Statistical Analyses of Wind and Solar Energy Resources for the Development of Hybrid Microgrid

Abubakar Abdulkarim, Sobhy M. Abdelkader and D. John Morrow

Abstract In this paper, a procedure for the statistical analyses of wind and solar energy resources are investigated in order to determine the accurate frequency distribution for the development of hybrid microgrid. The frequency distributions used for wind speed data analysis include Weibull, Rayleigh and Gamma distribution functions. On the other hand the frequency distributions used for the analysis of solar radiation data include Weibull, Logistics, lognormal, Beta and Gamma functions. The performance of the probability distributions used in the wind speed analyses are based on the error evaluations between the predicted and the theoretical wind power densities of the site. Similarly, the performance of the probability distribution functions used in the solar radiation data were judged based on Kolmogorov-Smirnov, Anderson-Darling and Chi-Square tests. The goodness of fit tests (GOF) results of the wind speed analyses show that Weibull distribution performed better compared to Rayleigh and Gamma distributions. On the other hand Beta distribution fitted the solar radiation data better than all other distributions models.

1 Introduction

Solar and wind energy are non-dispatchable sources, site dependant, pollution free and therefore act as one of the leading potential sources of alternative energy. However, the factors that judge the possibility of utilizing these sources of energy are the solar and wind energy potentials of the site under consideration.

To accurately assess the renewable energy potentials of any site for production of electrical energy, historical records of the wind speed or solar radiation data are analysed. This acts as the preliminary step in siting the hybrid energy system.

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The factors to be analyse if available all includes wind speed and its prevailing direction, turbulence intensity, wind distribution, solar radiation, scale and shape parameters and class etc. In order to use the historical record of the site, it is recommended that a data for at least 30 year period should be used. Some of the drawback of the historical approach includes difficulty in getting accurate data, time consuming, technical challenges and very expensive. This results in some researchers into analyses with data for a period between 1 and 5 years. This may not accurately result in an optimum performance of the system under consideration. Recently, the statistical methods are gaining popularity. Some of the reasons leading to the popularity of the statistical methods include economics, time and possibility of predicting the behaviour of the system with less error to mention just a few. Therefore, in this work, the feasibility study of the site under consideration for hybrid microgrid application is conducted by statistical judgments.

Recently efforts been made in analysing the renewable energy potentials of a particular site include the statistical analysis of wind speed data [1] and Turkey [2]. In some site such as Pakistan [3] Weibull distribution was not suitable for them. Wind energy potentials of India [4] and in [5], the wind energy potential of Penjwen region, Iraq has been investigated using Weibull distribution model. On the other hand, the application of statistical analysis of solar radiation data in Taiwan has been considered in [6]. Others include the solar energy variations in some sites in Nigeria [7] and fitting Weibull distribution to Ultraviolet radiation data in Kuwait [8]. It can be observed that literature for the assessments of both wind and solar energy potentials of a particular site is very limited. Therefore, the paper demonstrated the applications of some statistical models to fit the wind and solar energy data of the sites under consideration for the development of hybrid renewable energy system. Most of the research effort focused on the use of Weibull distribution. It has been established that, the probability distribution function for predicting the behaviour of wind and solar resources may be different from one site to another. In this work the mentioned probability distributions are employed to fit both solar and wind energy of a particular site separately. This is because the design of hybrid renewable energy systems is based on the performance of individual system [9]. The mathematical or statistical judgments used are based on some factors such as accuracy in fitting the available data from the site.

2 Determination of the Mean Wind Speed of the Sites

The analysis starts from the determination of the mean wind speed and acts as important parameter in power generation from wind energy. Therefore, the mean wind speeds for the two sites were obtained from the data collected for a period of 1 year. The data involved the sample of wind and solar radiation at 5 min interval. The rmc velocity was used in the analysis in order not under estimate the wind energy potentials of the sites as in (1). The average wind power density can be defined as the annual average power per unit area as defines in [10]. The expression for the power used in the analysis is given in (2).

$$v_{rmc} = \sqrt[3]{\frac{1}{N}\sum\nolimits_{i=1}^{N} v_i^3} \tag{1}$$

where v_i is the wind speed observation at ith time, v_{rmc} is the root means square cube wind speed and N is the number of wind speed data points.

$$\overline{P_W} = \frac{1}{2}\rho \sum\nolimits_{i=1}^{N} P(v_i) \cdot v_i^3 \tag{2}$$

where $\overline{P_W}$ the average wind is power density at the given site, and ρ is the observed air density if available. The air density is assumed to be 1.225 (kg/m^3).

3 Probability Density Functions for Wind Speed Data

3.1 Weibull Distribution

Weibull distribution is one of the most widely used probability distribution in the statistical analysis of experimental data. The most important property of this distribution is that it has no specific shape [11]. The sites average power densities can be determine based on shape and scale parameters [12]. The Weibull average wind power density is calculated using (3).

$$WPD_w = \frac{1}{2} \times \rho \times c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{3}$$

3.2 Rayleigh Distribution

The second proposed probability distribution used in the analysis is called Rayleigh distribution and its probability density function is given in [13]. The Rayleigh probability density function is also defined in [13]. The Raleigh wind power density can be defined in terms of c and k parameters as in (4).

$$WPD_R = {}^{3}/_{\pi} \times \rho \times c^3 \sqrt{\frac{\pi}{4}} \tag{4}$$

3.3 Gamma Distributions

The Gamma has similar properties to those of Weibull distribution that is; it is a two parameter distribution with shape α and scale β parameter defined in [12]. Similarly, the wind power density of gamma function in term of c and k parameter can be define as

$$WDP_{Gam} = \frac{1}{2}\rho \times c^3[k(k+1)(k+2)] \tag{5}$$

3.4 Goodness of Fits

In this work, the performance of the models used in predicting the wind power densities of the sites were investigated by evaluating the error between the actual and the predicted powers of different probability density functions as in [5]. Comparison is made by quantifying the errors evaluated such that the closer the error to 0 %, the more accurate the model is in predicting the wind power density of the site.

3.5 Application of the Procedure

Applying the procedure above on a data for both Northern Ireland and Nigeria, the results of the analyses are presented in Table 1. On the whole Weibull distribution fits best in all the sites followed by Gamma distribution; Rayleigh has the least fitting compliance. This has further confirmed that when modelling wind speed for power generation, Weibull distribution could be regarded as the most preferred approach.

4 Analyses of Solar Radiation

In this section, the solar radiation data was analysed by fitting three more distributions. These includes Lognormal distribution in [6], Beta Distribution and Logistic as defined as [3]. On the other hand, solar radiation goodness of fits used in the proposed tests includes Kolmogorov-Smirnov, Anderson-Darling and Chi-Square tests [14]. Application of the procedure presented for the analysis of solar radiation

Table 1 Annual average errors of site in Belfast, UK and Abuja, Nigeria

		Weibull		Rayleigh		Gamma	
Parameter		WPD	Error	WPD	Error	WPD	Error
Ave.	Bel.	194.2	0.02	342.1	0.73	208.2	0.07
	Nig.	173.7	0.03	306.2	0.84	178.7	0.10

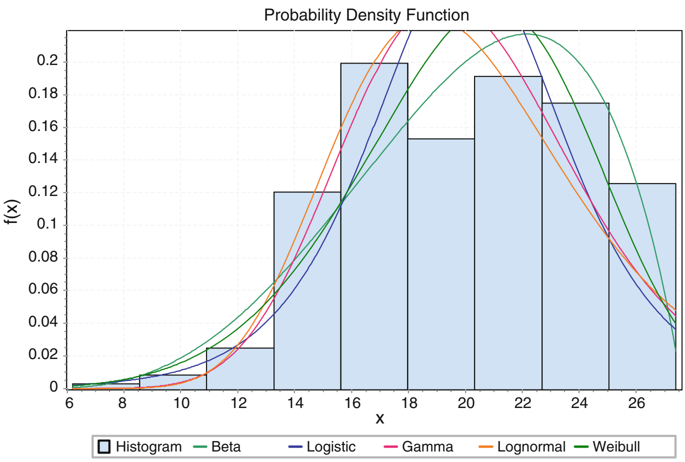

Fig. 1 Average solar radiation Abuja, Nigeria

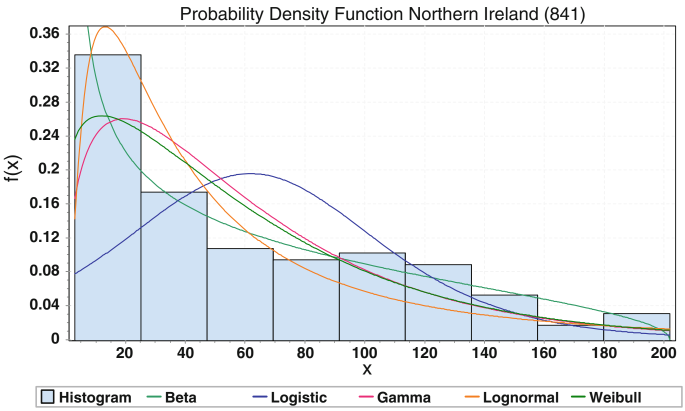

Fig. 2 Average solar radiation Belfast, United Kingdom

data were applied to the solar radiation data for the sites under consideration. The results obtained are presented in Figs. 1 and 2 for Abuja, Nigeria and Belfast, United Kingdom in that order.

5 Conclusion

In this paper, throughout the study, Weibull distribution performed batter follow by Gamma and Rayleigh ranked lowest in predicting the average wind power densities of the two sites. The analysis of solar radiation data indicated the good performance of Beta compared to Gamma, Logistic, Lognormal and Weibull distributions in that order for both Nigeria and Northern Ireland. The findings in this paper can be further use in the areas that are having similar meteorological conditions with the study areas.

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