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Validation of the WAsP Model for a Terrain Surrounded by Mountainous Region

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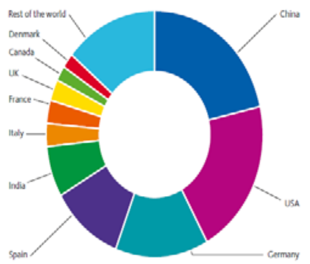
***Abstract*—**The problems associated with wind predictions of WAsP model in complex terrain are already the target of several studies in the last decade. In this paper, the influence of surrounding orography on accuracy of wind data analysis of a train is investigated. For the case study, a site with complex surrounding orography is considered. This site is located in Manjil, one of the windiest cities of Iran. For having precise evaluation of wind regime in the site, one-year wind data measurements from two metrological masts are used. To validate the obtained results from WAsP, the cross prediction between each mast is performed. The analysis reveals that WAsP model can estimate the wind speed behavior accurately. In addition, results show that this software can be used for predicting the wind regime in flat sites with complex surrounding orography.

***Keywords*—**Complex terrain, Meteorological mast, WAsP model, Wind prediction

I. INTRODUCTION

IN 2010, the world celebrated the 194 GW mark in installed wind energy total capacity. Fig. 1 shows the top 10 countries in wind energy installed capacity in 2010 [1].Iran is one of the countries that have recently paid a great attention to install, and build wind turbines. Wind power generators can be a proper replacement for fossil fuel and are considered as one of the cleanest methods of producing electricity. So far, Iran has made some initial progress towards promoting wind energy [2].



Country	MW	%
China	42,287	21.8
USA	40,180	20.7
Germany	27,214	14.0
Spain	20,676	10.6
India	13,065	6.7
Italy	5,797	3.0
France	5,660	2.9
UK	5,204	2.7
Canada	4,009	2.1
Denmark	3,752	1.9
Rest of the world	26,546	13.7
Total TOP 10	**167,844**	**86.3**
World Total	**194,390**	**100**

Fig. 1 Top 10 total installed capacity [1]

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One of the most important tasks during the wind farm design is the accurate prediction of wind resource in the site. Thus in the wind energy literature, many relevant works have been developed to predict the wind resource of a wind farm precisely. In some cases, wind farms are located in mountainous regions where the surrounding environment has complex nature. This could lead to the wind regime would be dominated by highly localized flow and consequently the results will become inaccurate. The current well-established flow modeling software package for wind energy is WAsP, which is developed by Risø National Laboratory, Denmark [3]. Because of the linear flow model is used in WAsP model, users must be careful when assessing wind resource in complex terrain with this model.

Simulation of the atmospheric flow behavior is bound with uncertainty due to its complex nature. The irregularity of the terrain surface and the atmospheric instability are factors that push numerical models, and wind energy meteorology, to their limits. The fame of linear models like WAsP is unmatched because of their simple use and fast results. Several studies have been performed in the field of estimating wind potential in complex terrain. For example, [4] considered micrositing of wind turbines in complex terrain and found that the effects of flow separation and reattachment in wind stream are crucial to the task .Reference [5] uses both WAsP and CFD software to estimate wind resource atlas and concludes that in flat plain the results are the same but in highly complex terrain the CFD model is more accurate than WAsP [5].

WAsP applies a modified potential flow model that has a good prediction for simple terrain. Since most windy sites in Iran are located in flat plains, which are surrounded by mountains, it is necessary to estimate the accuracy of the WAsP model in these areas.

This paper investigates the accuracy of established WAsP model against the observed wind data collection at the two masts in complex terrain. Concurrent obtained data from two masts on complex site in Manjil, Iran is used as the baseline to WAsP model in a cross prediction each mast location from the other mast, for the wind flow models.

II. MODELS & METHODS

A. The Wind Resource Estimation Program WAsP

WAsP (Wind Atlas Analysis and Application Program) is one of the most popular models in simulation of wind farms. It contains models for the vertical extrapolation of wind data taking into account sheltering of obstacles, surface roughness changes and terrain height variations.

"In WAsP, meteorological models are used to calculate the regional wind climatology from the raw data series. In the reverse process - the application of wind atlas data - the wind climate at any specific site may be calculated from the regional climatology" [6].

B. Statistical Distribution for Wind Data and Wind Power Generation

The Weibull distribution is a two-parameter probability density function that models the observed or predicted frequency distribution of wind speeds at a particular site very well. It represents wind speed data given initially as a histogram, to a smooth curve described by a specific formula [7],[8]. Equation (1) gives the probability density function (PDF) of the wind speed.

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^{k}} \qquad (1)$$

- f(V) is the probability density function of the wind speed;
- c is the Weibull scale parameter (m/s);
- V is wind speed (m/s);
- k is the dimensionless Weibull shape parameter

In general, k specifies how steep the peak of the curve is, while c is a value close to the mean wind speed. The Weibull parameters k and c are empirically derived by statistical calculations based on the wind data. Equation (2) defines the cumulative distribution function (f(V)).

$$f(V) = 1 - e^{-\left(\frac{V}{c}\right)^{k}} \qquad (2)$$

The available wind power P(V) (W) that can be obtained by a cross sectional area A (m^2) perpendicular to the wind at a given speed with air density ρ (Kg/m^3), is done by (3).

$$P(V) = \frac{1}{3} C_p \rho A V^3 \qquad (3)$$

- C_p is the coefficient of the power, which will always be less than 0.59, as determined by Betz

Equation (4) defines the wind energy (E) that can be extracted by a wind turbine.

$$\frac{P}{A} = \int_0^\infty P(V).\, f(V)\, dV = \frac{1}{2}\rho c^3 \Gamma \qquad (4)$$

- Γ is Gamma function

III. Site Specification

In this study, the site area is located in Northern part of Iran and site center is located at N: 360 42' 36" and E: 490 18' 42". Two masts (mast 1 and mast 2) are installed in this site for assessing wind resource of the region (Fig. 2). As shown in Fig. 3, the site area is a flat plain between two mountainous areas in north and south. The steepness contour of site is depicted in Fig. 4. Although in the site area and mast locations are classified as low-steep lands (less than 5 deg.), site is surrounded by high-steep areas (25-90 deg.).

Fig. 2 a view of installed meteorological mast in site (mast 2)

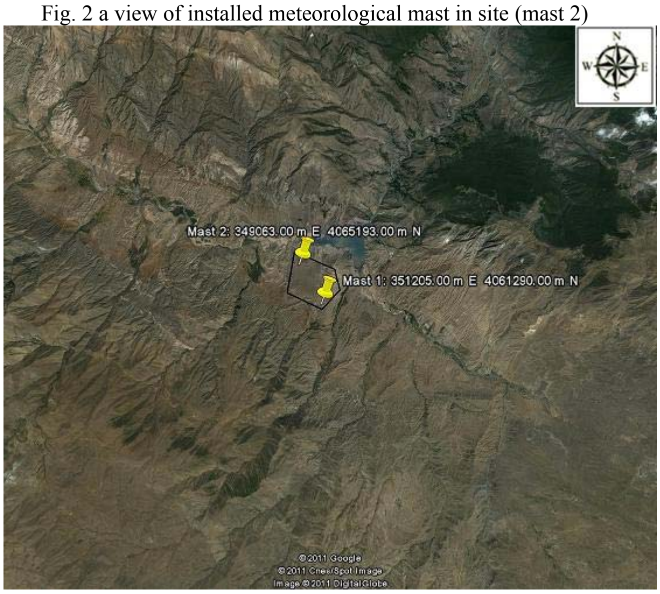

Fig. 3 Overview map showing the site area. The height scale is exaggerated by a factor of three. Coordinates are UTM (zone 39S, WGS 84)

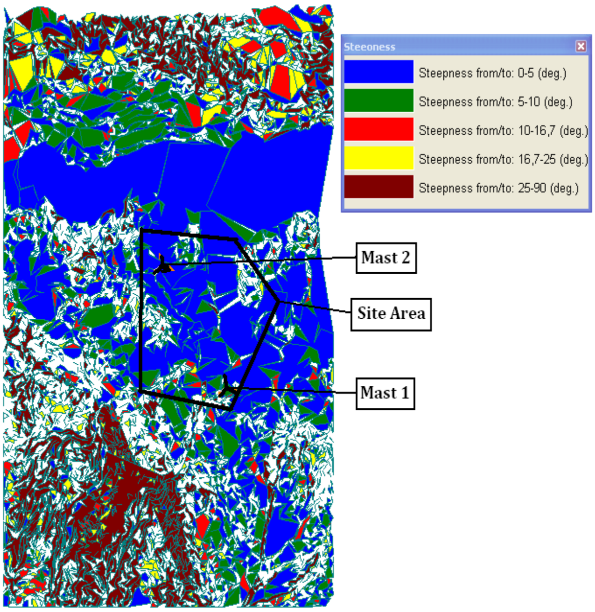

Fig. 4 steepness contour of the land in which the site area is located

The mast 1 and mast 2 are located across approximately 4.3km and their elevations are 390m and 355m above mean sea level, respectively. The elevation profile between mast 1 and mast 2 is shown in Fig. 5. Elevation changes in range of 357 m to 400 m while slope changes from 5% to -0.3%.

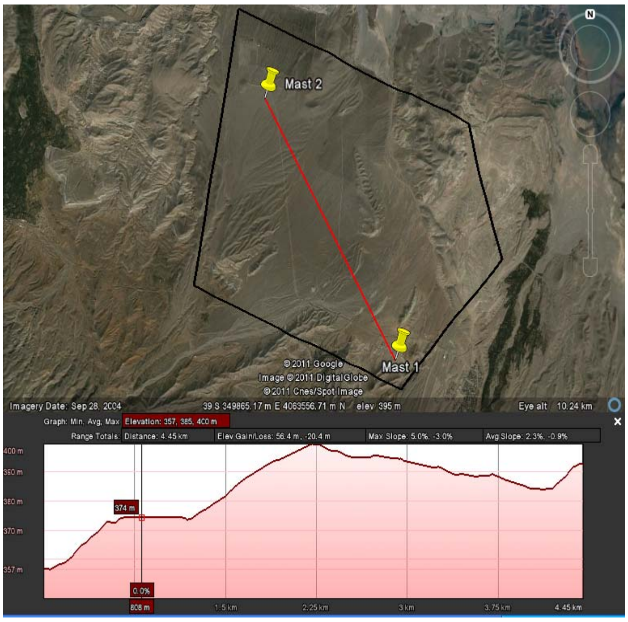

Fig. 5 Elevation profile across the line (red line) that connects two mast locations to each other

For simulation, the erroneous data should be eliminated from time series. Therefore, this task has been done in WAsP software package by comparing three concurrent data sets.

Digital 3D maps, with scale of 1-25000, are used for inserting orography of site and extended to cover at least 5km from each mast location. This 3D maps are prepared by Iran Survey Organization. The surface roughness data was supplied for this area from Iran Forest, Range and Water Shed Management (FRW) Organization with scale of 1:50000 raster images.

IV. Results & Discussion

Probability for different wind speed versus the wind speed and fitted Weibull distributions for mast 1 and mast 2 are shown in Fig. 6 and Fig. 7. In addition, comparison of Weibull distributions and Weibull parameters for mast 1 and mast 2 are presented in Fig. 8 and TABLE I, respectively.

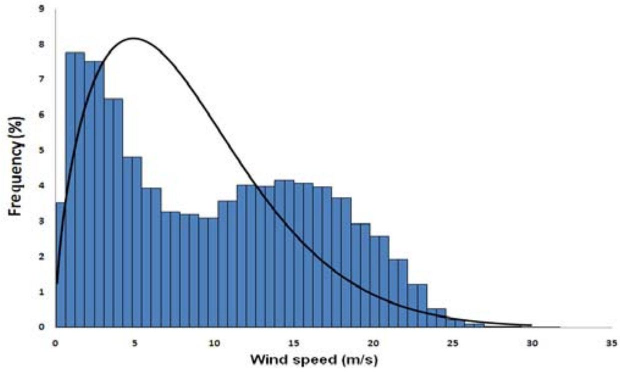

Fig. 6 Weibull distribution for mast 1 at 4o m

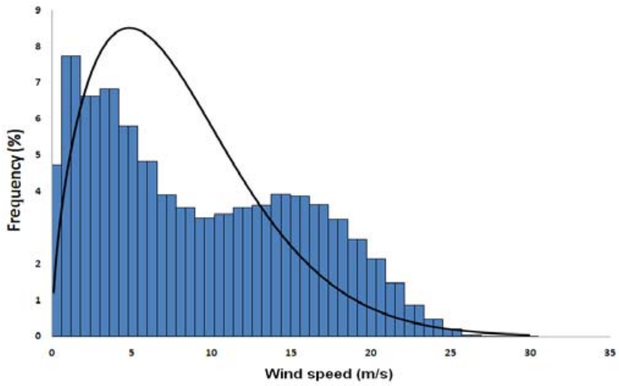

Fig. 7 Weibull distribution for mast 2 at 40 m

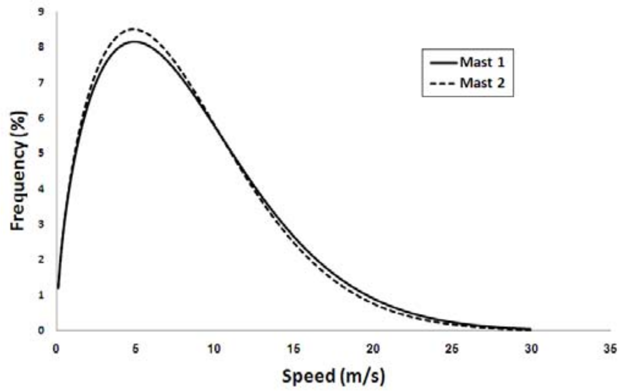

Fig. 8 Comparison of Weibull distributions for mast 1 and mast 2 at 40 m

TABLE I
COMPARISON OF WEIBULL PARAMETERS

Mast	C Parameter (m/s)	k Parameter
Mast 1	9.27	1.5771
Mast 2	8.94	1.5986

The most important results of simulation are shown in TABLE II that includes the predicted wind speed by WAsP, the amount of over predication, and over prediction percentage.

TABLE II
CROSS PREDICTION ERRORS

Predictor	Predicted at	Measured wind speed	Predicted wind speed	Over prediction wind speed	Over prediction percent
Mast 1 @ 40 m	Mast 2 @ 40 m	9.61	9.5	-0.07	-0.7%
Mast 1 @ 20 m	Mast 2 @ 20 m	9.32	8.99	-0.05	-0.6
Mast 1 @ 10 m	Mast 2 @ 10 m	8.62	8.18	-0.48	-5.5
Mast 2 @ 40 m	Mast 1 @ 40 m	9.57	9.55	-0.07	-0.7%
Mast 2 @ 20 m	Mast 1 @ 20 m	9.04	9.35	0.04	0.4%
Mast 2 @ 10 m	Mast 1 @ 10 m	8.65	9.15	0.52	6%

Obtained results from TABLE II show that the percent of error for 40-m and 20-m data, which are the most important heights to predict the wind speed, is less than 1%. Based on the small error in cross prediction of WAsP, it is clear that the model can predict the wind resource accurately. Due to the effects of near ground obstacles at 10m, the amount of error is more than 5% for this height. In Fig. 9 measured wind speed and predicted wind speed curves are depicted.

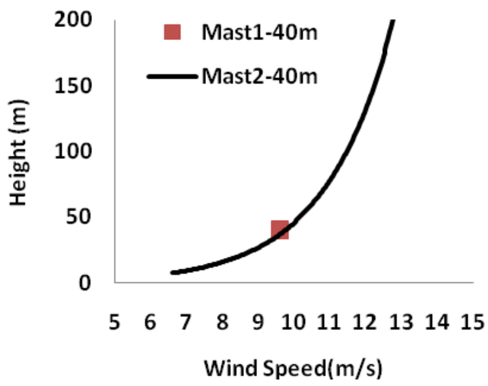

Fig. 9 a Prediction from mast 2 to mast 1 at 40m

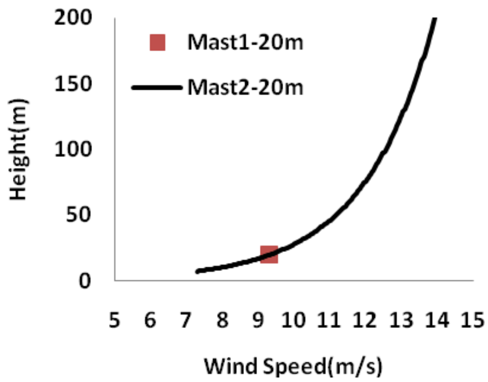

Fig. 9 b Prediction from mast 2 to mast 1 at 20m

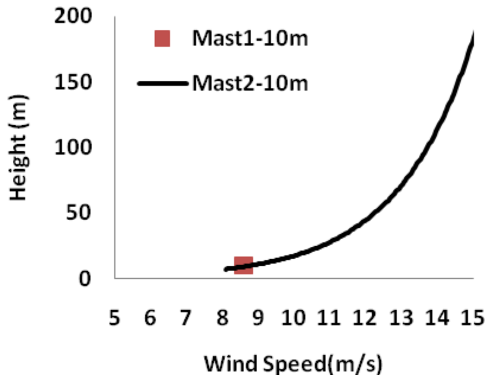

Fig. 9 c Prediction from mast 2 to mast 1 at 10m

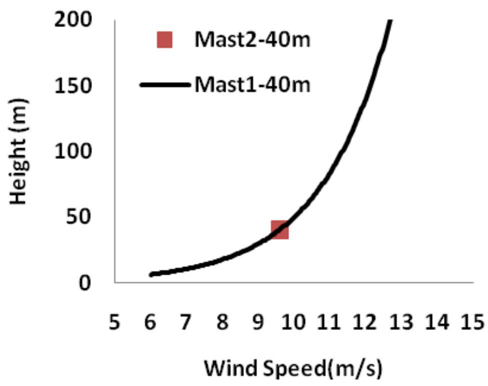

Fig. 9 d Prediction from mast 1 to mast 2 at 40m

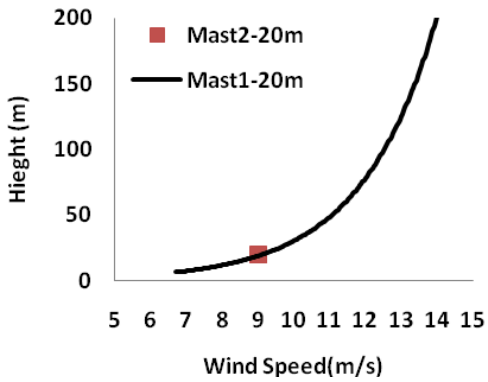

Fig. 9 e Prediction from mast 1 to mast 2 at 20m

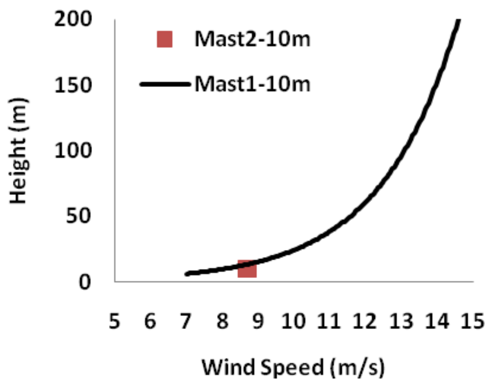

Fig. 9 f Prediction from mast 1 to mast 2 at 10m

Fig. 9 Comparison of predicted and measured wind speed

V. Conclusion

In present paper, the accuracy of WAsP model for a windy site in Manjil with flat terrain and complex surrounding topography is studied. For this purpose, the gathered data from two masts with cross-distance of approximately 4.3km is used. The results show that the calculations of WAsP model are precise enough to predict the wind regime in the site. Since the topographical condition of most wind sites in Iran is similar to this site (flat terrain surrounded by complex mountainous terrain), it seems that WAsP is a reliable model for wind prediction in most cases.

References

[1] GWEC e Global wind 2010 report
[2] A. Mostafaeipour, A. Sadeghian Development of wind turbine in Iran. Melbourne, Australia: WWEC; 2005.
[3] I. Troen, N.G. Mortensen, E.L Pedersen, WAsP. Wind Atlas Analysis and Application Programme. Risø National Laboratory, Dept. of Meteorology and Wind Energy, Roskilde, Denmark.
[4] Russell G. Derickson, Michael McDiarmid, Brad C. Cochran, John A. Peterka, Resolving difficult issues of wind power micrositig in complex terrain, Conference AWEA Global Wind Power, Chicago, USA, March 2004
[5] A. Llombart, A. Talayero, A. Mallet, E. Telmo (2006). Performance analysis of wind resource assessment programs in complex terrain. Proceedings of the 2006 International Conference on Renewable Energy and Power Quality. Palma de Mallorca, Spain. 5- 7 April.
[6] I. Troen, and E.L. Petersen, (1989). European Wind Atlas. Published for the Commission of the European Communities, Brussels, Belgium, by Risø National Laboratory, Roskilde, Denmark, ISBN 87-550-1482-8, 656 pp.
[7] Takle Y Brown. Note on the use of Weibull statistics to characterize wind speed data; 1977.
[8] Nielsen Review of Weibull statistics for estimation of wind speed distributions; 1994.