WIND FARM PRODUCTION ASSESSMENT IN COMPLEX TERRAIN: NEW VALIDATIONS OF METEODYN WT

Tristan Clarenc[1], Nicolas Girard[2], Didier Delaunay[1], Aurélien Chantelot[1]

[1] METEODYN, 75, bd Alexandre Oyon, 72100 Le Mans, France, tel. +33 (0) 243 862 124
[2] MAIA EOLIS, Tour de Lille, bd de Turin, 59777 Lille, France, tel. +33 (0) 320 214 214

ABSTRACT

Meteodyn WT is a new generation software package including a full Navier Stokes equations solver, as well as an automatic boundary-fitted mesher. Boundary conditions are also automatically generated. It allows non expert users to access to CFD methods, which are particularly suited for computing the flow over complex terrains.
This paper presents some new validation cases for the software: three sites in the North-East of France are studied. Meteodyn WT results are compared with measured data, both in term of wind speed-up factors and production.

1. INTRODUCTION

Atmospheric stability plays an important role in a wind farm production assessment. Indeed, the neutral case may often be not representative of the measurement period.
Moreover, this effect has to be taken into account when simulations are carried out on short periods (for instance one day), what is interesting from an exploitation point of view.
Meteodyn WT, thanks to its one-equation turbulence closure scheme, directly includes those effects during the computations.

The theoretical basis of the models implemented in the software is presented.
Then, experimental and numerical results for three French sites are presented (figure 1).

Figure 1: location of the three test sites in France

2. THE MODELLING APPROACH

The principle of the CFD approach is to solve the full Reynolds-Averaged Navier-Stokes equations, which allows to compute detached and recirculating flows that occur over complex terrains. By integrating the more recent numerical techniques, and particularly a coupled multi-grid solver [1], meteodyn WT solves these equations in a very efficient way. Moreover the automatic mesh refinement strategy allows performing "typical windfarm size domain" computation without inherent problems of nesting techniques. The drag effect of forests on the flow is directly computed trough an additional drag term inside the equation of motion.

The turbulence closure scheme, based on Yamada and Aritt works [2], is realized by the prognostic equation on the turbulent kinetic energy, *k,* and a mixing length approach for the diffusivity calculated from atmospheric conditions.

The turbulence kinetic energy is then given by:

$$U_j \frac{\partial k}{\partial x_j} = P_k - \varepsilon + \frac{\partial}{\partial x_j}\left[\left(\frac{\nu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]$$

Where:

$$P_k = \nu_T\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_j}{\partial x_j}$$

$$\nu_T = k^{1/2} L_T$$

The dissipation is given by:

$$\varepsilon = C_\mu \frac{\nu_T}{L_T^{\;2}} k$$

The length scales of turbulence LT, as well as the Cμ coefficient, are depending on atmospheric stability through the Richardson Flux number *Rif* as follow:

$$L_T = \sqrt{2} S_m^{\;3/2} l$$

$$\begin{cases} \dfrac{1}{l} = \left(\dfrac{1}{l_0} + \dfrac{1}{\kappa z}\right), \; where\ z = height \\ S_m = \begin{cases} 1{,}96\dfrac{(0{,}1912 - R_{if})(0{,}2341 - R_{if})}{(1 - R_{if})(0{,}2231 - R_{if})}, \; si\ R_{if} < 0{,}16 \\ 0{,}085, \; si\ R_{if} \geq 0{,}16 \end{cases} \end{cases}$$

$$C_\mu = \frac{4 S_m}{B_1}$$

Meteodyn provides 10 stability classes (i.e. ten Richardson Flux number), for running computations. It allows the user to finely reproduce the measured wind profiles according to the measurement periods.

2. TEST SITE: RILLY SAINT SYRE

The site as been equipped with a 80 meters mast, on which data have been collected at 3 heights (10, 40, and 80 meters) during 5 months, between November 2006 and March 2007.
All the data have been filtered to exclude suspected iced periods.
The main wind sector (240 degrees) has been selected in order to compare the numerical results with the measured data.
As a result, a total of 3006 data (10 minutes average) was available.

Computation were performed on a 6 km radius around the met mast location, with a minimal resolution of the cell of 25m horizontally and 4m vertically, which represents a mesh of 202 160 points.
The collected data have been partitioned according the following criterions:

Ri <-0.15	Class 0
Ri >= - 0.15 & Ri < - 0.02	Class 1
Ri >= - 0.02 & Ri < 0.01	Class 2
Ri >= 0.01 & Ri < 0.04	Class 3
Ri >= 0.04 & Ri < 0.07	Class 4
Ri >= 0.07 & Ri < 0.15	Class 5
Ri >= 0.15	Class 6

Where Ri is the Richardson Number, expressing the ratio between the turbulence created by buoyancy forces (thermal) and by wind shear (mechanical). It is calculated from the measurements as follow:

$$Ri = \frac{g}{T_1} \cdot \frac{\dfrac{T_{80} - T_1}{79} + 0.0065}{\dfrac{V_{80} - V_{40}}{40}}$$

With:

T80 : measured temperature at 80 meters (K)
T1 : measured temperature at 1 meter (K)
V80 : measured velocity at 80 meters (m/s)
V40 : measured velocity at 40 meters (m/s)

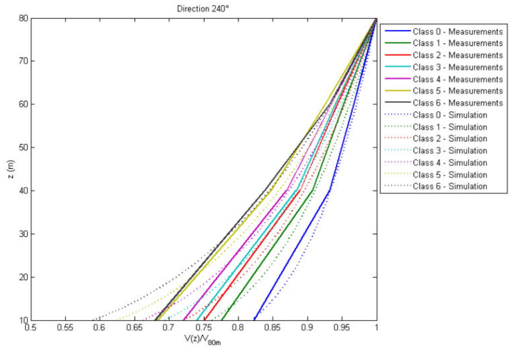

Figure 2: Measured and computed wind profiles on the 80 meters met mast

Six different stability classes have been used in meteodyn WT to reproduce the measured wind profiles, varying from very unstable (class 0) to very stable (class 6).

As we can see on the figure 2, the computed wind profiles are well reproducing the measured ones.

3. TEST SITE: HAUTEVESNES

The site as been equipped with a 80 meters mast, on which data have been collected at 3 heights (10, 40, and 80 meters) during 6 moonths, between October 2006 and March 2007.
All the data have been filtered to exclude suspected iced periods.
The main wind sector (220 degrees) has been selected in order to compare the numerical results with the measured data.
As a result, a total of 3853 data (10 minutes average) was available.

Computation were performed on an 8 km radius around the met mast location, with a minimal resolution of the cell of 25 m horizontally and 4 m vertically, which represents a mesh of 1 134 000 points.

The CPU time needed for the complete computing of the flow for each stability class (including mesh generation and result interpolations) was about 34 minutes.

The collected data have been partitioned in the same way as those of the Rilly Saint Syre site (refer to section 2).

Six different stability classes have been used in meteodyn WT to reproduce the measured wind profiles, varying from very unstable (class 0) to very stable (class 6).

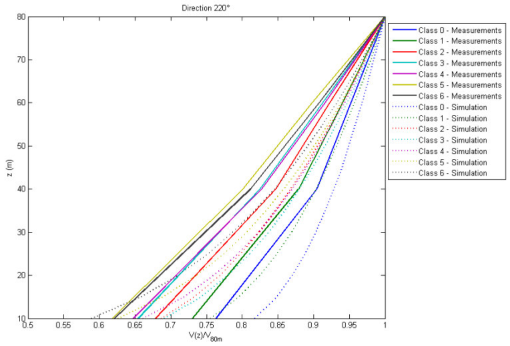

Figure 3: Measured and computed wind profiles on the 80 meters met mast

For this second test site, we can see on figure 3 that the computed profiles are not directly well matching the measured ones.
This may come from the forested area located around 350 meters upwind from the met mast. Further investigations need to be done in order to check if the used roughness is in accordance with the tree's height (and, if necessary, to tune the effective drag coefficient which is applied in the computation cells lying in the forest).
Eventually, we can note that, thanks to the number of stability classes available in the software, it even though remains possible to well reproduce the mean measured profile, as well as the short term measured ones.

3. TEST SITE: REFFROY

The Reffroy site consists of 12 operating 80 m hub height Repower MM82.

Figure 3: Location of the wind turbines

The results of simulation are compared with the actual 2006 production, which was corrected to take into account the losses due to stopping of the turbines (maintenance, failure…).

The wind time series from a 40m height on-site met mast were used as input data.

The results are also presented with wake correction computed by the software.
As the met mast is lying in wind turbines wake, the first step consists in correcting the measured wind time series. This is done in meteodyn WT thanks to semi analytical G.C. Larsen wake model (first order approach) [3].
Once the input time series have been corrected, the wake effects on the wind turbines are evaluated by the software thanks to the well-known N.O. Jensen model [4].

For both models, we can note that, instead of using a turbulence intensity estimated form the surrounding roughnesses, meteodyn WT directly uses the computed one.

The results are presented on figure 4. In both cases the error is lower than 10 %.

Further investigations need to be done in order to check the production on shorter periods (monthly and daily). The atmospheric stability effects will have to be studied.

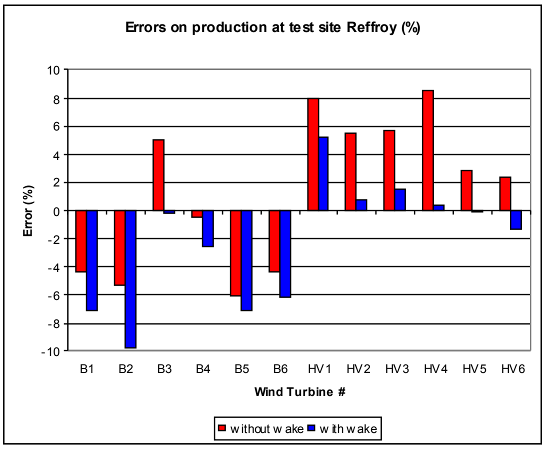

Figure 4: Validation of productions simulations

CONCLUSION

Further investigation will be carried out to validate more precisely the profiles. In particular the role of the roughness length should be checked and other directional sectors should be studied.
In addition a well instrumented 80 m metmast (sonic anemometers, pyranometers, temperature probes) will be erected on the site of Reffroy next summer.

This method will enable us to determine the influence of the atmospheric stability on the production of the turbines, making of meteodyn WT an interesting tool to check the production of operating wind parks.

REFERENCES

1. M. Ferry. *New features of the MIGAL solver*; Proc. Of the Phoenics Users Int. Conf., Moscow, sept 2002.

2. P. J. Hurley. *An evaluation of several turbulence schemes for the prediction of mean and turbulent fields in complex terrain*; Boundary-layer Meteorology, 83: 43-73, 1997.

3. G.C. Larsen, J. Højstrup, H.A. Madsen. *Wind Fields in Wakes*; EUWEC '96, Gothenburg, 1996.

4. I. Katic, Højstrup, N.O. Jensen. *A Simple Model for Cluster Effeciency*; European Wind Energy Association Conference and Exhibition, 7-0 October 1986, Rome, Italy.