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Micro-Scale Modelling for Wind Atlas and Wind Climate Prediction at RGPV Hill Top, Bhopal (India)

Chetan Awasthi [1], Anurag Gour [2], Pankaj Jain [2] and Mukesh Pandey [3]
[1]*Scholar*, [2]*Asst. Professor*, [3]*Professor*
Department of Energy Technology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal (M.P.)

Abstract

In the micro-scale modelling for wind resource, details of elevation contour map, roughness of the site and its surroundings, obstacles near the measurement site is used for WAsP software to increase accuracy in the output. The micro-scale modelling is crucial for the understanding the wind potential of the area, options available for the planning and development of wind energy plants and installation of wind turbines at the place of maximum power density to generate electricity from wind. The purpose of this paper is to provide generalized wind climate (GWC) or wind atlas, power density, wind climate prediction of wind turbines and resource grid with power density and mean wind speed for RGPV Hill Top based on the data measured from an anemometer mast at RGPV Energy Park, Bhopal (India) using WAsP wind software for micro-scale modelling.

Index Terms — Generalized wind climate, micro-scale modelling, wind power density, resource grid, WAsP.

1. Introduction

Windmills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. From as early as the thirteenth century, horizontal-axis windmills were an integral part of the rural economy and only fell into disuse with the advent of cheap fossil-fuelled engines and then the spread of rural electrification [1]. The wind is the fuel, which drives the turbine, which generates electricity. But unlike fossil fuels, it is free and clean [3].

Thus, wind resource assessment is vital for the generation of electricity from wind. Several approaches are available when investigating the wind resource within a given land area. These approaches can be categorized as three basic scales or stages of wind resource assessment [2]: preliminary area identification, area wind resource evaluation, and micro siting. These approaches are explained in [2].

Once the wind speed on the site has been estimated, it is then vital to make an accurate and reliable estimate of the resulting energy production from a wind farm that might be built there. This requires wind farm modelling and detailed investigation of the environmental constraints [3].

2. Micro-Scale Modeling with WAsP

The method of modelling for wind current formation in consideration of the influences of a relief conditions, shading obstacles and the character of a bedding surface roughness is stated. Further, the theoretical bases of the wind energy potential modelling are set forth [4].

Micro-scale modelling relies on two key components or inputs, namely terrain and wind climate. The terrain can be broken down further into orography, roughness and obstacles. Wind climate can be observational wind atlas (OWA) derived from measurements [5]. This paper will address the use of observed raw wind data for providing Wind Atlas and predicted wind climate in WAsP. As with any computer simulation, the more accurate the input data, the more accurate will be the results.

The modelling methodology for wind atlas and predicted wind climate is well explained in [7], [8]. This methodology has two main parts: analysis and application. The analysis process provides the Wind atlas from recorded wind data (wind speed and direction) and measurement site description. In application process, predicted wind climate is calculated from wind atlas or generalised wind climate and wind turbine site description.

1. Time-series of wind speed and direction → observed wind climate (OWC)
2. OWC + met. mast site description → generalised wind climate (wind atlas)
3. Generalised wind climate + site description → predicted wind climate (PWC)

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Accurate and reliable estimate of the resulting energy production of a wind energy conversion system, wind flow modelling of the site is a prerequisite [9].

3. Vector Map

Vector maps are used to describe the elevation (orography) and land cover (surface roughness) of the area surrounding calculation sites such as meteorological stations, reference sites, turbine sites or the sites in a resource grid. WAsP uses vector maps, in which terrain surface elevation is represented by height contours and roughness lengths by roughness change lines. The map coordinate system must be Cartesian and the coordinates must be given in meters [6], [7].

Prediction errors can be reduced with smaller contour intervals with a contour interval of 20 m or less [10], [11]. Vector map of the site is developed using SRTM 90m data [12] and elevation contour lines are generated by Global Mapper and WAsP Map Editor. Roughness change lines of the area are created from land cover data in Google Earth.

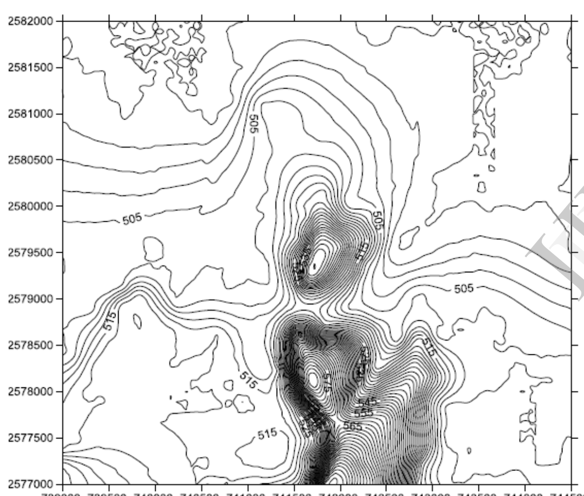

Fig. 1 Vector map of RGPV Hill Top

Study site under consideration covers an area of approximately 28 square kilometers in undulating topography, interspersed with water bodies, cultivated and barren land and semi urban dwellings. The map of the whole area was digitised with elevation contours at 5m intervals.

The map has 132 elevation contour lines and 12 roughness change lines. It describes an area with SW/NE corners thus: (738971.6, 2576972.0)/ (744527.8, 2582000.0). The width is 5.556188 km, the height is 5.02775 km, and the area is 27.935122 km².

4. Wind Atlas

Typically, these wind-mapping programs will derive a graphical representation of mean wind speed (for a specified height) across an area. This may take the form of a 'wind atlas', which represents the wind speed over flat homogeneous terrain, and requires adjustments to provide a site-specific wind speed prediction to be made with due consideration of the local topography [3].

Obstacle groups are used to describe objects in the vicinity of one or more calculation sites (met. station, turbine site or reference site) which might affect the behaviour of the wind at the site. Examples of sheltering obstacles include buildings, shelter belts and groups of trees. Data in WAsP obstacle groups describe the obstacles using a site-relative coordinate system and obstacles are represented as 3-dimensional boxes with a rectangular footprint and cross-section. A maximum of 50 obstacles can be specified in one list [7].

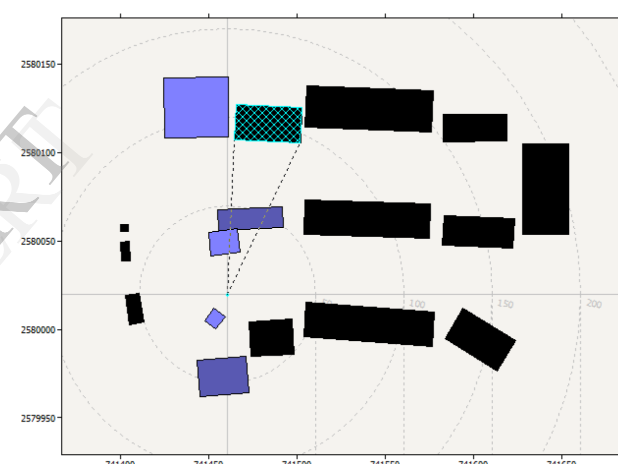

Fig. 2 Obstacle group model

The analysis of any time-series of wind measurements provides a statistical summary of the observed, site-specific wind climate. This part is implemented in separate software tools: the WAsP Climate Analyst. Analyzed wind data can be converted into a generalized wind climate or wind atlas data set. In a wind atlas data set the wind observations have been 'cleaned' with respect to the site-specific conditions. The wind atlas data sets are site-independent and the wind distributions have been reduced to certain standard conditions [6], [7]. Location of 'Energy Park RGPV' in the map: (741460.5, 2580020.0).

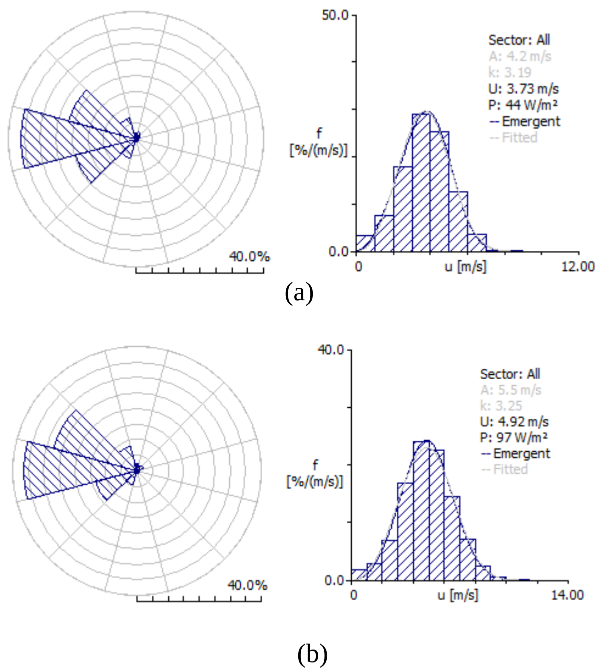

Fig. 3 Wind rose and Weibull distribution (a) for 20m and (b) for 40m height of RGPV Energy park mast

Table 1 and 2 show the wind atlas calculated for two heights. The wind atlas has been calculated at default air density of 1.225 Kg/m^3.

Table 1 Wind Atlas at 20m

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m	1.50 m
10.0 m	Weibull A [m/s]	5.6	4.1	3.6	2.8	1.8
	Weibull k	3.30	2.94	2.88	2.87	2.59
	Mean speed [m/s]	5.05	3.65	3.17	2.50	1.64
	Power density[W/m²]	106	42	28	14	4
25.0 m	Weibull A [m/s]	6.2	4.9	4.4	3.7	2.8
	Weibull k	3.40	3.16	3.07	3.04	2.72
	Mean speed [m/s]	5.54	4.37	3.91	3.29	2.48
	Power density[W/m²]	137	70	51	30	14
50.0 m	Weibull A [m/s]	6.6	5.6	5.1	4.4	3.6
	Weibull k	3.49	3.51	3.37	3.30	2.92
	Mean speed [m/s]	5.95	5.06	4.59	3.98	3.19
	Power density[W/m²]	168	103	78	52	28
100.0 m	Weibull A [m/s]	7.2	6.6	6.1	5.3	4.5
	Weibull k	3.40	3.72	3.67	3.69	3.29
	Mean speed [m/s]	6.45	5.98	5.46	4.82	4.00
	Power density[W/m²]	217	166	127	87	53
200.0 m	Weibull A [m/s]	7.9	8.1	7.4	6.6	5.6
	Weibull k	3.26	3.59	3.54	3.57	3.24
	Mean speed [m/s]	7.10	7.31	6.67	5.91	5.00
	Power density[W/m²]	295	308	235	164	103

Table 2 Wind Atlas at 40m

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m	1.50 m
10.0 m	Weibull A [m/s]	6.1	4.4	3.9	3.0	2.0
	Weibull k	3.22	2.85	2.84	2.79	2.61
	Mean speed [m/s]	5.46	3.94	3.43	2.68	1.78
	Power density[W/m²]	135	54	36	17	5
25.0 m	Weibull A [m/s]	6.7	5.3	4.7	4.0	3.0
	Weibull k	3.32	3.06	3.02	2.95	2.74
	Mean speed [m/s]	5.99	4.71	4.23	3.54	2.69
	Power density[W/m²]	175	89	65	38	18
50.0 m	Weibull A [m/s]	7.2	6.1	5.5	4.8	3.9
	Weibull k	3.40	3.41	3.32	3.20	2.94
	Mean speed [m/s]	6.43	5.45	4.97	4.27	3.45
	Power density[W/m²]	215	130	100	65	36
100.0 m	Weibull A [m/s]	7.8	7.2	6.6	5.7	4.8
	Weibull k	3.31	3.62	3.62	3.58	3.29
	Mean speed [m/s]	6.98	6.45	5.91	5.18	4.33
	Power density[W/m²]	278	210	162	109	67
200.0 m	Weibull A [m/s]	8.6	8.8	8.0	7.1	6.0
	Weibull k	3.19	3.49	3.49	3.46	3.24
	Mean speed [m/s]	7.68	7.88	7.21	6.35	5.42
	Power density[W/m²]	377	391	299	205	131

The generalized wind climate contains data for 5 reference roughness lengths (0.000 m, 0.030 m, 0.100 m, 0.400 m, 1.500 m) and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level. The roses of Weibull parameters have 12 sectors each.

5. Predicted Wind Climate

Using a wind atlas data set calculated by WAsP or one obtained from another source – e.g. the European Wind Atlas – the program can estimate the wind climate at any specific point and height by performing the inverse calculation as is used to generate a wind atlas. By introducing descriptions of the terrain around the predicted site, the models can predict the actual, expected wind climate at this site [7].

In general terms, accurate predictions using the WAsP program may be obtained provided [7], [8]:

- the reference site (meteorological station) and predicted site (wind turbine site or met. station) are subject to the same overall weather regime,
- the prevailing weather conditions are close to being neutrally stable,
- the reference wind data are reliable,
- the surrounding terrain (of both sites) is sufficiently gentle and smooth to ensure mostly attached flows, and
- the topographical model inputs are adequate and reliable.

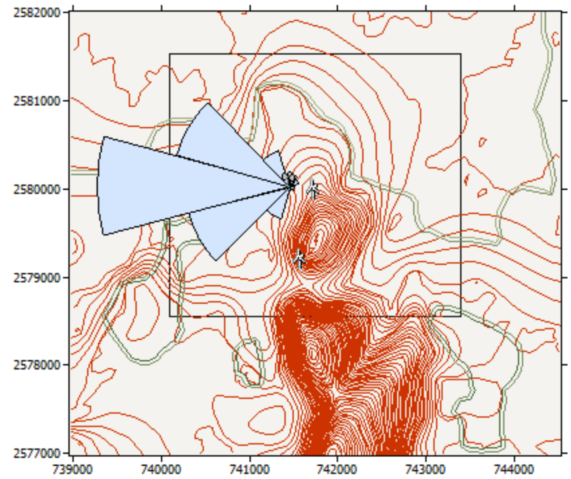

Fig. 4 Observed wind frequency at 20m

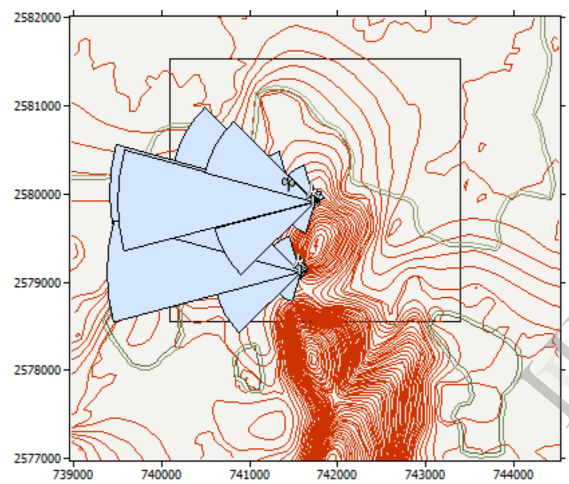

Fig. 5 Predicted wind frequency at 20m

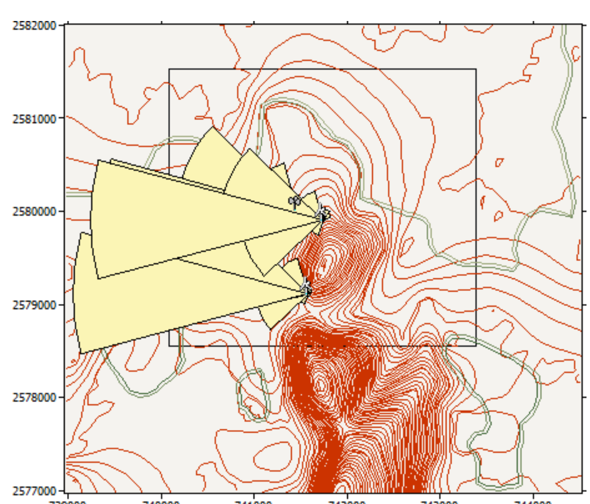

Fig. 6 Predicted power density at 20m

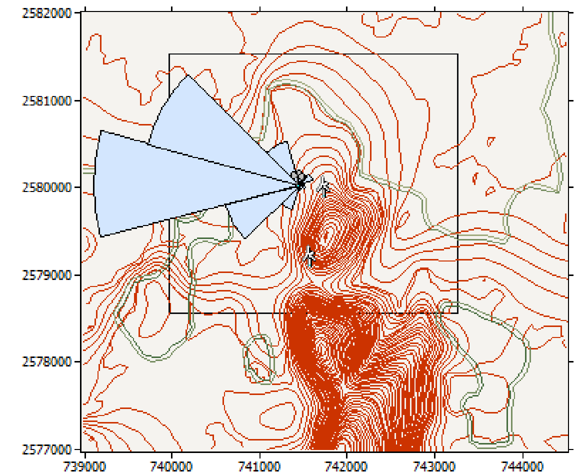

Fig. 7 Observed wind frequency at 40m

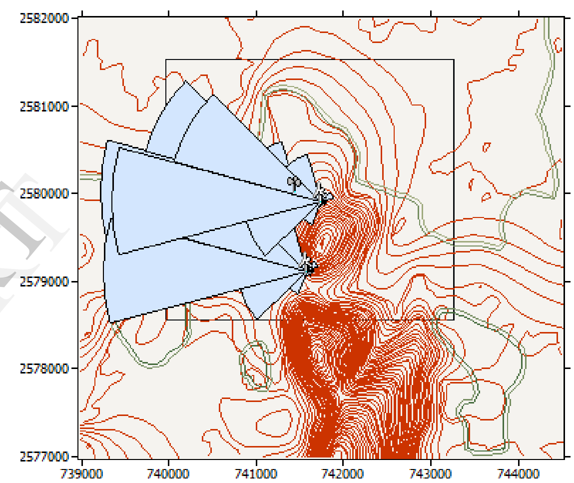

Fig. 8 Predicted wind frequency at 40m

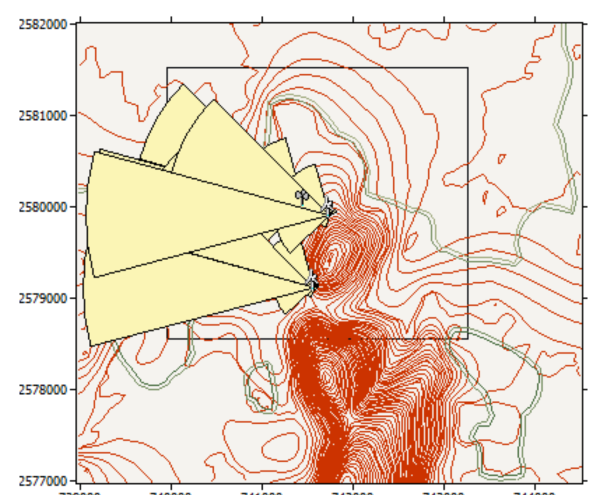

Fig. 9 Predicted power density at 40m

6. Resource Grid

Resource grids let you manage a rectangular set of points for which summary predicted wind climate data are calculated. The points are regularly spaced and are arranged into rows and columns. This lets you see a pattern of wind climate or wind resources for an area. You don't need to create each point in the grid individually. Instead you just specify the location of the grid, the number of rows and columns and the distance between the points [7].

WAsP is a linear flow model for neutrally stratified flow. It does not account for Coriolis accelerations. Hence, it can only simulate flow over weak to moderately steep terrain on scale of less than a few kilometres distance. Considering the simplifications made to the physics it is astonishing, how well the model can be applied in many situations. WAsP is used all over world for wind resource assessment. Typical errors of the annual energy prediction of wind turbines are about 10 %. In complex terrain as e.g. mountains larger errors must be expected. The so-called self-prediction of a station is usually very accurate, with errors of less than 2 %. It is the prediction for exactly the same location where the original data was measured using the wind atlas generated from it [13].

The structure of resource grid has 10 columns and 9 rows at 330 resolutions give 90 calculation sites. Boundary coordinates are from (740091, 2578556) to (743391, 2581526) and nodes from (740256, 2578721) to (743226, 2581361) for height 20m above ground level. For height 40m above ground level, boundary coordinates are from (739964, 2578557) to (743264, 2581527) and nodes from (740129, 2578722) to (743099, 2581362).

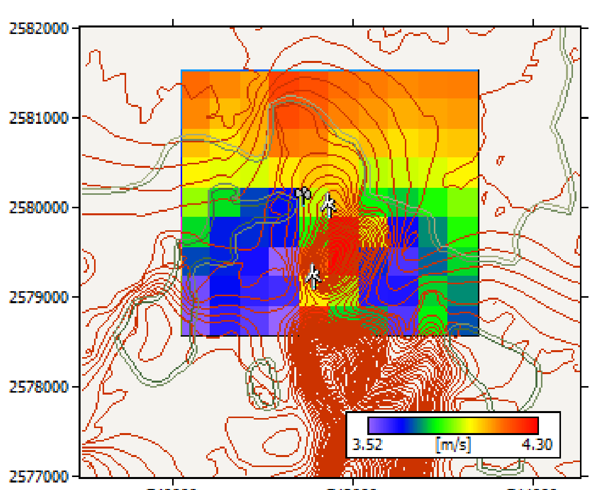

Fig. 10 Mean wind speed of resource grid at 20m

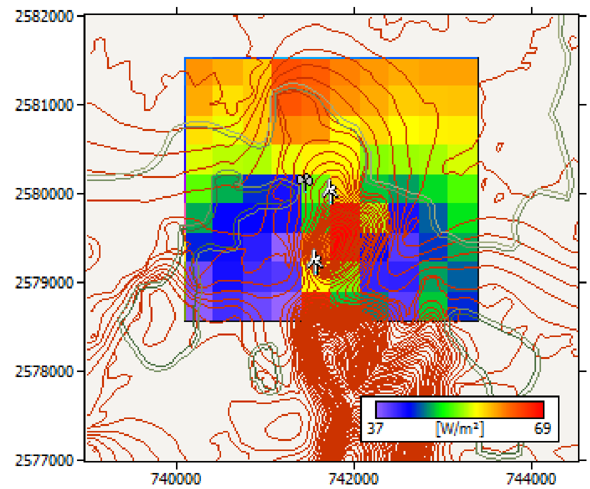

Fig. 11 Power density of resource grid at 20m

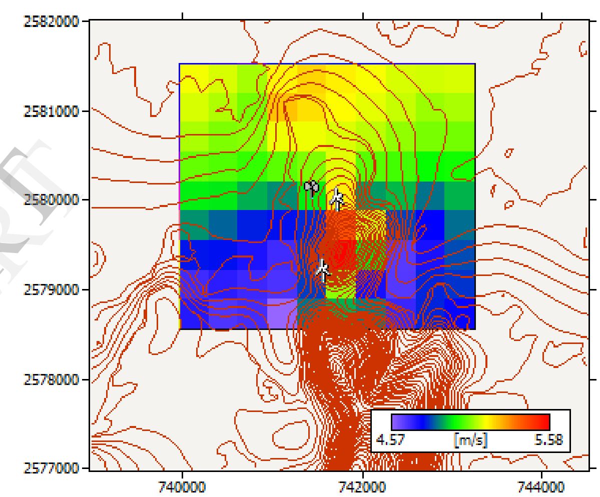

Fig. 12 Mean wind speed of resource grid at 40m

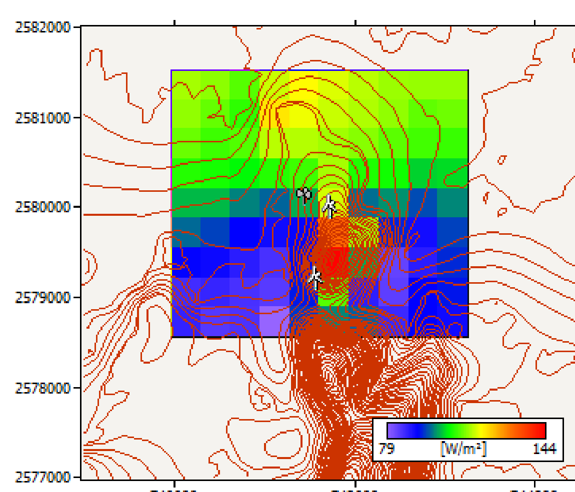

Fig. 13 Power density of resource grid at 40m

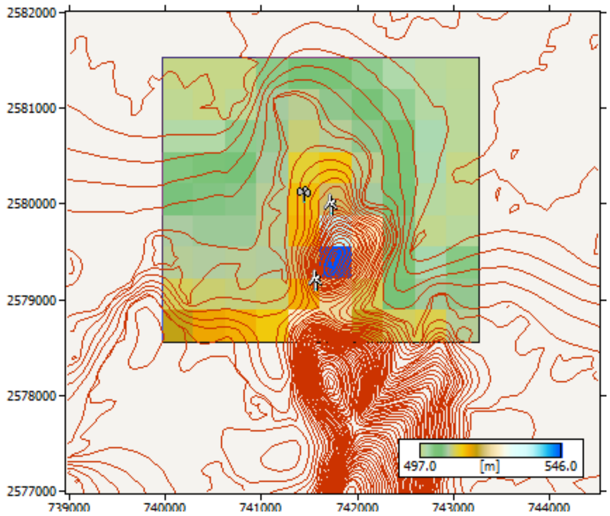

Fig. 14 Elevation Profile of Resource Grid

7. Conclusion

The following points are concluded from this study:

1) Wind atlas for two reference heights i.e. 20m and 40m are calculated from the observed wind climate.
2) Predicted wind climate for 20m and 40m height is also calculated. Observed wind frequency, predicted wind frequency and power density for the mast and sites have been obtained at 20m and 40m height.
3) Resource grids are also obtained with mean wind speed and power density at 20m and 40m height.
4) It is seen that the minimum wind speed is 3.52 m/s at (741246, 2578721) and maximum wind speed is 4.30 m/s at (741906, 2579381) with mean wind speed of 3.91 m/s from 20 m resource grid.
5) It is also seen that the minimum power density is 37 W/m² at (741246, 2578721) and maximum power density is 69 W/m² at (741906, 2579381) with mean power density of 52 W/m² from 20 m resource grid.
6) It is seen that the minimum wind speed is 4.57 m/s at (741119, 2578722) and maximum wind speed is 5.58 m/s at (741779, 2579382) with mean wind speed of 4.97 m/s from 40 m resource grid.
7) It is also seen that the minimum power density is 79 W/m² at (741119, 2578722) and maximum power density is 144 W/m² at (741779, 2579382) with mean power density value of 102 W/m²from 40 m resource grid.
8) In this study only 12 roughness change lines are used. More accurate roughness inputs can help in more accurate results of the modeling.

8. Acknowledgment

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