Renewable Energy 93 (2016) 228–244

Contents lists available at ScienceDirect

Renewable Energy

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

A surface-layer wind speed correction: A case-study of Darling station

Zaccheus O. Olaofe*

Climate and System Analysis Group, University of Cape Town, Cape Town, 7701, South Africa

ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form
30 January 2016
Accepted 18 February 2016
Available online 3 March 2016

Keywords:
Local wind speed
Satellite winds
Orography effects
Surface roughness changes
Statistical downscaling
Darling station

ABSTRACT

In previous study, the vertical wind speed extrapolation from measurement station to modern turbine hubs over an open homogenous terrain was considered. It was presented that an assumption of wind shear exponent under different stability conditions was an inaccurate representation of the actual wind climates as the precise knowledge of the site's wind characteristics at different levels and seasons are essential for planning and implementation of a proposed energy project. In this study, the surface-layer wind speed correction at Darling using the WRF modeling with mesoscale terrain corrections is presented. An hourly mesoscale modeled winds at 3 km grid spacing obtained for one month are post-processed for estimation of local wind speed profiles at 10 and 50 m height AGL. The sensitivity of the modeled winds to surface terrain corrections is investigated using mesoscale topography parameterizations. Furthermore, 6-hourly mesoscale modeled and satellite observed winds as well as measurements from Darling station are utilized for validation of the statistical downscaling method utilized for the postprocessing of the boundary layer winds over land. It is presented that the precision of the mesoscale modeled winds for local wind speed estimates at potential site without historical measurements can be significantly improved. The confidence in the validity of this methodology for local wind speed correction is estimated at 96–98%.

1. Introduction

Prior to wind farm development, the precise knowledge of the site's wind characteristics and stability conditions at different heights is essential for the planning, and implementation of a proposed energy project. At potential wind location, the basic approach in determination of the wind resource statistics is to analyze the wind speed distributions of different station heights or extrapolate a reference wind measurements and relate with power curve function of a selected wind turbine. However, for detailed wind resource estimates, the influence of local topography (surface roughness changes and orography effects) and the atmospheric stability on the vertical wind profiles across the turbine rotor-disk must be investigated. In addition, the interaction of the winds with topography takes place within the lowest part of the atmospheric boundary layer, ABL, (1–3 km AGL) but in wind energy study; this is often considered within the vertical levels of 200 m above the surface and the vertical wind speed profile is strongly influenced by nature of the terrain. Above the surface boundary layer, SBL, (>200–300 m), the vertical wind shear for modeling of wind speed profile become influenced by other scaling factors that are negligible in the SBL; such as the boundary-layer height (BLH) and baroclinicity [1]. For the long-term wind speed projection, the atmospheric information regarding the long-term stability conditions are required, and can be analyzed from the turbulent fluxes of heat and momentum measured from tower height or the mesoscale modeling such as WRF.

The historical wind climatology retrieved from different sources such as the: land-based measurement stations, ships, radiosondes, buoys, remote sensors (lidars and sodars), satellites and aircrafts at different temporal resolutions (5-min, 10-min, hourly, 6-hourly and 12-hourly) have different levels of precision. However, the accuracy of the wind measurements in energy application is crucial for short to long-term forecasting of the wind farm operation. To obtain a more accurate wind resource estimates that covers a large region and time period of interest, these rely on the use of numerical weather prediction (NWP) model such as the advanced weather and research forecasting (WRF). In this case, the WRF modeling require important inputs such as: (1) the orography and roughness description of the wind field derived from land-use specification and vegetation coverage; (2) the climatology of the external forcing which for the mesoscale model is the large-scale pressure

* Tel.: +27 780330486.
E-mail address: zakky201@gmail.com.

http://dx.doi.org/10.1016/j.renene.2016.02.055
0960-1481/

gradients, or background motion of the wind field [2]. To predict the local wind climates of a specific wind farm site, high-resolution mesoscale wind field from WRF modeling is transformed to surface wind field of standard conditions, taking into consideration the local (associated with orography, surface roughness change, near-by obstacles or presence of other mounting towers) and stability effects in the wind site.

The wind speed projection from reference height or station to potential wind farm site involves modeling effects of combination of sheltered areas from near-by obstacles, surface roughness changes and local orography. In wind turbine sitting, it is worth noting that there are limitations to local wind speed extrapolation because of the following: (1) it is often based on the neutral stability boundary layer modeling, (2) it is often based on the vertical extrapolation of measured winds from a single observing station or interpolation between stations which is linear and local effects such as site-specific topography are introduced making local wind climates difficult to accurately assess for low-resolution topographical data (3) low quality station measurements from wind sensors over time often misrepresent the wind climates of potential site, among others.

In previous study, the 5-min wind measurements for the period of 24 months at Geelbek Automated Weather Station (DWS), situated in Darling (Fig. 1a) were obtained and transformed into hourly wind records. For the measured wind speed and direction at 10 m height AGL, there were no station measurements available to analyze the vertical wind profiles at levels of 50, 60 and 70 m. On the basis of surface description of DWS, the station terrain was parameterized by wind shear coefficient, $\alpha = 0.142$, and the vertical wind profiles at higher hubs (50, 60 and 70 m) were assessed using the power law under neutral conditions. Similarly, the accuracy of the power and logarithmic laws in vertical wind speed projection were validated with the station measurements (Vredenburg) retrieved at 10 and 40 m heights AGL. Vredenburg measured winds at 10 m reference height were assumed and under adiabatic conditions the anemometer wind speeds were vertically projected to 40 m AGL over open homogenous terrain using $\alpha = 0.142$, and $z_0 = 0.03$ m. The accuracy of the projected wind speeds was verified with upper level measured wind speeds at 40 m height (Fig. S1). Furthermore, the measured wind shear parameters at station heights of 10 and 40 m AGL were compared with land-use description for vertical wind speed extrapolation. Large discrepancies were observed for the projected vertical wind speeds in non-neutral conditions and making energy assessment inaccurate without consideration to local and stability effects at higher hubs. Lastly, the validity of the wind shear exponent (α) and surface roughness length (z_0) in vertical wind speed extrapolation was also determined using the anemometer measurements (owc) and mesoscale modeled winds (wrf) corrected to the same standard conditions at 20 and 60 m heights AGL. The estimated hourly wind shear parameters (α and z_0) for assumed neutral conditions in summer day are presented (Fig. 2). Results show varying wind shears ($\alpha \neq 0.142$ and $z_0 \neq 0.03$ m) driven by variations in stability of the atmosphere in different time of the day (Fig. 2S), thus, misrepresenting the actual wind speed profile in vertical projection for assumed shear parameters ($\alpha = 0.142$ and $z_0 = 0.03$ m) in non-neutral conditions. On this basis; the hourly wind shear parameters are more sensitive to stability effects using the diabatic wind speed profile than in adiabatic conditions. The surface roughness description of owc strongly disagreed with wrf for assumed adiabatic conditions (Fig. 2), except for the hours of 03:00:00, 10:00:00, 17:00:00 and 19:00:00 UTC; thus, reflecting the real atmospheric conditions in summer day ($z_0 \neq 0.03$ m, $\{z/L\} \neq 0$). At Vredenburg, the boundary layer wind shear exponent is observed to be function of the height, roughness length and the stability of the atmosphere [3].

From review, Gryning et al. [4] adjusted the roughness length using the logarithmic wind speed profile to match a 10 m average wind speed under a given atmospheric conditions (10-min. profiles were classified into a number of stability classes based on Monin-Obukhov length values, L, estimated from sonic anemometer at 10 m). The surface roughness, z_0, was found to be function of atmospheric stability; under neutral conditions, $z_o = 0.014$ m and slightly increase and decrease under unstable and stable conditions, respectively. Similarly, Peña et al. [5] used the logarithmic wind speed profile in neutral conditions to estimate value of z_o and found $z_o \approx 0.016$ m in winter. Another study presented by Motta et al. [6], found the inclusion of atmospheric stability function essential for the improvement of vertical wind speed profile. From the wind studies conducted by Gryning et al., Peña et al. and Motta et al. at different locations, the diabatic wind speed profile was found to fit well the observed wind speeds within the surface boundary layer (SBL). Therefore, using a constant wind shear exponent, $\alpha = 0.143$, or surface roughness, $z_0 = 0.03$ m, for vertical wind speed modeling in non-neutral conditions would mis-represents the local wind speeds for a given station height, z. In wind energy-related studies, it is essential that the vertical wind speed profile at Darling and potential wind sites be modeled as

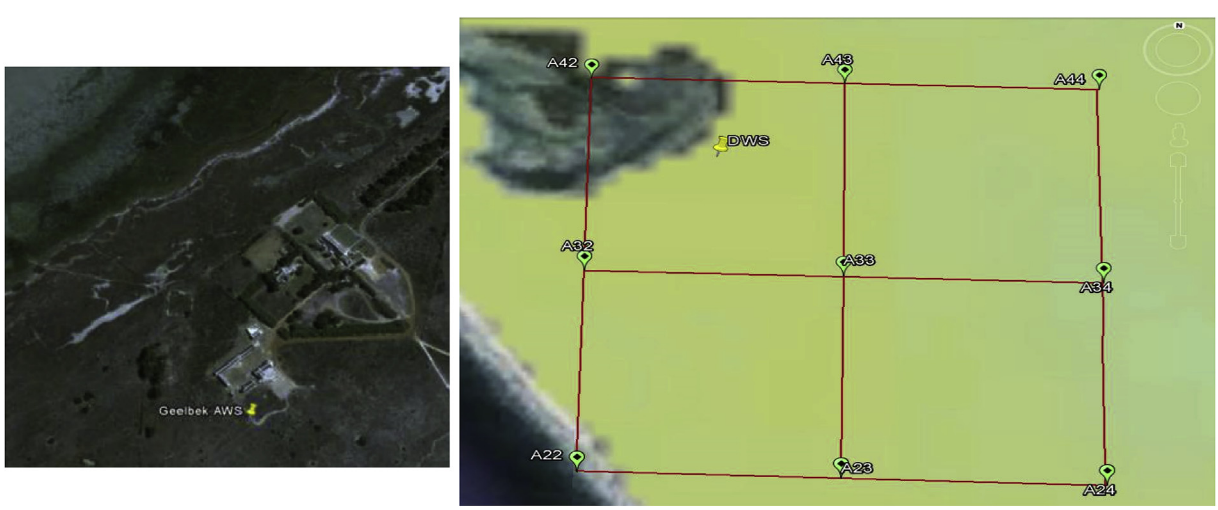

Fig. 1. Location of Darling station (DWS) and surrounding virtual stations.