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Wind Resource Assessment using Computer Simulation Tool: A Case Study

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Abstract

Wind resource assessment is the key step in windfarm deployment at pre-investment stage. In a wind farm, it is often the case that wind climate data is measured at one place and it is required to estimate wind resource potential at any other point in the vicinity. Also, the wind resource potential depends on the effect of terrain at the wind farm site. In this paper, using computer simulation software, the effect of terrain is considered in assessing wind resource potential at a site. A case study of actual wind farm consisting of 33 wind turbines installed at Tamilnadu, India is simulated using Meteodyn software to assess the wind power potential in-terms of capacity factor.

Peer-review under responsibility of the organizing committee of CPESE 2016
Keywords: wind energy, wind resource potential; wind power density; capacity factor; Meteodyn

Nomenclature

m	meter
MW	Megawatt
GWh/year	Gigawatt hours per year

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1. Introduction

Wind energy is one of the renewable energy sources which are maximally utilized and commercialized. It is environmentally clean and free source of electric power. Even though there are many advantages of wind energy for power generation, it is important to note that there are technical challenges in wind power generation, since wind is intermittent source of energy. It varies from time to time, season to season and location to location. As on December 2015, India ranked 4th in the world with the installed wind power generation capacity of 25,088 MW with China as leading nation followed by USA and Germany [1]. According to survey carried out by NIWE (National Institute of Wind Energy), the estimated wind power potential in India is 49130 MW at 50 m height above ground level [2]. With respect to the installed wind power generation capacity, India has still 49 % remaining to be tapped.

Wind resource assessment (WRA) is the first step in developing wind farm project at a site of potential for power generation. The economic viability of wind farm project is largely determined by accurate estimates of potential for wind power generation. The WRA is an extensive exercise, therefore prior to undertaking campaign for detailed WRA, efforts should be made to analyze available wind data for the region and estimate the wind power potential in the region. For the successful operation of a wind farm, a reliable wind resource assessment is a prerequisite. Such an analysis may consider short term data recorded over a period up to one year. In general, the procedure for wind resource assessment is demonstrated for estimates of wind power density at the point of measurement. However, the effect of terrain at the site is not taken into account. In this paper, industry standard commercial software is used for estimating wind resource potential on area of land for wind farm when data measured at one point is available. The software tool used takes into account on details of terrain, such as orography (height variation of terrain) and roughness (obstacles due to tall buildings, vegetation) at the site.

2. Description of Wind farm Site

The wind farm site represents grid integrated wind farm in India situated at Periyapatti, TamilNadu, (Lat.10º45'18.50"N, Long. 77°15'11.0"E), altitude 327 m mean sea level. The site is located approximately 22 km from Udumalpet, Coimbatore, TamilNadu, India. The site provides detailed wind climatological data measured for a period of two years from 1 October 2010 to 30 September 2012. The data includes wind speed measured at a height of 85 m at an interval of 10 minutes, wind direction measured at 83 m AGL and air temperature measured at 6 m AGL are used for the analysis. Fig. 1 shows the met mast installed at the site. The raw time-series measured data is processed using Windographer, Ver 3.3 [3]. The measured data is represented as graphical time-series data and measured wind direction data is represented as wind-rose diagram for the site.

Fig. 2 shows month-wise daily variation of mean wind speed measured at 85 m (AGL). It is observed that, the daily mean wind speed varies between minimum of 1.38 m/s occurring on 3 December 2011 and maximum of 12.8 m/s occurring on 24 May 2012. Fig. 3 shows the predominant direction with the wind speed distribution as wind rose diagram. It is observed that 35 % of the time the wind speed lies in the range of 8 m/s to 12 m/s in the western part of the site.

2.1. Wind Farm Modeling Software

Wind farm modeling software can be used to identify optimum locations of wind turbines in a given region. Further, the software tools facilitate improvements in cost efficiency and annual energy production (AEP). The software tools for complex terrain use Computational Fluid Dynamics (CFD) based mathematical models, whereas those for flat terrain use linear tools [4]. Meteodyn WT was developed in 2003 by Didier Delaunay [5]. Meteodyn WT software uses CFD computations in complex terrain as WindSim software does [6]. Meteodyn WT is also a CFD software including a Navier stokes equation solver as well as automatically boundary fitted mesher. Meteodyn WT has calculation ability over very large domains and unequaled speed of calculation because of the MIGAL solver [7]. The CFD code in Meteodyn WT is fully developed by Meteodyn, which removes all the limitations of Phoenics, used by WindSim, especially regarding the mesh. Mesh automatically aligned with the flow, it avoids numerical dispersion (better convergence with Meteodyn) [5]. The researchers in the past have presented some validation cases for real wind farm sites using Meteodyn-WT software [8]–[10].

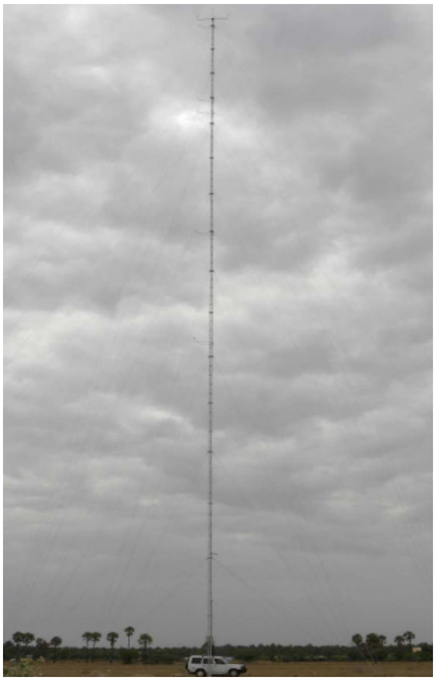


Fig.1. Met mast of 85 m

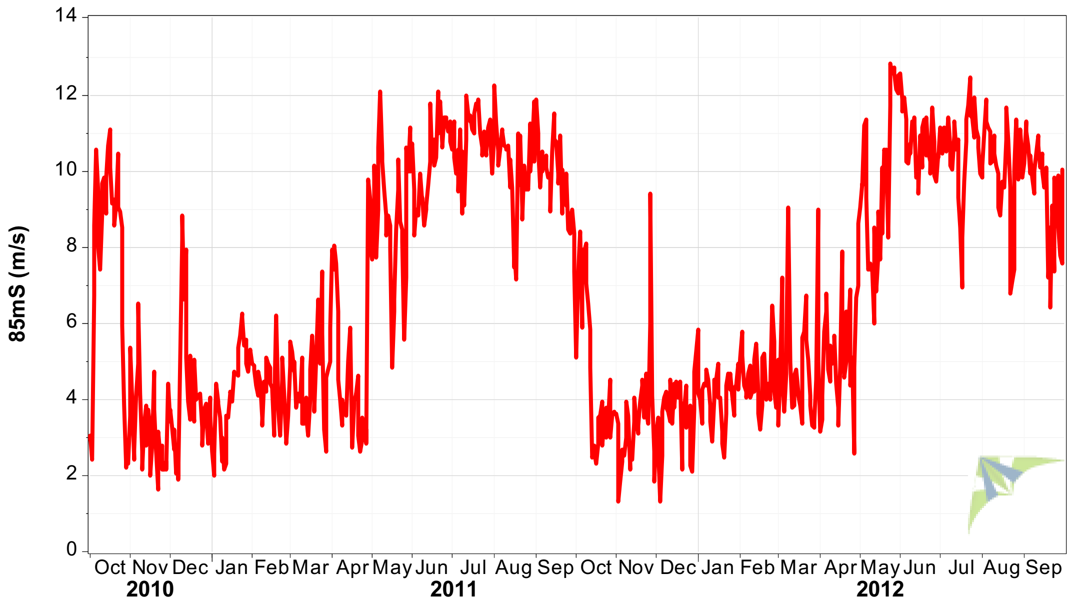


Fig.2. Variation of daily average wind speed (85 m)

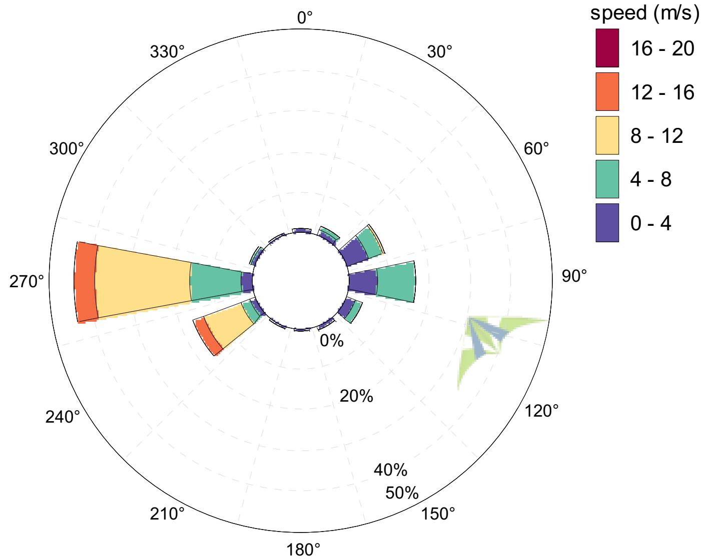


Fig.3. Wind rose diagram

2.2. Details of wind farm site needed for using Meteodyn software

The terrain data in-terms of orography and roughness of the site is shown in Fig.4 and Fig 5, respectively. The histogram showing the distribution of wind speeds are shown in Fig. 6. It is observed that 35% of the time the wind speed lies in the range of 8m/s to 12 m/s in the western part of the site.

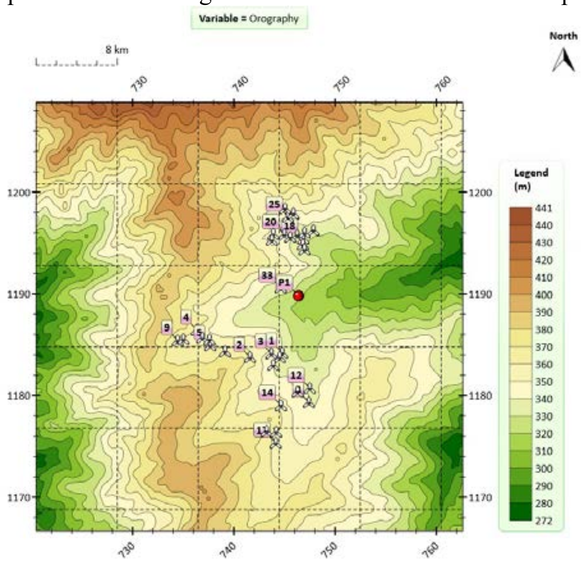


Fig.4. Orography of the site

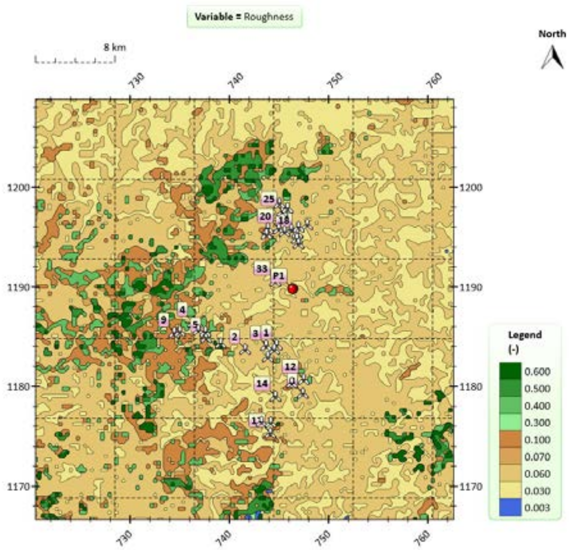


Fig.5. Roughness of the site

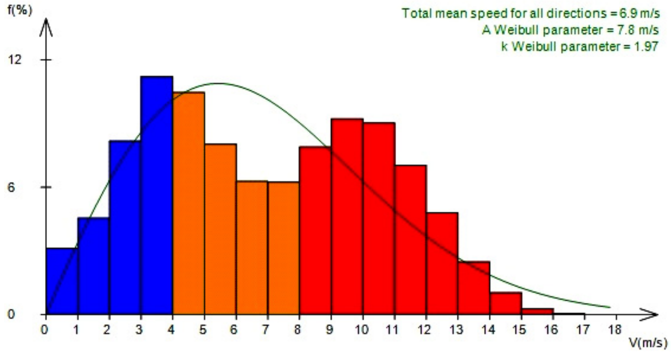


Fig.6. Histogram of wind speed distribution

The wind farm consists of 33 wind turbines that are located at widely separated locations on the site. Table 1 provides information of the turbine locations (turbine ID), height of the hub above mean sea level, nearest turbine and the distance from the nearest turbine. These wind turbines and met mast are installed at a height of 85 m AGL at the site. The co-ordinate system used is Universal Transverse Mercator (UTM) co-ordinate system. The terms Eastings and Northings are geographic Cartesian coordinates for a point. Easting refers to the eastward-measured distance (or the x co-ordinate), while northing refers to the northward-measured distance (or the y co-ordinate) UTM-zones.

Table 1. Location of wind turbine positions specified in-terms of UTM co-ordinates at the site

Turbine ID	Eastings (m)	Northings (m)	Height (m)	Nearest turbine ID	Distance to nearest turbine (m)	Average wind speed (m/s)	Wind power density (W/m^2)
1	744820	1184171	333	15	499.2	6.83	369.3
2	741636	1183743	361	3	2145.7	6.85	375.3
3	743752	1184099	345	15	899.5	6.87	376.9
4	736383	1186434	356	6	948.9	6.71	358.8
5	737708	1184902	358	7	590.9	6.86	382.1
6	736932	1185660	353	7	720.8	6.72	361.3
7	737632	1185488	353	5	590.9	6.80	371.0
8	747458	1179314	340	12	1397.5	6.84	374.3
9	734493	1185390	364	10	580.7	6.75	369.3
10	735059	1185520	360	9	580.7	6.73	365.4
11	739179	1184331	360	5	1577.9	6.88	385.8
12	747541	1180709	335	13	1251.2	6.84	375.4
13	746338	1180365	339	12	1251.2	6.93	389.1
14	744693	1179009	350	13	2131.8	6.97	397.4
15	744575	1183736	334	1	499.2	6.74	355.4
16	743936	1182983	338	15	987.6	6.76	359.9
17	744176	1175324	357	27	1082.9	6.83	373.1
18	746895	1195407	331	24	577	6.79	361.7
19	746290	1195750	331	18	695.5	6.74	355.3
20	745026	1195822	335	23	645.3	6.71	351.3
21	743944	1195863	342	30	605.9	6.71	351.0
22	747898	1196242	334	28	905.8	6.81	364.3
23	745613	1195554	333	20	645.3	6.75	356.6
24	746861	1194831	329	31	518.4	6.75	357.0
25	745392	1197556	345	29	623	6.86	377.3
26	743285	1176472	363	27	936.3	6.93	391.3
27	744219	1176406	358	26	936.3	6.89	384.1
28	747026	1195997	338	18	604.4	6.83	367.5
29	745914	1197896	347	25	623	6.88	380.8
30	743798	1195275	345	21	605.9	6.76	360.5

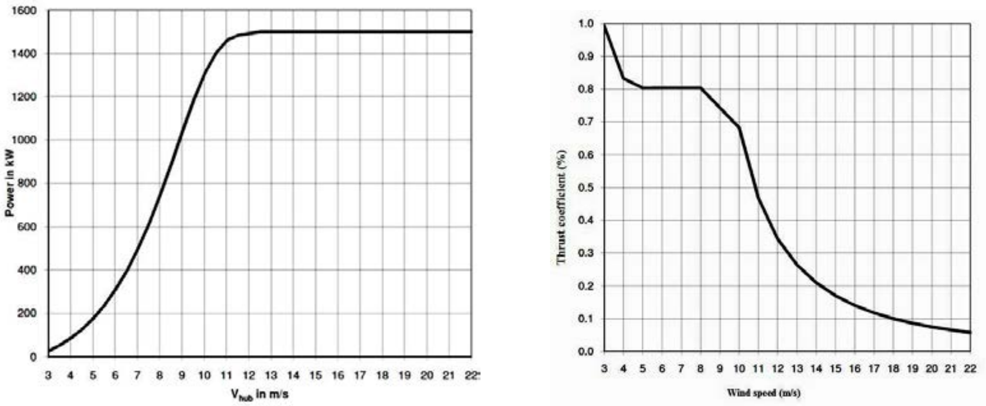
31	747015	1194336	327	24	518.4	6.78	362.4
32	745103	1198371	354	25	864.7	6.92	389.1
33	744680	1190579	336	31	4423.5	6.96	393.6

2.3. Wind turbine properties

The wind turbines used in the wind farm are manufactured by ReGenTech, Vensys82 with rated power of 1500 KW [11]. The wind turbine properties are listed in Table 2. Also the power curve and thrust coefficient curve of the wind turbine used are shown in Fig. 7.

Table 2. Specifications of wind turbine used at the site.

Name	Vensys82
Manufacturer	ReGen Tech
Hub height and rotor diameter	85 m and 82 m
Cut-in, Rated ,Cut-out speed (m/s)	3 ,12.5 & 22



(a) Power curve (b) Thrust curve

Fig.7. Power curve and thrust coefficient curve of wind turbine used for simulation

3. Simulation results obtained using Meteodyn software

This section describes the results obtained after integration of the real climatology of the site. Table 1 also lists the detailed characteristics of the site including mean wind speed and wind power density for the site. It is observed from the table that the minimum mean wind speed of 6.71 m/s occurs at turbine ID-21 and maximum mean wind speed of 6.97 m/s at turbine ID-14. Further, the wind power density is recorded to be minimum for turbine ID- 21 with 351 W/m^2 and maximum of 397.4 W/m^2 recorded for wind turbine ID-14. The wind speed and wind power density map for the site are shown in Figs. 8 and 9, respectively. Similarly, for the mast location the wind speed and wind energy density recorded are 6.92 m/s and 384.2 W/m^2, respectively.

The annual energy production (AEP) with and without wake, wake losses and capacity factor are presented in Table 3. From the table, it is observed that the minimum AEP without wake is estimated as 5296 MWh/year for turbine ID- 21 and maximum of 5627 MWh/year is estimated for turbine ID-14. The maximum wake loss is estimated to be 5.8 % for turbine ID-19. Similarly, the minimum and maximum AEP with wake is estimated as 5031 MWh/year for turbine ID-19 and 5619 MWh/year for turbine ID-14, respectively. The minimum and maximum capacity factor is estimated as 38.29 % and 42.76 % for turbine ID-19 and turbine ID-14, respectively.

The wind-farm production characteristics using Meteodyn software for the entire wind farm are listed in Table 4. The gross AEP (without wake) is estimated as 179.281 GWh/year. Therefore, the capacity factor estimated without considering the wake effect is estimated as 41.34 %. The total wake losses are estimated as 2.547 GWh/year. Thus, the net AEP estimated for the site after wake losses, is found to be 176.734 GWh/year (i.e., 1.42 % losses). Finally, the capacity factor of site with wake effect is estimated as 40.75 %.

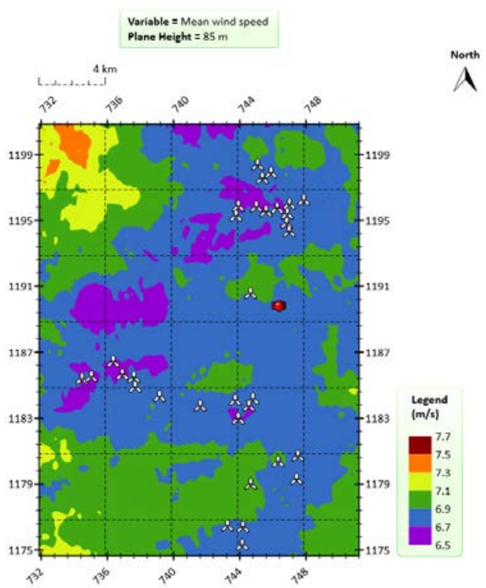


Fig. 8. Simulated average wind speed using Meteodyn

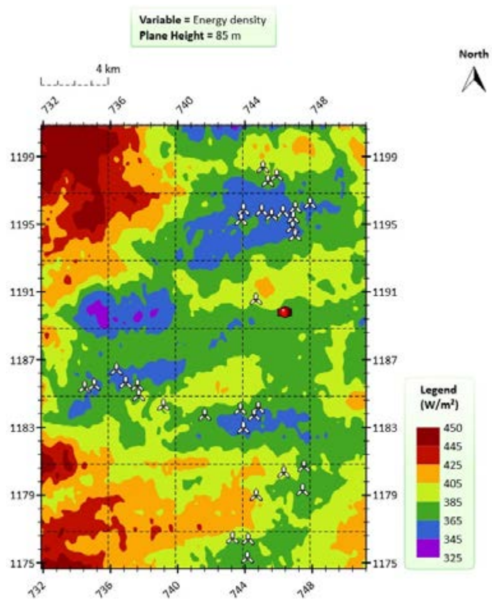


Fig.9. Simulated wind power density map

Table 3. Comparison of AEP and capacity factor with and without wake generated by Meteodyn software

Turbine ID	Without wake losses		Wake losses (%)	With wake losses	
	AEP (MWh/year)	Capacity factor (%)		AEP (MWh/year)	Capacity factor (%)
1	5443	41.42	2.7	5295	40.30
2	5461	41.56	0.6	5431	41.33
3	5488	41.77	1.4	5410	41.17
4	5296	40.30	0.4	5275	40.14
5	5482	41.72	0.5	5454	41.51
6	5315	40.45	1.5	5237	39.86
7	5408	41.16	2.7	5260	40.03
8	5479	41.70	0.6	5448	41.46
9	5347	40.69	0.8	5304	40.37
10	5324	40.52	4.7	5076	38.63
11	5498	41.84	0.3	5484	41.74
12	5472	41.64	1.2	5404	41.13
13	5575	42.43	0.3	5556	42.28
14	5627	42.82	0.1	5619	42.76
15	5327	40.54	0.7	5287	40.24
16	5384	40.75	0.2	5342	40.65
17	5453	41.50	0	5453	41.50
18	5394	41.05	2.4	5265	40.07
19	5342	40.65	5.8	5031	38.29
20	5301	40.34	4.3	5074	38.61
21	5296	40.30	0.6	5264	40.06
22	5419	41.24	2.7	5272	40.12
23	5347	40.69	2.5	5212	39.17
24	5346	40.68	0.4	5324	40.52
25	5493	41.80	0.4	5473	41.65
26	5580	42.47	0.4	5555	42.28

27	5533	42.11	3.3	5353	40.74
28	5445	41.44	3.4	5257	40.01
29	5517	41.99	1.5	5435	41.36
30	5365	40.83	0.4	5342	40.65
31	5382	40.96	0.1	5377	40.92
32	5563	42.34	0.1	5558	42.30
33	5612	42.71	0	5610	42.69

Table 4. The wind farm production characteristics using Meteodyn software

No. of turbines	Capacity (MW)	Gross AEP (GWh/year)	Capacity factor (%)	Wake losses (%)	AEP with wake losses (GWh/year)	Capacity factor (%)
33	49.5	179.281	41.34	1.42	176.734	40.75

4. Conclusions

In this paper, Meteodyn software is used to estimate the wind resource potential for the existing wind farm. Also, in this paper the effect of terrain on wind resource assessment is considered. The wind resource characteristics of the site are predicted at different locations of the site, where turbines can be installed. Further, the wind resource maps for the site are developed which provide insight to the developers to install turbines at the potential positions in wind farm to capture maximum energy production. The characteristics of wind resource determined from the met mast location can be used to predict to other locations at the site where measurements are not available. These lead to improved accuracy of estimation of wind power potential at the site. The following conclusions are drawn:

1). The average wind speed at mast location is found to be 6.9 m/s. Whereas, the maximum wind speed in the windfarm site is found to be 7.7 m/s. Also the maximum wind power density at the site is found to be 450 W/m^2.

2) The annual energy production without wake at the site is estimated as 179.281 GWh/year and with wake effect is 176.734 GWh/year.

3) The capacity factor of the site, without and with wake is estimated as 41.34 % and 40.75 %, respectively.

Acknowledgements

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References

[1].Global Wind Energy Council (GWEC), http://www.gwec.net/wpcontent/ uploads/vip/GWEC-Global-Wind-2015-Report-April-2016.19.04.pdf.

[2] National Institute of Wind Energy (NIWE), http://niwe.res.in/departmentwra.php.

[3] Windographer Software, https://www.windographer.com/.

[4] M. Strack and V.Riedel,"State of the art in application of flow models for micrositing", in Proceedings of DEWEK, Germany, pp.1-6, 2004.

[5] Meteodyn WT Software, http://meteodyn.com/en/.

[6] Carlos Diaz Asensio Mancebo," Comparison study for WRA in complex domain using Meteodyn and WindSim", M.S. thesis, Uppsala University,May 2014.

[7] M.Ferry,"New features of MIGAL solver", in Proceedings of the Phoenics Users, International Conference", September, Moscow, 2002.

[8] W. Promsen, I. Masiri and S. Janjai,"Development of microscale wind maps for Phaluay Island, Thailand",Procedia Engineering, Vol.32,pp.369 -375,2012.

[9] A.Chantelot, D.Delaunay, T.Clarenc and D.Koulibaly," Wind resource assessment in forested and complex terrain", European Wind Energy Conference, Athens, Greece, pp.1-4, 2006.

[10] A.Chantelot, D.Delaunay, T.Clarenc and D.Koulibaly, "Wind farm production assessment in complex terrain: New validations of Meteodyn WT", European Wind Energy Conference, Milan, pp.1-3, 2007.

[11] ReGen Powertech, http://www.regenpowertech.com/.