Science World Journal Vol 11 (No 3) 2016
www.scienceworldjournal.org
ISSN 1597-6343

THE USE OF ENERGY PATTERN FACTOR (EPF) IN ESTIMATING WIND POWER DENSITY

Dogara M. D., Aboh H.O., Gyuk P.M. and Onwumere M.K.O.

Department of Physics, Kaduna State University, Kaduna.

ABSTRACT

The Energy Pattern Factor (EPF) method is a less computational method of estimating the available wind power density of an area and wind speed variation account for the energy power density throughout a given period. Using the Average daily wind speed data for an 11 year period (2004-2014) obtained from the Nigerian Meteorological (NIMET) Station located around the Kaduna Airport, Mando, Kaduna. The Average Annual Energy Pattern Factor of Kaduna was estimated to be 1.03 and from the energy pattern factor, the average annual available wind power density was calculated to be 222.13 W/m^2. This calculated wind power density falls within the stipulated values under wind power class 4 of the National Renewable Energy Laboratory (NREL) of the US Department of Energy (DOE), and is considered very adequate to drive utility sized wind turbines.

Keywords: Energy Pattern Factor, Wind Speed, Wind Power Density, Utility Sized Wind Turbines.

INTRODUCTION

Wind energy is another form of Renewable Energy. Wind is air in motion, and is produced by the rotation of the earth and heating of the atmosphere by the sun. When air at the equatorial regions is heated by the sun, the air becomes lighter and starts to rise; and cold air at the poles start to sink, this rising air at the equator gains Kinetic Energy, it moves northward and southward. The differential heating of the sea and the nature of a terrain (ranging from mountains and valleys to local obstacles such as building and trees), causes minor changes in the flow of wind and hence, have an important effect on the wind (Walker and Jenkins, 1997)

In order to exploit wind energy for power generation, it is important to assess available wind energy potential at various regions; the estimation of potential energy resource or available wind power is an important aspect of wind energy investigations, analysis and studies (Ngala et al, 2007) Wind speed is an important parameter for estimating the available wind power of a region. Various methods have been used to analyse the wind speed of a region, in other to estimate the available wind power. The energy pattern factor (EPF) presents another means for the estimation of available wind power. Pam and Bala (2006) estimated the monthly and annual energy pattern factors for some parts of Northern Nigeria using a five year wind speed data (1998-2002); and found the Annual Energy Pattern Factor of Kaduna to be 1.61 and that of Zaria to be 1.46. Wind speed is dynamic and changes over time; hence, it is necessary to update these researches overtime to ascertain the state of the climatic condition (speed) and compare with previous researches. Secondly, apart from calculating the EPF of Kaduna Town, the estimated available wind power density is also obtained from the EPF. Hence, the Justification for this work.

The principle of wind power generation can be stated as follows, 'for all wind turbines, wind power is proportional to wind speed cubed.' Since wind energy is the kinetic energy of moving air (Ohunakin, 2010) The kinetic energy of a mass m with velocity v is given by

$$E_{kinetic} = {}^{1}\!/_{2}\, mv^2 \ldots\ldots\ldots.. \quad 1)$$

The air mass m, can be determined from the air density ρ, and the air volume V according to

$$m = \rho V \ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

Then,

$$E_{kinetic(wind)} = {}^{1}\!/_{2}\, V\rho v^2 \ldots\ldots.. \quad (3)$$

Since power is energy divided by time, we consider a small time, Δt, in which the air particles travel a distance $s = v\Delta t$ to flow through. We multiply the distance with the rotor area of the wind turbine, A, resulting in a volume of

$$\Delta V = Av\Delta t \ldots\ldots\ldots\ldots. (4)$$

Which drives the wind turbines for the small period of time. Hence, the wind power is given as

$$P_{wind} = \frac{E_{kinetic\ (wind)}}{\Delta t}$$

$$= \frac{\Delta V \rho v^2}{2\Delta t}$$

$$= \frac{\rho A v^3}{2} \ldots\ldots\ldots (5)$$

The variations in wind speed, makes the use of wind speed and air density alone, unreliable for analysis of wind power potential. The Energy Pattern factor method, analyzes these variations and estimates a unique wind power density for each location.

Manwell et.al. (2002) defined the available mean power density at any location as:

$$\bar{P_a} = \frac{1}{2}\rho \bar{v}^3 K_e \ldots\ldots\ldots (6)$$

Where $\bar{v}$ is the mean wind speed and K_e is the energy pattern factor. Spiegel (1992) defined the mean wind speed as the moment of a probability distribution given by:

$$\bar{v} = \int_0^\infty v p(v) dv \ldots\ldots\ldots\ldots (7)$$

Energy Pattern Factor (EPF)

The Energy Pattern Factor (EPF) Method, is defined by Akdag and Ali (2009) as an 'easier and less computational' method, by the following equation:

$$K_e = EPF = \frac{1}{(\bar{v})^3} \times \left(\frac{\sum_{i=1}^{n} v_i{}^3}{n}\right) \ldots\ldots \ (8)$$

where v_i is the wind speed in meter per second for the ith observation, n is the number of wind speed samples, and $\bar{v}$ is the monthly mean wind speed.

METHODOLOGY
Average daily wind speed data for an 11 year period (2004-2014) was obtained from the Nigerian Meteorological (NIMET) stations situated on the global coordinates of Longitude 07°19'E and Latitude-10°41'N, at an Altitude of 632m above the sea level, located in the Kaduna Airport, Mando, Kaduna.

Instrumentation and Data Acquisition
The average daily wind speed data was captured by a cup-anemometer (Figure 1) at a height of 10m, and was converted from knots to m/s. The cup-anemometer consists of three cups attached to short rods that are connected to a vertical shaft at right angles. When the wind blows, it pushes the cups, which turn the shaft. (Encyclopædia Britanica, 2012). The number of turns per minute is translated into wind speed by a system of gears similar to the speedometer of an automobile (Redmond, 2008)

$$1\ turn = 2\pi r \ldots\ldots\ldots (7)$$

Where r is the length of one arm of the anemometer

Figure 1: Cup-Anemometer

The cubed of daily wind speed for each day was computed. And the monthly average for an eleven year period was found (table 1). The cubed of the monthly and annual mean speeds were also computed (table 2). The monthly and annual energy pattern factors were then computed using equation (8) (table 3) and bar charts were developed (figure 2). The estimated available wind power density was obtained from equation (6) (table 3).

RESULTS AND DISCUSSION
Analysis of daily average wind speed data (2004-2014) showed that the month of May had the highest average wind speed at a height of 10m of 8.80m/s; next to it was the month of June with 8.60m/s. The month of October recorded the lowest average wind speed with 6.00m/s. The average annual wind speed for the 11 years was 7.15m/s; with 11.91m/s being the highest in the month of June 2014 and 4.67m/s was found to be the lowest in the month of December 2004 as seen in table 1. The monthly energy pattern factor of Kaduna range from 1.02 to 1.11 with the month of April having the highest EPF of 1.11 and the month of November having the lowest EPF with 1.02 as shown in table (3) and figure (2); and the average annual energy pattern is 1.03. Which is below by a factor of 0.58 from Pam and Bala (2006). Wind speed variations and other climatic changes account for this difference. Hence, the need for a continuous update of wind energy assessments, if wind energy is to be harnessed for the upgrade of the power resource in Nigeria.

The annual available average power density was estimated to be 222.13 W/m^2 with 438.25W/m^2 to be the highest for the month of May and 135.09 W/m^2 was computed to be the lowest for the month of October. Based on the National Renewable Energy Laboratory (NREL), U.S. Department of Energy (DOE) Wind Power Class Chart, (table 4), the estimated annual available average power density of 222.13W/m^2 falls in Power Class 4, which is sufficient to power utility sized wind turbines. Also, excess wind energy generated by wind turbines during the months of May, can be stored to be used in the month of October. Hence, wind energy can be exploited for power generation in Kaduna at a commercial scale, throughout the year.

Conclusion
Average daily wind speed data captured with a cup-anemometer at a height of 10m from Nigerian Meteorological Station, Kaduna for a period of eleven years was obtained. The monthly energy pattern factor of that area was estimated to range from 1.02 to 1.11 with the month of April having the highest EPF of 1.11 and the month of November having the lowest EPF of 1.02. The average annual energy pattern factor was found to be 1.03. These energy pattern factors were used to estimate the average available power density which was found to be 222.13 W/m^2. This power density is significant to impact meaningfully to the development of the Nigerian Power Sector; hence, the energy pattern factor has shown its relevance in the study of climate and seasonal variation with respect to wind.

Table 1: Eleven Year Period (2004-2014) Monthly Average Wind Speed in m/s for Kaduna Town**.**

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2004	5.64	8.81	6.75	6.40	8.19	8.67	7.99	5.19	7.78	4.89	5.57	4.67	6.71
2005	6.33	6.21	5.45	6.30	7.35	6.00	6.33	7.39	6.66	5.53	6.56	5.81	6.33
2006	5.60	4.92	5.48	6.94	9.34	8.52	6.02	6.29	7.99	6.48	6.57	6.75	6.74
2007	7.43	6.32	5.08	7.26	8.09	9.04	6.38	6.66	5.87	5.66	5.22	6.74	6.65
2008	7.32	7.36	5.59	6.09	9.34	7.86	7.71	7.40	7.83	6.26	6.20	5.97	7.08
2009	5.35	6.06	6.55	6.93	6.79	8.47	7.79	7.04	6.63	4.92	5.57	6.27	6.53
2010	5.71	6.10	8.30	7.96	8.82	7.05	7.41	6.41	8.07	5.85	6.33	7.51	7.13
2011	8.37	6.53	7.66	8.99	11.79	8.17	9.18	7.91	10.20	7.56	6.71	7.54	8.38
2012	7.44	6.67	7.02	11.03	9.96	9.08	8.36	9.33	8.30	7.44	6.16	6.66	8.12
2013	6.30	6.82	6.73	7.28	10.23	10.49	7.26	6.94	9.70	5.81	5.63	6.69	7.49
2014	6.59	7.13	6.31	7.02	6.95	11.91	8.69	7.16	8.65	5.62	7.03	7.40	7.54
Average Wind Speed	6.55	6.63	6.45	7.47	8.80	8.66	7.56	7.07	7.97	6.00	6.14	6.55	7.15

Table 2: Eleven Year Period (2004-2014) Monthly Cubed Average Wind Speed in m^3/s^3 for Kaduna Town

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean (cubed)
2004	179.41	683.80	307.55	262.14	549.35	651.71	510.08	139.80	470.91	116.93	172.81	101.85	302.11
2005	253.64	239.48	161.88	250.05	397.07	216.00	253.64	403.58	295.41	169.11	282.30	196.12	253.64
2006	175.62	119.10	164.57	334.26	814.78	618.47	218.17	248.86	510.08	272.10	283.59	307.55	306.18
2007	410.17	252.44	131.10	382.66	529.48	738.76	259.69	295.41	202.26	181.32	142.24	306.18	294.08
2008	392.22	398.69	174.68	225.87	814.78	485.59	458.31	405.22	480.05	245.31	238.33	212.78	354.89
2009	153.13	222.55	281.01	332.81	313.05	607.65	472.73	348.91	291.43	119.10	172.81	246.49	278.45
2010	186.17	226.98	571.79	504.36	686.13	350.40	406.87	263.37	525.56	200.20	253.64	423.56	362.47
2011	586.38	278.45	449.46	726.57	1638.86	545.34	773.62	494.91	1061.21	432.08	302.11	428.66	588.48
2012	411.83	296.74	345.95	1341.92	988.05	748.61	584.28	812.17	571.79	411.83	233.74	295.41	535.39
2013	250.05	317.21	304.82	385.83	1070.60	1154.32	382.66	334.26	912.67	196.12	178.45	299.42	420.19
2014	286.19	362.47	251.24	345.95	335.70	1689.41	656.23	367.06	647.21	177.50	347.43	405.22	428.66
Average Wind Speed (cubed)	298.62	308.90	285.82	462.95	739.80	709.66	452.39	373.99	542.60	229.24	237.04	293.02	374.96

Table 3: Eleven Year Period (2004-2014) Energy Pattern Factors (EPF), Air Density, and Estimated Available Power Density (PD)

MONTHS	*EPF*	AIR DENSITY (Kg/m³)	P_D (W/m²)
JAN	1.06	1.18	175.74
FEB	1.06	1.18	182.26
MAR	1.07	1.17	167.96
APR	1.11	1.17	270.67
MAY	1.09	1.18	438.25
JUN	1.09	1.18	417.67
JUL	1.05	1.19	269.94
AUG	1.06	1.19	222.89
SEP	1.07	1.18	319.60
OCT	1.06	1.18	135.09
NOV	1.02	1.18	139.30
DEC	1.04	1.19	173.89
ANNUAL AVERAGE	1.03	1.18	222.13

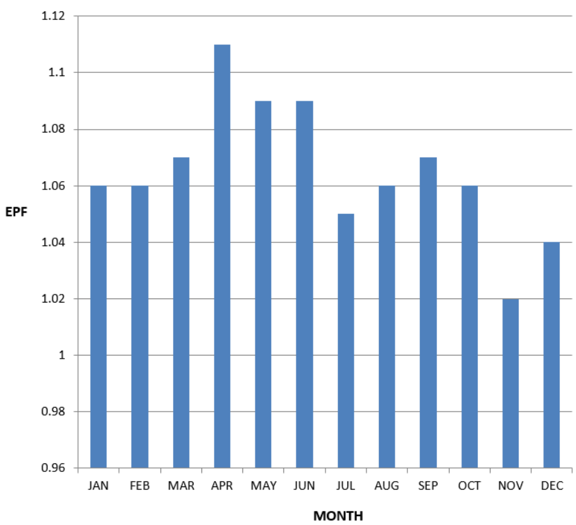

Figure 1: Monthly Energy Pattern Factor for Kaduna

Table 3: Wind Power Class at 10m Elevation Chart (NREL, 2006)

POWER CLASS	AVAILABLE POWER DENSITY (W/m²)
1	0-100
2	101-150
3	151-200
4	201-250
5	251-300
6	301-400
7	401-1000

REFERENCES

Akdag , S .A., Ali ,D .A., (2009): "New method to estimate Weibull parameters for Wind energy applications" , Energy convers, Manag 5 , pp.1761-1766.

Encyclopædia Britannica.2012. Anemometer. Encyclopædia Britannica Library Ultimate Reference Suite. Version 2007. Chicago.

Manwell, J.F., McGowan, J.G. and Rogers, A.L. (2002). Wind Energy Explained. John Wiley & Sons Ltd, West Sussex, England.

Ngala, G.M., Alkali, B., and Aji, M.A., (2007). Viability of wind energy as a power generation source in Maiduguri, Borno State, Nigeria. Renewable Energy 32, 2242–2246.

NREL (National Renewable Energy Laboratory).,(2006): "Wind Farm Area Calculator", *Power Technologies Energy Data Book*. Retrieved from: http://www.nrel.gov/analysis/power_databook/calc_wind.php.

Ohunakin, O.S., (2010): Energy Utilization and renewable energy source in Nigeria. Journal of Engineering and Applied Science 5 (2), 171-177.

Pam, G.Y., and Bala, E.J., (2006): Monthly and Annual Energy Pattern Factors for Locations in Northern Nigeria. International Journal of Science Laboratory Technology (JOSCILT). Vol. 6. September, 2006.

Redmond, W.A., (2009): "Anemometer". Microsoft® Encarta® DVD Encyclopaedia.

Spiegel, M.R., (1992): Theory and Problems of Statistics. Second Edition, Mc Graw Hill Inc., New York.

Walker, J.F., and Jenkins, N., (1997): Wind Energy Technology. John Wiley & Sons