A Comparison Between Theoretically Calculated and Pratically Generated Electrical Powers of Wind Turbines: A Case Study in Belen Wind farm, Turkey

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Abstract:
The increasing interest in wind energy requires reliable and accurate methods for the wind resource estimation. Wind Atlas Analysis and Application Program (WAsP) are widely utilized to predict wind resource. In this paper, performance analyses are investigated at Belen wind farm installed in Hatay region and has been working for three years. For this purpose, power curve of a wind farm is first modelled by the use of WAsP program and real values of the wind farm are then measured. Following, Wind power diagram predicted by using wind estimation program WAsP is compared with the real power data obtained from the wind farm. Compared results have shown that both curves are very close in each other.

Keywords: *Wind farm; WAsP program; Wind power predict; Power quality*

1. Introduction

The rapid depletion of fossil fuel reserves and the increasing of public awareness to protect the environment on a worldwide have necessitated to research new and alternative energy sources urgently [1-2].

Institutions, governments, private sectors and researchers have begun to give priority to the use of renewable energy sources such as wind, hydro, geothermal, solar and bioenergy sources [3]. Particularly, among the many types of competitive alternative sources of energy, wind power generation has experienced a very fast development in the whole world [2,3].

The effective utilization of wind energy needs a detailed knowledge of the wind characteristics. The distribution of wind speeds is very important for the design of wind farms and power generators. For these reasons, it is becoming increasingly important to analyse the fundamental characteristics of a set of wind turbines, namely the wind speed to which they are exposed and their corresponding power output [4]. Since many factors must be taken into consideration, it is not an easy task to choose a site for a wind turbine. The most important parameters are wind speed, energy of the wind, turbine type and the feasibility study in order to design a wind farm. To maximize the electricity generation of a wind farm when connected to the electric grid, it is

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necessary to predict as much possible as the power production of a wind turbine. However, this power production can be influenced by many factors and usually fluctuates rapidly [2].

Wind Atlas Analysis and Application Program (WAsP) are usually used in order to predict wind resource accurately. The program is based on methodology from the European Wind Atlas. Input data of the program are wind speeds and direction measured at wind farm. On the other hand, it is required to create regional vector topographic map and map of surface roughness of the region, and also to make models of the obstacles around the mast in order to measure correct and accurate results [5]. Both data are then used as input to the WAsP program for the calculations of the regional wind power potential and the amount of production of a wind power plant.

In this work, a validation study for an installed wind farm at Hatay region has been performed by inter-comparisons of real and estimated parameters. Only very few measurements are available for a validation of WAsP for comparison. With the new data from wind farm an evaluation of WAsP is attempted for the use in wind farm applications. It is not the intention of this study to improve WAsP. The remaining sections of this paper are organized as follows: Sec-tion 2 describes the Basic knowledge of wind power and formulations; Section 3 is used to give short explanation of wind power estimation program WASP; Section 4 presents brief technical properties of installed wind farm; Section 5 establishes a comparison between power data measured and estimated by WAsP at the same wind farm and output parameters of installed wind turbines; finally, conclusions of overall study are presented in Section 6.

2. Basic Knowledge of Wind Power

2.1. Wind Power

Wind occurs due to different cooling and heating phenomena within the lower atmosphere and over the earth surfaces. Most of these winds occur under different pressure meteorological systems and are influenced by topographic conditions to a certain extent. Such conditions give rise to occasional extreme wind velocities, which should be predicted prior to any wind farm planning, siting, design, operation and maintenance [5,6]. Prevailing winds combine with local factors, such as presence of hills, mountains, trees, buildings, and bodies of water, to determine the particular characteristics of the wind in a specific location. Since air has mass, moving air in the form of wind carries with it kinetic energy. A wind turbine converts this kinetic energy into electricity. The transition probability estimations are necessary for the recurrence interval predictions and as the Weibull, Rayleigh, lognormal or Gamma frequency distribution functions in order to predict the magnitude of the wind speed [5,7].

In wind engineering applications extreme winds are important, especially, at turbine design cut-in and cut-off wind level considerations. Although strong wind speeds are described as risk values, low wind speeds also have important risk potentials for desired electricity generation. These values are known as out of cut-in and cut-out wind speeds. Wind turbines produce electricity approximately between 3 and 25 m/s wind speeds interval, and the highest generations are evaluated after 10–12 m/s values. Each turbine has cut-in and cut-out values depending on design rule with magnitude and each wind turbine power curve that indicates the amount of the electrical power output versus different wind speeds [2,8].

The power curves and thrust coefficients provided by their respective manufacturers are shown in Fig.1. Wind generators are selected according to the graph.

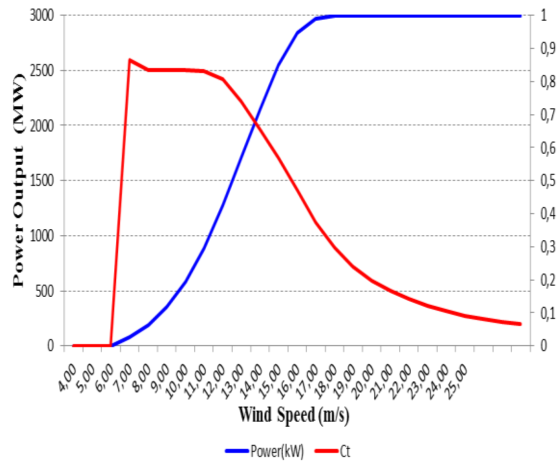

Figure 1. The power curve for the chosen wind turbine.

In order to determine power estimation, it is necessary to simultaneously consider the frequency of wind velocities and the power curves of the wind turbines. When selecting this design parameter, a careful process should be implemented to determine best model, which fits the power curve of the wind turbine. The feasibility of wind turbines depends largely on a suitable selection of their characteristics so that they match the winds at the location [2, 9].

2.2. Wind energy formulation

Wind energy E is defined as;

$$E = \frac{1}{2} m v^2 \quad (1)$$

Where m is the moving air mass, v is wind speed, Since the measurement of m is almost impossible in aero-dynamics one can express it in terms of volume, V. It is preferable to convert the volume to specific mass   Hence, the substitution of m into Eq. (1) gives,

$$E = \frac{1}{2} \rho V v^2 \quad (2)$$

The volume can be defined as   in which A is vertical control cross-section and L is the horizontal distance. Physically, and its substitution into Eq. (2) lead to,

$$E = \frac{1}{2} \rho A t v^3 \quad (3)$$

Practically, it is preferable to consider the wind energy per vertical unit area per time as unit wind energy,

$$E_u = \frac{1}{2} \rho v^3 \quad (4)$$

The air density is assumed as a constant equal to 1.263 kg/m3 at the sea level. This assumption is valid for instantaneous measurements of the air density and wind speed at a given area. However, its generalization over an area requires parameterization through a regional analysis[9]. On the other hand, The considerations of possible random variations in the air density and wind speed may give rise to a general parametric definition of the wind energy in the form of a power function as:

$$E = a V^b \quad (5)$$

The theoretical derivation of wind power initiates from the consideration of the kinetic energy definition in physics, and for any given instantaneous wind speed, V, the instantaneous wind power, P, expression becomes as [10,11].

$$P = \frac{1}{2} \rho V^3 \quad (6)$$

3. Wind Power Estimation Program

The Wind Atlas Analysis and Application Program (WAsP) is a PC-program for horizontal and vertical extrapolation of wind, for predicting wind climates and power productions from wind turbines and wind farms [12]. The predictions are based on wind data measured at stations in the same region. The program contains a complete set of models to calculate the effects on the wind of sheltering obstacles, surface roughness changes and terrain height variations. Wind data (speed and direction distributions) can be converted into a regional wind climate or wind atlas data set in which the wind observations have been cleaned with respect to site specific conditions (orography, wakes, obstacle, etc.) and reduced to some height and roughness standard conditions [13]. By application of a particular wind atlas data set, the pro-gram can estimate the wind climate, the total energy content of the mean wind, or the annual mean energy production of a wind turbine at any specific siting [4]. Flowchart of wind atlas and turbine siting methodologies are given in Fig.2.

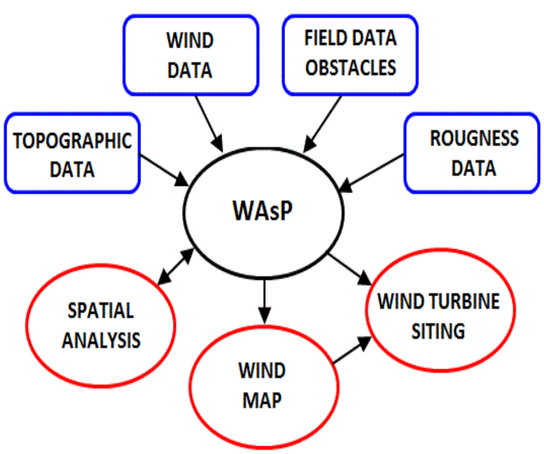

Figure 2. Flowchart of wind atlas and turbine siting methodologies.

By introducing descriptions of the terrain around the predicted site, the models can calculate the actual, expected wind climate at this site. The total energy content of the mean wind is calculated by WAsP. Furthermore, an estimate of the actual, annual mean energy production of a wind turbine can be obtained by providing WAsP with the power curve of the wind turbine. Given the thrust coefficient curve of the wind turbine and the wind farm layout, WAsP can finally estimate the wake losses for each turbine in a farm and thereby the net annual energy production of each wind turbine and of the entire farm [12, 14].

4. Technical Properties of Installed Wind Farm

The rapid development in wind energy technology has made it an alternative to conventional energy systems in recent years and wind power as a potential energy has grown at an impressive rate in Turkey. The Republic of Turkey, located in South eastern Europe and South western Asia (that portion of Turkey west of the Bosporus is geographically part of Europe), has an area of about 780,580 km^2 and a population of over 75 million [6,15]. Turkey has been one of the fast growing power markets of the world for the last two decades. Turkey's geographic location has several advantages for extensive use of most renewable energy sources [16,17]. Wind Power Monitoring and Forecast Centre (RITM) was established in 2010 under the Ministry of Energy and Natural Resources (MENR). RITM is responsible to coordinates all wind power generated in Turkey with the participation of General Directorate of Electrical Power Resources Survey and Development Administration, Space Technologies Research Institute and Turkish State Meteorological Service [18].

Belen wind farm is installed at Hatay province of Turkey in the Mediterranean region. Wind farm has been installed with a total capacity of 36 MW and constituted by 12 wind turbine. Rotor diameters and hub heights of wind turbines are 90 m. and 80 m. respectively. The nominal power of each turbines are 3 MW manufactured by Vestas V90. Wind farm has worked effectively so far and produced expected amount of electrical energy. There is a wind mast, located as indicated in Fig. 3. There are six anemometers and two wind vanes on it: at heights 80m and 65m. Wind speeds and directions are measured by anemometers at different heights along with the locations and measurement periods.

The picture of wind farm derived from Google earth is shown in Fig. 4. Additionally, a picture of the wind farm including wind measuring mast is given in Fig.5. The data logger (model CAMPBELL–39700) has been continuously recorded average wind speed. Data sampling interval of data logger is one second and wind speed is recorded every fifteen second.

Figure 3. Photograph of the wind farm including wind measuring mast.

In wind turbines of installed wind farm, three-phase wound rotor induction generator is used. Each wind turbine generator has been connected to its own 0.69/34.5 kV star-delta connected transformer. The neutral point of the transformer is grounded to diminish the third harmonic voltages. These generators are connected to 154 kV power lines via 154/34.5 kV, 50 MVA transformers. The substation also ensures that the electric power generated from wind is delivered to the transmission line at constant voltage level of 154 kV and 50 Hz.

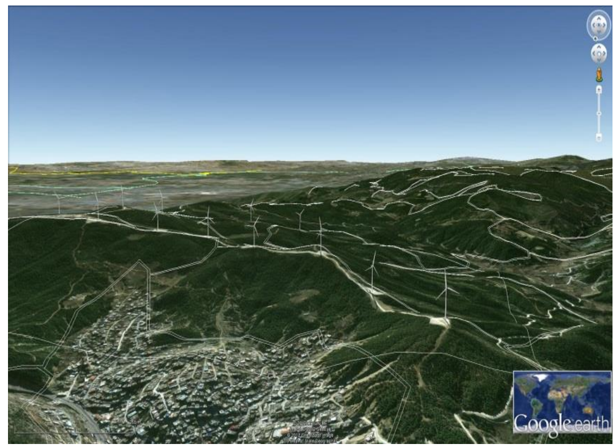

Figure 4. Picture of wind farm derived from Google Earth.

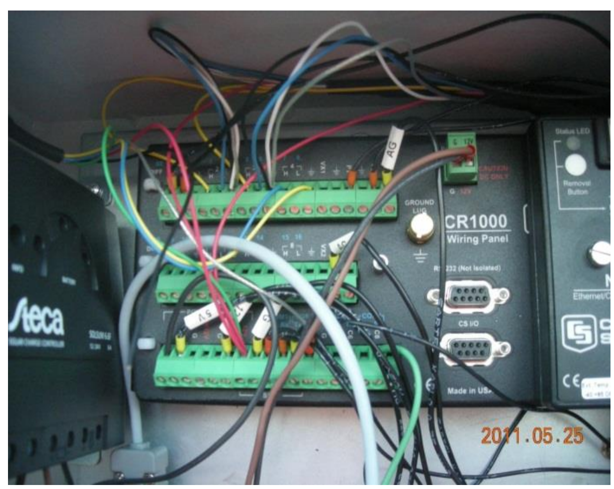

Figure 5. Picture of data logger.

5. Results and Discussion

In this study, wind power diagram predicted by the use of wind estimation program WAsP was compared with the real power data obtained from the wind generator in order to see the performance of estimation program. For this purpose, wind parameters (wind speed and directions) are measured on the wind power plant for three days. Power estimation curve of the wind farm has been predicted by using wind parameters and WAsP program. At the same time period, real power values have been measured from the same wind generator to be used for the comparison. Power data measured and estimated by WAsP are shown at the same diagram in Fig.6. Power graphs measured and predicted by WAsP are illustrated blue and red coloured curves respectively.It is clearly seen from the Fig.6 that the WAsP-predictions are almost identical with the actual measured values. Deviations between measurements and WAsP-predictions are quite small. It can be obviously said that WAsP prediction is very successful program in modelling of wind farms.

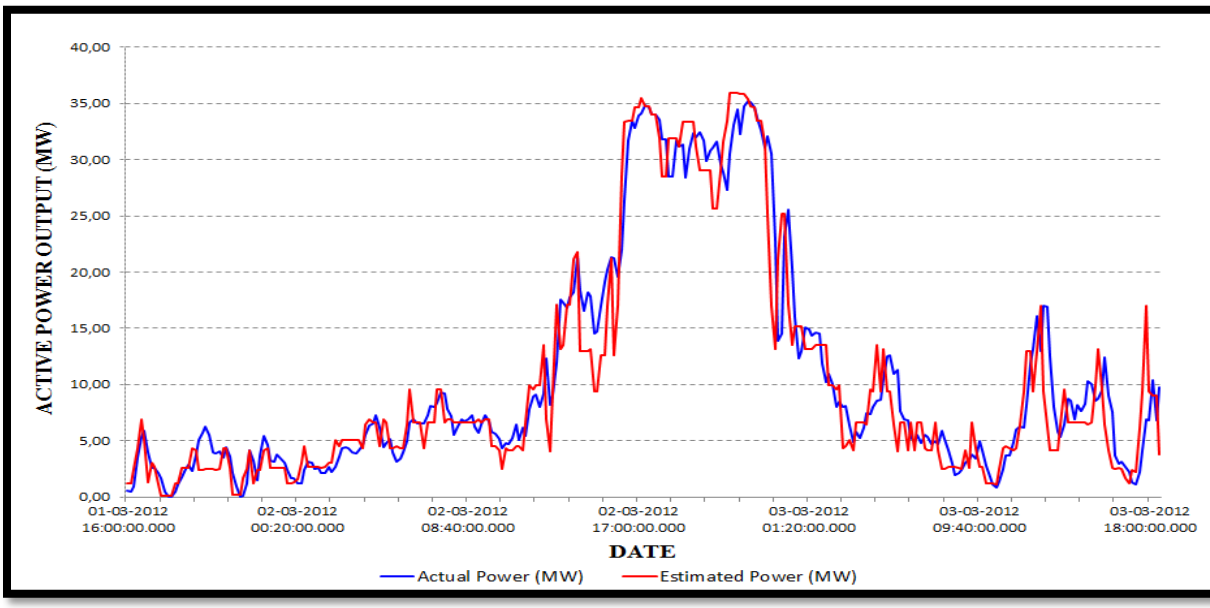

Figure 6. Power datas measured and estimated by WAsP at the same wind generator

6. Conclusion

In this study, theoretically calculated electrical powers are compared with actually generated power of a wind turbine installed at Hatay region. Wind power plant has been producing electrical energy and working for three years. Theoretical turbine powers are predicted by the use of WAsP estimation program within a certain period of time. Real power values are measured from the wind turbine at the same time. Both values are compared at the same diagram in order to see performance of the estimation program. Results showed that there is no significant deviation between the two values. It was found that the predictions of wind turbines were in good agreement with the measurements of actual power values.

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