The Aerodynamic Performance Study on Small Wind Turbine with 500W Class through Wind Tunnel Experiments

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Abstract: - For urban usage of an Archimedes spiral horizontal axis wind turbine, the aerodynamic characteristics including output power, power coefficient, and effect of the angle of attack was investigated using proto-type wind turbine model with Archimedes spiral shape. To provide the aerodynamic performance, the experimental model was consisted with Archimedes spiral wind turbine model, torque meter, powder brake with PWM (Pulse Width Modulation) control basic and RPM sensor. The power coefficient as a function of tip speed ratio with more than 85% of Betz limit can be observed successfully. The Archimedes spiral wind turbine model employed in this study shows the similarity with Modern multiblade turbine type. And the maximum power coefficient as a function of the TSR shows the similar that of Ideal Efficiency of Propeller-type turbine. Through the experiments on the angle of attack change, the fundamental information for the automatic yawing system may be provided.

Key-Words: - Archimedes Wind Turbine, Power Coefficient, Tip Speed Ratio, Angle of Attack

1 Introduction

Wind as a source of renewable energy receives a great attention as an increasingly viable solution to one of the most important issues of our time, that is, pollution free electricity for sustainable living. The continued dependence on depleting fossil fuel sources or nuclear power has the potential to wreck the world's economy and security. If the issue is not addressed with a sense of urgency, then the havoc that the recent nuclear power plant meltdown in Japan of 2011 or oil spills of the Gulf of Mexico of 2010 caused, will pale in comparison threatening mankind's very existence (Ahmed, 2013). Skea (2014) described that the make-up of the EU's energy RD & D portfolio has changed to new technologies such as wind and solar from fossil energy conversion system. And he also mentioned that the political environmental change related on renewable energy leaded the growth of the investment and R & D funding on the renewable energy system. Bahaj et al. (2007) described that small scale wind turbines installed within the built environment is classified as microgeneration technology and such turbines may soon become a commercial reality in the UK as a result of both advancements in technology and new financial incentives provided by the government. And they also mentioned the proliferation of small scale wind turbine for urban and suburban usage within near future. Some researches into urban energy generation showed that it is possible to predict with a high degree of accuracy the expected financial payback period for a typical domestic household. A variety of wind turbines were analyzed (Simic et al. 2013, Bortolini et al. 2014, Arifujjaman et al. 2008).

Howell et al. would like to provide the performance coefficient prediction on small vertical axis wind turbine through experimental and numerical study. They mentioned on dynamic behavior of the over tip vortex as a rotor blade rotating through each revolution. These studies reported the effects of the blade geometry on the power curve, the turbine's rated power related to its swept area, the total electricity production, and the pay-back period. Herbert et al. reviewed the wind resources assessment models, site selection models and aerodynamic models including wake effect. They also discussed that the differences exist in performance and reliability evaluation models, various problems related to wind turbine components (blade, gearbox, generator and transformer) and grid for wind energy system.

Hirahara et al. studied on very small wind turbine system with 500 mm as a diameter of blades. Through their experimental study, they mentioned that the maximum power coefficient employed in their study showed approximately 40 % at 2.7 as a tip speed ratio. Quasim et al. have studied for the power coefficient on cavity shape vane vertical axis wind turbine model through wind tunnel experiment. Through their experimental study, they mentioned that the frame of vertical axis wind turbine may affect the power coefficient. Ragheb et al. discussed the Betz limit for horizontal and vertical axis wind turbine systems. And they also mentioned that the wind turbine must be designed to operate at their optimal wind tip speed ratio in order to extract as much power as possible from the wind stream.

Even though there are lots of previous research work on small wind turbine, there are strong needs on the aerodynamic characteristics including Power coefficient, Output power according to the approaching wind condition and blade feature. In this study, we would like to provide the aerodynamic characteristics on the 500 watt class Archimedes Spiral Wind Turbine through two types of wind tunnel employed in this study. And to provide the fundamental information on yawing system, the aerodynamic characteristics with respect to the angle of attack were also investigated through large wind tunnel experiments. The results employed in this study on aerodynamic characteristics through wind tunnel experiments may be applied for generator optimal design.

2 Experimental Setup and Methods

Figure 1 shows the experimental model of Archimedes spiral wind turbine with 0.5kW placed on atmospheric boundary layer wind tunnel at Pusan National University. The open suction type wind tunnel employed in this study has 2m×2m as a cross-sectional area. The experimental model was placed in the center of the wind tunnel. The ball bearings were installed in the frontward and backward of the blade shaft. Wind turbine model employed in this study was consisted with Archimedes spiral wind blade, torque meter, powder brake and rpm sensor. The torque meter was mechanically assembled backward of Archimedes spiral wind blade through main shaft of wind turbine model. For the power coefficient calculation as a function of tip speed ratio, Torque meter, Powder Brake and RPM sensor was employed, respectively.

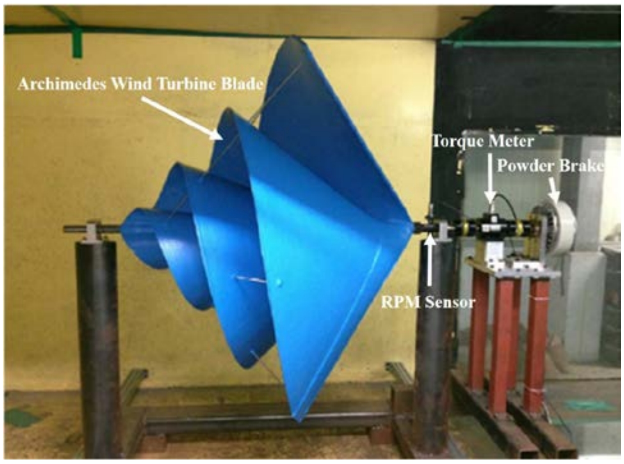

Figure 1 Archimedes wind turbine model placed in the wind tunnel (at PNU)

The Archimedes Spiral wind blade with 1.5m as a diameter was made of FRP resin and Fiber Glass Sheet through by-layer process. The thickness of the blade was approximately 3 mm in the blade tip region and approximately more than 5 mm in the center region for bonding force with stainless steel shaft, respectively.

The rotating force control from powder brake employed in this study can provide an optimal performance of generator. And to calculate the aerodynamic power, torque meter was employed downstream of the blade model. To prevent of the downstream wake flow passing through the frame, the frames of wind turbine model have airfoil shape.

In the case of high flow condition, to provide the stability of the spiral wind turbine model, the frame was tied up the wind tunnel with damper for minimizing the vibration between the wind turbine model and wind tunnel. To investigate the approaching wind speed, the Pitot tube was placed 2 m downstream from the wind turbine model same with the center of the experimental model.

3 Results and Discussions

Aerodynamic power production and power coefficient from wind turbine is closely related with the interaction between the rotor and the incoming wind speed. The power coefficient of wind turbine is defined as how efficiently the wind turbine converts the energy from wind into electricity. Tip speed ratio of wind turbine is an essential parameter to how efficient that turbine will perform.

Equation (1) represents the definition on Tip Speed Ratio.

$$\mathrm{TSR} = \frac{\mathrm{R} \times \omega}{U_{in}} \quad (1)$$

Where R[m] is the radius of the wind blade, ω[rad/s] is the angular velocity and U_{in}[m/s] is the approaching wind velocity.

The input and output power through the wind energy conversion can be represented as equation (2) and (3), respectively.

$$P_{out} = T \times \omega \quad (2)$$

$$P_{in} = \frac{1}{2} \times \rho \times A \times U_{in}^{3} \quad (3)$$

Where, ρ means the air density, A means the cross sectional dimension of wind turbine, U_{in} means the wind speed, T means the torque, ω means the angular velocity of wind turbine, respectively. As following to IEC-61400, ρ can be represented as 1.225 kg/m3.

According to the Betz Limit, the theoretical maximum coefficient of power for any wind turbines could not convert more than 59.3% of the kinetic energy of the wind into mechanical energy rotating the wind blade. Good wind turbine generally fall in the 35~45% range of electricity.

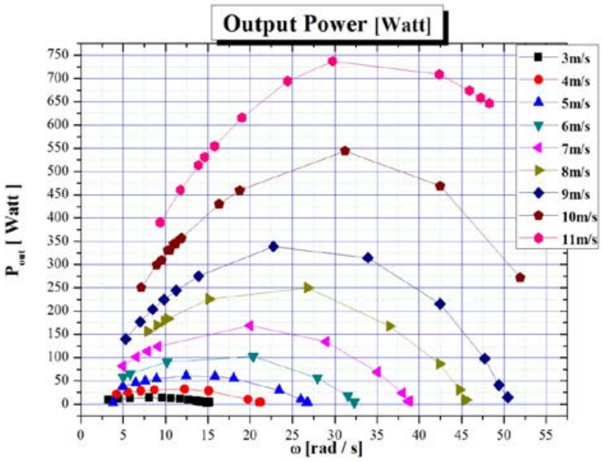

Figure 2 Generated Power as a function of the Angular Velocity [from PNU Wind Tunnel]

Figure 2 shows the power curve with respect to the angular velocity through wind tunnel experiments. The experiments condition on the approaching wind speed were controlled from 3 m/s to 11 m/s with step of 1 m/s. In the case of 3m/s as wind speed, even though the generated power was not so sufficient, the generated maximum aerodynamic power with approximately 13.32 Watt through Archimedes spiral wind blade can be observed at 8.08 as angular velocity. The rotational power was controlled using powder brake and the maximum aerodynamic power was observed at 16% as PWM (Pulse Width Modulation) control value. In the case of 4m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 32.03 Watt at 12.26 as angular velocity. In this case, PWM control value had 17%. In the case of 5m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 60.27 Watt at 12.44 as angular velocity. In this case, PWM control value had 24%. In the case of 6m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 102.58 Watt at 20.34 as angular velocity. In this case, PWM control value had 20%. In the case of 7m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 168.96 Watt at 19.96 as angular velocity. In this case, PWM control value had 25%. In the case of 8m/s as wind speed, the

Table 1 Aerodynamic Characteristics on Spiral Wind Blade

Wind Velocity	Maximum Aerodynamic Power	Maximum Power Coefficient[%]	RPM	Angular Velocity	Tip Speed Ratio
3 m/s	13.32	45.57	77.15	8.08	2.02
4 m/s	32.03	46.24	117.09	12.26	2.30
5 m/s	60.27	44.55	118.84	12.44	1.87
6 m/s	102.58	43.88	194.27	20.34	2.54
7 m/s	168.96	45.51	190.55	19.96	2.14
8 m/s	250.31	45.17	255.98	26.81	2.51
9 m/s	339.10	42.98	217.26	22.75	1.90
10 m/s	544.16	50.27	298.27	31.23	2.34
11 m/s	737.22	51.17	284.27	29.77	2.03

on Spiral Wind Blade generated the maximum aerodynamic power seems to be approximately 250.31 Watt at 26.81 as angular velocity. In this case, PWM control value had 25%. In the case of 9m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 339.10 Watt at 22.75 as angular velocity. In this case, PWM control value had 30%. In the case of 10m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 544.16 Watt at 31.23 as angular velocity. In this case, PWM control value had 30%. In the case of 11m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 737.22 Watt at 29.77 as angular velocity. In this case, PWM control value had 35%.

Figure 3 shows the power coefficient as a function of tip speed ratio with respect to the wind speed change from 3m/s to 11m/s with step as 1m/s. The maximum power coefficient for each experimental condition from 3 m/s to 11 m/s as an approaching wind velocity can be observed between 1.87 ~ 2.54. In the case of 11 m/s, the maximum power coefficient with 51.17 % can be observed. From this result, we can consider that approximately 86.35% from the optimal value of the performance coefficient called as Betz Limit. From this figure, the performance characteristics of the Archimedes spiral wind turbine employed in this study shows the similarity with Modern multiblade turbine. And the maximum power coefficient as a function of the TSR shows the similar that of Ideal Efficiency of Propeller-type turbine (J. N. Libii, 2013). Table 1 represents the experimental results through the Wind Tunnel of Pusan National University with 2 m × 2 m as a test section.

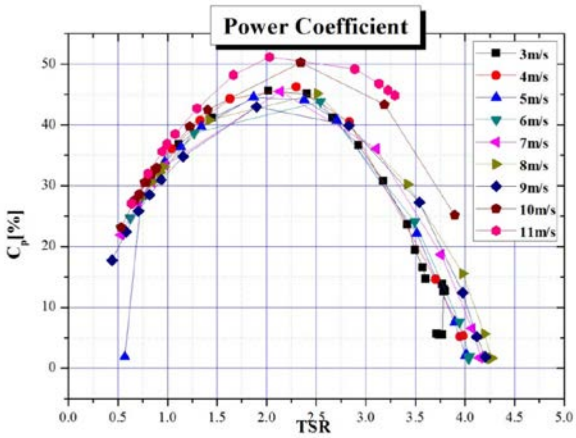

Figure 3 Power Coefficient as a function of Tip Speed Ratio [from PNU Wind Tunnel]

To investigate the aerodynamic characteristics on the Archimedes wind turbine model according to the angle of attack change and to compare the results through Pusan National University Wind Tunnel by reducing the blockage effect, the experimental model with turning plate was placed on the large wind tunnel with 4 m × 2 m (width × height) as a test section. The blade model for aerodynamic characteristics investigation except turning plate was same as previous experimental model. Figure 4 shows the definition of angle of attack.

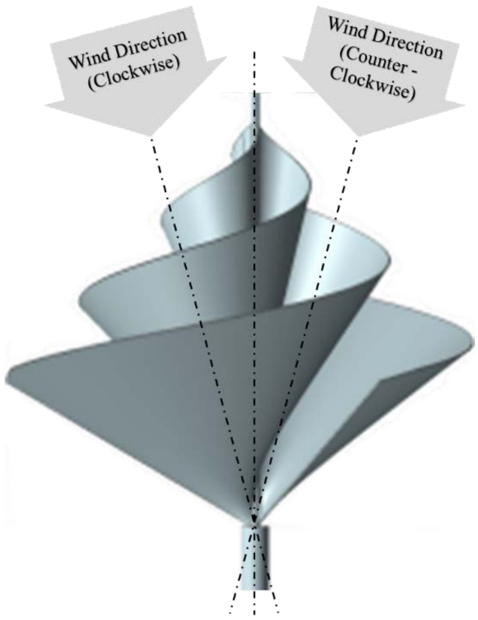

Figure 4 Definition of Angle of Attack

Figure 5 shows the power curve with respect to the angular velocity through wind tunnel experiments. The experiments condition on the approaching wind speed were controlled from 6 m/s to 12 m/s with step as 3 m/s. In the case of 6m/s as wind speed, even though the generated power was not so sufficient, the generated the maximum aerodynamic power with approximately 123.80 Watt through Archimedes spiral wind blade can be observed at 19.44 as angular velocity. The rotational power was controlled using powder brake and the maximum aerodynamic power was observed at 24% as PWM (Pulse Width Modulation) control value.

In the case of 9m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 382.33 Watt at 26.43 as angular velocity. In this case, PWM control value had 45%. In the case of 12m/s as wind speed, the generated the maximum aerodynamic power seems to be approximately 915.94 Watt at 37.95 as angular velocity. In this case, PWM control value had 45%.

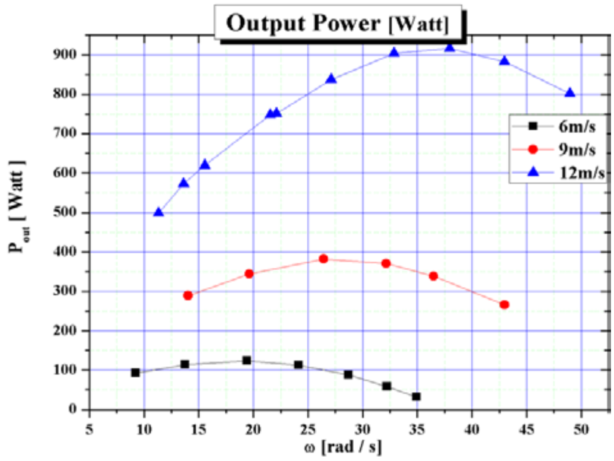

Figure 5 Aerodynamic Power as a function of the Angular Velocity [CKP Wind Solutions]

4 Conclusion

To investigate the aerodynamic characteristics on the 500 Watt class Archimedes spiral wind turbine, proto-type experimental model was employed through two types of wind tunnel. The aerodynamic characteristics on the small wind turbine with Archimedes spiral shape through an experimental studies can be summarized as follows;

(1) Through wind tunnel experiments on 2 types of wind tunnel, the higher output power as a function of rotational velocity than design specification was investigated successfully. And also power coefficient as a function of tip speed ratio with more than 85% of Betz limit can be observed successfully. From this sense, aerodynamic conversion performance through Archimedes spiral wind turbine model employed in this study from wind energy seems to have very higher efficiency between the small wind turbine models. The performance characteristics of the Archimedes spiral wind turbine employed in this study shows the similarity with Modern multiblade turbine. And the maximum power coefficient as a function

of the TSR shows the similar that of Ideal Efficiency of Propeller-type turbine.

(2) Through the experiments on the angle of attack change, the fundamental information for the automatic yawing system design may be provided. In the lower wind speed condition similar with local wind condition for urban such as between 3 ~ 6 m/s, the highest output power and power coefficient can be observed in the case of 0° wind condition than angle of attack change. From this sense, to provide the highest efficiency to the household user, the automatic yawing system for the Archimedes wind turbine with easily facing to the approaching wind direction seems to be most effective. In the lower wind condition similar with urban normal wind condition, the angle of attack can be relatively estimated an important parameter for the Archimedes spiral wind turbine employed in this study.

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