

# SITE SPECIFIC EVALUATION METHODS BY AERO-ELASTIC WIND TURBINE AND LES TIME VARIANT WIND MODELS

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Site specific evaluation is essential for wind farms as it affects to the economics of the wind farms such as energy production, costs of maintenance and repair, in addition to financing and insurances. Although, all of the wind conditions are available in the design standard or guidelines for the design of wind turbines, but those standard conditions are not applicable to the individual site validation directly. Local area CFD is commonly used for that in particular in complex terrain. In particular, LES (Large Eddy Simulation) is a useful tool to reproduce the characteristics of the wind in complex terrains. Considering the situations above, a wind model converter “LES2wnd”, which directly converts the time history of three dimensional wind speed data from LES into input of aero-elastic codes, was developed for site specific evaluation of wind turbines. Through the case study, the commercial LES code RIAM-COMPACT was shown to express complex wind characteristics in the complex terrain in low frequency components as spatial variations of wind shear in particular long term variation, which affect the load fluctuations in rotor speed and blade passing frequencies. However, there still be large disagreement in high frequency components.

**Keywords:** wind turbine, multi-rotor system, coherence, load

## BACKGROUND

Site specific evaluation is essential for wind farms as it affects to the economics of the wind farms such as energy production, costs of maintenance and repair, in addition to financing and insurances. Detailed wind conditions, such as average, spectrum, and coherence, average wind shear and so on, are necessary for the evaluation. Although, all of the wind conditions are available in the design standard or guidelines for the design of wind turbines, but those standard conditions are not applicable to the individual site validation directly. They are defined by combining measurements and numerical analysis in most cases, as spatial distributions are necessary for the evaluation. Local area CFD is commonly used for that in particular in complex terrain. In particular, LES (Large Eddy Simulation) is a useful tool to reproduce the characteristics of the wind in complex terrains.

Considering the situations above, a wind model converter “LES2wnd”, which directly converts the time history of three dimensional wind speed from LES into input or aero-elastic codes, was developed for site specific evaluation of wind turbines.

## OUTLINE OF THE EVALUATION PROCEDURE

- (1) Wind Simulation: 3D time variant wind speed distributions are calculated by LES.
- (2) Wind Model Definition: The wind calculated in (1) will be converted to be applicable to aero-elastic codes by LES2wnd.
- (3) Aero-elastic Simulation: It is used for the load calculation. The wind model defined in the previous section is used here.

- (4) Evaluation: The calculated loads are evaluated by the design loads. The latter is assumed by the calculation in the design wind conditions. In cases the load in the site exceeded the design loads, structural analysis need to be done.

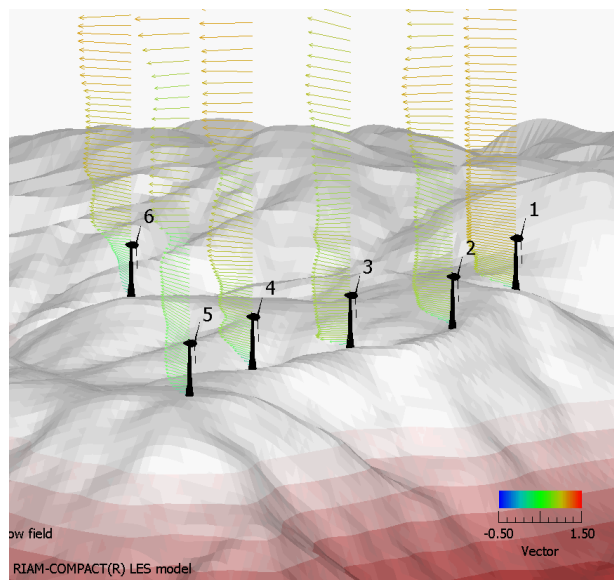


Figure 1 Case Study Site Overview (WSW Wind)

## CASE STUDY OUTLINES

### Analysis Method

A commercial LES code RIAM-COMPACT[1] and an

aero-elastic code Bladed[2] were used in the case study.

### Site

The site assumed in this case study is Taikoyama in Kyoto Prefecture. Overview of the site is shown in Figure 1. The #3 turbine was analyzed in this study.

### Wind Turbine

Outlines of the wind turbine model are shown in Figure 2, Table 1, and Table 2, which were defined based on reference [3]. The wind turbine controller, which consist with variable speed pitch and generator torque, are defined based on reference [4].

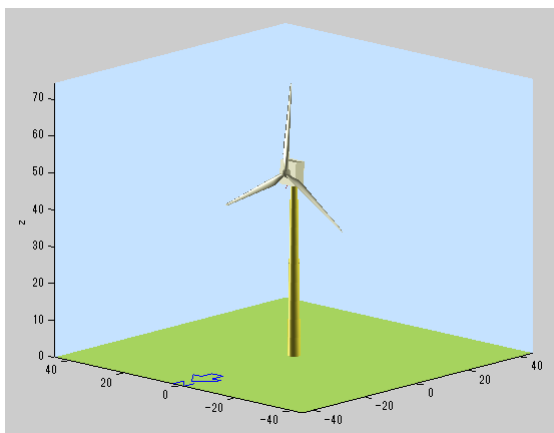


Figure 2 Wind Turbine Model Outline

Table 2 Structural Properties of the Turbine

<b>Mass</b>		
Bottom Tower		t
Middle Tower		t
Top Tower		t
Nacelle	10.0	t
Generator	29.4	t
Hub	13.0	t
Blade	1.9	t
Total	54.3	t
<b>Vibration</b>		
Rotor Overhang	3.1	m
Tower 1st Mode Damping	0.5	%
Tower 1st Mode Freq(Long.)	0.532	Hz
Tower 1st Mode Freq(Lat.)	0.542	Hz

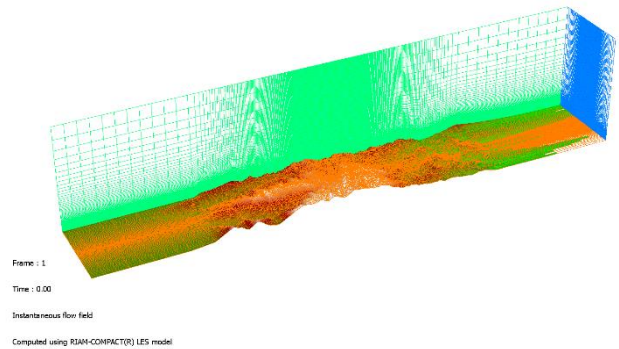


Figure 3 CFD Mesh

Table 1 General Specifications of the Turbine

<b>General</b>		
Model	LW750	
Rated Power	750	kW
<b>Rotor</b>		
Rotor Diameter	50.5	m
Hub Height	50	
Blade Length	23.35	m
Hub Diameter	1.9	m
<b>Nacelle</b>		
Width	5.6	m
Length	3.3	m
Height	6.5	m
<b>Tower</b>		
Wall Thickness	10~25	mm
Tower Height	46	m
Bottom Diameter	3.5	m
Top Diameter	2.0	m
<b>Control</b>		
Cut-in Wind Speed	3	m/s
Rated Wind Speed	13	m/s
Cut-out Wind Speed	25	m/s
Speed Control	Variable Pitch	
Rotor Speed	13~33	min-1
Rated Speed	27	min-1

Table 3 CDF Mesh Parameters

➤ Wind Direction	: WSW
➤ Domain X (Longitudinal)	: 9km
➤ Domain Y(Lateral)	: 2.4km
➤ Domain Z(Vertical)	: 3.267km
➤ Max Altitude	: 681
➤ Min Altitude	: 13m
➤ Altitude Deviation	: 668m
➤ Number of Mesh in X	: 451
➤ Number of Mesh in Y	: 121
➤ Number of Mesh in Z	: 101
➤ Min Mesh Width in X	: 7.522m
➤ Min Mesh Width in Y	: 9.587m
➤ Min Mesh Width in Z	: 2.003m
➤ Max Mesh Width in X	: 340.537m
➤ Max Mesh Width in Y	: 79.052m
➤ Max Mesh Width in Z	: 400.523m

### Simulation Conditions

The wind assumed here was WSW wind at 8.1 m/s of average wind speed. The nacelle direction is also WSW. Simulation was conducted for 10 min each 0.2 s. CFD mesh for the SWS wind and its parameters are shown in Figure 3 and Table 3.

Four different wind models were assumed for the aero-elastic simulation. The first one was calculated by the LES and converted by LES2wnd. And the remaining three are defined by Kaimal spectrum with each turbulent seed.

## CASE STUDY RESULTS

### Wind Simulation

Vertical distributions of average and standard deviation (SD) of wind speed are shown in Figure 4 and Figure 5. Wind shears were ignored here. The straight lines indicate those in the design standards or guidelines. Very steep wind shear and local distributions of the standard deviation are not expressed by the standard wind models. And turbulences are also not uniform as the standards or guidelines.

Figure 6 shows the PSD at representative positions around the rotor. As compared with IEC Kaimal model, power spectral density (PSD) is lower in high frequency range. This must be improved by the future research.

### Aero-elastic Simulation

Figure 7 shows the wind speed and yaw angle at rotor center. LES does not express high frequency elements as indicated by PSD in Figure 6. Figure 8 shows the rotor speed and power output in the first 60 s. There are no remarkable differences between the wind models.

Figure 9 and shows tower top nodding ( $M_{YK}$ ) and fore-aft shear force ( $F_{XK}$ ). 0.45 Hz and 1.3 Hz components are correspondent with rotor speed (1P) and blade passing (3P) frequencies. The remarkably higher 3P components are shown by LES. Unusual wind speed like this can be expressed by applying LES for the wind simulation.

Figure 10 shows the tower base side-side ( $M_{XT}$ ) and fore-aft ( $M_{YT}$ ) bending moments. General trends are same as the previous figure.

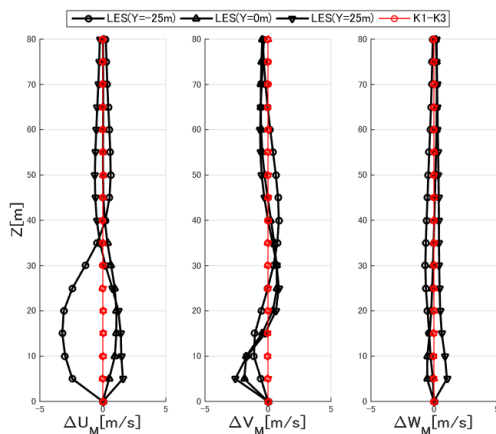


Figure 4 Vertical Distributions of Average Wind Speed

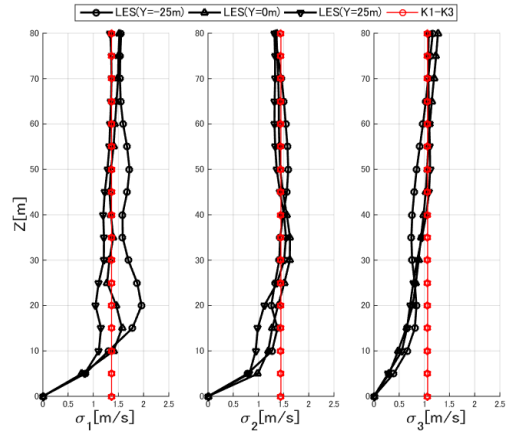


Figure 5 Vertical Distribution of Wind Speed SD

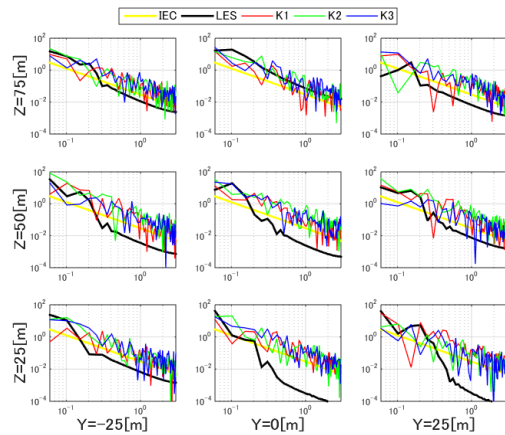


Figure 6 PSD of Longitudinal Wind Speed

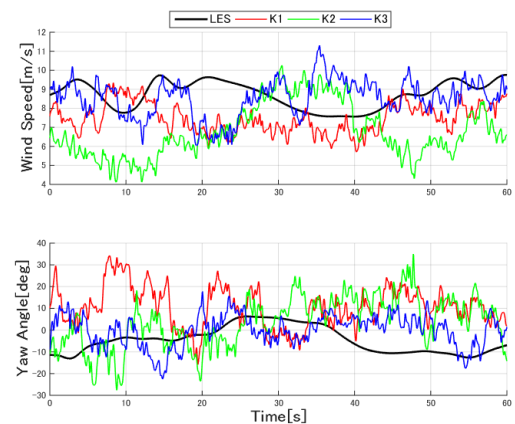


Figure 7 Wind Speed and Yaw Angle at Rotor Center

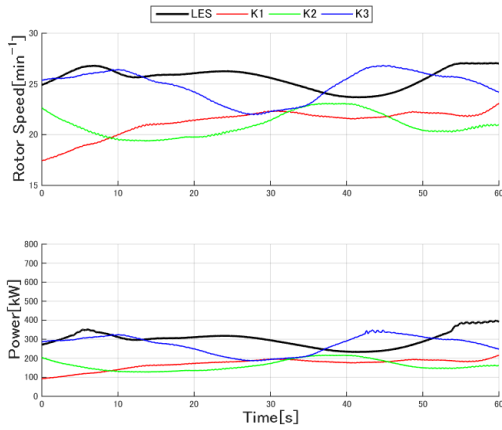


Figure 8 Rotor Speed and Power

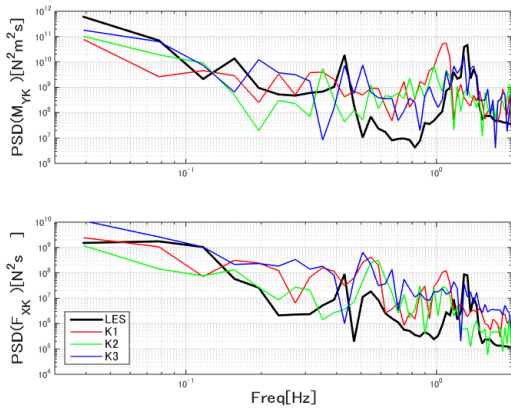


Figure 9 PSD of Tower Top Nodding and Fore-aft Shear Force

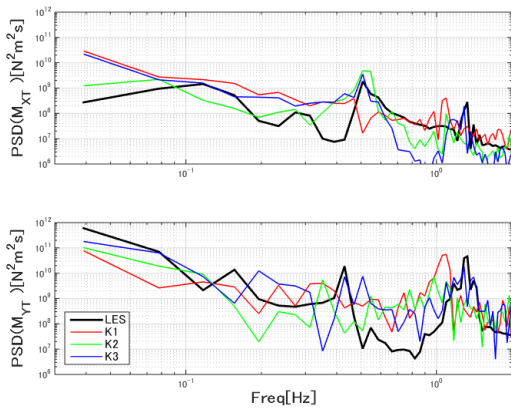


Figure 10 PSD of Tower Base Side-side and Fore-aft Bending

## CONCLUSIONS

The site specific evaluation method was proposed combining LES and aero-elastic simulation, combined by wind converter “LES2wnd” which developed here.

A case study was carried for the #3 wind turbine in Taikoyama wind farm of Kyoto Prefecture, a typical complex wind farm in a complex terrain, at 8.1m/s of average wind speed from WNW, using RIAM-COMPACT and Bladed. The LES results were compared with three Kaimal models. The result shows The LES was shown to express complex wind characteristics in the complex terrain such as spatial variations of wind shear in particular long term variation. It affects to the load fluctuations in rotor speed and blade passing frequency.

However, the present LES does not provide appropriate characteristics in high frequency components. Finer mesh and/or some model to express them will be studied in succession.

## FINAL NOTES

### Acknowledgements

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### References

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