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Estimation of wind resources in the coast of Ceará, Brazil, using the linear regression theory

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ABSTRACT

This work is concerned with the estimation of onshore wind resources in the coast of Ceará, Brazil by using the linear regression method. The main focus is to estimate the average wind speed at several altitudes from data collected at the surface. Two specific areas are investigated i.e. Paracuru and Camocim, which are located in the state of Ceará, Brazil. The same methodology is adopted in both cases, where the regions are initially characterized by obtaining the daily and monthly average wind speed profiles from raw data collected by a Platform for Data Collection (PDC) and an Anemometric Tower (AT). Data regarding the prevailing wind direction are also recorded. By using the logarithmic wind profile equation, it is possible to estimate the average wind speeds at altitudes of 20 m, 40 m, and 60 m from data collected at 10 m, as it is possible to determine correlation coefficients between the data and those collected by the AT. Linear regression model is used to estimate the average speed for new altitudes. This procedure is carried out during the calibration and model validation. In both periods, the linear regression model has shown good performance in terms of high level of agreement for the data series, estimated data and related correlation coefficients, and also low error values involving the aforementioned series.

Contents

1. Introduction

The wide access to clean and sustainable energy sources is undoubtedly one of the greatest challenges facing the modern

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world [1]. Nowadays it is possible to notice that several issues regarding energy consumption and generation are widely discussed in media either directly or indirectly.

The encouragement and incentive towards the use of wind energy must be permanently present in public policies related to national energy security. The state of Ceará reached 671 MW of installed wind power generation capacity in 2013 and became the largest wind energy producer in Brazil. Of the total amount, 509.3 MW are produced by 14 wind farms that have been implemented since 2007, while 17.4 MW are from three farms that were installed during the 1990s (Secretary of Infrastructure of Ceará-SEINFRA/CE, 2013).

The energy matrix must be based on the variety of energy sources, which is associated to the complementarity of hydro-environmental systems. This concept depends on the seasonal precipitation cycle, which is directly related to hydropower generation, and also on other atmospheric variables such as the wind speed and solar radiation. For instance, the first semester of the year in northeastern Brazil is known as the rainy period, where higher cloudiness and lower wind speeds are predominant, being the most favorable season for the power generation. When the rainy season ceases or precipitation decreases from June, the use of wind energy is more adequate due to increased wind speeds and solar radiation levels associated to the decreased cloud cover [2,3].

The variability of meteorological parameters is associated to the influence of prevailing weather systems and their performance during the year in a given region depends on local peculiarities of the boundary layer, which cause particular features of wind profiles to change.

In northeastern Brazil, the role of weather systems marks the seasonal wind cycle. On average, from November to January, the frequent incursion of frontal systems moving from sub-tropics of South America to south-central sector of Brazilian northeast region causing rainfall tends to stick with predominant winds blowing from southwest to northeast and in some cases from south to north [4].

In the austral summer and autumn (from January to May), the winds begin to blow climatologically between east and north, with prevailing winds coming from the northeast. During some years, there are different influences on this phenomenon associated with the interannual variability of sea temperature anomalies in the tropical Atlantic Ocean [5], which may modify this regime. During years in which the temperatures of the sea surface (TSS) anomalies in the Tropical North Atlantic are warmer than the TSS anomalies in the Tropical South Atlantic, there is higher frequency of winds blowing from southeast in this part of northeastern Brazil (NEB) [6]. However, within the period from January to May, particularly between March and April in the northern part of northeast Brazil, the Intertropical Convergence Zone (ITCZ) causes more frequent rain events and also weaker winds.

From June to early November, the semi-arid Northeast of Brazil is marked by a period of low rainfall, except for the eastern sector of the region, whose rainy season occurs between April and July. Due to the influence of the so-called wave disturbances from the east, atmospheric disturbances move from the Atlantic Ocean towards the continent, causing rain in the forest zone of northeast Brazil [7].

Dry air masses are predominant between June and November not only in northeast Brazil, but also in most of South America. This phenomenon is associated with the displacement of high pressure system called semi-stationary anticyclone to the east coast and southeastern Brazil, resulting in the predominance of winds blowing from the east-southeast quadrants in northeast Brazil. During the first half of the year, this system lies predominantly in the southeastern sector of the Atlantic Ocean.

In addition to synoptic features that influence the wind regime in northeast Brazil inter annually, local circulations such as land and sea breezes and local effects of planetary boundary layer (which are mainly associated to turbulent processes) are also factors that play an important role in the daily wind direction and speed [8–12]. The land and sea breezes caused by the thermal contrast continent–ocean are responsible for changes in wind direction during the day and night in coastal areas of the northeast. During the day, mainly in the afternoon, when the continent is warmer than the sea, a lower pressure center of the wind is created, which tends to blow into the continent in the form of the sea breeze. Overnight, the characteristics are the opposite, while the sea loses heat more slowly than the continent generating lower pressures and causing winds to blow from the continent towards the ocean in the form of land breeze. Procedures for instability and atmospheric boundary layer characteristics such as roughness and even differences in vegetation and topographical features are also very responsible for diurnal changes in the regime of wind speed and direction [10,11].

In northeast Brazil, the states of Maranhão, Piauí, Ceará, and Rio Grande do Norte are favored by the combination of winds from the east with land and sea breezes, leading to annual average wind speeds within the range from 6 m/s to 9 m/s. The coastline that stretches across the states of Paraíba and Bahia offers speeds from 3.5 m/s to 6 m/s. The areas of hills and plateaus that extend over the Rio Grande do Norte coast to the state of Rio de Janeiro have annual average wind speeds from 6.5 m/s to 8 m/s [20].

Additionally, the production of electricity in 2011 increased by 9.1% and the percentage of renewable energy in the Brazilian energy matrix reached 45.4%. The generation of energy from renewable sources increased by 5%, while wind energy showed the highest growth rate (50.5%) followed by biomass (18.1%). The Brazilian incentive program for alternative energy sources (PROINFA) created in 2002 associated with wind energy auctions promoted by the federal government since 2007 have been responsible for the significant increase of wind energy generation in the energy matrix.

Even in noncoastal areas of the northeast, there are sites whose wind potential must be tapped e.g. Araripe, which is a

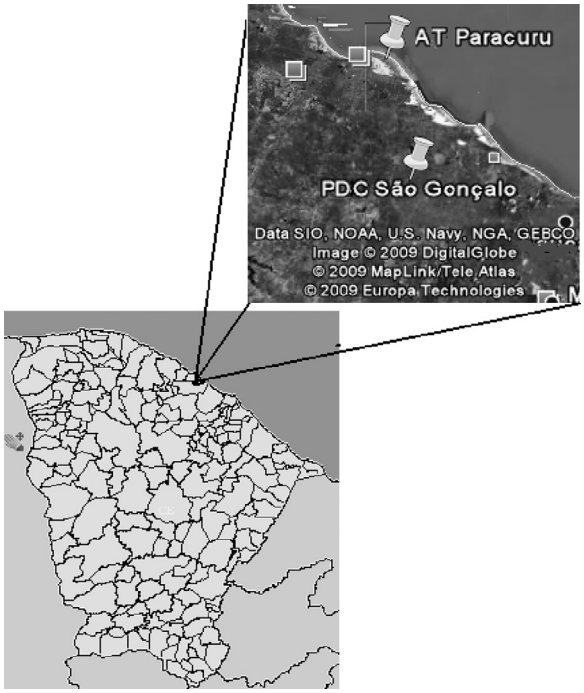

Fig. 1. Map of the state of Ceará highlighting the study area (Paracuru). Source: Adapted from the Google maps