Energies **2011**, *4*, 458-474; doi:10.3390/en4030458

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Latest Developments in Numerical Wind Synopsis Prediction Using the RIAM-COMPACT® CFD Model—Design Wind Speed Evaluation and Wind Risk (Terrain-Induced Turbulence) Diagnostics in Japan

Takanori Uchida * and Yuji Ohya

Research Institute for Applied Mechanics (RIAM), Kyushu University, 6-1 Kasuga-koen, Kasuga-City, Fukuoka, 816-8580, Japan; E-Mail: ohya@riam.kyushu-u.ac.jp

* Author to whom correspondence should be addressed; E-Mail: takanori@riam.kyushu-u.ac.jp; Tel.: +81-92-583-7776; Fax: +81-92-583-7779.

Received: 17 December 2010; in revised form: 17 February 2011 / Accepted: 4 March 2011 / Published: 7 March 2011

Abstract: Because a significant portion of the topography in Japan is characterized by steep, complex terrain, which results in a complex spatial distribution of wind speed, great care is necessary for selecting a site for the construction of Wind Turbine Generators (WTGs). We have developed a CFD model for unsteady flow called Research Institute for Applied Mechanics, Kyushu University, COMputational Prediction of Airflow over Complex Terrain (RIAM-COMPACT®). The RIAM-COMPACT® CFD model is based on Large-Eddy Simulation (LES) technique. The computational domain of RIAM-COMPACT® can extend from several meters to several kilometers, and RIAM-COMPACT® can predict airflow and gas diffusion over complex terrains with high accuracy. First, the present paper proposes a technique for evaluating the deployment location of WTGs. Next, wind simulation of an actual wind farm was executed using the high resolution elevation data. As a result, an appropriate point and an inappropriate point for locating WTGs were shown based on the numerical results obtained. This cause was found to be a topographical irregularity in front of WTGs.

Keywords: CFD; LES; design wind speed; micro-siting; wind risk diagnostics

---

1. Introduction

The wind energy industry has been growing at an unprecedented rate across the World. The reason for this growth is the fact that the cost-effectiveness of wind energy in terms of fossil fuel elimination and CO_2 reduction is the highest of all the reusable energy sources. Wind energy without a doubt has also become the leading reusable energy source in Japan, and it is our belief that further utilization of wind energy will contribute globally to the "green innovation" which attempts to combat global warming [1,2].

One of the technical issues which needs to be resolved in the wind energy field is how to establish a numerical wind synopsis prediction technique that can accurately take into account the local wind conditions relevant for wind turbine generators (hereafter WTGs) and is able to evaluate the wind synopsis of a potential WTG deployment site with much higher accuracy than the existing techniques. Another significant issue is that quantitative characteristics of airflow within the wake of WTGs need to be well understood (existing wake models need to be improved). This second issue is important because it addresses: wind risks (terrain-induced turbulence) on WTGs; WTG noise propagation concerns, which have become a societal problem; and effective deployment of multiple WTGs [3,4].

The wind synopsis technique Research Institute for Applied Mechanics, Kyushu University, COMputational Prediction of Airflow over Complex Terrain (RIAM-COMPACT®) that has been developed by our research group has the potential to resolve the above-mentioned issues [5]. The core technology of RIAM-COMPACT® was originally developed and continues to be developed at the Kyushu University Research Institute for Applied Mechanics (RIAM). An exclusive license of the core technology has been granted by Kyushu TLO Co., Ltd. to RIAM-COMPACT Co., Ltd. (Please refer to following URL: http://www.riam-compact.com/), an IT venture corporation that was founded by the authors and other individuals and that originated at Kyushu University in 2006 (a trademark, RIAM-COMPACT®, and a utility model patent were granted in 2006). In the meantime, a development consortium has been formed for the RIAM-COMPACT® Natural Terrain Version software. The development consortium consists of RIAM-COMPACT Co., Ltd., West Japan Engineering Consultants, Inc. (a member of the Kyushu Electric Group), Environmental GIS Laboratory Co., Ltd., and FS Consulting Co., Ltd. The consortium has been working together to promote the software as an industry-wide standard. The RIAM-COMPACT® software has been used by a large number of corporations and institutions including J-POWER/Electric Power Development, Co., Ltd., Japan Wind Development Co., Ltd., and Eurus Energy Japan Corporation, which has the largest share of the wind power generation industry in Japan.

In this paper: (1) evaluation of the design wind speeds for WTGs and (2) an example of the wind risk (terrain-induced turbulence) diagnostics, both with the use of the RIAM-COMPACT® Natural Terrain Version software, will be discussed.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

[redacted]

3. Wind Risk (Terrain Induced Turbulence) Diagnostics

Recently, it has been reported that the utilization rates of WTGs on wind farms situated on complex terrain fall short of expectations; that is, reports of damage and breakage of the exteriors and interiors of WTGs as well as WTGs with notably low power output have surfaced. Terrain-induced turbulence is considered as the major cause of these issues [12]. The source of terrain-induced turbulence is small variations in the topographical relief in the vicinity of WTGs at which turbulence is mechanically generated. In this section, an example of wind risk (terrain-induced turbulence) diagnostics is presented.

3.1. Overview of the Wind Farm

In cooperation with the Kumamoto Prefectural Enterprise Bureau, a wind synopsis analysis is performed for the Asokurumagaeri wind farm (operation of this wind farm was initiated in October, 2005). A summary of the wind farm is shown in Table 4.

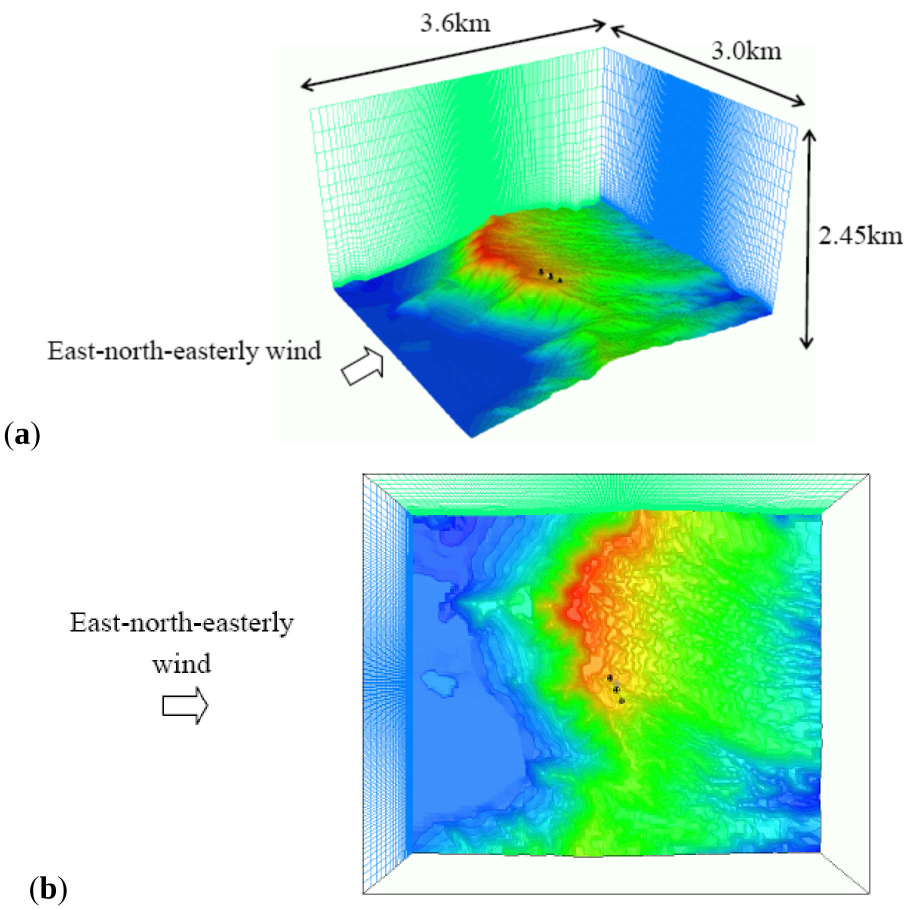
Table 4. Summary of the Asokurumagaeri wind farm.

	WTG No. 1	WTG No. 2	WTG No. 3
Maximum output	**600 kW**		**300 kW**
Annual power production	2,707,782 kWh (Equivalent to the annual power consumption of approximately 700 households)		
Wind turbine height (Ground to the blade tip)	59.05 m		44.55 m
Blade diameter	47 m		29 m

3.2. Simulation Set-Up

The dimensions of the computational domain (Figure 7) are 3.6 (x) × 3.0 (y) × 2.45 (z) km, and the number of grid points is 241 × 201 × 41 points (approximately two million points).

Figure 7. Computational domain. (**a**) Bird's-eye-view; (**b**) Top view.



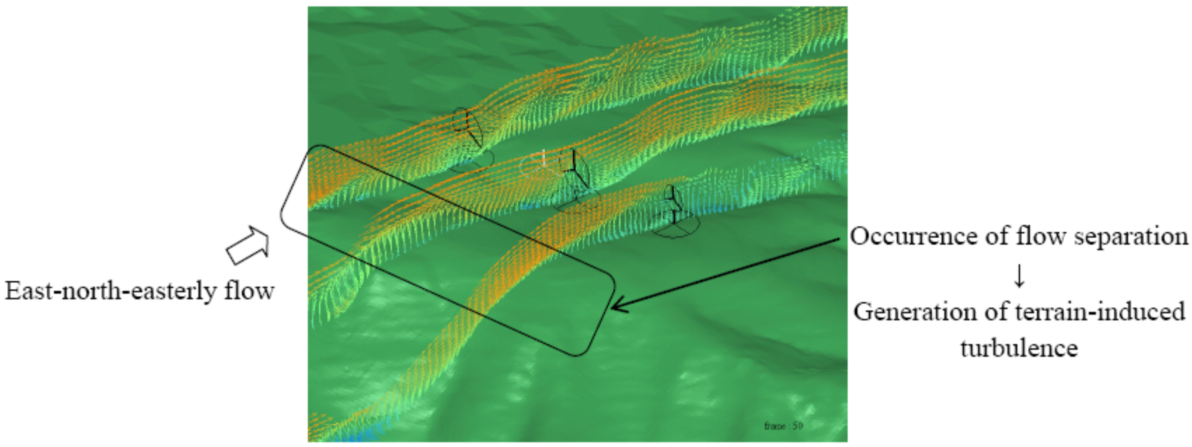
The high resolution elevation data of 10 m or less that reflects the current state of land use is indispensable for this simulation. We developed a technique for constructing high resolution elevation data of 10 m or less based on both of the paper map and the Computer Aided Design (CAD) data form by using the Geographical Information System (GIS) technique. In the present study, the high resolution elevation data with 3 m spatial resolution were constructed from CAD data based on the use of the latest land development information. The minimum horizontal and vertical grid widths are 6.5 m and 1.25 m, respectively. The wind directions considered for the simulation are east-north-easterly and west-south-westerly. At the inflow boundary, the vertical profile of the horizontal wind speed is given using a 1/7 power law. Other simulation settings are the same as those used for the simulation in Section 2.

3.3. Simulation Results and Discussion

Because of space limitations, only the simulation results for the east-north-easterly wind case will be discussed in the present sub-section. The wind velocity vectors along vertical cross-sections which include the individual WTGs (Figure 8a) suggest that all the three WTGs in the figure are subject to significant influence from separated flow (terrain-induced turbulence) which is generated upwind of the WTGs.

In other words, the WTGs are completely immersed in the terrain-induced turbulent flow. An examination of the animation of the airflow in the computational domain reveals that: (1) the WTGs are affected by the turbulent eddies which are generated locally and periodically upwind of the WTGs and (2) flows form which travel in the opposite direction of the meteorological flow. Furthermore, the wind velocity vectors at the locations of the WTGs in Figure 8b illustrate that large velocity deficits are present at multiple heights; that is, there exist large differences in the wind velocities between the lower and upper ends of the area swept by the blades of the individual WTGs.

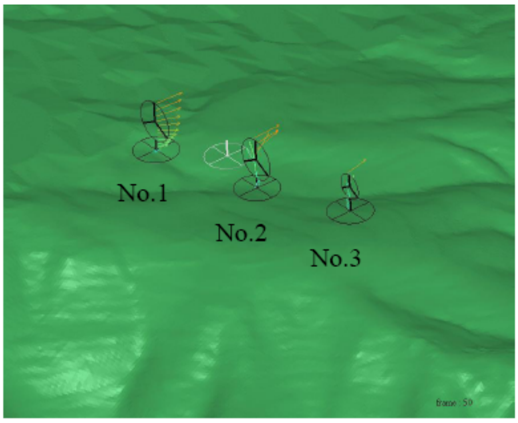
Figure 8. Simulation results: east-north-easterly wind. (**a**) Wind velocity vectors along vertical cross-sections which include the individual WTGs; (**b**) Wind velocity vectors at each of the WTGs; (**c**) Trajectories of virtual particles released from the locations of the individual WTGs.



(**a**)

Figure 8. *Cont.*

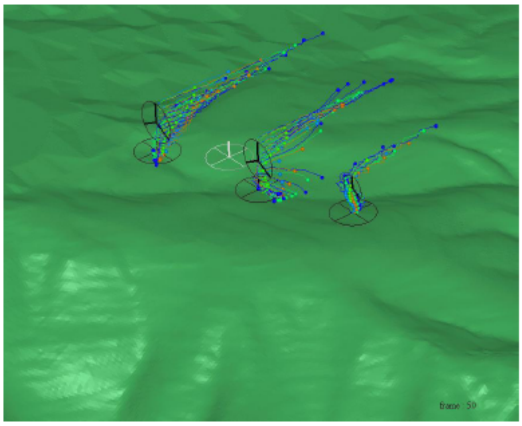
East-north-easterly flow



- A large difference in wind velocity occurs between the upper and lower ends of the area swept by the blades
- Formation of flow in the opposite direction of the large-scale flow

(**b**)

East-north-easterly flow



- Visualization of local wind conditions (terrain-induced turbulence) in three dimensions

(**c**)

The unexpected large differences in the wind velocity across heights may induce vibrations of the WTGs and may also cause internal damage and breakage of the WTGs. Deployment of virtual particles and examination of the trajectories of these particles are an effective method for the assessment of the three-dimensional wind conditions at a site of interest. Figure 8c vividly shows the three dimensional structure of the terrain-induced turbulence discussed above.

In future research, detailed wind synopsis diagnostics as those discussed in the present paper need to be performed for all wind directions at a WTG in order to gain an accurate understanding of the three-dimensional local wind conditions at the location of the individual WTG (e.g., the temporal change in the vertical profile of the wind speed at the deployment location of the WTG, the wind speed at both the right and left as well as the upper and lower ends of the area swept by the blades, and the temporal change of turbulence intensity). If (1) the wind directions in which the wind risks are expected to be large for a WTG of interest can be identified in advance using the results of the wind synopsis diagnostics and (2) the findings from the wind synopsis diagnostics can be applied for the operation of WTGs, the troubles due to terrain-induced turbulence can be reduced significantly, and the utilization rates of WTGs can be improved considerably.

In addition to the research findings reported in the present paper, the latest advancements associated with the RIAM-COMPACT® CFD model will be briefly described below. Because simulations of unsteady turbulent flows are the primary focus of the RIAM-COMPACT® CFD model, computational time is a concern when executing the model. However, the solver of the model is compatible with multi-core CPUs such as Intel Core i7, which shortens the computational time significantly so that no particular problems exist in terms of the practical use of this model. Applications of the RIAM-COMPACT® CFD model among users ranges widely from the economical evaluations of annual power production which are made by simulations with hundreds of thousands of grid points to the analyses of terrain-induced turbulence which are conducted by simulations with millions of grid points. The latest research by the authors led to the confirmation that large-scale calculations which involve hundreds of thousands of grid points can be completed on a single general-purpose PC with a 64-bit Windows OS in approximately one to two weeks. With the purpose of accommodating these large-scale calculations, a new solver is scheduled to be provided in the near future.

In order to conduct the numerical wind analysis recommended by the authors for worldwide locations, acquisition of terrain elevation data for sites outside Japan is crucially important. For addressing this issue, the authors have focused on the use of 3-D global elevation data (ASTER data) with 30 m spatial resolution and 3-D global elevation data (ALOS data) with 10 m spatial resolution. The former data were created jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and the National Aeronautics and Space Administration (NASA), and the latter data were created by a collaborative effort of the Japan Aerospace Exploration Agency (JAXA) and NASA. The authors have developed and continue to develop techniques to automatically convert the above-mentioned data into a format which can be loaded into the RIAM-COMPACT® model as input data. The present techniques have enabled numerical wind synopsis predictions for almost any area in the world, and the pre-processing time required for the wind synopsis predictions has also been shortened significantly from a few days to approximately an hour.

4. Summary

[redacted]

[redacted]

Subsequently, a detailed wind synopsis analysis was performed for the Asokurumagaeri wind farm (operation of this wind farm was initiated in October, 2005) in cooperation with the Kumamoto Prefectural Enterprise Bureau. In this simulation, high-resolution terrain elevation data which included the latest land development information were utilized. The simulation results suggested that the effects of wind risks (terrain-induced turbulence), which have been reported in the media, were successfully reproduced.

Acknowledgements

The present study was partially funded by (1) a Grants-in-Aid for Scientific Research for Young Researchers (A) for the Fiscal Year 2010—2011, “Development of a Local Wind Synopsis Prediction Technique for Improvement of the Atmospheric Environment in Mega-Cities in Asia and for the Effective Use of Wind Energy” (Principle Investigator: Takanori Uchida), (2) a 21st Term Research Grant from the Research Foundation for Electrotechnology of Chubu: Fiscal Year 2010, “Development of a High-Accuracy Wind Turbine Micro-Siting Technique for the Dissemination of Wind Power Generation” (Principle Investigator: Takanori Uchida), and (3) a Research Grant from the Hatayama Cultural Foundation: Fiscal Year 2010, “Development of a Wind Turbine Micro-Siting Technique Contributing to the Appropriate Deployment of Wind Power Generation Facilities” (Principle Investigator: Takanori Uchida). Various datasets used in the present study were provided by Graham Li of the Eurus Energy Japan Corporation and the Kumamoto Prefectural Enterprise Bureau. We wish to express our gratitude to the above-mentioned funding agencies and individuals.

References

1. Lee, S.C.; Shih, L.H. Renewable energy policy evaluation using real option model—The case of Taiwan. *Energy Econ.* **2010**, *32*, S67–S78.
2. Chen, Y.H.; Chen, C.Y.; Lee, S.C. Technology forecasting of new clean energy: The example of hydrogen energy and fuel cell. *Afri. J. Bus. Manag.* **2010**, *4*, 1372–1380.
3. Bechmann, A.; Berg, J.; Courtney, M.; Jørgensen, H.; Mann, J.; Sørensen, N. *The Bolund Experiment: Overview and Background*. Technical Report for Risø DTU: Roskilde, Denmark, 2009.
4. Sumner, J; Watters, C.S.; Masson, C. Review: CFD in Wind Energy: The Virtual, Multiscale Wind Tunnel. *Energies* **2010**, *3*, 989–1013.
5. Uchida, T.; Ohya, Y. Micro-siting Technique for Wind Turbine Generators by Using Large-Eddy Simulation. *J. Wind Eng. Ind. Aerodyn.* **2008**, *96*, 2121–2138.
6. The Ministry of Construction. *The Building Standard Law of Japan*; The Ministry of Construction: Tokyo, Japan, 2000.
7. Uchida, T.; Maruyama, T.; Ohya, Y. New Evaluation Technique for WTG Design Wind Speed using a CFD-model-based Unsteady Flow Simulation with Wind Direction Changes. *Modell. Simul. Eng.* **2011**, in press.
8. JSCE. *Guidelines for the Design of Wind Turbine Support Structures/Commentary*; Japan Society of Civil Engineers: Tokyo, Japan, 2010.
9. AIJ. *Recommendations for Loads on Buildings/Commentary*; Architectural Institute of Japan: Tokyo, Japan, 2004.
10. Uchida, T.; Maruyama, T.; Takemi, T.; Oku, Y.; Ohya, Y.; Graham, Li. Proposal of Designed Wind Speed Evaluation Technique in WTG Installation Point By Using the Meteorological Model and CFD Model. *J. JWEA* **2010**, *34*, 118–124, in Japanese.
11. Homepage of Pennsylvania State University, National Center for Atmospheric Research Numerical Model. Available online: http://www.mmm.ucar.edu/mm5/ (accessed on 2 March 2011).
12. Uchida, T.; Ohya, Y. Application of LES Technique to Diagnosis of Wind Farm by Using High Resolution Elevation Data. *JSME Int. J. B. Fluid T* **2006**, *49*, 567–575.