EWEA 2013 - RESOURCE ASSESSMENT PART 1

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2013 /2 /5

# APPLICATION OF CFD FOR TURBULENCE RELATED OPERATIONAL RISKS ASSESSMENT OF WIND TURBINES IN COMPLEX TERRAIN

## PRESENTATION SPEECH

### Slide 1 - Cover

- In Japan, about 70% of the land is covered by mountains and hills. A very high percentage can be classified as extremely complex. Needless to say, with such terrain, the wind conditions can be extremely turbulent - a significant risk and challenge for the industry.

- After the Fukushima nuclear accident, wind energy, part of the renewable energy mix, has taken on a renewed and important role. So, it is vital to understand the turbulence risk associated with siting turbines in these extremely complex terrain environments.

- Today I will be talking about the application of CFD in assessing such risk for an existing wind farm.

### Slide 2 - Contributors

- I would just very breifly mention the contributors of this work. Firstly there is myself from Tsubasa Windfarm Design, a company I found July last year, specializing in designing wind farms in complex terrain.

- This work was started about two years ago when I was working with Eurus Energy, the leading developer in Japan. Later, I was joined by Susumu Takakuwa and together we carried out the investigation. He is sitting somewhere in the audience.

- Finally, Dr Takanori Uchida from Kyushu University, who developed the CFD codes

RIAM-COMPACT that we used for this work, he has kindly provided us guidance on the CFD modelling.

Slide 3 - Case

- Now I will jump to straight to the case. Here is a graph showing the total number of yaw-related failures seven years since the start of the operation. As you can see, turbine T7 stood out from the rest, recording a total number of 32 failures.

Slide 4 - Damage

- Here I show photos of typical damages. On the left is an engineering drawing of the yaw system, and on the right are photos of a broken shaft and cracks in the gear and motor section.

- It is pretty obvious that the damage was caused by some very large, abnormal loads acting on the system. Loads that exceed the design limit.

Slide 5 - Windfarm

- And here is the windfarm, it is called Kihoku Windfarm located in Kagoshima Prefecture, Kyushu, Japan. Developed and operated by Eurus Energy, consisting of 16 Siemens SWT1.3 (or formally Bonus 1.3MW).

- Each of them has a hub height of 60m and a rotor diameter of 62m. IEC Class A. The wind farm has been operating since February 2004. And in the middle of the photo, there is T7.

Slide 6 - Approach

- Now here is the approach. I started off making the hypothesis that the cause is related to turbulent wind conditions. To verify my hypothesis, we make full use of the SCADA data collected from all 16 turbines.

- We looked at many different SCADA data variables in particularly yaw related ones, including yaw status, yaw related errors, etc, trying to see if there is a relationship between these variables and damage frequencies of the turbines.

- But we found the key variable to be the Turbulence Intensity. I will tell you why I said that in the next slide. And from the turbulence intensity, we identified the wind direction that we think likely to be the problem.

- Finally for the identified wind direction, we carried out CFD to reproduce the flow pattern. This is the basic approach. Now I will show you the key results.

<u>Slide 7 - TIraw minus TIiec</u>

- This graph you are seeing here shows, for each of the 16 turbines, the total number of data points which exceeds IEC Class A standard. Plotted against wind speed bins. 7 years of data is used. The number on the top right of each graph, that is the failure frequency.

- As you can see, T7 has registered a particularly high count from 5 to 10 m/s when compare with other turbines. And a good proportion of these points has high exceedance level as shown by the presence of the yellow and blue colour band. Yellow band has TI exceedance of 0.15 to 0.20 and 0.20 to 0.25 for blue band.

- This high exceedance level is not prominent in the other turbines. So, it seems there is a correlation between high turbulence level and yaw damage frequencies.

<u>Slide 8 - T7 - Rose</u>

- To give you an idea of the wind direction, here is a slide showing the annual wind rose. The dominant wind direction is North-West and the secondary direction is South-East.

<u>Slide 9 - T7 - TI</u>

- Now I go on to finding the problematic wind direction. For T7, we plot the TI vs wind speed in 10 degree wind direction sectors. So here we have 36 graphs with the wind direction label on top of each graphs. The yellow line is the measured characteristic TI and the red line is IEC class A line.

- You can see for the South-East (120-150 degrees) the yellow line falls below the red line. In sharp contrast to that, in the West to North-West sector, the yellow lines are above red line, in particularly in the 240 to 260 sector. The yellow line started falling as the direction shifts towards North-West or 320 degrees. So it is clear that the turbulent wind are concentrated in the West to North-West sector.

Slide 10 - T7 - Topography - TI

- To examine that more closely, I have extracted the 260 to 310 degree plots from the last slide, and plotted them alongside with the elevation cross section profile and the TI count exceeding IEC.

- And on the far left is a elevation map showing the turbines along the ridge with T7 in the middle. You will notice straight away, immediately to the west of T7 there is another ridge with many mini-ridges branching out from that. These mini ridges are creating the undulating terrain in the direction 290 to 300 from T7. This is a unique terrain feature for T7 only. So, from examining the terrain closely, we suspect the 290 to 300 is the problematic direction.

- Although the TI level for 260 to 280 is showing the largest departure from the IEC standard. The data count of TI exceeding IEC above 10m/s is a lot less when compared to the 290 to 300. This is the another key reason why we believe 290 to 300 degree sector is likely to be the problem.

Slide 11 - Topography

- Here is a photo showing the terrain west of T7, the undulating terrain close to T7 I just mentioned is clearly visible in this photo. You can also see the site is heavily forested.

Slide 12 - CFD - Model

- Here is a figure of the CFD model, here you can see the ridge extending out from T7 very clearly. Details of the model are given on the left.

- The software name is RIAM-COMPACT and the turbulence model is Large-Eddy-Simulation (LES).

- The calculation area covered the whole of the site with T7 in the middle. Mesh concentration is applied along the wind direction, so in the outer area we have 50m and as it gets close to the site, the mesh is gradually reduced to 10m. The total number of grid points is roughly around 15 million.

- Inflow wind direction is set at 290. And for the boundary conditions, a uniform flow wind speed at 7m/s and shear exponent 0.14. Finally atmospheric stability is set at neutral.

<u>Slide 13 - CFD Vector</u>

- To visualise the CFD results, I have created some animations. First I will show you the vector plot. On the left it is a vector animation on a vertical plane, and on the right a horizontal plane, cutting across the middle of the rotor.

- Strength of the wind speed is represented by the colour. Going from highest to lowest, red-orange-green and blue. Due to the presence of the undulating terrain, flow separation occurred in the upstream; regions of reverse flow can also be seen, the swirling flow or the turbulent vortex is flowing into the rotor face.

- On the horizontal plane you can see from the movement of the arrows the wind direction is fluctuating. The three dimensional nature of the turbulence T7 is seeing is quite obvious from the animation.

<u>Slide 14 - Shading</u>

- To visualise the wind speed variation across the rotor face a bit better, here we switch to shading mode.

- As you can see, the colour is changing a lot across the rotor face of T7 both vertically and horizontally, meaning the wind speed is fluctuating. In contrast with T7, the neighboring turbine T5 shows very little fluctuation.

- The difference of the wind condition between the two turbines basically explains why for the 7 years of its operational life, T5 has only recorded three yaw failures, compare with 32 recorded at T7.

Slide 15 - Time Series

- The horizontal wind speed component from the animations are extracted and plotted here for four different rotor positions. The top graph shows the rotor top and bottom.

- And the bottom graph, left and right. During the course of roughly 10 minutes simulation time, wind speed is fluctuating greatly. In particular at the rotor bottom, and the lines for left and right at times crossing each other.

Slide 16 - Time Series

- If we take the difference of the wind speed in the previous graphs, we obtain the graphs here. The wind speed difference ranges from near zero to 8 m/s for top-bottom and for left-right fluctuating between -4m/s to 6m/s.

- I should compare these time-series against the IEC extreme wind shear design load case, I have not done it yet but I am pretty sure the turbulent wind condition is in excess of the IEC design load case.

Slide 17 - Summary

- So to sum up, what we did is to make full use of the SCADA data. We analysed the TI data and identified the wind direction where high frequency of high TI data was recorded at or above medium wind speed. We identified that to be around 290 to 300 degrees.

- We ran LES-based CFD for this direction and found highly fluctuating wind speed difference across the rotor face. And these fluctuating wind speed differences translated to fluctuating loads, causing excessive stress to the yaw system and eventually led to the numerous yaw failures.

Slide 18 - Implications - Future

- Now I am coming to the last slide. I just like to make three points. Firstly, the same approach (SCADA + LES based CFD) has been applied to other existing wind farms with satisfactory results. The approach is not innovative but simple and logical.

- The second point is that the temporal and spatial wind speed distribution is extremely important when we comes to assess the turbulence risk. So, if we have turbines locate at critical positions, we should use the simulation result as inputs for calculating the loads to see if it exceeds the design load.

- This brings me to the last point. CFD simulation, in particularly LES based CFD, has the potential for assessing the operational risk associated with turbulent wind conditions for not just the existing operational wind farms but also for new wind farms under planning.

**QUESTIONS from the Audience**

(1) The turbulence intensity data are derived from the nacelle anemometer ?

Yes. They are from the nacelle anemometers. Come straight out from the SCADA. I understand there is high uncertainty with the nacelle data due to the rotor interaction. However, it still gives you an idea of the turbulence level. Here the study is not a quantitative study it is more of a qualitative study. So using the SCADA is useful. You can compare the level between turbines, and between direction sectors of the same turbine.

(2) Did you implement any operational strategy like wind sector management to minimize damages ?

No, we did not implement wind sector management. But we did install torque limiter to the yaw system, a device to prevent excessive load transfer. Also we keep a good stock of the yaw spare parts to minimize downtime.

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