WIND ENERGY ESTIMATION FOR PRODUCTION OF ELECTRICITY IN IRAN

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Abstract This paper covers the estimation of the average yearly production of an appropriate wind turbine for different locations in Iran. The effects of topography, the influence of obstacles such as buildings and shelters, the collective effects of the surrounding terrain, roughness classifications, and orographic elements such as hills, cliffs, etc., all have been included in the calculations. A full sitting procedure such as availability of power lines, the present and future use of land, etc., have also been taken into account. In order to have an accurate estimation, the selected climatology stations are located no more than 50 km from the site. Information such as number of sites, number and types of typical turbines and their specification, nominal and available power capacity, overall efficiency, and yearly energy production are calculated by the developed mathematical model for 13 different locations. The total nominal power capacity for these sites is close to 5000 MW with an overall efficiency between 33% to 45%. This is equivalent to an annual energy production of 15333 (GWh/yr). The present study shows a promising future for the application of wind energy to produce electricity in Iran.

Key Words Wind Energy; Wind Turbines; Wind Farms; Renewable Energy; Site Selection; Wind Resources Simulation; Electric Demand

چکیده دراین مقاله مقدار انرژی سالیانه تولیدی برای یک توربین بادی مناسب در نقاط مختلف ایران توسط یک مدل ریاضی طراحی شده محاسبه گریده است. دراین مدل اثرات توپوگرافی، موانع نظیر ساختمانها و سرپناه ها، پستی و بلندیهای طبیعی اطراف سایت، زبری زمین و طبقه بندی آنها، جزئیات اروگرافی نظیر تپه ها، صخره ها و غیره همگی در مدلسازی و محاسبات درنظر گرفته شده اند. اثرات سایر موارد نظیر مسیر خطوط برق فشار قوی، کاربری فعلی و آتی زمین، مسیر مهاجرت پرندگان و غیره یز مورد ارزیابی قرار گرفته اند. بمنظور انجام محاسبات با دقت بالا از ایستگاه های هواشناسی حداکثر به فاصله ۵۰ کیلومتری سایت موردنظر استفاده شده است. توسط مدل ریاضی توسعه یافته اطلاعاتی نظیر سایتها در هر منطقه، تعداد و نوع توربینها و مشخصات آنها نظیر قدرت اسمی و قابل عرضه، راندمان کلی، انرژی سالیانه تولیدی برای سیزده منطقه مختلف محاسبه شده است. ظرفیت اسمی قدرت نصب شده دراین سایتها بالغ بر ۵۰۰۰ مگاوات تخمین زده میشود که در آن توربینها با راندمان کلی ۳۳ درصد الی ۴۵ درصد کار می نمایند. در واقع این پتانسیل معادل تولید انرژی سالیانه بالغ بر ۱۵۳۳۳ (Gwh-yr) میباشد این مطالعات نشاندهنده آینده ای روشن و برای بکارگیری انرژی باد در تولید برق کشور میباشد.

INTRODUCTION

During the 1970's and 1980's international conferences meetings were held to discuss how different countries could become, as much as possible, independent of fossil fuels. In recent years, wind energy in the form of a large number of wind powered turbines connected to the national electricity grid system, has been identified as another source of energy. Using the mathematical model for the assessment of wind energy resources on selected sites, potentially suitable for wind energy applications, has been a major part of this work [1]. Eventhough wind turbines have demonstrated technical and economical viability on a large scale for many places in the world, and eventhough wind turbines in principle are considered better suited for operation in remote areas, accurate prediction of outputs from a wind energy project is more difficult than those from traditional electrification [1].

The major environmental benefit of wind energy is that it generates high-grade without producing carbon dioxide, ash, or emissions that contribute to acid rain [2].

GENERAL CONCEPTS

The main goal of this paper is to predict average yearly energy production of a specific wind turbine at a specific location, and to select suitable sites in the country.

In order to calculate the effects of topography on the wind, it is necessary to describe systematically the characteristics of the topography. The collective effect of the surrounding terrain and obstacles, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain. Vegetation and houses are examples of topographical elements which contribute to the roughness. Orographic elements such as hills, cliffs, escarpments and ridges exert an additional influence on the wind. Near the summit or crest of these features the wind will accelerate, while near the foot and in valleys it will decelerate.

A sitting procedure includes some or all of the following steps:

1) Selecting the appropriate regional wind climatology
2) Determining the influence of the roughness of the surrounding terrain
3) Determining the influence nearby sheltering obstacles
4) Determining the effect of local Orography
5) Calculating the resulting Weibull distribution
6) Calculating the mean power by means of the Weibull distribution and the power curve of the wind turbine

It is preferable to select a station in a topographical setting similar to that of the site. This consideration is particularly important in mountainous and coastal areas. The selected station should preferably be no more than 50 km from the site.

Roughness Classification and Calculation of Statistics for a Site

The roughness classification of the terrain at a given site is a matter of assigning the correct roughness lengths or roughness classes to the various types of surface around the site. The horizon is first divided into twelve 30 degree sectors and the classification is then done sector by sector. Then the corresponding Weibull distributions are found in the selected regional statistics. If the terrain is of the same roughness class for all sector, the statistics are obtained directly from the "Total" columns. Most often the terrain roughness is not the same in all directions and, therefore, the sector statistics have to be combined into one Weibull distribution function for the site [3].

The Roughness of a Terrain

The different terrains have been divided into 4 types, each characterized by its roughness elements. Each terrain type is referred to as a "roughness class"[4].

Figure 1 shows the wind profile and roughness

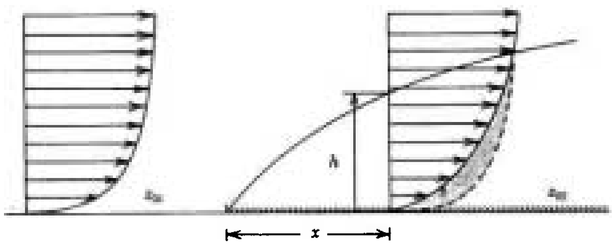

Figure 1. Idealized Situation of Flow with a Marked Change of Roughness Class

change, together with the modified profile at a distance x downwind from the change. The roughness after the change is z_{02}. The height of the internal boundary layer is a function of x.

If the hub height is less than h(height of internal boundary layer), then the Weibull parameter A, determined for the upwind condition is corrected to the site condition as follows:

$$A_{site(z_{02})} = A_{upwind(z_{01})} \cdot Cor$$

$$Cor = \frac{\ln(z/z_{02}) \ln(h/z_{01})}{\ln(z/z_{01}) \ln(h/z_{02})}$$

Figure 2 shows height of the boundary layer as a function of distance x downstream from a roughness change, for the 4 following roughness classes:

class 0	z_o= 0.0002 m
class I	z_o= 0.03 m
class II	z_o= 0.10 m
class III	z_o= 0.40 m

Calculation of Shelter

The location of wind turbine close to the buildings should be avoided, because the life time of the turbine might be shortened due to the disturbed flow around the buildings and thus the power production would reduce, [5].

Whether an obstacle provides shelter at the specific site, depends upon:

- The distance from the obstacle to the site
- The height of the point of interest at the site
- The height of the obstacle
- The length of the obstacle
- The porosity of the obstacle

Figure 3 shows the reduction of the wind speed D due to the shelter by a two-dimensional obstacle. In the shaded area, the sheltering is quite dependent on the detailes geometry of the obstacle, and the wind speed is usually increased close to and above the obstacle, similar to the speed-up effects over hills.

Orography

It is well known that at the crest of a hill, the wind will often be stronger than over the surrounding terrain. Therefore, it might be advantageous to place the turbines on the top of a hill.

In the orographic model, the digital height contours of a simple Gaussian hill may be generated. The height, location, orientation, and horizontal dimen-

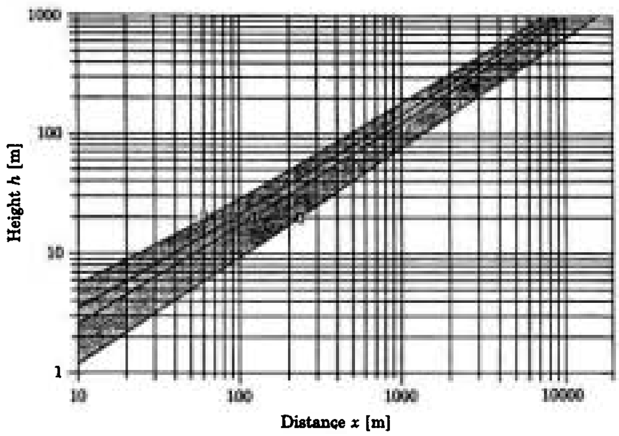

Figure 2. Height of internal boundary layer (h), as a function of distance x downstream from a roughness change, for four Roughness classes

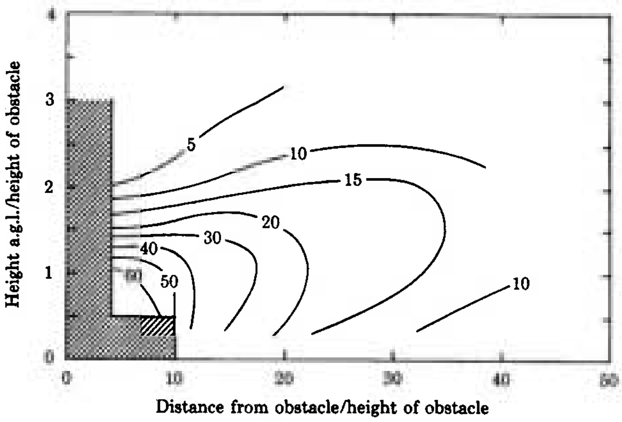

Figure 3. Reduction of the wind speed (R_1) in percent due to shelter by a 2-D obstacle based on the expressions by Perera [5]

sions of the hill are specified by the user. This model can also employ a high-resolution zooming polar grid to simulate the flow over the hills [3]. In this model, the "inner-layer" structure is calculated using a balance condition between surface stress, advection, and the pressure gradient. It uses a simplified geostrophic drag law to calculate u_* from G.

$$u_* = 0.485\, G \left(\ln \frac{G}{|f|\, z_0} - A\right)^{-1}$$

$$G = \frac{u_*}{K} \sqrt{\left(\ln \left(\frac{u_*}{f z_0}\right) - A\right)^2 + B^2}$$

u_*= Surface friction velocity
G= Geostrophic wind speed
f= Coriolis parameter (= 2Ω sin (latitude))
z_0= Surface roughness length
A= 1.8 (for neutral condition)
B= 4.5 (for neutral condition)
K= The Von Karman constant

Power Production

The power production by a wind turbine, varies with the wind that strikes the rotor. If the probability density function is determined through the sitting procedure, it is given as Weibull function in which case the expression of the mean power production becomes:

$$P = \int_0^{\infty} (k/A)\, (u/A)^{k-1} \exp\left(- (u/A)^k\right) P(u) du$$

As a general rule, this integral can not be computed analytically and numerical methods have been applied.

FIELD INVESTIGATIONS

The field investigations were carried out by a survey team from 13 selected sites. Originally 20 locations

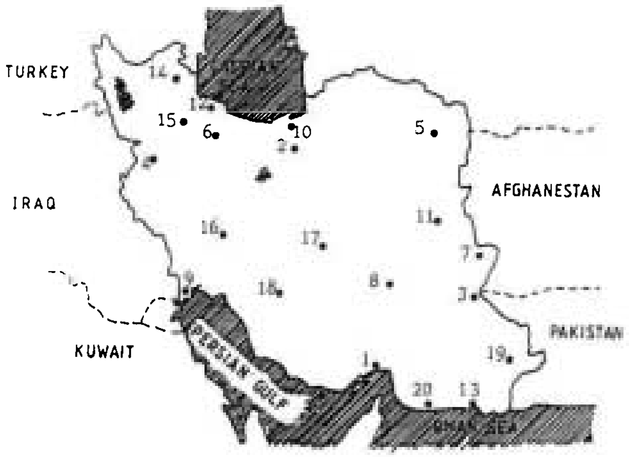

Figure 4. The selected sites for investigation (site numbers are indicated in Figure)

were selected (Figure 4), on the basis of different pieces of information such as population, electricity demand, meteorological conditions, etc. [1]. The survey team filled in a questionnaire (Appendix I) with required pieces of information.

A software was written to organize recorded data, eliminate unwanted records, and draw the required wind rose. Topographical, social, and political maps of all regions were obtained. The team determined the earth surface roughness on azimuth sectors (30°) around the meteorological mast, type, length and height of obstacles and their porosity up to a radius of 5 km and orographic features [4], the possibility of snowing, freezing and flood, soil condition, the distance of the sites from the roads, power lines, airport, mines, dams, radar, telecommunication beams, radio-and T.V.-transmitters, distance from inhabited areas, and the migration routes of the birds. By using a roughness model, for each azimuth sector the classification of roughness was done and the Weibull parameters were determined. The effects of obstacles were also considered by a applying a shelter model up to 30-40 times obstacel's height downstream. Finally the power curve of a convenient wind turbine was calculated and drawn graphically.

THE RESULTS OF COMPUTATION

Using the computer mathematical model, it is found that two types of turbines, i.e. turbines with a nominal capacity of 300 kW and 500 kW are most suited for the selected sites of wind farms. To have a base for comparison, two parameters are defined. First, "Power Density" (PD), which is defined as possible installed capacity per square kilometer of the selected site (MW/km2). Second, "Energy Density" (ED), which is the possible annual energy production per square kilometer of the selected site (MW/km2). The results of calculations per 13 sites are presented below. The following abbreviations are used:

SCN: Site Code Number
W: Prevailing Wind Speed (m/Sec)
WD: Direction of Prevailing Wind Speed (Degree)
NS: Number of Sites
TC: Nominal Turbine Capacity (kW)
NT: Number of Turbines
U: Wind speed at hub height (m/Sec)
E: Energy production (W/m^2)
TNC: Total Nominal Capacity (MW)
AEP: Annual Energy Production (GWh/yr)
SA: Site Area (km^2)
PD: Power Density (MW/km^2)
ED: Energy Density ($GWh/yr/km^2$)

The site code numbers are assigned to locations presented in Table 1.

Table 2 shows the results of the mathematical

TABLE 1. Site Code Numbers for Each Location.

SCN	location	SCN	location	SCN	location
1	Bandar-Abbas	6	Ghazvin	11	Birjand
2	Semnan	7	Zabol	12	Rasht
3	Zahedan	8	Kerman	13	Chah-Bahar
4	Sanandaj	9	Abadan		
5	Torbat, H.	10	Babolsar		

TABLE 2. The Potential of Electricity Production for Various Sites.

SCN	W (m/Sec)	WD (Deg.)	NS	TC (kW)	NT	U (m/Sec)	E (W/m^2)	TNC (MW)	AEP (GWh/yr)	SA km^2	PD (MW/km^2)	ED ($GWh/yr/km^2$)
1	4.4	180	2	*300	1000	5.0	163	300	407.368	9	33.3	45.26
2	4.6	330	1	300	400	6.0	878.44	120	233.368	4	30	58.342
3	6.0	0	2	*500	1000	7.0	359	500	1258.48	9	55.55	139.83
4	5.2	180	3	500	675	5.78	233.99	337.5	564.873	9	37.5	62.76
5	3.9	60	4	300	1075	4.5	104.775	322.5	308.909	13	24.80	23.76
6	4.2	120	2	500	1025	8.49	1435	512.5	1455.1	11	46.59	132.28
7	7.8	330	1	500	1000	11.1	1255	500	2716	7	71.428	388
8	6.1	330	3	500	1400	16.08	19856.7	700	2577.35	13	53.846	198.25
9	5.3	300	3	500	1025	8.40	706.33	512.5	1872.8	12	42.708	156.0
10	2.7	300	1	500	400	5.6	228	200	327.08	4	50	81.77
11	3.9	120	2	300	800	16.25	21581.99	240	790.2	8	30	98.77
12	3.4	270	2	300	800	15.73	19073.76	240	844.68	8	30	98.77
13	4.2	120	2	500	1200	8.85	1507.11	300	1976.8	10	30	197.68

*Bonus type turbines (Denmark, 1990)
The rest of indicated turbines are vestas type (Denmark, 1990)

simulations applied for each selected site. The results indicate that 11800 turbine can be installed with capacities of 300 or 500 (kW) for each turbine, and a total nominal capacity (TNC) of 4785 MW. The total annual energy production for these sites is 15333 (GWh/yr) which is 27.9% of annual energy demand of I.R.I. in 1991, which was about 55000 (GWh/yr).

The results of efficiency calculations vary from 33% up to 45%. These wind farms cover a total area of 117 km^2. Considering that the total area of ideal sites for I.R.I. is 124442 km^2 or at least 87494 km^2 [1], this area is only a fraction of total potential sites.

Since the total capacity of different types of power plants in I.R.I. is almost 18000 MW [6] therefore this accounts for 26.5% of the power demand.

Currently a site investigation is under way for 14 new locations which is expected to be completed by mid 1997, and which will increase the convenient sites at least by twice.

At the present time U.S. has 16000 wind turbines with a capacity of 1400 MW which accounts for 1% of total electricity need for that country. U.S. is planning to increase the share of wind energy to, at least, 10% by the year 2000. Table 3 indicates the installed wind energy for various countries [7].

Further review shows that many European countries are planning to have a share of 10-20% of their electricity supply from wind energy by the years 2000. Obviously all economic aspects have been considered for such achievements.

CONCLUSIONS

Wind energy has now reached the stage where it is being included in the long-term energy policies of many countries (Table 3). Currently, the share of the wind energy for production of electricity in I.R.I. is negligible. Considering 8-10% annual increase in electricity demand, the electricity demand of I.R.I. by the year 2000 would be 27000 MW. In order to have a share of 1% of this demand from the wind energy (One tenth of E.C. long term plans), it is necessary to install wind turbines with a total capacity of 270 MW. The present selected sites show this goal is easily achievable. Considering a realistic investment of $1700/kW [1], the present potential for investment is about 8.13 billions of dollars, and for 1% share of energy, an investment of 459 million of dollar is

TABLE 3. The Installed Wind Energy Capacities and Wind Energy Targets of Various Countries.

Country/State	National/State Wind Energy Programme	No of turbines installed	Installed Capacity (MW)
California	10% of electricity supply by year 2000	16,000	1,400 (1% of electricity needs)
Denmark	200 MW of utility d'ment by 1993 & 10% electricity supply by 2000	2,000	190(1.5% of electricity needs)
Holland	150 MW by 1991 & 1,000 MW by year 2000	?	40
Italy	300 MW by year 2000	?	2
Germany	200 MW (no time specification)	?	10
Spain	90 MW by 1993	68	5.3
India	5,000 MW by year 2000	250+	35
The United Kingdom	No official target for wind (target for 1000 MW renewables by 2,000)	20+	7.5
Greece	400 MW by year 2000	15+	2

required.

In 1993 the annual energy production in I.R.I. was 54452 million kWh. To produce this amount of energy 1103 million liters of gasoil, 4833 million liters of heavy oil and 9858 million cubic meters of natural gas were used [6]. With the present rate of increase in demand, it is expected that these figures will in case to 1654, 7249, and 14787 respectively by the year 2000.

Substituation of 1% to 10% of these amounts of fossil fuel and natural gas by wind energy will save nonrenewable energy and will bring positive environmental consequences. Therefore, it is feasible to encourage private investors. By applying state tax incentives along with lower labour costs and local industries, it is possible to reduce initial expenses and make the production of this type of energy more profitable and environmentally more attractive.

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APPENDIX I

"Questionnaire for Wind-Observation Sites"

- Name of station
- Country:
- Location (Latitude, Longitude):
- Anemometer height:
- Average Period:
- Site coordinates (x= y= z=)
- Period of measurements (time of start and end)
- Is the station equipped with automatic recording of average wind speed and direction?
  Describe instrumentation. If not, give a brief description of observational practice.
- Further information regarding the station (change of observational practice or relocation of instruments during the period)
- Averaging period for wind speed (minutes)
- Description of anemometer location (a series of photographs should be provided showing the meteorological mast and the surroundings as seen from near the mast looking in all directions)
- Obstacle Description Form (type, length, height, porosity)
- Roughness Classification Form (z_0, X)
- Orographic Characteristics (complex or gaussian model)
- Description of Site (Obstacles, Roughness & Orography) [9]
- The distance of site from:
  - roads

- rail roads
- power lines
- air port
- mines
- dams
- radar
- telecommunication beams
- radio & T.V.-transmitters
- inhabited areas

- Possibility of snowing, freezing, flood
- Soil condition
- Migration routes of birds