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Evaluating the suitability of wind speed probability distribution models: A case of study of east and southeast parts of Iran

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ABSTRACT

Precise information of wind speed probability distribution is truly significant for many wind energy applications. The objective of this study is to evaluate the suitability of different probability functions for estimating wind speed distribution at five stations, distributed in the east and southeast of Iran. Nakagami distribution function is utilized for the first time to estimate the distribution of wind speed. The performance of Nakagami function is compared with seven typically used distribution functions. The achieved results reveal that the more effective function is not similar among all stations. Wind speed characteristics, quantity and quality of the recorded wind speed data can be considered as influential parameters on the performance of the distribution functions. Also, the skewness of the recorded wind speed data may have influence on the accuracy of the Nakagami distribution. For Chabahar and Khaf stations the Nakagami distribution shows the highest performance while for Lutak, Rafsanjan and Zabol stations the Gamma, Generalized Extreme Value and Inverse-Gaussian distributions offer the best fits, respectively. Based on the analysis, the Nakagami distribution can generally be considered as an effective distribution since it provides the best fits in 2 stations and ranks 3rd to 5th in the remaining stations; however, due to the close performance of the Nakagami and Weibull distributions and also flexibility of the Weibull function as its widely proven feature, more assessments on the performance of the Nakagami distribution are required.

1. Introduction

Wind energy is one the fast growing and widely used renewable energy sources utilized to supply the demands in cities and remote areas [1]. In fact, the pollution caused by over use of fossil fuels and also their limited reserves make wind as an alternative energy source to conquer the environmental issues created by human being. Utilization of wind energy as a green and sustainable energy can reduce dependency on fossil fuels, which are the main sources in the energy supply chains of the countries. Wind energy has been used around the world during the last decades, but its growth has been most significant in recent years. Evaluating the wind energy characteristics and potential is a primary and important step for economical wind energy development. In fact, the probability distribution of wind speeds represents the wind speeds collected over a long period. Thus, its information is essential for assessing the wind energy potential of a particular location. It should also be mentioned that wind turbines installed at two locations with similar average of wind speed may typically generate completely different energy output owing to the differences in the characteristic of wind speed. This further highlights the importance of having knowledge of wind speed distribution.

Generally, a frequency distribution can be computed for a series of thresholds. The frequency distribution of wind speed can be determined using two approaches: (1) time-series wind speed data and (2) probabilistic distribution functions. The time-series approach appears to be more accurate due to the direct use of original wind speed data. However, since the time-series wind speed data are often enormous, it would be favorable to have only a few main parameters to explain the behavior and characteristics of wide ranges of wind speed data [2–4]. In this regard, the wind speed data can be fitted using probability distribution functions (PDFs) that helps to simplify a record's characteristics to only a limited parameters [2–4]. Therefore, since a few decades ago, this has motivated researchers to employ different PDFs for settling this issue and subsequently identifying the more appropriate ones.

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The PDF of a random variable is a mathematical model that characterizes the probability for this variable to occur at a certain point in each interval of observation. The cumulative distribution function (CDF) specifies the likelihood that a variable will be smaller than or equal to a particular value.

Rayleigh and 2-parameter Weibull distribution functions are two popular functions that have been widely used in many researches [5–15]. There are many other PDFs that have been typically used for wind energy assessments such as: Generalized Gamma distribution (GGam), the Gamma (Gam), Inverse Gamma (IG), Inverse Gaussian (IGA), 2 and 3-parameter Lognormal (LN2, LN3), Gumbel (Gum), 3-parameter Beta (B), Pearson type III (P3), Log-Pearson type III (LP3), Burr (BR), Erlang (ER), Kappa (KAP) and Wakeby (WA) distributions [16–21]. In this regard, identifying the more suitable function that provide the best fits to the observed data is of vital significance. As a matter of fact, use of a probability distribution function that fit more accurately to the wind data sets is helpful for reducing uncertainties in the wind power estimation.

There is a lack of detailed study about determining the suitable probability distribution models for estimating wind speed distribution in windy locations of Iran. Consequently, in this study the capability of different distribution functions is appraised to provide a better fit for wind speed data in the five stations distributed in the east and south-east of Iran. The main aim is introducing the more appropriate distribution function for wind speed data set in the nominated stations named Chabahar, Khaf, Lutak, Rafsanjan and Zabol. In this context, the Nakagami distribution function is applied for the first time to estimate the wind speed distribution.

The Nakagami distribution (also known as Nakagami-*m* distribution) is a generalized model proposed by Nakagami [22]. It is a probability distribution with two parameters which is related to the gamma distribution. Nakagami distribution has been widely used in communications as an effective model for mobile radio and fading channels [23–26]. It has obtained considerable attention because of its capability for modeling a wider class of fading channel conditions as well as fitting well the empirical data [27]. Nakagami distribution has found an appealing application by providing the best fit to land-mobile, indoor mobile multipath propagation and also scintillating ionospheric radio links [27,28]. Moreover, it has been shown that Nakagami offers the most suitable fit for satellite-to-indoor and satellite-to-outdoor radio wave propagation [27,29,30]. Other important applications of Nakagami distribution function are in Medical [31,32] and Hydrological sciences [33–35]. This distribution has been also used to model the hazard rate in reliability theories because of its memory less property. It has been shown the Nakagami distribution is the more appropriate function to evaluate the reliability of electrical components compared to the Weibull and Gamma [36].

Due to successful use of Nakagami distribution in different fields, assessing its proficiency to estimate the wind speed distribution in the nominated case studies could be interesting. Therefore, the performance of Nakagami distribution is tested against some previously used distribution functions including Exponential, Weibull, Gamma, Lognormal, Log–Logistic, Inverse-Gaussian and Generalized extreme value. The effectiveness of all eight distribution functions is assessed statistically based upon widely used statistical parameters.

Owing to lack of wind turbine installation in these regions of Iran, the results of this research may provide useful insight and information for the purpose of wind energy development.

The rest of this paper is structured as follows: Section 2 describes wind speed data and case studies. The probability density functions employed for modeling the wind speed probability distribution are discussed in Section 3. In Section 4, the statistical parameters utilized to appraise the performance of the employed probability distribution functions are discussed. In Section 5, the results and discussion are presented. Finally, conclusions are drawn in Section 6.

2. Case study and wind speed data

Iran is a vast country situated in Middle East with an area of 1,648,195 km^2. It has borders with Iraq and Turkey from the west side, with Afghanistan and Pakistan from the east side, Azerbaijan, Armenia and Turkmenistan from the north side. The Caspian coastline is located in the northern part of Iran extended around 650 km. Also, Iran has around 1770 km coastline in the southern part with Persian Gulf and Oman Sea [37].

Iran enjoys highly diverse climatic conditions with the high temperature difference between hottest and coldest regions of the country. The weather condition in the northern regions is moderate with substantial level of rainfall. In the western regions, the weather condition is cold and humid during the cold season and also dry and mild in the warm seasons. In the southern regions, air temperature and relative humidity is usually high, experiencing very hot weather in summers and mild weather in winters. East and southeast parts of Iran enjoy a desert climate with remarkable changes in air temperature during the day. In fact, the weather conditions are especially dry in these regions with extremely low rainfall and high evaporation in many parts. The arid climate of the east and southeast parts of the country is owing to the predominance of semi-permanent subtropical high pressures and associated dry descending motion [38].

For this research, the wind speed data measured at 10 m height for five stations distributed in the east and southeast of Iran were considered. Fig. 1 illustrates the locations of selected stations on the map of Iran. Also, Table 1 provides information on the geographical coordinates, altitude from the sea level, the time period, measurement intervals and the total number of the utilized wind speed data for the five selected stations.

Three stations of Khaf, Lutak and Zabol are situated in the regions that are under the direct influence of the strong persistent northwesterly to northeasterly winds known as the "wind of 120 days" [38,39]. 120-day winds, chiefly blow from the north and north-west directions, follows an obvious annual cycle that its peak occurs throughout the dry season typically from late spring till early autumn. Basically, winds of 120 days, as really powerful regional winds, usually begin to below in the middle of May to the middle of September. The wind of 120 days is related to the pressure gradient of north–south and is between a cold high-pressure system over the high mountains of the Hindu Kush in north of Afghanistan and a thermal low-pressure system in summer which is common over the desert of eastern Iran and western Afghanistan due to sustained surface warming. It is significant to state that the topographic wind channel effect of Babaei and Hindu Kush Mountains to the northeast and the Palanghan Mountains to the west of the region are the factors that accelerates this wind [40]. More details regarding these 120-days winds can be seen in [38].

Table 2 presents some descriptive statistics including maximum, mean, standard deviation, median, coefficient of variation (COV), skewness and kurtosis of the used wind speed data for selected stations. Skewness and Kurtosis are measures of the asymmetry and the peakedness of the distribution, respectively. According to Table 2, Khaf station has a very excellent wind energy potential so that it has the highest mean wind speed with the value of 8.81 m/s. While Rafsanjan has the lowest mean wind speed with the value of 4.47 m/s. The COV ranges from 0.44 for Chabahar to 0.83 for Zabol. The values of Skewness are positive for all stations which indicate that all distributions are skewed to the right. Furthermore, the coefficient of kurtosis varies between 2.16 and 3.59.