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Preliminary assessment of remote wind sites

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Abstract

Wind energy is becoming a reliable and affordable source of clean energy and is rapidly expanding to remote places around the world. A crucial input for wind farming prospect is the assessment of potential wind sites. Sites, especially remotely located, often do not have a wind resource map and thus lack credible historical records of wind resources. Measurement campaigns to map these sites are costly and time consuming. In this paper, a method for preliminary wind resource assessment for remote sites is proposed. The method is a combination of interpolation and extrapolation of data from the surrounding sites to the potential wind farm site. Two interpolation techniques, viz., Inverse Distance Weighting (IDW) and Triangulated Irregular Network (TIN), are applied to the data set recorded by Sonic Detection and Ranging (SODAR) in West Texas, USA with the surrounding sites within 300 km radius of the potential site. Extrapolation is done by using a power law with the exponent equal to 1/7. The resulting values of the wind speeds are validated with the available 200 m meteorological tower measurements at the potential site in Reese, Lubbock West-Texas, USA. Root mean square error (RMSE) of daily averages of wind speed ranged from 1.5 to 3 meters per seconds.

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"Keywords: Wind resource assessment; wind interpolation; remote sites"

Introduction

Wind is one the fastest growing green and clean energy alternative in the world. Almost all suitable onshore sites have been utilized especially in northern Europe, so the focus is now shifting towards either upgrading these sites with bigger and advanced turbines or going offshore. The latter is still very expensive and requires skilled work force. One possibility of expanding the wind energy onshore is to find newer places, which have not been explored in the past due to lack of credible wind resource measurements. Keeping in view this strategy of expansion, a preliminary method for wind resource assessment is proposed. It takes advantage of the measurement on the surrounding sites and predicts the wind speed at the site of interest. The method uses combination of extrapolation and interpolation techniques with minimum resource requirements in terms of computational power and time. The main objective of this study is to provide a basic preliminary wind resource assessment tool so that further investigation of the resources could be carried out.

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Literature review

Lou et al. [1] compared various geostatistical and deterministic methods of interpolation to evaluate their suitability for estimating mean wind speed surfaces. Quantitative results showed geostatistical methods to be superior to the deterministic ones and the accuracy of interpolation was substantially influenced by the measurement accuracy. Newman et al. [2] evaluated the power law method of extrapolation using Monin-Obukhov similarity theorem in two different forms.[3] The Monin-Obukhov similarity theory produced accurate results for unstable regimes only, whereas the power law method, produced the smallest mean wind speed errors for all heights and stability regimes. Ali et al. [4] estimated wind speeds in Iraq using various spatial interpolation techniques. Best results were obtained by inverse distance weighting technique, followed by ordinary kriging. Chinta [5] tested six geostatistical and deterministic interpolation techniques. Based on root mean square errors, it was concluded that a global polynomial was the best approach followed by local polynomial and ordinary kriging.

Data and Methods

Data set

The West Texas mesonet is an independent project collaborating with the Atmospheric Science Group and the National Wind Institute at the Texas Tech University, Lubbock, TX. Their network consists of 84 mesonet stations and 7 boundary layer SODAR units, covering 58 counties in the state. Four of these stations are located within 300 km radius from the Reese meteorological tower from where wind speed and wind direction data is extracted. The data is recorded every 10 minutes at heights changing by 30m. The Reese meteorological tower data is used for validation. The 200m tower has ten vertical levels and the atmospheric parameters (velocity, temperature, humidity and pressure) are recorded at a frequency of 50 Hz (0.02 s). Appropriate heights for both SODAR and tower data are selected depending upon error values from measured data sets. Fig. 1 shows the location of four SODAR stations around the Reese meteorological tower while the X and Y distances between SODAR stations and the tower calculated from the haversine formula, are summarized in Table 1.

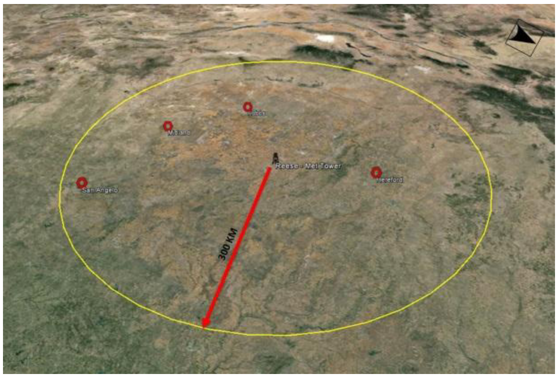

Fig. 1. Location of measuring stations

Table 1: XY distances of four SODAR stations from Reese tower

Distance from	To SODARS at	X distance [KM]	Y distance [KM]
Reese tower	Hereford	18.3853	139.7430
	Hobbs	74.1029	-94.4326
	Midland	10.4304	-184.3579
	San Angelo	-99.1529	-229.6139

Wind speed extrapolation

Wind speed measurements can be extrapolated to different heights, within the boundary layer, by using a power law and application of Monin-Obukhov similarity theory [3], given by:

$$\frac{V_{desired}}{V_{given}} = \left[\frac{H_{desired}}{H_{given}}\right]^{\alpha}$$

Where, $V_{desired}$ is the wind speed at the required height $H_{desired}$, V_{given} the given wind speed at the known height H_{given} and α is the power law exponent. A value of 1/7 is assigned to the exponent [6], and can be calculated as follows [7]:

$$\alpha = a_m + b \times \ln V_{desired}$$

where, $a_m = \frac{1}{\ln\frac{Z_g}{Z_o}} + \frac{0.088}{\left[1-0.088\ln\frac{H_{desired}}{10}\right]}$; $b = -\frac{0.008}{\left[1-0.008\ln\frac{H_{desired}}{10}\right]}$; $Z_g = (H_{desired} \times H_{given})^{1/2}$

Zo is the surface roughness length and depends on several local factors, making it rather difficult to calculate. Therefore, here α = 1/7 is used. Historically, neutral conditions are associated with α = 1/7, higher values indicating stable conditions and lower values unstable conditions [2].

Wind speed interpolation

Inverse distance weighting (IDW)

IDW is one of the deterministic methods of interpolation that uses the idea of vicinity adopted by Thiessen polygons [8] with steady change of a trend surface. Measured values closest to the prediction location have greater influence on the predicted value than those farther away. This approach is often used for the interpolation of climate data [9, 10]. IDW assumes that each measured point has a local influence that diminishes with distance. It is given by:

$$Z_{prd}(s_o) = \frac{\left[\sum_{i=1}^{N} w(d_i) \cdot Z_{obs}(s_i)\right]}{\sum_{i=1}^{N} w(d_i)}$$

where $Z_{prd}(s_o)$, $Z_{obs}(s_i)$ are the predicted and observed values at location s_o and s_i, respectively, N is the number of measured points, w(d) is the weighting function, and d_i is the distance between s_o to s_i. The selection of the weighting function has large influence on the interpolation output. A number of weighting functions and their merits are analysed by Lancaster and Salkauskas [11]. Default weighting function in Quantum Geophysical Information System (QGIS) is used for the interpolation.

Triangulated irregular network - TIN

TIN interpolation is another popular tool in QGIS. A common TIN algorithm is called Delaunay triangulation. It consists of creating a surface formed by triangles of nearest neighbour points. To do this, circumcircles around selected sample points are created and their intersections are connected to a network of non-overlapping compacted triangles. Default settings of TIN are used for the simulations.

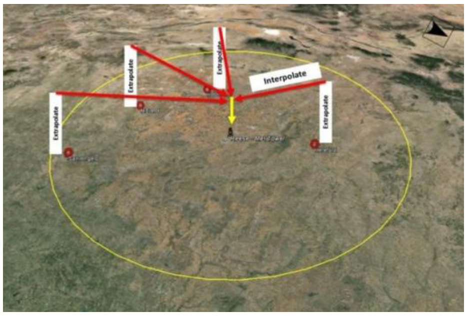

Fig. 2. Methodology

Results and Discussion

The hourly wind speed data from the surrounding SODAR stations, between 12th - 14th January 2013, 22nd October 2013 and 11th - 14th January 2014 are processed. This is according to the available measured data for validation. The data are extrapolated to 1000m height using power law. The data are then interpolated using IDW and TIN using QGIS and further extrapolated to typical hub height of 75m or 30m at the Reese tower location. These heights are selected after going through the complete data set for minimum errors and least missing data points. The process is described in Fig. 2. Fig. 3 shows the resulting hourly predicted values of wind speed against the measured values on 12th January 2014. Both techniques followed the measured wind speed with some errors. The hourly root mean square error (RMSE) for both techniques is shown in the Fig 4. The maximum RMSE of IDW is 3.158 which is lower than the maximum of TIN 4.623. The minimum RMSE of IDW 0.0049 is also lower than the minimum of TIN 0.0753. Based on RMSE values, IDW appears to produce slightly better results in comparison to TIN.

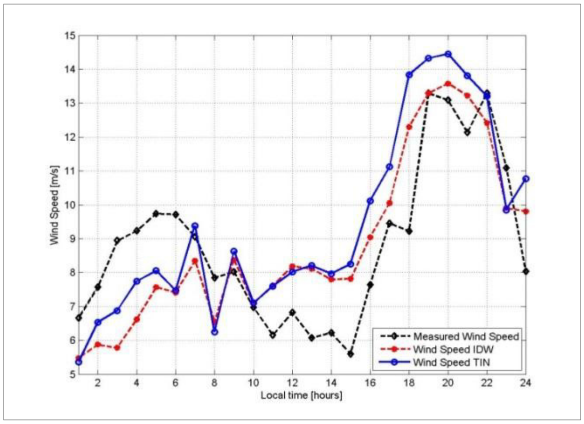

Fig. 3. Comparison of hourly wind speed (12.01.14)

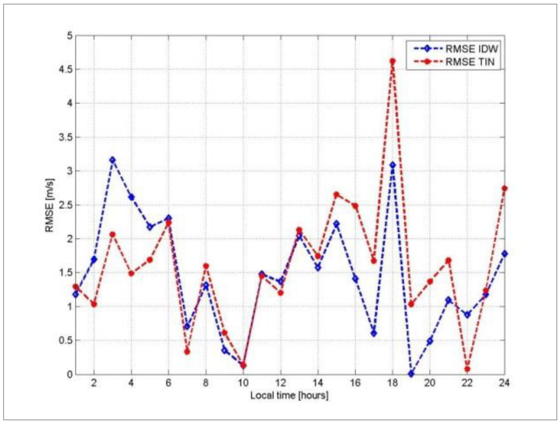

Fig. 4. Hourly root mean square error (12.01.14)

Fig. 5 shows the trend of daily RMSE values for the predicted against measured wind speed, which is quite acceptable for the preliminary evaluation of wind resources at remote site. This is particularly attractive it is extremely resource friendly in terms of computational capability and time consumption. The proposed method can be improved by categorizing the hourly values of wind speed according to the prevailing atmospheric conditions such as stable, unstable or neutral and, more realistic value of α can be selected for the extrapolation. This improvement will be explored in future in a research project on the wind farm located in the Nygårdsfjell area of Troms, Norway.

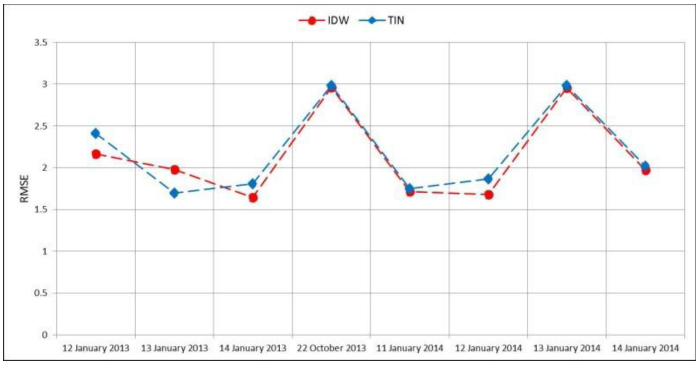

Fig. 5. Daily RMSE

Conclusion

The proposed method offers a practical and resource friendly scheme of conducting a preliminary assessment of wind resources at remote sites. IDW results were than those from TIN. The average hourly wind speed-RMSE for IDW was 9% lower than that of TIN, whereas the average daily wind speed-RMSE for IDW was 3% lower than that of TIN. Improvements to the method will be explored in future in north Norway.

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Biography

Muhammad Bilal is a Ph.D. candidate in the Department of Physics and Technology at the Arctic University of Norway (Uit). His research interests are in the areas of short term wind power prediction in the Arctic with emphasis on numerical modeling and performance analysis.