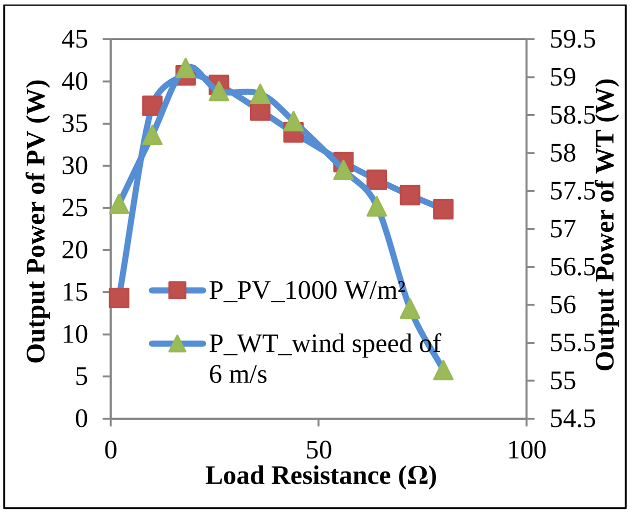

Figure 6. Power characteristic of PV and wind turbine at various loads.

4. CONCLUSIONS

The experiment of PV and wind turbine system have been studied well. The characteristic of PV model indicated that the higher the irradiation, the bigger the power was achieved. At irradiation of 1000 W/m^2, the produced current from PV system was 1.84 A and the produced voltage was 28 V. The efficiency of PV system at irradiation of 1000 W/m^2 was 8.8%. In the other hand, the characteristic of wind turbine shows similar characteristic with PV system. The bigger the wind speed, the higher the power was produced. At wind speed of 6 m/s, with a fixed resistance load 50 W, the wind turbine produced power of 45 W with power coefficient of 0.23. The reasonable wind speed to operate the wind turbine was 5 m/s since the power coefficient was high enough. The maximum power point obtained from PC system at 1000 W/m^2 and wind turbine at 6 m/s was 40.7 W and 59.1 W, respectively. The experimental results showed good agreement for PV system and wind turbine.

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