Experimental study on influence of wind characteristics on wind turbine performance

Yutaka Hasegawa¹, Yusuke Niwa², Hiroshi Imamura¹ and Eiji Asakura³

1. EcoTopia Science Institute, Nagoya University, Nagoya, Japan
2. Department of Micro-Nano Systems Engineering, Nagoya University, Nagoya, Japan
3. Department of Mechanical Science and Engineering, Nagoya University, Nagoya, Japan

Abstract: The present study aims at clarifying the influence of wind characteristics on the aerodynamic performance of Wind Turbine Generator System (WTGS) mainly by experimental procedures. The measurements of the incoming wind, the power output and acoustic noise from WTGS have been conducted for a micro WTGS with rated power of 400W installed on the roof top of the building. The wind speed over the building decreases with the horizontal distance from edge of the building and increases with the vertical distance from the roof top. Electric power generated by the WTGS is the largest when the WTGS is placed at a non-dimensional distance of 0.2, which is the ratio of the distance from edge of the building to the building’s height, because the wind blows upward near the edge of the building. Sound pressure level of acoustic noise emitted from the WTGS increase with the wind speed, and high frequency component of acoustic noise dominates over the broadband.

Keywords: Wind Energy, Wind Turbine, Wind Measurement, Turbulence, Acoustic Noise

1. INTRODUCTION

The installed capacity of Wind Turbine Generator System (WTGS) in Japan is much less than that in Europe. One of the reasons is the severe wind characteristic for WTGS observed in Japan, where the terrain is considerably complex, resulting in the high turbulence of the wind. In order to convince it and extend utilization of the wind power in Japan, it is necessary to develop an accurate prediction system of the local terrain effects on the WTGS. The present study aims at clarifying the influence of wind characteristics on the aerodynamic performance mainly by experimental procedures.

The measurements of the incoming wind, the power output and noise from WTGS have been conducted for a micro WTGS with rated power of 400W installed on the roof top of the building. For the wind measurements, several sets of a cup anemometer and a wind vane were placed near the WTGS. The acoustic noise measurements were conducted in accordance with the standard of IEC 61400-11[1].

The present paper describes the wind characteristics of the incoming wind such as the averaged velocity profile and the turbulent intensity, and evaluates their effects on the turbine performance by measuring the power output simultaneously. The effects of the wind characteristics on the turbine noise are also examined especially about the sound pressure level and the frequency properties.

2. MEASUREMENT PROCEDURE

The measurements have been conducted for a micro WTGS installed on the roof top of the building as shown in Fig. 1. The rotor diameter, rated output, rated rotating speed, cut-in wind speed and cut-out wind speed of the WTGS are 1170mm, 400W (at wind speed 12.5m/s), 1650rpm, 3m/s and 16.5m/s, respectively. The installed position of the WTGS was shifted along the line O-O’ in Fig. 2 (a), and each position is denoted as Gₙ corre-
sponding to the horizontal distance from the edge as defined in Fig. 2 (a). The hub height of the WTGS was also changed as 2.5m (Bottom), 3m (Middle) and 3.5m (Top) from the roof top as shown in Fig. 2 (b).

For the wind measurements, three sets of a cup anemometer and a wind vane were used. The one set was fixed at the point 2m distant from the west end of the building as a reference point, and the others were placed at both sides of the WTGS. The inflow velocity of the WTGS was defined as the mean value of the measured velocities obtained from the latter two anemometers. The electric power output by the WTGS and the signals from the anemometers were recorded by PC simultaneously with sampling frequency of 5Hz and averaged every one minute. For the analysis of inflow wind and power output, only the data whose 1 minute average of reference wind direction is within 270 ± 5 degree were adopted.

The acoustic noise measurements were conducted in accordance with the standard of IEC 61400-11. The WTGS was placed at the position G5 and the hub height was set 3m from the roof top. A microphone was placed at the reference point with the distance $R_0$, defined below, from the foot of the WTGS mast,

$$R_0 = h + d/2 = 3.0 + 1.2/2 = 3.6 \text{ m}$$

where $h$ is hub height and $d$ is rotor diameter. The microphone was set on the circular board of 1m diameter in order to decrease the influence of the surface characteristics as shown Fig. 3. The data whose 1 minute average of inflow wind direction is in 270 ± 15 degree were used for the analysis of acoustic noise.

3. NUMERICAL ANALYSIS

Numerical analysis of flow around the building was carried out by using non-linear 3-dimensional low-Reynolds $k-\epsilon$ model. Calculation area had the size of 200m in east-west direction, 200m in north-south direction and 40m in height, and total number of grid point was about 200 million. The boundary conditions were imposed as follows: the atmospheric boundary layer flow inflows from the west, and free outflow runs out from north, south, east and top surface. The exponential velocity distribution was used for the atmospheric boundary layer flow,

$$V(h) = V_r (h/H_r)^\alpha$$

where $V_r = 3\text{m/s}$, $H_r = 10\text{m}$, and $\alpha = 0.2$, respectively.

Figure 4 shows the velocity distribution in vertical plane including the point where the WTGS was placed. It can be found from the figure that the flow around the edge of the building blows upward and forms retarded region over the building.

4. RESULTS AND DISCUSSIONS

4.1. Characteristics of wind

Figure 5 shows the variation of velocity ratio of the inflow and the reference wind when the WTGS was moved from the west end to the east. The wind speed ratio decreases with the distance from the edge of the building. The velocity ratio is plotted against the distance from the building’s edge for three different hub heights in Fig. 6.

![Figure 3. Setting of microphone](image)

![Figure 4. Velocity distribution around building](image)

![Figure 5. Ratio of inflow to reference wind speed at hub height $h = 3\text{m}$ (Middle)](image)
The speed ratio decreases drastically with the distance when the hub height is \( h = 2.5 \text{m} \) (Bottom), while it remains almost constant for the hub height of Middle (3.0m) and Top (3.5m). These results qualitatively agree with those of numerical analysis.

Figure 7 shows the variation of turbulent intensity, which is the ratio of standard deviation to the one minute average for the inflow wind speed, when the WTGS was installed at the hub height of \( h = 3.0 \text{m} \). In the figure "Class TI" means bin average plus standard deviation, and "Class A" and "Class B" are the turbulent classes defined by IEC[2]. The turbulent intensity at the present site exceeds IEC classes and increases with distance from the edge of the building. The distributions of the turbulent intensity are plotted in Fig. 8 for the different hub heights, where values of turbulent intensity are normalized by the value measured at G2 with the hub height \( h = 2.5 \text{m} \). The turbulent intensity is largest when the hub height is 2.5m.

### 4.2. Performance of the WTGS

Figure 9 shows the variation of electric power generated by the WTGS against the inflow velocity, for three different positions in the horizontal direction. "Reference value" in the figure denotes the data of G3 when the hub height is 3m. The electric power increases with the horizontal distance from the upstream edge until the positions G3 or G4, and then decreases with the further distance. The spatial variation of power coefficient is plotted in Fig. 10, where the values of power coefficient are normalized by the value of G2 when the hub height is 2.5m. Electric power takes the largest value at the non-dimensional distance \( x/H = 0.2 \), which is the ratio of distance from the end of the building \( x \) to the building’s height \( H \). The reason why the electric power slightly decreases near the upstream edge of the building can be attributed to the direction of the wind blowing upward. The effect of the hub height on the electric power increases in the downstream direction.

### 4.3. Acoustic noise emitted from the WTGS

Figure 11 shows one minute average of the sound pressure level emitted from the WTGS in comparison with that of the background noise. The acoustic noise from the WTGS increases with the inflow wind speed mainly due to the increased rotational speed of the rotor. In order to examine the frequency property of the acoustic noise, 1/3 octave band spectrum is plotted in Fig. 12 when the 1 minute average wind speed is 6m/s. It can be

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*Figures and tables are not included in the text representation.*
seen from the figure that high frequency components dominate over the broadband.

5. CONCLUSION
- The wind speed above the building decreases with the horizontal distance from the edge of the building, and the wind blows upward near the edge of the building.
- The turbulent intensity above the building increases with the horizontal distance from the edge of the building, and decreases in the vertical direction from the surface of the roof top.
- The electric power generated by the WTGS is largest when the WTGS is installed at the horizontal distance of approximately 20% of the building’s height from the upstream edge of the building.
- The acoustic noise emitted from the WTGS increases with inflow wind speed, and the high frequency components dominate over the broadband.

REFERENCES