Wind energy potential in Bulgaria

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Abstract: *In this study, wind characteristic and wind energy potential in Bulgaria were analyzed using the wind speed data. The wind energy potential at different sites in Bulgaria has been investigated by compiling data from different sources and analyzing it using a software tool. The wind speed distribution curves were obtained by using the Weibull and Rayleigh probability density functions. The results relating to wind energy potential are given in terms of the monthly average wind speed, wind speed probability density function (PDF), wind speed cumulative density function (CDF), and wind speed duration curve. A technical and economic assessment has been made of electricity generation from three wind turbines having capacity of (60, 200, and 500 kW). The yearly energy output capacity factor and the electrical energy cost of kWh produced by the three different turbines were calculated*

1. INTRODUCTION

The utilization of wind energy has been increasing at an accelerating pace. However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind resource data in many parts of the world. Such data are needed to determine the priority that should be given to wind energy utilization and to identify potential areas that might be suitable for development. The distribution of wind speeds is important for the design of wind farms and power generators.

Bulgaria has a large potential for renewable energies. One of the very effective renewable energy sources for Bulgaria is wind energy. The previous technical research proves that some parts of Bulgaria are endowed with strong wind conditions. Particularly, some parts of the coastal region of Black Sea and locations with rugged mountains are especially promising regions.

In the last decade, a lot of studies related to the wind characteristics and wind power potential have been made in many countries worldwide [1–3]. For proper and beneficial development of wind power at any location, wind data analysis and accurate wind energy potential assessment are the key requirements.

The annual average wind speed for Bulgaria ranged from 3 to 9.5 m/s and a mean wind power density from 80 to 167 W/m^2 at standard height of 10 m. There are determined the optimum configuration of a stand-alone wind power system and wind farms by using long-term wind potential theoretical investigations for several regions in Bulgaria.

2. Theory

Before the installation of any wind turbine, it is necessary to estimate the expected power output in order to assess the economic viability of the project. It is usually based on wind statistics measured over a period of at least 2 year.

Wind energy projects are generally more financially viable in “windy” areas. This is due to the fact that the power potential in the wind is related to the cube of the wind speed. However, the power production performance of a practical wind turbine is typically more proportional to the square of the average wind speed. The difference is accounted for by the aerodynamic, mechanical and electrical conversion characteristics and efficiencies of the wind turbines. This means that the energy that may be produced by a wind turbine will increase by about 20% for each 10% increase in wind speed. Wind energy project sitting is critical to a financially viable venture. It is important to note that since the human sensory perception of the wind is usually based on short-term observations of climatic extremes such as wind storms and wind chill impressions, either of these “wind speeds” might be wrongly interpreted as representative of a windy site. Proper wind resource assessment is a standard and important component for most wind energy project developments.

Wind power density (wpd, Wm^{-2}) can be calculated according to

$$wpd = \frac{1}{2}(\rho C_{PR} C_T) V^3$$

where ρ is the air density (kg/m^3) and ***V*** is the wind speed (m/s). Pressure and temperature correction terms (C_{PR} and C_T, respectively) are applied to account for deviations from standard atmospheric density (1.225 kg/m^3) due to differences from standard sea level pressure (1013.25 hPa) and temperature (288.15 K). The correction factors are computed as

$$C_{PR} = \frac{P_a}{1013.25}; \quad C_T = \frac{288.15}{T_a}$$

where P_{abs} is the sea level pressure (hPa) and ***Ta*** is the air temperature (K) at the site.

It is important to know the number of hours per month or per year during which the given wind speeds occurred, i.e. the frequency distribution of the wind speeds.

Simple knowledge of the mean wind speed is not sufficient for the computational demands of the available regional wind potential. Additionally, thorough information is needed for the probability distribution of the appearance of several wind speed values in the course of time, with an emphasis on recording the stillness intervals and the intervals of the appearance of very strong winds [1].

It is important to determine the theoretical model, which fits the real wind data in Bulgaria most accurately. It can be used the two- parameter Weibull probability model, the lognormal, gamma and Rayleigh models [2,5]. Practice and investigations show, that the Weibull probability distribution function is found to fit the monthly frequency distribution of wind speed measurements. This means that, most wind speed distribution characteristics at any site can be described by two parameters: the shape parameter ***K***, and the scale parameter ***C***. The fraction of time duration that the wind blows at speed ***V*** is thus determined by

$$f(V)=\frac{K}{C}\cdot\left[\frac{V}{C}\right]^{K-1}\exp(-\left[\frac{V}{C}\right]^{K}$$

This expression is valid for ***K*** >1, ***V*** ≥ 0, and **C** > 0. The shape factor will typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. ***C*** is the scale factor, which is calculated from the following equation [2,6]:

$$C=\frac{\overline{V}}{\Gamma(1+\frac{1}{K})}$$

where $\overline{V}$ is the average wind speed value and ***Γ*** is the gamma function.

In order to estimate Weibull ***K*** and ***C*** parameters, numerous methods have been proposed over last few years. In this study, the two parameters of Weibull are determined by using mean wind speed-standard deviation method [2].

The input parameters required for the software have been calculated and estimated as follows: The shape parameter ***K***, which is an indication of the breadth of the distribution of wind speeds, is calculated by applying equation proposed in [1] and also by repeatedly running the program, by way of trial and error, checking the results against the measured data. The value that fits best for K is found to be

$$K=(\frac{\sigma}{\overline{U}})^{-1.086}$$

where, $\overline{U}$ is the mean wind speed and σ is the standard deviation.

Typical example for the Weibull probability distribution function is given on fig. 1 – region Kaliakra (near the Black Sea)

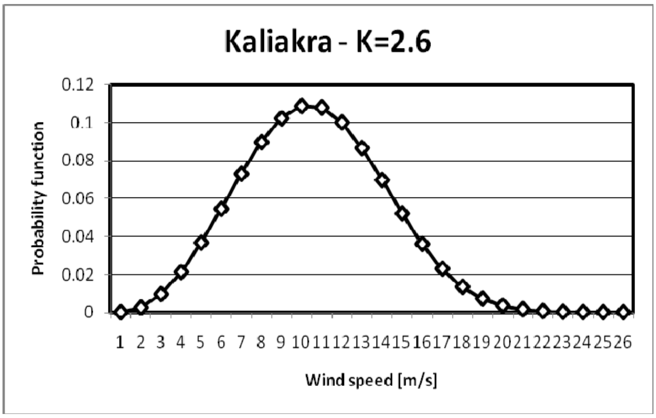
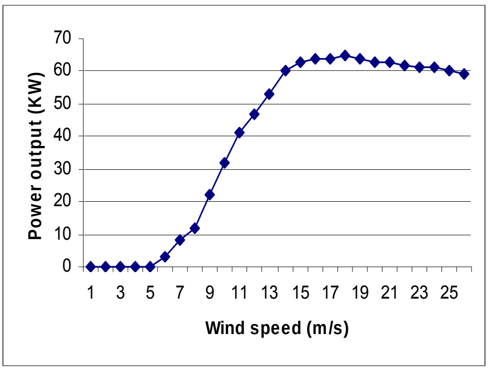


Fig. 1 Weibull probability distribution function

Energy curve

The energy curve data is the total amount of energy a wind turbine produces over a range of annual or monthly average wind speeds. In fig.1, the energy curves for Atlantic Orient Corporation AOC 15/50 - 60 kW wind turbine (rotor diameter - 15 m) and Vestas V47-600kW - 600 kW (rotor diameter – 47 m) are specified over the range of 3 to 25 m/s average wind speed, and are displayed graphically.



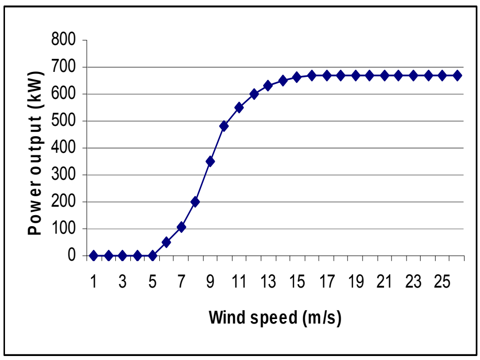


Fig.1 Energy curves for 60 KW and 600 kW wind turbines

The user specifies the wind turbine power curve as a function of wind speed in increments of 1 m/s, from 0 m/s to 25 m/s. Each point on the energy curve, *Ev* , is then calculated as:

$$E_{\overline{V}} = T \sum_{i=1}^{25} P_i \cdot p(i)$$

where v is the mean wind speed considered, P_i is the turbine power at wind speed ***i***, and p(i) is the Weibull probability density function for wind speed ***i***,calculated for an average wind speed v .
Gross energy production is the total annual energy produced by the wind energy equipment,before any losses, at the wind speed, atmospheric pressure and temperature conditions at the site.

3. WIND_ENERGY Software

Wind_Energy is a computer program that provides a gross energy production of wind energy. It uses a monthly and yearly mean wind speed data and Weibull probability model for assessment of wind speed distribution. **Wind_Energy** calculates energy production on the base of wind speed distribution and energy curve of a given wind turbine. Software is developed by Delphi programming tool.

WINDOWS environment for the **Wind_Energy** program provides for user friendly input of data, processing and viewing of the results.
Data input is interactive (mouse driven) via WINDOWS dialogue boxes, selection lists drop down lists and entry fields on a series of screens running through general Project information.

Wind Energy potential in Bulgaria

Calculations for many places in Bulgaria have been made with the software program with two wind turbines. Result for gross energy production was presented as energy for unit 'swept' area of wind turbine rotor – kWh/m^2. This information was summarized and graphically presented by geographical map – fig.2. From this map can be seen, that in Bulgaria are some places with very good energy potential, but very big part of territory is not suitable for wind energy utilization.

CONCLUSION

New technologies in planning, design and operation for wind energy utilization often require the use of computers, and with the developing of desktop computing programs, wind energy assessment and economical reliability of wind projects is expected to grow in importance. We demonstrated engineering compliance software, **Wind_Energy**, tailored for use by professionals to perform calculations aimed at achieving economical and energy efficiency in wind projects. Preliminary results for wind energy potential in Bulgaria are presented (geographical map). Wind map for Bulgaria will be actualizing with receiving a new wind speed data.

WIND ENERGY - Theoretical Potential

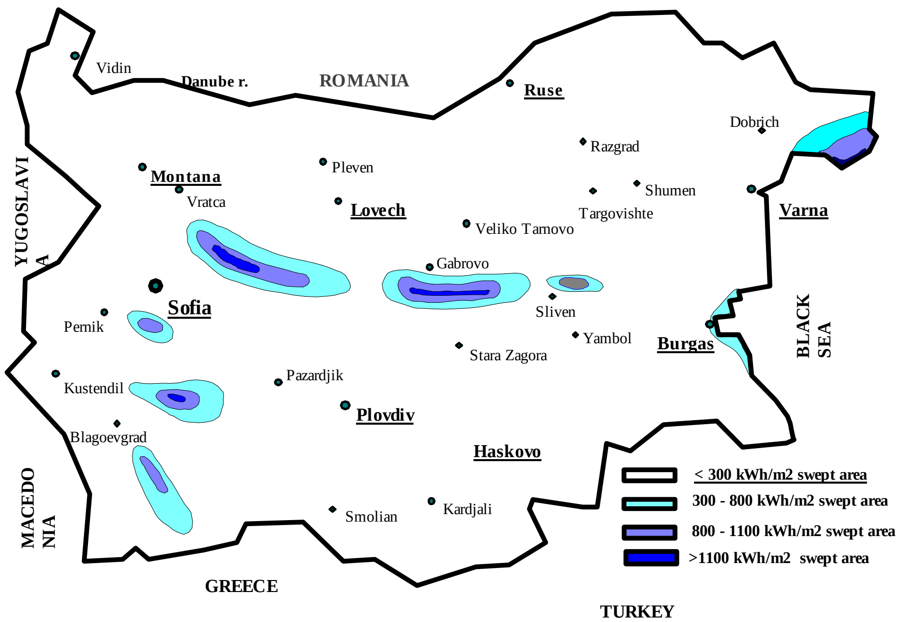


Fig. 2. Geographical map – Wind energy potential

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