**Journal of Theoretical and Applied Information Technology**
15th May 2017. Vol.95. No 9


ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

# PERFORMANCE ANALYSIS OF A WIND TURBINE WITH PERMANENT MAGNET SYNCHRONOUS GENERATOR

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**ABSTRACT**

This paper presents performance analysis of a 2 kW wind turbine with permanent magnet synchronous generator. The Government of the Republic of Indonesia through the Ministry of Energy and Mineral Resources (ESDM) targets by 2025 of at least 23% of the total national electricity supply comes from renewable energy sources. Government programs must be supported by all regions to help build renewable energy power plants to its potential of each. In this case, the district of Bantul, Yogyakarta Special Region Province, Indonesia, particularly the southern coastal region is very likely to be developed wind power plant. In this research, the create-designing and testing of wind power with maximum capacity of 2 kW is done. The test has been carried out on September 5 and 6, 2016 at the Baru Beach, Srandakan, Bantul. The test results on September 5, 2016 showed that the highest power generator occurred at 12:40 PM is 768.96 watts, with a wind speed of 8.76 m/s, AC voltage of generator is 40.00 volts, the DC voltage generator after rectified be 53.40 volts, and the load current is 14.40 ampere. In this condition, the 2 kW wind turbine has the efficiency of 38.4%. Furthermore, the test results dated 6 September 2016 found that the highest power generator at 10:50 PM is 842.20 watts, with a wind speed 9.53 m/s. At this peak condition resulting AC voltage of generator of 39.00 volts, the DC voltage of 49.60 volts, the load current of 17.00 amperes, and resulting in efficiency of 42.1%. The research results indicate that wind turbine is an alternative solution in the southern coastal region of Bantul for the supply of renewable energy sources.

**Keywords:** *Wind Turbine, Synchronous Generator, Permanent Magnet, Renewable Energy, Efficiency.*

## 1. INTRODUCTION

The Government of the Republic of Indonesia through the Ministry of Energy and Mineral Resources (ESDM) has set a target that by 2025 a minimum of 23% of the total electricity supply must come from renewable energy sources [1]-[3]. These targets are unrealistic because of the lack of conventional energy sources that rely on fossil fuels and coal, besides environmental issues, namely pollution generated by conventional sources of electrical energy. One source of renewable electrical energy potential in Indonesia is wind power. Among the regions with the potential to generate electricity from wind power is the coastal region of the southern coast of the island of Java, particularly the districts of Bantul, Yogyakarta Special Region Province, which has a wind speed range of 3-12 m/s [4]-[6].

By taking lessons from countries in continental Europe, wind power is a renewable energy power plants are the fastest growing [7]-[9]. Has a lot of wind power plants are built with an installed capacity ranging from a few kilowatts to megawatts capacity are interconnected with the electrical power distribution network. For example, Enercon has built wind turbines with a capacity of 4.5 MW and a rotor diameter of 112.8 m. Application-scale wind power plants are usually using a doubly-fed induction generator (DFIG) [10]-[11] to control blade pitch angle in order to produce optimal power [12]-[13]. Both of these technologies have been tried separately in several research in Europe but in

Journal of Theoretical and Applied Information Technology
15th May 2017. Vol.95. No 9

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

large power capacity in units of mega-watt accordance with the conditions in Europe which have a higher wind speeds and relatively stable (10-15 m/s) [14]. Meanwhile, for small to medium capacity, wind turbine very efficiently using synchronous generator [15]. This type of generator is in accordance with the geographical condition of Indonesia, particularly the southern region of Bantul, the location of these research trials. Therefore very interesting to design-build wind turbine appropriate wind conditions in Indonesia, especially in the southern region of Bantul.

This research is expected to contribute to strengthening the National Innovation System (SINAS) in order to achieve energy independence and the main economic activity in the MP3EI. The research can also help realize the government program to provide electricity generation coming from renewable energy sources and help preserve the environment.

## 2. WIND TURBINE WITH PERMANENT MAGNET SYNCHRONOUS GENERATOR

Today has been a lot made the development of wind power generation systems either in terms of increased electrical power generation capacity to increase the efficiency of the system. Production of electrical energy from wind energy sources was first performed by Charles Brush in Cleveland, Ohio, USA in 1887 [12]. In this case use the DC generator to produce electrical power and are designed to charge the battery. While the first induction generator once used as part of a wind power plant was in 1951.

Wind turbines convert the kinetic energy derived from the wind into mechanical energy in the form of a round windmill. Kinetic energy is dependent on air density and wind speed. Therefore, the power generated by wind turbines is given by the following equation [16]-[18].

$$P = 0,5\, C_p \rho A V^3 \tag{1}$$

by $C_p$ is the power coefficient, ρ is the wind speed in kg/m$^3$, A is the area of the turbine blade in m2, and V is the wind speed in m/s. Windmill tip speed ratio is the ratio of a linear rate and the rate of wind turbine blades, according the following equation:

$$\lambda = R\omega/v \tag{2}$$

Substitution of equation (2) into the equation (1), is obtained:

$$P = 0,5\, C_p(\lambda)\rho A(R/\lambda)^3(\omega)^3 \tag{3}$$

Furthermore, the power output of wind turbines can be calculated using the following equation:

$$P = 0,5\, \rho A\, C_p\, (v/\lambda) \tag{4}$$

R is the radius of the turbine rotor in meters.

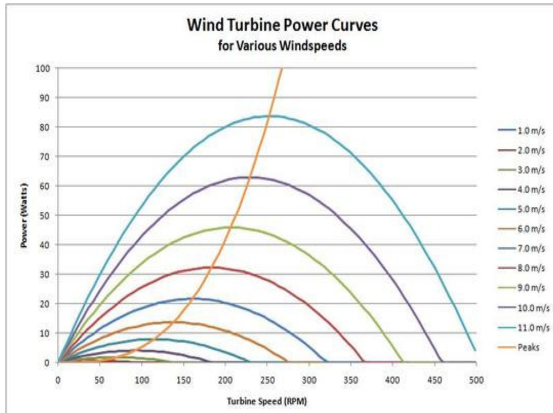


*Figure 1. Graph of wind turbines characteristics [9].*

Figure 1 shows how the operating rate varying turbine will generate electricity from wind. The maximum power follow cubic relations unit. For the generation of a variable rate, then use the induction generator because it has the characteristics of a flexible rotor speed, while the synchronous generator has a constant speed. In this research, the rotor speed at subsinkron conditions for the wind speed is less than 10 m/s and conditions supersinkron to the wind speed over 10 m/s.

## 3. METHODOLOGY

Stages and flow of research activities is shown in Figure 2. In the Figure can be seen that the research activities initiated by designing a wind power plant in the software Matlab-Simulink. Having obtained a valid model in Matlab-Simulink software then followed by designing-build wind power plants in the form of hardware devices. The main component of the hard-wind power plant consists of a permanent magnet synchronous generator (PMSG) and the controller, turbine blades, rectifier circuits and inverter.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

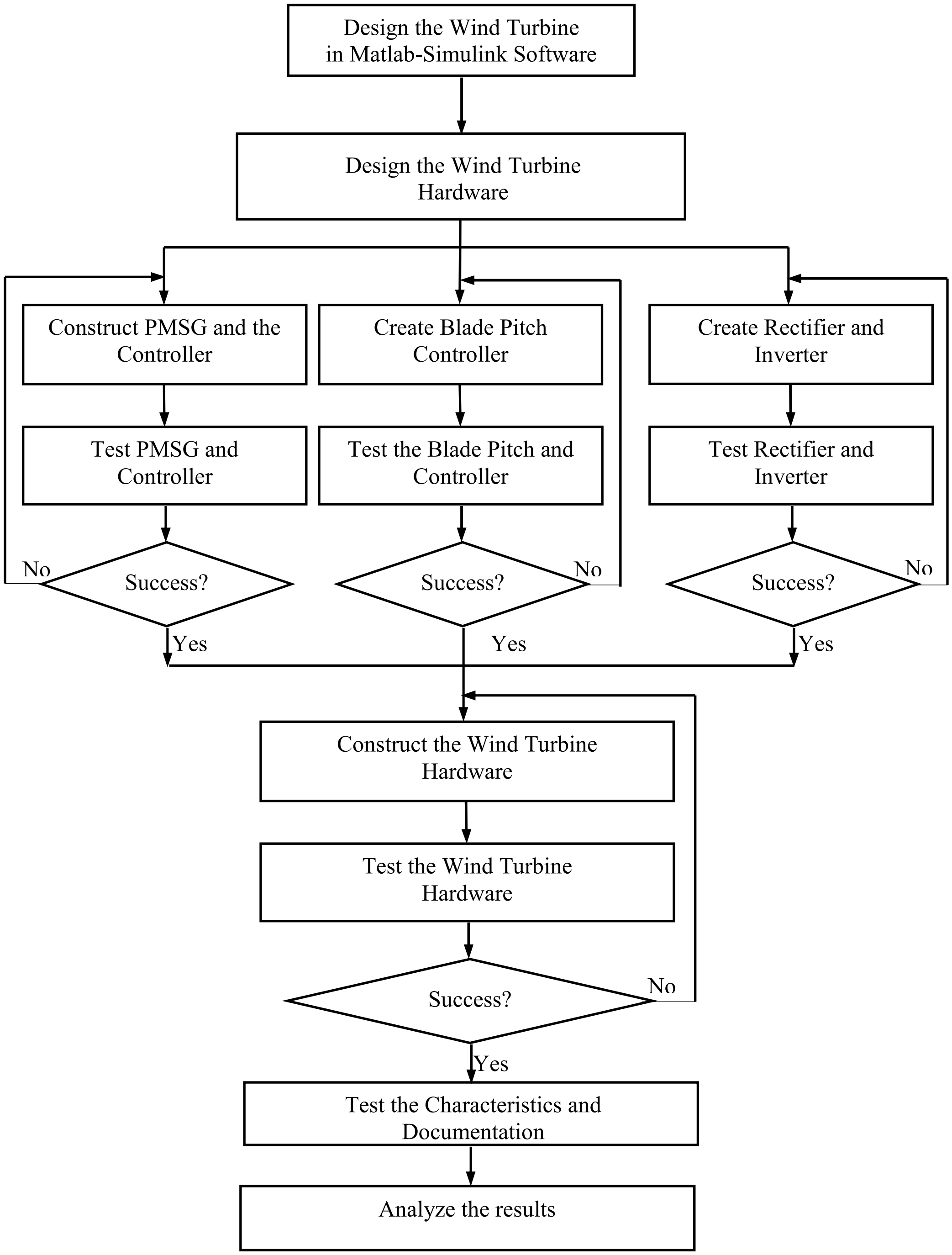


*Figure 2. Research Steps Of This Research*

## 4. RESULTS AND DISCUSSION

In this research has been in the design-build wind power plants with a maximum capacity of 2 kW with horizontal type blade shape, as shown in Figure 3 and Figure 4. The generator used is a type of permanent magnet synchronous generator 3 phase.

Figure 3. A 2 kW wind turbine with permanent magnet synchronous generator

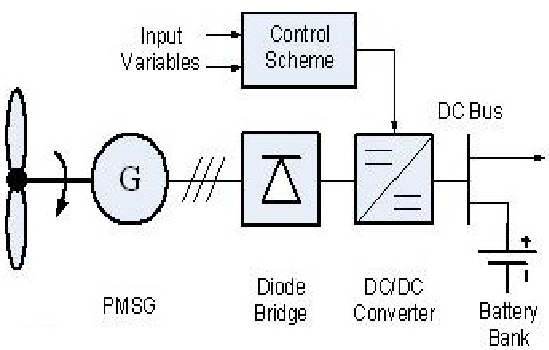


*Figure 4. Diagram of a 2 kW wind turbine with permanent magnet synchronous generator*

Specifications of permanent magnet synchronous generator used in wind turbine are as follows:

Maximum power: 2000 watts
Nominal rotation: 400 rpm
Nominal current: 18.8 amperes

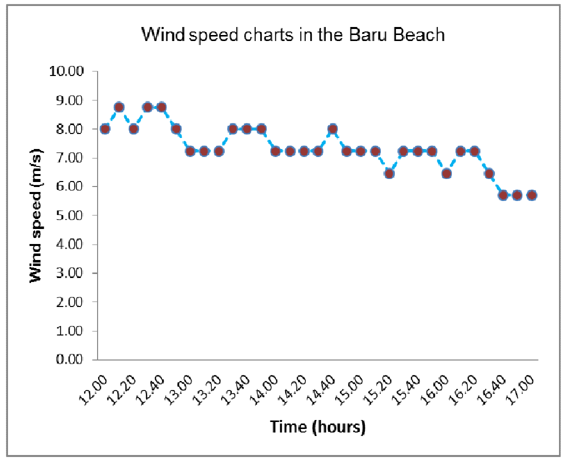


*Figure 5. Wind speed charts in the Baru Beach on September 5, 2016*

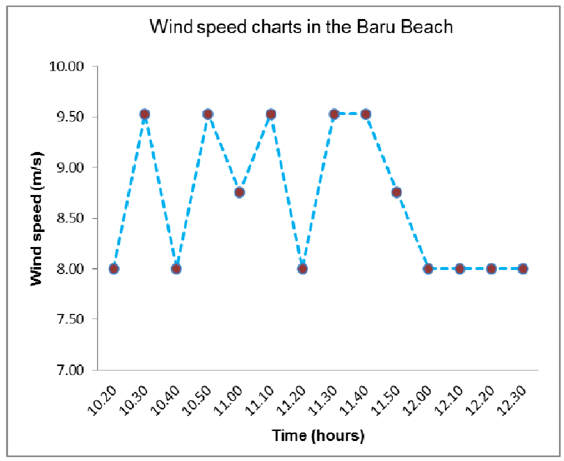


*Figure 6. Wind speed charts in the Baru Beach on September 6, 2016*

Wind power plant design results are then conducted a trial to determine its performance. The tests have been carried out on September 5 and 6, 2016 located at Baru Beach, Srandakan, Dictrict of Bantul, Yogyakarta Special Region Province. By the time the trial takes place, the weather in Baru Beach location is very sunny with temperatures is approximately 30°C. Wind speed charts in the Baru Beach on September 5, 2016 is shown in Figure 5, while the wind speed chart dated September 6, 2016 is shown in Figure 6.

On September 5, 2016, wind turbine trials conducted at 12.00 pm until 17.00 pm. Based on the wind speed graph in Figure 5 shows that the highest wind speed on 5 September 2016 is 8.76 m/s, which occurred at 12:10, 12:30, and 12:40 pm, respectively, while the lowest wind speed of 5.71 m/s happened in at 16:40, 16:50, and 17:00 pm, respectively.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Furthermore, on September 6, 2016, the trial of wind turbine performed at 10:20 pm until 12:30 pm. Based on the wind speed graph in Figure 6 shows that the highest wind speed on September 6, 2016 is 9.53 m/s which occurred at 10:30, 10:50, 11:10, 11:30, and 11:40 pm, respectively, while the lowest wind speed of 8.00 m/s that occurred at 10:20, 10:40, 12:20, and 12:30 pm, respectively.

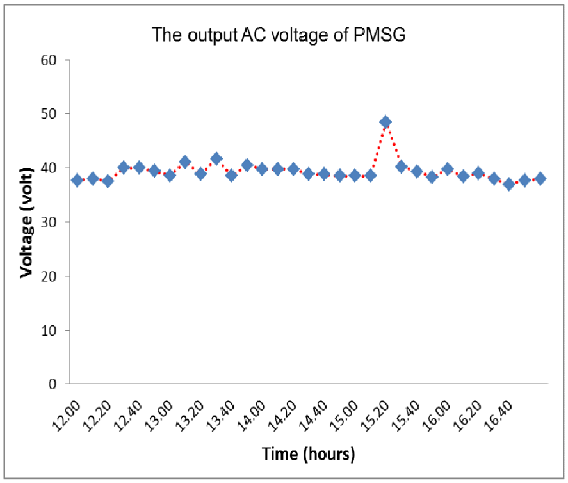


*Figure 7. The Output AC Voltage Of PMSG On September 5, 2016*

Based on the graph in Figure 7 shows that the output voltage of the generator is relatively stable in the range 37.70 volts to 48.51 volts at the variation of wind speed 5.71 m/s to 8.76 m/s. In Figure 8 also shows that the generator output voltage to remain stable in the range 37.40 volts to 40.90 volts on the wind speed ranges from 8.00 m/s to 9.53 m/s.

AC output voltage of the generator subsequently rectified using rectifier 3 phase to generate a nominal direct current (DC) voltage of 48 volts. DC voltage by a rectifier rectification results were observed on 5 and 6 September 2016 is shown in Figure 8 and Figure 9.

Based on the graph in Figure 9, it is shown that the output voltage of the rectifier is relatively stable in the range 47.80 volts to 53.40 volts at the variation of wind speed 5.71 m/s to 8.76 m/s. In Figure 10 also shows that the rectifier output voltage remains stable in the range 48.00 volts to 53.00 volts on the wind speed ranges from 8.00 m/s to 9.53 m/s. The rectifier output voltage as expected is in the range of 48 volt according to the nominal voltage of the battery to be used as electrical energy storage of the wind turbine.

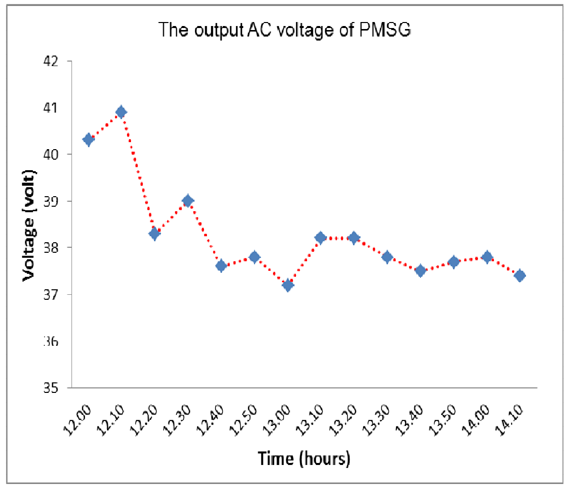


*Figure 8. The Output AC Voltage Of PMSG On September 6, 2016*

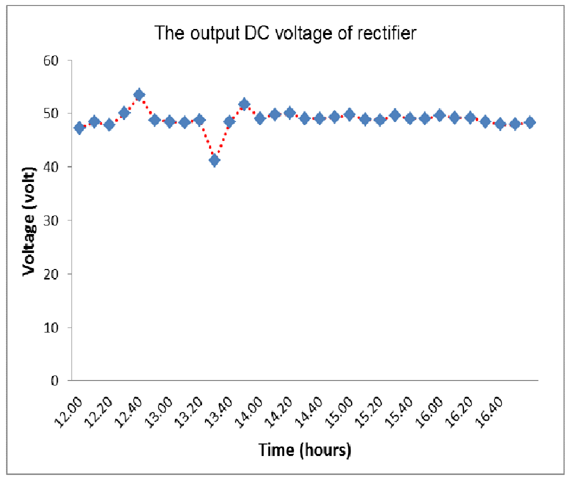


*Figure 9. The Output DC Voltage Of Rectifier On September 5, 2016*

Electrical energy from wind turbines then stored in a 12-volt battery connected in series to produce as much as 4 battery equivalent voltage 48 volts. In the current observational study was done loading the battery so that the quantity of electric power stored in the battery during the test period. Thus, the battery serves as a load to absorb electrical energy, which can be observed power and efficiency of wind power.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

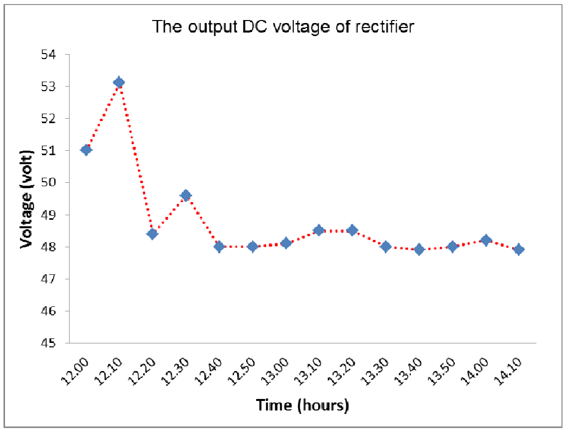


*Figure 10. The Output DC Voltage Of Rectifier On September 6, 2016*

Data of power wind turbine test results dated on September 5, 2016 is shown in Figure 11, while the test results dated on September 6, 2016 is shown in Figure 12. According to Figure 11, it can be seen that in testing of wind turbine on September 5, 2016 in Baru Beach, Bantul, power at 12:40 pm generator produced the highest value that is equal to 768.96 watts. It is caused when the wind speed is relatively high at 8.76 m/s. At this peak condition resulting voltage AC generator (phase to phase) of 40.00 volts, the voltage is rectified into DC generator after 53.40 volts, and the load current to charge the battery is 14.40 ampere. In this condition 2 kW wind turbine engineering results have amounted to 38.4% efficiency generator.

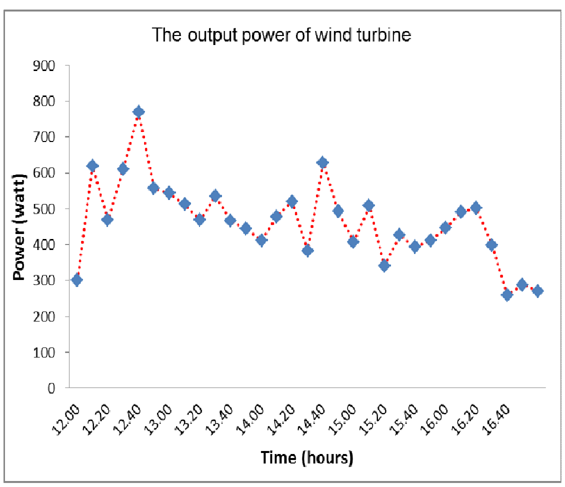


*Figure 11. The Output Power Of Wind Turbine On September 5, 2016*

Furthermore, the results of testing of 2 kW wind turbine with a 48 V battery charging on September 6, 2016 in Baru Beach, Bantul is shown in Figure 12. The figure shows that the Based on testing 2 kW wind turbine on September 6, 2016 in Baru Beach, Bantul, power generator the highest generated at 10:50 pm in the amount of 842.20 watts. It is caused when the wind speed is relatively high at 9.53 m/s. At this peak condition resulting voltage AC generator (in phase to phase voltage) of 39.00 volts, the voltage is rectified into DC generator after 49.60 volts, and the load current to charge the battery is 17.00 ampere. In this condition, 2 kW wind turbine has an efficiency of generator of 42.1%.

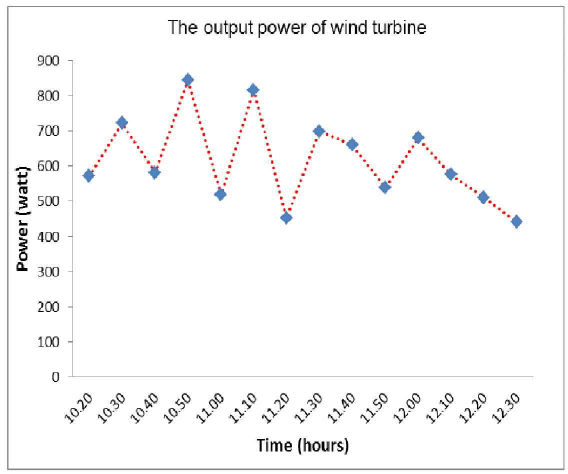


*Figure 12. The Output Power Of Wind Turbine On September 6, 2016*

The results of the test of the 2 kW wind power, it can be seen that the power plant is still able to increase the efficiency becomes higher than 42.1% if the wind in the wind turbine has a higher rate of 9.53 m/s. Observations indicate that the pace of wind in the southern coastal region of Bantul can reach 12.3 m/s [4].

## 5. CONCLUSION

In this research has been in engineering and tested wind power plant with a capacity of up to 2 kW. The tests have been carried out on September5 and 6, 2016 at the Baru Beach, Srandakan sub-district, Bantul, Yogyakarta. The test results on 5 September 2016 showed that the highest power generator occurred at 12:40 pm in the amount of 768.96 watts, with the wind speed is 8.76 m / s. At this peak condition resulting voltage AC generator of 40.00 volts, the voltage is rectified into DC generator after 53.40 volts, and the load current to charge the battery is 14.40 ampere. In this condition 2 kW wind turbine engineering results have

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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**ACKNOWLEDGEMENTS**

The research team would like to thank profusely to the Ministry of Research, Technology and Higher Education for funding this research. Hopefully this good cooperation can be continued so as to contribute to the research development and strengthening of national innovation system.

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