Characteristics of Electrical Power Generation by Wind for Al-Tweitha Location Using Weibull Distribution Function

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Abstract

In this paper, the 5 minutes measured wind speed data for year 2012 at 10 meter height for Tweitha have been statically analyzed to assess the time of wind turbine electrical power generation. After collection Tweitha wind data and calculation of mean wind speed the cumulative Weibull diagram and probability density function was ploted, then each of cumulative Weibull distribution, cut-in and furling turbine wind speed could be used as a mathematical input parameters in order to estimate the hours of electrical power generation for wind turbine during one day or one year. In Tweitha site, found that the average wind speed was (v= 1.76 m/s), so five different wind turbines were be selected to calculate hours of electrical generation for Al-Tweitha site, the best of them was SWG 20 kW wind turbine.

Keywords: wind energy cumulative function, hours of power generation.

خصائص توليد الطاقة الكهربائية من الرياح لموقع التويثة باستخدام دالة توزيع ويبل

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الخلاصة:

في هذا البحث، تم جمع بيانات سرع الرياح و بفاصل زمني كل 5 دقائق لسنة 2012 وعلى ارتفاع 10 متر لمحطة التويثة في بغداد . ثم تحليل هذه البيانات لغرض تخمين عدد ساعات إنتاج توربين الرياح للطاقة الكهربائية. بعد جمع بيانات الرياح لمنطقة التويثة وحساب متوسط سرعة الرياح نتمكن من رسم تخطيطي لدالة كثافة الاحتمالية لتوزيع ويبل، بعدها نستخدم كل من دالة توزيع ويبل التراكمي ة ومعلمات التوربين المقترح (معلمة سرعة الرياح التي يبدأ عندها التوربين بالتوليد cut–in ومعلمة سرعة القطع والتي يتوقف فيها التوربين عن التوليد furling) يمكن أن تستخدم بمثابة متغيرات الإدخال الرياضية من أجل تقدير ساعات توليد الطاقة الكهربائية لتوربين الرياح خلال يوم واحد أو سنة واحدة. اظهر العمل على بيانات محطة التويثة الانوائية إن معدل سرعة الرياح (v=1.76 m/s)، كما تم اختبار خمسة أصناف مختلفة من التوربينات لغرض إجراء صيغة حساب عدد ساعات توليد القدرة الكهربائية لهذه التوربينات في منطقة التويثة وفق بيانات المحطة الانوائية للمنطقة وكان أكثر التوربينات ملائمة للمنطقة من بينها نوع SWG بقدرة 20 kW.

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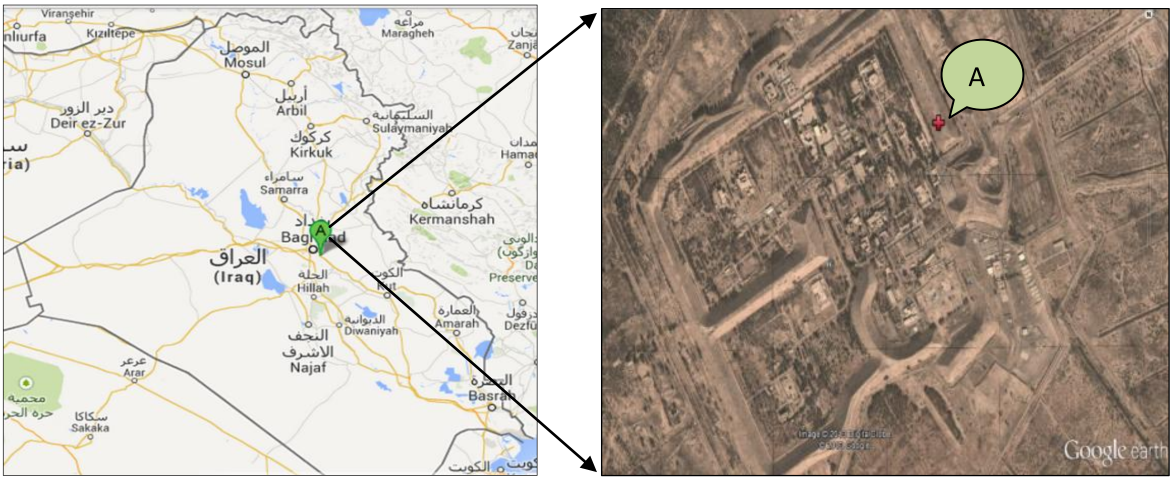
Introduction:

Due to the present day energy demand and growing environmental consciousness, it has become imperative to supplement our energy base with clean and renewable sources of energy. Wind is one of the potential renewable energy sources which can be harnessed in a commercial way, thus there is no doubt that wind power will play a major role as the world moves towards a sustainable energy future. A detailed knowledge of wind characteristics is required for efficient planning and implementation of any wind engineering project. Fortunately, most regions of the world experience moderate range of wind speeds that can allow human to extract energy from the wind, [1]. According to that, we care about the amount of time which produces wind turbine electrical power generation, and this amount will be increased depending on the degree of matching of wind turbine type with the wind speed distribution belongs to that site.

Study Area:

Al-Tweitha lies in easting south of Baghdad. This area contains an artificial hills affect on wind speed and productivity of the electric power in the event of wind turbine erected in that area. Iraqi map was shown in figure 1-a, which appear the location of Al-Tweitha and the location of the metrological station at 33°12'27.58" N Latitude & 44°31'10.22"E longitude. Figure-1, shows a satellite image for the location of the meteorological station in Al-Tweitha site.



(a) **(b)**

Figure 1-(a)The position of Al-Tweitha on Iraq map, (b) Satellite image for Al-Tweitha site.

Power Generation

The power generation of a commercial wind turbine is time variant, but follows regular daily and seasonal patterns. Power generation varies considerably over time, but significant diurnal and seasonal patterns are evident in the data.

One of the goals of this study is to know the effect of wind distribution on the wind turbine power generation as a function of time for a day or a full year. Meteorological data was obtained from a commercial weather station located in the Al-Tweitha site.

Wind Turbine Generator

Wind turbine power generation characteristics are affected by a wide range of factors including: seasonal changes in air density, blade soiling (insect debris, dust, etc.), control system interactions with turbulent winds, maintenance procedures, and connection issues to the electrical transmission system. These factors impact both the cost and the value of wind power production.

Wind Turbine Generator, WTG characteristics are different from one to another. Also, the characteristics of the wind speed are different from site to site. Pairing between the performance parameters of WTG and the wind speed characteristics of each site can increase the wind energy captured considerably and reduce the cost of the generated energy. The main performance parameters of the WTG are, cut in, rated and furling wind speeds respectively and rated power of the WTG. Also, the main characteristics of wind speed in a certain site are the shape parameter (k) and the scale parameter *(A)* that can be obtained from Weibull distribution statistical technique, [2].

Wind Turbine Classes

Wind turbine class is one of the factors which is need to be consider during the complex process of planning a wind power plant. Wind classes determine which turbine is suitable for the normal wind conditions of a particular site. They are mainly defined by the average annual wind speed (measured at the turbine's hub height), the speed of extreme gusts that could occur over 50 years, and how much turbulence is there at the wind site. There are three wind classes for wind turbines, which are defined by an International Electro technical Commission (IEC) standard and correspond to high, medium, and low wind, as table-1, shows, [3].

Table 1- Specifications for wind classes

Wind turbine class	Annual average wind speed (m/s)	Extreme 50-year gust (m/s)
IEC I high wind	10	70
IEC II medium wind	8.5	59.5
IEC III low wind	7.5	52.5

Weibull distribution

The Weibull distribution (named after the Swedish physicist W. Weibull, who applied it when studying material strength in tension and fatigue in the 1930s) provides a close approximation to the probability laws of many natural phenomena. The Weibull distribution gives a good match with the experimental data, as mentioned in many references. This distribution is characterized by two parameters: the shape parameter (*k*) (dimensionless) and scale parameter (A) (m/s), [4]. In Weibull distribution, the variations in wind velocity are characterized by the two functions; (1) The probability density function *f(V)* and (2) The cumulative distribution function F(V). The probability density function *f(V)*indicates the fraction of time (or probability) for which the wind is at a given velocity *V*. It is given by [5];

$$f(V)=\frac{k}{A}\left(\frac{V}{A}\right)^{k-1}e^{-\left(\frac{V}{A}\right)^{k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

The cumulative distribution function of the velocity V gives us the fraction of time (or probability) that the wind velocity is equal or lower than V. Thus the cumulative distribution F(V) is the integral of the probability density function. Thus,

$$F(V)=\int_{0}^{V} f(V)dV = 1-e^{-\left(\frac{V}{A}\right)^{k}} \quad \ldots\ldots\ldots\ldots\ (2)$$

The cumulative distribution function can be used for estimating the time for which wind is within a certain velocity interval. Probability of wind velocity being between V1 and V2 is given by the difference of cumulative probabilities corresponding to V2 and V1, thus:

$$P\,(V_1 < V < V_2) = F\,(V_2) - F\,(V_1) \quad \ldots\ldots\ldots\ldots\ (3)$$

That is,

$$P\,(V_1 < V < V_2) = e^{-\left(\frac{V1}{A}\right)^{k}} - e^{-\left(\frac{V2}{A}\right)^{k}} \quad \ldots\ldots\ldots\ldots\ (4)$$

We may be interested to know the possibilities of extreme wind at a potential location, so that the system can be designed to sustain the maximum probable loads. Now, for how many hours in a day (consequently in a year) will the turbine generate power, its most convenient to know the wind turbine cut-in velocity V_1 and cut-out velocity V_2 in addition to the site Weibull shape factor and scale factor, then by applying all these variables in eq.4, and multiplied the result by 24 hours we can get the turbine generated power in a day or year.

Wind rose

Information on the velocity and direction of wind, in a combined form, can be presented in the wind roses. The wind rose is a chart which indicates the distribution of wind in different directions. The chart is divided into 8, 12 or even 16 equally spaced sectors representing different directions. Three types of information can be presented in a wind rose: (1) The percentage of time for which we receive wind from a particular direction. This can show us the direction from which we get most of our wind. (2) The product of this percentage and the average wind velocity in this direction. This tells us the average strength of the wind spectra. (3) The product of time percentage and cube of the wind velocity. This helps us in identifying the energy available from different directions [5].

Power Density

Wind power density, expressed in Watt per square meter (W/m^2), takes into account the frequency distribution of the wind speed and the dependence of wind power on air density and the cube of the wind speed, illustrated in equation (11). Therefore, wind power density is generally considered to be a better indicator of the wind resource than the wind speed itself [4].

Site statistics

The formula for the probability density function of the general Weibull distribution is

$$f(V) = \frac{k}{A}\left(\frac{V-\mu}{A}\right)^{k-1} e^{-\left(\frac{V-\mu}{A}\right)^{k}}\ V \geq \mu;\ k, A > 0 \qquad \text{………(5)}$$

Where, k is the shape parameter, μ is the location parameter and A is the scale parameter. The case where μ = 0 and A=1 is called the standard Weibull distribution. The case where μ = 0 is called the 2-parameter Weibull distribution. The formulas below are with the location parameter equal to zero and the scale parameter equal to one, [6].

Mean= $\Gamma\left({}^{k+1}/_{k}\right)$, ..……. (6)

where, Γ is the gamma function

Median=$\ln(2)^{1/k}$ ……... (7)

Mode=$\left(1-\frac{1}{k}\right)^{1/k}$, ……. (8)

where k >1

Standard Deviation $= \sqrt{\Gamma\left({}^{k+2}/_{k}\right) - \left(\Gamma\left({}^{k+1}/_{k}\right)\right)^{2}}$ …... (9)

Coefficient of Variation C.V. = $\sqrt{\frac{\Gamma\left(\frac{k+2}{k}\right)}{\left(\Gamma\left(\frac{k+1}{k}\right)\right)^{2}}-1}$ ...……….(10)

Power Density=$\frac{1}{2}\rho A^{3}\,\Gamma\left(1+{}^{3}/_{k}\right)$ ………….(11)

Results and discussions

Wind data

The wind speed data are generally available in time series format, in which all data represent an instantaneous sample wind speed or an average of wind speed taken at short intervals of time. This paper used data belongs to the second category, which collected from weather station located at Al-Tweitha site at five minutes interval [3]. In this study, the five minutes wind speed data intervals were being collected at Al-Tweitha for a whole year from January-2012 to December-2012. Visual Basic code program is used to study the wind speed distribution in addition to calculate Weibull parameters (shape and scale parameters) to assess hours of power generation.

The collected data through the period listed before present the variation of wind speed daily. As shown in figure-2.

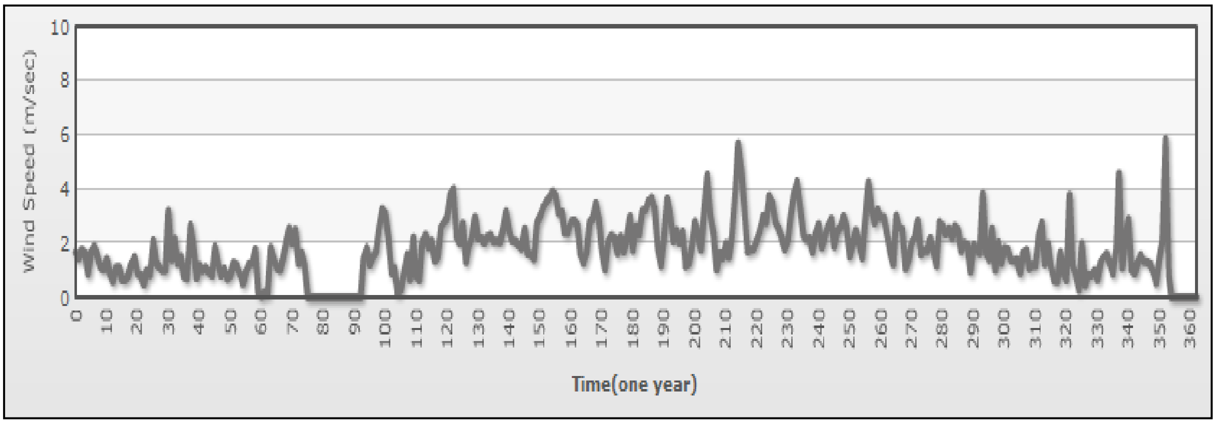


Figure 2-Seasonal variation wind speed at 10 m above ground level

The daily variation of wind speed values show cyclic change in the values during the year and limited between a minimum of 0 m/s and a maximum of 6 m/s.

Wind data analysis and Weibull distribution

It is one of the most flexible distributions that can be used to represent various types of physical phenomena. It is important to know the number of hours per a day or per a year during which the wind speeds occurred, i.e. the frequency distribution of the wind speeds. When the percentage frequency distribution is plotted against the wind speed, the frequency distribution emerges as a curve. The top of the curve shown in figure-3, being the most frequented wind speed. This frequency distribution is used also to identify the most suitable site for the wind turbine. At our selected site the availability of wind in different wind speed bins obtained using each 5 minutes mean wind speed values during a year 2012, as shown in figure-3.

If we join the midpoints of the frequency histogram in figure-3, we get a smooth curve with a well defined pattern. This shows that it is a logical method to represent the wind velocity distributions by standard statistical functions. Various probability functions were fitted with the field data to identify suitable statistical distributions for representing wind regimes. It is found that the Weibull and Rayleigh distributions can be used to describe the wind variations in a regime with an acceptable accuracy level (see continues line in figure-3 and figure-4), [5].

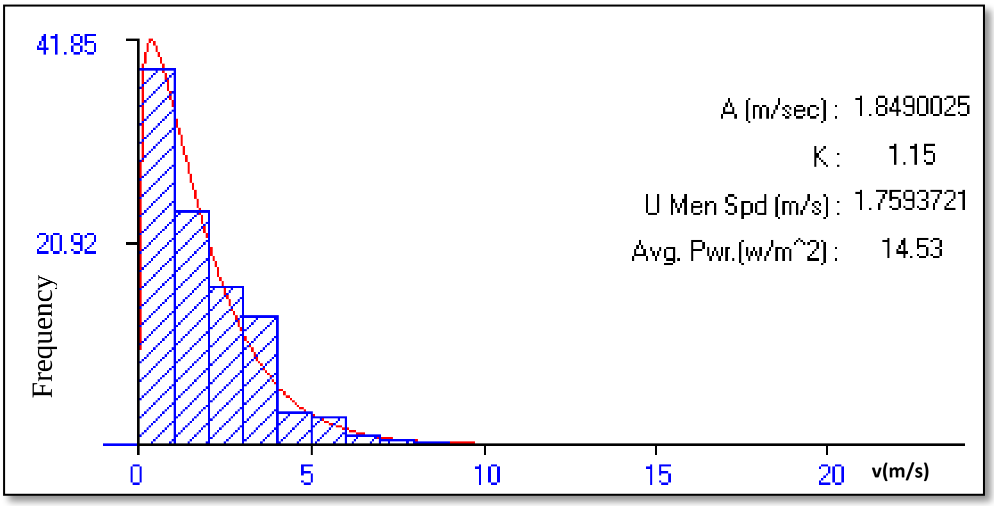


Figure 3-The wind frequency histogram based on wind speeds for Al-Tweitha site

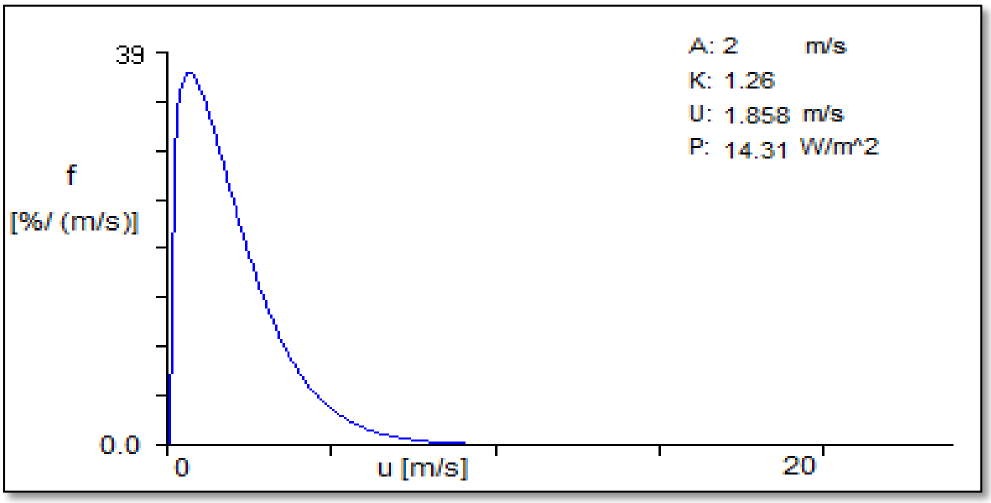


Figure 4-Weibull probability density function

Wind roses for a percentage of time for which we receive wind from a particular direction of our selected site are shown in figure5-.

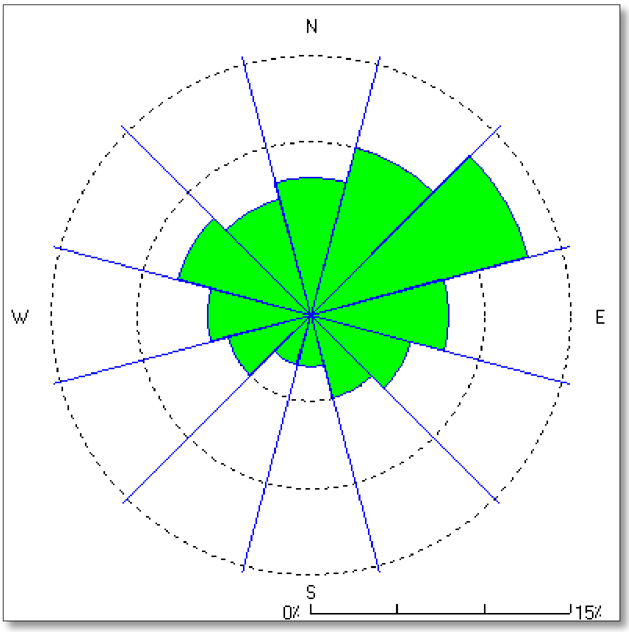


Figure 5-Wind rose

The dependence of power density in our site on each wind speed value was shown in figure 6- also, Weibull shape factor and scale factor, mean wind speed value and total power density in year 2012 were allocated at figures-(3, 4 and 6).

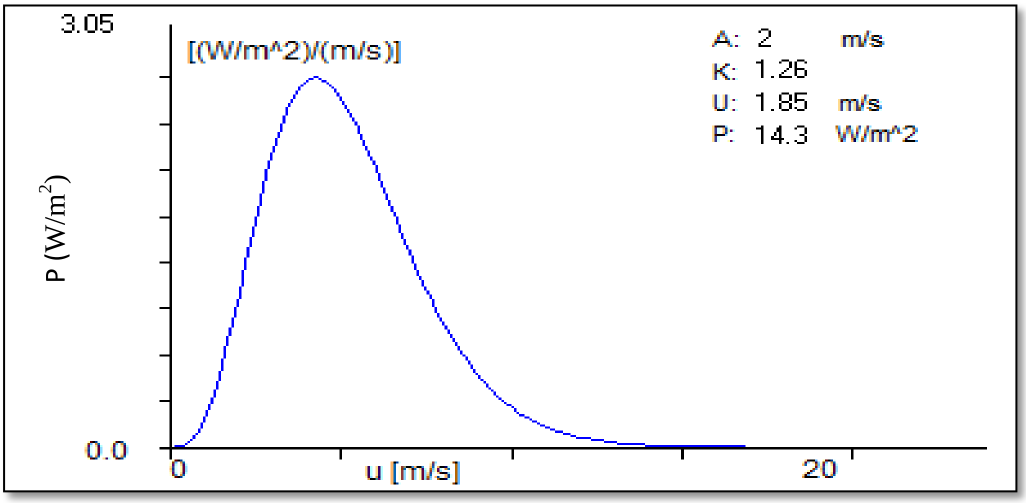


Figure 6-wind power density according to wind velocities for Al-Tweitha site

Different turbines are used for pairing between sites and wind turbines. Five wind turbines were selected to have much more suited one to our site. Table-2, shows the main parameters for the five selected wind turbines (rated power, cut-in and furling wind speeds)

Table 2-Hours per year and per day for Tweitha site in 2012

No.	Turbine	Rated Power	Cut-In speed (m/s)	Furling speed (m/s)	Hours/day	Hours /year
1	SWG	300 w	3	25	4.5	1654
2	SWG	500 w	3	25	4.5	1654
3	SWG	2 kw	3	25	4.5	1654
4	SWG	20 kw	2.5	20	6.3	2329
5	Hummer	2 kw	3	25	4.5	1654

While table-3, shows the statistics values of Tweitha site like mean wind speed, median of data, mode, standard deviation and the coefficient of variation.

Table 3- Statistics of the site

Property	Value
Mean	1.76 m/sec
Median	1.4 m/sec
Mode	0.29
Standard Deviation	1.48
Coefficient of Variation	2.2

Conclusions

For Tweitha site, the average wind speed was (v= 1.76 m/s) during the period January to December 2012. The Weibull Shape and Scale are 1.15 & 1.84 m/s respectively. The average power is 14.5W/m^2. The mostly wind speed during the year was less than 3 m/s which mean less than cut-in speed for most turbines. So for the five selected wind turbines in this paper; the average running hours per day for four turbines was found 4.5 h/day, and 6.3 h/day for SWG turbine with 20 kW power.

References

1. Ahmad Sh., W M A., Hussin W., Bawadi M A and Mohd Sanusi S A, **2009**, “Analysis of Wind Speed Variations and Estimation of Weibull Parameters for Wind Power Generation in Malaysia” *Repository@usm, Universiti Sains Malaysia.*
2. Katsigiannis Y.A. **2012**. “Effect of Wind Turbine Classes on the Electricity Production of Wind Farms in Cyprus Island” Hindawi Publishing Corporation, Conference Papers in Energy, 2013, 19 November.
3. Hassan M. F., Ali M. E. and Mohamed A. A., **2012**. “Wind Energy Assessment for Five Locations in Saudi Arabia”, International Conference on Future Environment and Energy. IPCBEE vol.28. IACSIT Press. Singapore.
4. Ahmed A.S. **2008**. “Theoretical Investigation and Mathematical Modeling of A Wind Energy System Case Study for Mediterranean and Red Sea”, M.Sc. Thesis, Berlin.
5. Mathew S. **2006**. “*Wind Energy Fundamentals, Resource Analysis and Economics*” Springer.
6. Norman L. J., Samuel K. and Balakrishnan N., **1994**, “*Continuous Univariate Distribution*” Volumes I and II, 2nd Ed. John Wiley and Sons.