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Modeling of wind energy in some areas of Palestine

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ABSTRACT

The daily mean wind speed data for 4 locations in Palestine over a period of 5 years are collected, analyzed, and fitted to the Weibull distribution function. Weibull parameters are derived from the cumulative function of the observed data records (1997–2001), and used to calculate the mean wind speed and variance of the theoretical distribution. A quadratic polynomial is employed to fit the relationship between the wind power and the mean wind speed. The monthly mean wind power density found to be higher during summer and lowers during winter in most locations. However, in Hebron district the winter months have higher values than those for summer. The highest mean power values were 32.98 W m^{-2} in January and 37.85 W m^{-2} in July for Hebron and Nablus, respectively. The lowest mean power was 1.66 W m^{-2} in January for Jericho. The adjusted R^2 of the polynomial fit was about 99% for all stations except for Hebron was about 70%.

1. Introduction

The interest and motivation for harnessing wind power have grown tremendously during the 1980s in many developed countries as well as rich countries as a result of frequent energy crises on the one hand and persisting issues of environmental pollution on the other [1]. Due to the rapid population growing on earth, the increasing consumption of the limited petroleum resources and the rapid depletion of fossil fuel, there is a very challenging need for new and sustainable energy resources. Besides, petroleum and fossil fuel consumption is one of the major sources of air pollution with carbon-, sulfur-, and nitrogen-oxides. These pollutants are threatening the health of global ecosystem and climate change. Wind power, solar cells, ocean water are typical examples of sustainable energy sources. The renewable wind power offer a feasible and cheap solution to distribute power generators over vast areas worldwide. It became one of the most convenient and environmental friendly way of generating electricity. By the end of 2007, worldwide capacity of wind power generators was 94 GW (about 1% of world-wide electricity use).

Most of the commercial wind turbines operating today are at sites with average wind speed of 6 m s^{-1}. The power generated by a wind-generator is given by:

$$P(\text{watt}) = (1/2)\rho A v^3$$

where ρ is the density of air, A is area of rotor, and v is the wind speed.

The wind speed variation on a wind turbine is very complex one and demands sophisticated techniques to optimize power extraction [2]. Mahbub et al. [3] found that by changing the hub-height from 50 to 60 m increased the energy production with an overall average of about 8% in a study conducted in South Africa. One of the mathematical functions which have been successfully applied to fit wind speed distributions is the Weibull distribution. The two parameters in Weibull distribution (the shape parameter k (dimensionless) and the scale parameter c (m s^{-1})) describe the daily average wind speed with a reasonable accuracy [4]. The results of the Weibull function can be used with acceptable accuracy for predicting the wind energy output required for preliminary design and final assessment of wind power plants [5].

In an intensive study, Martin analyzed wind data for 11 stations along the East Coast of the Arabian Peninsula covering a period ranging from 5 to 17 years [6]. The monthly average wind speed data and the frequency distribution were employed to determine the wind power for these stations. The data showed that the potential usage of wind power plants could not be ignored.

Rehman et al. [7] calculated the shape and scale parameters of the Weibull density distribution function for 10 locations in Saudi Arabia. They used daily mean wind speed data collected from 1970 to 1990. The numerical values of the shape parameter were found to vary between 1.7 and 2.7 m s^{-1}, whereas the scale parameter varied from 3 to 6. They concluded that the wind data are well represented by the Weibull distribution function.

In Egypt, the wind data from 15 meteorological stations was used to assess monthly and annual wind power [8]. This study

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covered a long time period from 1973 to 1994. The analysis showed that along the Red Sea coast, the annual wind energy flux was found to be high. Such study will help in predicting the possible locations for wind energy plants utilization.

The wind energy characteristics and availability in the state of Oman were also studied by Sulaiman et al. [9] over a period of 5 years. Weibull parameters derived from the empirical cumulative function are used to calculate the mean wind speed. Results obtained showed that, the wind speed is higher during summer months and is lower in winter. The monthly mean wind power density varies from 9.71 W m^{-2} in November to 520.85 W m^{-2} in August.

The overall errors in estimating the wind-energy yield using the Weibull representative wind speed data were found to be around 3.2% for 4 days in the month [10]. Following a thorough study of wind energy in Turkey, Sinan and Ebru [11] proposed a theoretical approach of wind speed frequency distributions. They investigated four stations and concluded that; the two finite mixture distributions proposed very flexible models for wind speed studies.

The Weibull parameters of the wind speed distribution function were computed from the wind speed data for Izmir in Turkey [12]. Wind speed data over a 5 years period (1995–1999) were used. It was found that the numerical values of both Weibull parameters for Izmir are varying over a wide range. The yearly values of k ranged from 1.378 to 1.634 with a mean value of 1.552. While those of c are in the range of 2.956–3.444 with a mean value of 3.222. As a consequence, the Weibull distribution with no doubt is found to be suitable to represent the actual probability of wind speed data for Izmir (at annual average wind speed up to 3 m s^{-1}). Bagiorgas et al. [13] analyzed the variation of the two Weibull parameters for wind speed measured at different heights above the ground level in Saudi Arabia. The value of Weibull shape parameter is independent of height unlike the scale parameter.

In present study, the recorded average daily wind speed data was employed to study wind power at different locations in Palestine. The collected data was fitted well to Weibull distribution function.

2. Study area and dataset

This study was conducted in Palestine which is located on the Eastern coast of Mediterranean Sea with elevation ranging from −276 m (below sea level) in Jericho in the Jordan Valley to about 1000 m above the sea level in Hebron. Geographical coordinates are between 34°20′–35°30′ east longitude and 31°10′–32°30′ north latitude. Climate conditions widely vary: in the hilly areas of West Bank, cold winter and mild summer with relative humidity of 51–83%. Palestinians, like other developing country people need a lot of energy for achievement of sustainable development. Nevertheless, many obstacles are facing them, namely; political, economical, social, and environmental problems. Palestine imports all of its needs of petroleum from the Israeli market and also about 92% of electrical energy from the Israeli Electrical Corporation. The production of renewable energy contributes only 1.9% of the total energy. This small amount of energy is also strongly affected by political stability in the region, economic situation of the people, rising demand on energy and availability of the indigenous resources.

The lack of natural energy resources is strongly demanding Palestinians to look for renewable and sustainable energy sources like wind-power. However, generating electricity from wind requires studying wind speed based on the available data and topographical features of the land in various locations. The potential of wind energy seems to be limited to the mountains with heights about 1000 m above sea level. This would include regions of Nablus, Ramallah, and Hebron where the speed reaches 5 m s^{-1}, which is suitable for operating a wind turbine.

Al-Ahli Hospital is located in the south-western part of Hebron at 1000 m above sea level, where an average wind speed at 10 m above the ground-level reaches 6.2 m s^{-1}. The proposed and required wind turbines to be installed at Al-Ahli Hospital are expected to be around 700 kw total power production capacity. Therefore, utilization of wind-energy could be feasible in many locations for cutoff electricity production by petroleum [14].

Palestine can be considered as a country of moderate wind speed. Hilly regions have annual average speed of (4–6) m s^{-1}.

Wind speed data are obtained from the Palestinian meteorological stations network office, they were collected eight times a day using an anemometer. The collected data shows that some areas could have the potential of producing considerable wind-power. Two issues can be resolved:

1. Determining the exact potential of wind energy by installing modern computerized stations in different locations of Palestine.
2. Generating electrical-power from wind for many rural areas away from main electric network.

3. The Weibull distribution function

The Weibull distribution function provides a close approximation to the probability laws of many natural phenomena. As seen from literature, a considerable attention has been given to the Weibull distribution because it is found to give a good fit to the observed wind speed data. Justus and Mikhail [15] concluded that the Weibull distribution function provides the best fitting for the wind speed data for more than 100 stations of the United States National Climate Center. In a study conducted in Denmark, Weibull distribution function gave an excellent fitting to the wind speed distribution [16]. Moreover, Rehman and Al-Abbadi [17] found that Weibull parameters to be the best representative of the actual wind frequency distribution for wind speed measured at 20, 30 and 40 m above ground level in Saudi Arabia.

Recently several studies have been carried out to create an adequate statistical model for describing the wind-speed frequency distribution [12,13,16]. Nevertheless, the Weibull distribution function found to fit a wide collection of experimental wind data [18,19].

The general form of the Weibull distribution function for wind-speed is given by [20]:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where $f(v)$ is the probability of observing wind speed v, k, the dimensionless Weibull shape parameter, and c reference value in units of wind speed (so-called Weibull scale parameter).

The cumulative distribution function is given as [12,21]:

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

Determination of the parameters of Weibull distribution requires a reasonable fitting of Eq. (2) to the recorded discrete cumulative frequency distribution. Taking the natural logarithm twice of both sides of Eq. (2) gives:

$$\ln(-\ln[1 - F(v)]) = k\ln(v) - k\ln c \tag{3}$$

A plot of $\ln(-\ln[1 - F(v)])$ *versus* $\ln(v)$ should give a straight line. The gradient (slope) of the line is k while the Y-intercept is $-k\ln c$. The linear least-square algorithm was used to fit the Weibull distribution to the measured wind speed data [22].