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A novel energy pattern factor method for wind speed distribution parameter estimation

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ABSTRACT

Power output of wind turbine depends on many factors. Among them, the most crucial one is wind speed. Since wind speed data is a significant factor for wind energy analyses, it should be modeled accurately. Weibull distribution has been used extensively to model variation of wind speed. Therefore, the most appropriate distribution parameter estimation method selection is critical in order to minimize data set modeling errors. In this context, a novel, robust, efficient and better method than standard methods to estimate Weibull parameters is presented for the first time in this paper. The accuracy of the proposed method is verified using different data sets. Also, developed method is compared with Graphic Method (GM), Maximum Likelihood Method (MLM), Alternative Maximum Likelihood Method (AMLH), Modified Maximum Likelihood Method (MMLH), Moment Method (MM), Justus Moment Method (JMM), WAsP Method (WM) and Power Density Method (PD). The results indicate that the proposed novel method is adequate to determine Weibull distribution parameters.

1. Introduction

Fossil energy sources have served as the primary energy source and supplied about 86% of the world's final energy demand [1]. According to the statistics, the current trend of consuming scarce fossil energy sources causes these energy sources deplete within the next decades [2]. Due to fluctuating fossil energy source prices, increasing consumption of limited reserves, global population rise, growth in energy demand and energy supply security problems, many countries have been forced to use renewable energy sources. Installed wind power capacity accounts for 5% of global electricity generation, equal to the 480 TW h per year by the end of 2014. Wind energy's contribution to the global electricity supply is expected to reach 12% by 2020 and 22% by 2030 [3]. Wind energy has a technical potential to supply global electricity consumption.

Wind turbine power output depends on many factors such as mean wind speed, power density, wind speed distribution, turbine hub height, turbine rated power, shape of power curve, air density, turbulence intensity, and other factors. Among them, the most crucial one is wind speed distribution. As stated by Morgan et al. [4] main uncertainty in estimation of wind turbine annual output lies in the selection of accurate distribution, since power curve of wind turbine is known fairly accurate. According to the International Electrotechnical Comission Standard [5] and other international recommendations, Weibull distribution is the most appropriate and widely used one to determine wind energy potential. Moreover, Weibull distribution is the default option to estimate energy output of wind turbine or wind farm for numerous wind energy softwares [6,7]. Also, Weibull distribution is recommended as a main distribution for wind analysis in wind energy textbooks. Therefore, when a new distribution is proposed to describe wind speed distribution, it is often compared with commonly used Weibull distribution. Weibull distribution is not a universal distribution to represent wind distribution for all geographical locations in the world owing to the sharp differences in climate and topography [8,9]. In recent years, entropy based distribution and mixture distributions such as normal-Weibull, Weibull–Weibull distribution have been proposed as alternatives to the Weibull distribution in literature [9–13].

The main objective of the present article is to introduce a novel, robust, efficient, practical, empirical and better method than standard methods to estimate Weibull distribution parameters. The remainder of the paper is organized as follows. In section two, literature review for parameter estimation method was carried out. In Section 3, widely used eight methods to estimate parameters of Weibull distribution were revisited. In Section 4, a novel method was introduced. In Section 5, in order to verify the suitability of this proposed novel method, the introduced method was

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Nomenclature

AMLH	Alternative Maximum Likelihood Method	b_n	coefficient for shape parameter
CDF	cumulative density function	c_n	coefficient for scale parameter
GM	Graphic Method	d_n	coefficient for scale parameter
GOF	goodness of fit test	E_{pf}	energy pattern factor
JMM	Justus Moment Method	$F(v)$	cumulative distribution
MM	Moment Method	$f(v)$	probability density function
MMLH	Modified Maximum Likelihood Method	m_n	N_{th} moment of Weibull distribution
MLM	Maximum Likelihood Method	σ	standard deviation
MSV	Mean Sum Variation	v_m	mean wind speed
NEPFM	novel energy pattern factor method	$\Gamma(.)$	Gamma function
PD	Power Density Method	$\bar{v^3}$	mean of wind speed cubes and
PDF	Probability density function	$(v_m)^3$	cube of mean wind speed.
RMSE	Root mean square error	R^2	coefficient of correlation
WM	WAsP Method	m_n	N_{th} moment of Weibull distribution
k	Weibull distribution shape parameter (–)	m_{dn}	N_{th} moment of data sets
c	Weibull distribution scale parameter (m/s)	std_n	Weibull distribution standard deviation and std_d is data set standard deviation
a_n	coefficient for shape parameter		

compared with eight methods through Monte Carlo Simulations. This novel method was also compared with eight methods used in terms of goodness of fit tests (GOF). Then, the influence of parameter estimation methods on the wind characteristics of the 13 selected regions in Turkey was analyzed. Section 6 concludes the paper.

2. Literature review

The Weibull distribution was first introduced as Wallodi Weibull [14]. Utilization area of this distribution is vast and encompasses nearly all research areas. Thus, parameter estimation is considered as a critical topic due to the accuracy of feasibility and reliability analysis. Graphic Method (GM), Maximum Likelihood Method (MLM), Alternative Maximum Likelihood Method (AMLH), Modified Maximum Likelihood Method (MMLH), Moment Method (MM), Justus Moment Method (JMM), WAsP Method (WM) and Power Density Method (PD) are the most commonly used methods. Each of these methods has their own benefits and drawbacks.

In literature, these methods are compared several times in order to investigate their efficiency, accuracy and capability in modeling data set [15–22]. It is well known that in some cases these methods can provide dramatically different results in estimation the distribution parameters. Dorvlo [16] used the chi-square, moments and regression methods to determine Weibull distribution parameters and concluded that the moment and regression methods are not as well as chi-square method. The performance of GM, JMM and MLM methods was compared by Akdag and Guler [17] considering two goodness of fit tests. It was concluded that JMM is better than other methods. PD was introduced by Akdag and Dinler [21] to estimate Weibull distribution parameters for wind energy applications. This method was compared with GM, JMM and MLM methods. Result of the study revealed that PD is adequate and able to provide high accuracy for estimation of Weibull parameters. Saleh et al. [22], discussed four methods for distribution parameter estimation, namely, MLM, MMLM, GM and PD methods. Based on the goodness of fit test results, MLM was recommended. Chang compared six methods and concluded that if wind speed distribution matches well with Weibull distribution, these methods are applicable [23]. Also, a comparison among seven methods to estimate Weibull distribution parameter was presented, as regards to their accuracy and capability to model the wind speed distributions in Brazil [24]. Table 1 summaries the goodness of fit results of the seven methods for selected regions of Brazil [24]. Methods are ranked according to three goodness of fit criteria. The rankings were done by considering maximum coefficient of determination, minimum root mean square error and minimum chi square value. GM is the best method for three cases, second best method for one case and worst for one case. PD method is the best method for two cases, second good method for three cases and third method for one case. EEM is the best method for one case, second best method for one case, third best method for two cases and worst method for one case. It was revealed that GM method is the best and followed by PD and EEM.

The performance of seven parameter determination method was compared by Azad et al. [25] to find the best method in terms of six GOF tests. Results of the paper summarized in Table 2. The rankings were done by considering six GOF test results. MM method is best method for two case, second best method for one case and third method for two cases. PD is best method for two cases and second best method for two cases. It was revealed that MM method is the best and followed by MLM and PD.

According to Tables 1 and 2 none of the methods ranked as the best for all cases. However, some of the methods may perform better than others.

It can be concluded that there is not a single, universally accepted, best method to estimate Weibull distribution parameters. So, these literature show us that this topic is still open to exploration. In this paper, a novel method was outlined which can be efficiently and accurately used to determine Weibull parameters. Also proposed methods can be used for various distributions.

3. Methods for estimating Weibull parameter

A statistical distribution to show wind characteristics provides information about the wind regime at a measurement site. This

Table 1
Rank of parameter determination methods for Brazil [24].

	1th	2nd	3rd	4th	5th	6th	7th
GM	3	1	–	–	1	–	1
PD	2	3	1	–	–	–	–
EEM	1	1	2	–	–	1	1
MLM	–	1	2	2	–	–	1
MM	–	–	1	1	2	1	1
MMLM	–	–	–	2	1	2	1
JMM	–	–	–	1	2	2	1