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An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran

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ABSTRACT

In this paper, the statistical data of eleven years' wind speed measurements of the capital of Iran, Tehran, are used to find out the wind energy potential. Also, other wind characteristics with the help of two methods of meteorological and Weibull are assessed to evaluate of which at a height of 10 m above ground level and in open area. For this purpose, a long term data source, consisting of eleven years (1995–2005) of three-hour period measured mean wind data, was adopted and analyzed. Based on these data, it was indicated that the numerical values of the shape and scale parameters for Tehran varied over a wide range. The yearly values of k (dimensionless Weibull shape parameter), ranged from 1.91 to 2.26 with a mean value of 2.02, while those of c (Weibull scale parameter), were in the range of 4.38–5.1 with a mean value of 4.81. Corresponding values for monthly data of whole year were found to be within the range 1.72–2.68 and 4.09–5.67, respectively related to k and c Weibull parameters. Results revealed that the highest and the lowest wind power potential are in April and August, respectively. It was also concluded that the site studied is not suitable for electric wind application in a large-scale. It was found that the wind potential of the region can be adequate for non-grid connected electrical and mechanical applications, such as wind generators for local consumption, battery charging, and water pumping. In wind direction evaluation, it was found that the most probable wind direction for the eleven-year period is on 180°, i.e. west winds.

1. Introduction

Energy is one of the crucial inputs for socio-economic development. The rate at which energy is being consumed by a nation often reflects the level of prosperity that it could achieve. Among renewable sources of energies, wind power is an important source of environmental-friendly energy and has become more and more important in the recent years. The number of installed wind power plants is increasing every year and many nations have made plans to make large investments in wind power in the near future. The factors influencing the energy produced by a Wind Energy Conversion Systems (WECS) at a given location over a period are: (1) the power response of the turbine to different wind velocities, (2) the strength of the prevailing wind regime and (3) the distribution of wind velocity within the regime. The total energy generated by the turbine over a period can be computed by adding up the energy corresponding to all possible wind speeds in the regime, at which the system is operational. Hence, along with the power characteristics of the turbine, the probability density corresponding to different wind speeds also comes into our energy calculations. Knowing the wind speeds of a certain region is important in determination of characteristic speeds of the turbine which are its cut-in velocity, rated velocity, and the cut-out velocity. Also, the effective utilization of wind energy entails a detailed knowledge of the wind characteristics at the particular location [1].

The wind speed probability distributions and the functions representing them mathematically are the main tools used in the wind-related literature. Their use includes a wide range of applications, from the techniques used to identify the parameters of the distribution functions [2–4] to the use of such functions for analyzing the wind speed data and wind energy economics [5,6]. The first statistical studies of wind speed as a discrete random variable began 50 years ago, with the Gamma distribution [7]. Over this period, different distribution functions have been suggested to represent wind speed, including those of Pearson, Chi-2, Weibull, Rayleigh and Johnson functions [8–11]. Several non-normal distributions have been suggested as appropriate models for wind speed (inverse Gaussian [12], log-normal [13], Weibull [14–17] and squared normal [18]). Among these, the Weibull distribution function is the most commonly used in applications. The variation of wind velocity is

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often described using the Weibull two parameter density function. To date, this statistical method is widely accepted for evaluating local wind load probabilities and can be considered almost a standard approach [19–21]. Past researches have proven that the Weibull distribution function has its merits in wind resource assessment due to its great flexibility and simplicity, but particularly, it has been found to fit a wide collection of recorded wind data [22–26]. The Weibull density function was used by Weisser [27] for the analysis of wind energy potential of Grenada (West Indies) based on historic recordings of mean hourly wind velocity. Panda et al. [28] made a stochastic analysis of the wind energy potential at seven representative weather stations in India and a probability model for the wind data and wind potential was developed. They used Box–Cox transformation to transform the data for all stations to a normal distribution. Ulgen et al. [29] studied the wind variation for a typical site and found Weibull and Rayleigh distributions suitable. Availability of wind energy and its characteristics at Kumta and Sirsi in Uttar Kanada district of Karnataka were studied by Ramachandra et al. [30] based on primary data collected for a period of 24 months. Using a given type of wind electric generator and from official meteorological data, Ramachandra et al. [31] secured maximum output of power; the analysis showed that coastal and dry arid zones have good wind potential.

Wind energy potential is not easily estimated because, contrary to solar energy, it depends on the site characteristics and topography to a large degree, as wind speeds are influenced strongly by local topographical features [32]. The classification and characterization of an area as of high or low wind potential requires significant effort, as wind speed and direction present extreme transitions at most sites and demands detailed study of spatial and temporal variations of wind speed values. Before determining the wind farm site, the hourly and monthly mean wind speed, wind speed distributions as well as the wind power densities should be analyzed carefully.

2. Iran climate

Iran is both a vast country (1.6 million square kilometers) and a natural fortress connecting the Middle East to both Central Asia and India. The Zagros and Elbruz Mountain ranges define Iran's western and northern frontiers. At its southern terminus, the Zagros gives way to the flatlands and marshlands of southern Iraq (Basra province) and southwestern Iran (Khuzestan Province). The southern frontier is defined by the Persian Gulf, the Gulf of Oman and part of the Arabian Sea. Iran's eastern frontier is desert; the northern half is the Dasht-e-Kavir and the southern half being the Lut-e-Kavir. Both deserts are among the harshest deserts on the planet.

Iran enjoys considerable climatic diversity, which is subjected to various seasons in different parts of the country, in a way that in some areas the cold of the winter and the heat of the summer can be seen simultaneously. That is why weather in Iran must be considered regionally. The average annual temperature of Bandar Abbas in the south of Iran is 18.5 degrees Centigrade in January. The average annual rainfall is also highly varied in different parts of the country, the amplitude varying between 2000 mm in Gilan and less than 100 mm in the central parts of Iran. The average annual precipitation in Iran is 275 mm in January and February, there are three climatic zones in Iran. The shores of the Caspian Sea have mild and relatively cold weather, central parts experience winter weather conditions and southern parts enjoy moderate and pleasant weather. The whole country enjoys pleasant weathers in spring, especially in May, but in southern parts it grows very hot unexpectedly. The climatic condition of the country becomes complicated in summer. Due to high humidity, the weather of the coastal parts of the Caspian Sea changes in summers. During the day it is hot, but it relatively cools down at night. In southern coastlines of Iran (Persian Gulf), days are very hot and nights are relatively warm, with very high humidity, which is intolerable to non-natives.

The complex physical conditions of Iran including topography, vegetation cover and landscape have created a diverse climate pattern. The very hot and dry climate of the interior areas changes suddenly to the wet and moderate coastal climates of the Caspian coastal areas to the north of the Alborz mountains. The cold climates of Zagros are replaced by the warm desert climates to the east. If we accept that the climate is a very important factor in the development and progress of the country, it is important that it should be recognized and understood in any planning and policy decisions [33]. A terrain map of Iran is shown in Fig. 1.

3. Wind energy status and its assessment in Iran

Energy is essential to economic and social development and improved quality of life in Iran, as in other countries. Because of the social and economic development of the country, the demand for energy, and particularly for electricity, is growing rapidly. The global wind power capacity has increased by a factor of 4.2 during the last five years. It has been estimated that roughly 10 million MW of energy are continuously available in the earth's wind while the total global installed capacity was 39434 MW in 2004 [34]. Scientists and researchers began working on utilization of wind energy for electricity generation in Iran a decade ago. Based on calculations, Iran enjoys only a moderate supply of wind power, with some regions having continuous air flows with sufficient energy to produce electricity (the average wind velocity in such regions is measured at about 5 m/s). The potential capacity of wind power is figured at about 6500 MW for the country, mostly in the eastern sections [35]. As a matter of fact, this level of energy is considered to be of medium level among different countries; however, some locations in Iran are subjected to have strong winds to produce electricity. Considering the good potential of a well situated location, construction of the wind power stations began in 2003 in Iran (the 25 MW and 60 MW power stations at Manjil) reported by Fadai [36]. The wind atlas of Iran is shown in Fig. 2 as presented in [37].

The development of wind powered generators has gotten a deserving attention during the last decade leading to the construction of the country's first such power station [38]. Although Iran has a favorable wind resource, the use of wind energy in Iran is too limited. Although there are several companies attempting to establish wind power plants in different districts in Iran, it can not be said that the work in this field is satisfactory. Much more is needed to be done to increase interest in this subject. Wind energy will play an important role in future energy needs of Iran. Selecting a windy site with satisfactory wind power potential for wind power generation requires meteorological data for installation of wind generator. In the present work, the meteorological data of Tehran (Longitude: 51°20′ E, Latitude: 51° 25′ N) are processed in the next parts to assess the regional wind power potential.

4. Data collection and site description

Tehran's climate is largely defined by its geographic location, with the towering Alborz Mountains to its North and the central desert to the South. It can be generally described as mild in the spring, hot and dry in the summer, pleasant in the autumn, and cold in the winter. As a large city with a significant difference in elevation among various districts, the weather is often cooler in the hilly north as compared to the flat southern part of Tehran. Summer is usually hot and dry with very little rain, but relative humidity is generally low and the nights are cool. The majority of the light annual precipitation occurs from late-autumn to mid-spring, but no one month is particularly wet. The