Renewable and Sustainable Energy Reviews 54 (2016) 110–119

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Wind tunnel experimental analysis of a complex terrain micrositing

J.M.L. Mattuella [a,*], A.M. Loredo-Souza [a], M.G.K. Oliveira [b], A.P. Petry [c]

[a] Department of Civil Engineering, Construction Aerodynamics Laboratory, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
[b] Vento-S Consulting, Brazil
[c] Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form
12 June 2015
Accepted 18 September 2015
Available online 11 November 2015

Keywords:
Atmospheric boundary layer
Complex terrain
Micrositing
Wind energy
Wind tunnel

ABSTRACT

The technical and economic feasibility of wind energy projects are defined by identifying the correct wind potential in the site and by the technological choice of equipment. The optimal micrositing of wind turbines determines the success of the project. Most current tools are insufficient to evaluate air flow in a complex terrain where wind effects such as acceleration, deceleration are difficult to be predicted The uncertainties related to the energy outcome present an increasing problem as the precision regarding the amount of the energy that may be commercialized is even higher. The combined use of wind tunnel and mesoscale numerical modeling represents the solution for wind power site assessment in a complex terrain. This paper presents a review of the contribution that wind tunnels have recently made for physical modeling of both the velocity field and the turbulence intensity as a methodology for the atmospheric boundary layer study in a complex terrain. Hence, it describes an experimental simulation of the atmospheric boundary layer (ABL) in a wind tunnel over a complex area to characterize the mean flow (detachment and reattachment) and the turbulence intensity with emphasis in the wind energy production. The experiment was conducted in a wind tunnel and employed two terrain categories: Category I – plain terrain and Category III-IV – moderately rough, corresponding, respectively, to the power law exponent $p=0.11$ and $p=0.23$. The complex terrain wind profiles were correlated with that in the plain terrain to show the changes of the velocity and show the extension of turbulence wake caused the by variable topography of the area. The measurements of the wind velocity and turbulence intensity were performed with a hot wire anemometry system. Results demonstrate that velocity profile and turbulence intensity profile vary significantly over the complex area, which makes an accurate experimental evaluation necessary to certify the micrositing layout. Power losses due to wake effects can easily reach 20% of the total power, which may make a plant infeasible.

Contents

1. Introduction . . . 111
2. Research in complex terrain – models and methodologies-a review . . . 112
3. Atmospheric boundary layer (A.B.L) . . . 113
   3.1. Flow over complex areas . . . 113
4. Wind power assessment . . . 114
   4.1. Wind tunnel experimental simulation methodology . . . 114
   4.2. Experimental set up . . . 115
   4.3. Experimental model . . . 115
5. Results and discussion . . . 117
6. Conclusions . . . 118
Acknowledgment . . . 118
References . . . 118

* Corresponding author. Tel.: +55 51 3308 3745; fax: +55 51 3308 3746.
E-mail address: jussara.mattuella@ufrgs.br (J.M.L. Mattuella).

http://dx.doi.org/10.1016/j.rser.2015.09.088
1364-0321/

Nomenclature

α	Shear parameter
ABL	Atmospheric Boundary Layer
CFD	Computational Fluid Dynamics
GW	gigawatt
HP	Horse Power
L	hill characteristics length (m)
LES	Large Eddy Simulation
MW	megawatt
RANS	Reynolds Averaged Navier Stokes
T	period de integralização dos valores (t)
$U(z)$	mean wind speed, (m s^{-1})
$U(z_1)$	wind speed at the required or extrapolated height z_1 (m s^{-1})
$U(z)_d$	wind speed (dimensioness)
$U(z_r)$	wind speed at the reference elevation z_r (m s^{-1})
d	height elevation (m)
kHz	kilohertz
Iu	turbulence intensity (%)
p	power law exponent area
s	second (s)
u (rms)	ratio of the standard deviation to the mean wind speed (dimensionless)
μ^*	logarithmic law parameters
$\overline{V}$	average wind speed defined by Eq. (02) (m s^{-1})
$v(t)$	individual value of wind velocity, (m s^{-1})
x	horizontal coordinate, (m)
z	vertical coordinate, (m)
z_H	hub height equipment, (m)
z_1	height of projection of wind speed (m)
z_o	surface roughness (m)
z_r	reference height of wind speed (m)

1. Introduction

Wind represents an important source of energy and it plays, even more, a crucial role in the future energy supply worldwide. Brazil, in recent years, has shown an increase higher than that of economies like China, United States and India. In 2014, the wind capacity installed in Brazil reached 3369.8 MW, representing an increase of approximately 70% over the previous year. The wind growth forecast for 2016 is 40%, whereas that in a global scale is 9% [1]. According to the expansion plan of the Brazilian Electric System it is expected, that 8% of the electrical demand in the country will be supplied by wind energy until 2030 [2]. The total installed capacity of wind power plants in operation in Brazil, including those under construction and/or contracted until the year 2018, reaches 13,807 MW [1]. The estimated wind potential in this country is approximately 300 GW for 100 m height for wind velocity equal or greater than 7 m s^{-1} [2]. Currently, most of the wind power plants in Brazil are located on the coast. However, the intended future expansion will require the installation of wind farms in areas which include the variability of the topography and roughness. In addition, the Brazilian Institutional Model has recently defined that the physical guarantee energy of wind plants to be delivered to the interconnected system considers the value of annual energy with a probability of occurrence equal to or greater than 90% of the Reference Energy as contracted in the energy auction. This reduces the risk of non-compliance with the contracted energy in 10% [2]. These premises define that a greater accuracy in the definition of the wind potential is necessary in the project area, so that such potential is confirmed in the plant in operation. In this context of wind development, it is crucial to estimate both the technical and economical wind potential in complex areas.

Wind speed is the most important parameter in the wind energy conversion devices and utilization of potential areas for micrositing. The energy which is obtained from wind is directly proportional with the cubic power of the wind speed. In complex the wind flows are highly dependent on the local topography and roughness, since their patterns vary locally. As a result of the change of wind behavior, acceleration or deceleration occur, as well as change of direction of the airflow [3]. If the area is a complex terrain, anemometric measurement may not be enough to analyze the assessment area. In order to take the uncertainty of the wind into account, computational and experimental studies are tools that improve the evaluation of the area. The technical evaluation of the wind potential resources of an area is based, preliminarily, on site measurements performed with the use of anemometers and wind vanes. This methodology provides good response to analyze the wind behavior in flat terrains. However, the flow measurements (speed, direction, turbulence intensity and spectrum) over complex terrains become usually insufficient, when using only the mentioned method, particularly regarding the identification of the turbulence areas and the inclination flow. These parameters define the most appropriate wind farm configuration, in order to obtain the maximum array efficiency and the minimum wake losses, to confirm the predicted energy outcome.

The experimental simulation of Boundary Layer Wind Tunnel represented an advance in the study of flow separation and reattachment around bluff bodies of complex geometry. According to Loredo-Souza [4] from such simulation it is possible to parameterize the effects of the wind over a complex terrain. A complex and heterogeneous area containing a main hill with a 34° slope surrounded by other lower ones is investigated in a wind tunnel, in order to analyze the structure of the turbulent flow and characterize the detachment and reattachment of the flow with focus on the identification of the turbulence areas with emphasis in the micrositing wind turbines. The experimental simulations were conducted in the Atmospheric Boundary Layer Wind Tunnel Prof. Joaquim Blessmann, of Federal University of Rio Grande do Sul [5] over a tri-dimensional reduced model scale. Twelve points were measured and 24 profiles were constructed considering two types ABL, corresponding of two terrain categories, Category I – plan and Category III-IV – moderately rough, corresponding, respectively, to the power law exponent $p=0.11$ and $p=0.23$ [6]. The complex terrain wind profiles were correlated with that in the flat terrain to show the topographic interference on the airflow. The measurements of the wind velocity and turbulence intensity were performed with a hot wire anemometry system as reported by Mattuella [7].

Intensive research involving the numerical simulation [8] and/or experiments [7] has been carried out with the purpose of evaluating more precisely the wind potential in complex terrains. Field and wind tunnel experiments play a key role to study the interactions between the atmospheric boundary layer and wind turbines in wind farms as observed by Petry [9]. In particular, wind tunnel experiments offer valuable insights about the turbulent flow structure in micrositings. The average efficiency of an array of wind turbines found in classical models often overestimates the efficiency of large wind farms. Among the contributions of this