Short-term Wind Variability Analysis of Afe Babalola University

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***Abstract*—The increasing damaging effect of fossil fueled generators has necessitated the need for diversification into renewable energy sources. However, these abundant renewable sources are limited by their variability at various seasons which often results in stochastic output power. In this paper, short term variability analysis of wind resource in Afe Babalola University is presented from January 2018 to December 2018. Wind speed data were collected using the anemometer at various times and sites within this period and used to estimate the potential of wind resource in ABUAD. The results showed that the wind energy resource is higher between the months of April to September, but insufficient to meet the energy need of ABUAD, hence necessitating the need of a hybrid generating system. An optimized hybrid system comprising of one, 1650kW wind turbine, 2000kW PV panels, 1900kW Diesel generator, 2000kW Converter, and one Trojan T-105 battery was obtained from HOMER software, with levelized cost of energy (COE) of 0.414$/yr and Net Present Cost(NPC) of $41,353,948.**

***Index Terms*-- Wind speed, Wind Power Density Renewable Energy Sources (RES), anemometer, wind power plants (WPPs), Afe Babalola University(ABUAD)**

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I. INTRODUCTION

With increasing concerns on climate changes due to the disturbing effect of the conventional generators and the need to meet the increasing global energy demands through environmental friendly sources. Technology and research has been geared towards optimally harnessing renewable energy sources[1],[2]–[5]. Renewable energy sources such as wind and solar has been the focus of research due to its environmental friendliness and abundance, and being best suited to meeting the world's sustainable developmental goals [2].

Wind turbines are an important part of the renewable energy sources available for power generation as they provides a significant part of the annual energy demand in some countries [6]. For example , it was revealed by the Global wind Energy Council in 2016, that wind power accounts for about 2.4% of the total world's energy consumption, with significant contribution from India, Germany,China,Spain,France,Canada,United Kingdom, Denmark and United States[7]. However, wind turbine has been limited by the intermittency of its output power, which is due to differences in hub heights, geographic locations of wind farms, and variation in the Wind speed, thus only providing only about 20% to 40% of its maximum power output [3]. Therefore , the need to understand the variabilty of wind power in both the temporal and spatial scale is sacrosanct in order to effectively harness wind resource, and also aid energy planning and management. Fig. 1 shows the various factors that affect the output of wind turbine.

To this end ,this paper centres on the variability of wind resource in Afe Babalola University,Ado-Ekiti,Ekiti State,Nigeria between the period of January 2018 to December 2018. Section 2, wind turbine is modeled using standard equation. In section 3, the variability of the wind speed of Afe Babalola University is studied using the results obtained from Anemometer and a hybrid (PV-WIND-DIESEL) power system is modeled using HOMER, While Section 4 gives the results of the study and discusses the potential of wind resource in Afe Babalola University.

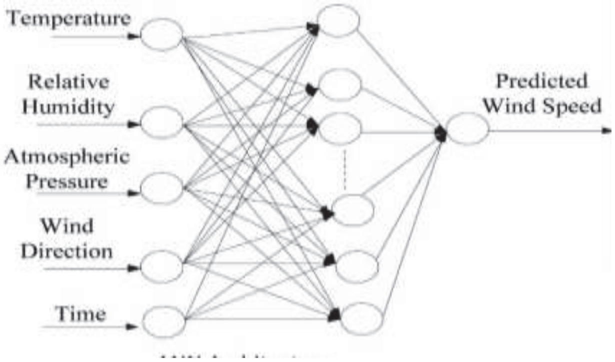

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Figure 1. Nexus between factors that affect the Output of wind turbine [8]

II. LITERATURE REVIEW

Several studies have been carried out on wind speed variability using strategically placed wind turbines with the aid of digital anemometer connected to a central data center or several data centers [6], [8]–[14]. These hubs collected data from sites on a minute to minute basis. For example, in 2000, the National Renewable Energy Laboratory collected data for a period of 10 years from large commercial wind power plants (WPPs) in southwest Minnesota using dataloggers and communication links. The resulting data were used to analyze wind power fluctuations, frequency distribution of changes, the effects of spatial diversity, and wind power ancillary services. Table I gives a list of various wind power plants (WPPs), their locations, plant capacities and time frame of data collected respectively.

TABLE I. LOCATIONS, CAPACITIES AND AVAILABLE DATA OF WPPS

WPP Name	Location	Plant Capacity (MW)	Data Available
Lake Benton(LB)	Minnesota	104	2000-2010
Storm Lake (SL)	Lowo	113	2001-2010
Blue Canyon(BC)	Oklahoma	75	2003-2010
Trent Mesa	Texas	150	2004-2010

A. *Wind Turbine Output Forcast*

Wind speed data collected over a period of time can be used to predict the output power of wind turbines using time-series modeling approach, which is then used to determine the economic viability of the wind turbine[15],[12],[16]. Conversely, forecasting methods such as persistence, physical, statistical, spatial correlation and artificial intelligence used for wind speed forecast have reduced accuracy for longer duration of forecast and are only suitable for short term prediction [8].

B. *Modeling of the Wind Turbine*

The output power of a wind turbine can be expressed as in equation (1),(2) and (3) and it is based on the principle of conversion of the kinetic energy from the wind to electrical output power.

$$E = \frac{1}{2} m v^2 \qquad (1)$$

$$P = \frac{dE}{dt} \qquad (2)$$

$$P_o = \frac{1}{2} \rho A v^3 C_p \,(watts) \qquad (3)$$

Where, E is the mechanical energy generated by the wind turbine at the shaft, P_o is the output power in kilowatts (kW), ρ is the rotor's efficiency or air density(kg/m^3) which is dependent on the air temperature , m is the air mass (kg) , d is the diameter of the rotor's disk, v is wind speed(m/s) and Cp is the power coefficient constant of the wind turbine also called the Betz limit and is based on the principle that wind turbine can convert a maximum of 16/29,(59.3%)of the wind's kinetic energy into mechanical energy available at the shaft of the rotor [6]. Figure 2 shows the schematic diagram of a wind turbine.

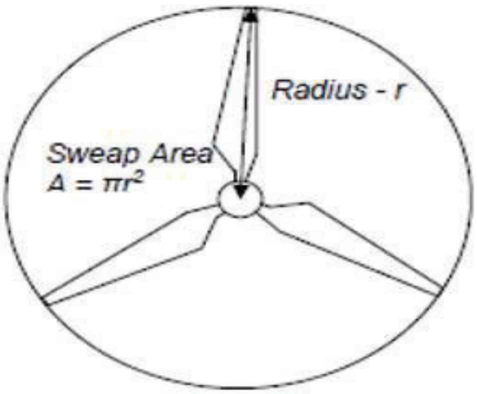

Figure 2. Wind turbine schematic diagram wind turbine [6]

From figure 2 the area swept by the turbine blade can be calculated from the length of the blades as given in equation (4)

$$A = \pi r^2 \qquad (4)$$

Where, r is the same as the blade length of the turbine.

Also, the wind turbine's power coefficient, C_p is dependent on the tip speed of the turbine.

The wind turbine tip speed ratio, λ as defined by equation (5)

$$\lambda = \frac{\text{blade tip speed}}{\text{wind speed}} \qquad (5)$$

While, the blade tip speed can be expressed in terms of the length and rotational speed of the turbine blades as in equation (6)

$$\text{blade tip speed} = \frac{\text{rotational speed(rpm)} * \pi * \text{D}}{60} \qquad (6)$$

C. *Variability of Wind Turbine with Height and Roughness coefficient*

The variability of wind speed also referred to as the power law exponent relation can be expressed as a function of the turbine height at site and the roughness coefficient [7], [11], [13], [14]. This relationship can be expressed as in equation (7).

$$\frac{V_o(h_o)}{V_1(h_1)} = \left(\frac{h_0}{h_1}\right)^{\alpha} \qquad (7)$$

Where, V_0 (h_0) (m/s) are the measured mean wind speeds at the reference height h_0(m) and height h_1(m) is the new height for which and V_1 (h_1) (m/s) is predicted. Also, α is the roughness coefficient which is defined as in equation (8):

$$\alpha = \frac{\ln V_0(h_0) - \ln V_1(h_1)}{\ln(h_0) - \ln(h_1)} \qquad (8)$$

Table II gives a list of six classes' of roughness coefficient as it varies with location, while Table III shows various manufacturers of wind turbine and their respective specifications.

TABLE II ROUGHNESS COEFFICIENT FOR VARIOUS SITE LOCATION [13]

Class	Description	Roughness coefficient
1	Perfectly smooth	0.1
2	Low grassland(country sides with farm lands)	0.2
3	Trees or hills, building around the area(rural sites with low forests)	0.3
4	Close to trees or buildings	0.4
5	Very close to trees or buildings	0.5
6	Surrounded by tall trees or buildings	0.6

TABLE III: A SAMPLE OF MANUFACTURERS' WIND TURBINE SPECIFICATIONS[8]

Turbine Index	Turbine manufacturers	Turbine operating speed range (m/s)			Rotor diameter (m)	Rated power (MW)	Hub height (m)
		V_{ci}	V_t	V_{co}			
WT1 WT2 WT3 WT4 WT5 WT6 WT7 WT8 WT9 WT10	EMERCON-E40	2.5	13	25	44	0.60	46
	VESTAS-V47	5	15	25	35	0.66	45
	FIKTIONAL	3.1	16	25	39	0.70	43
	FUHRLAENDER	2.22	15	26	62	1.30	50
	NEG-NICON	3.5	16	25	60	1.65	70
	VESTAS-V82	3	13	20	82	1.65	70
	VESTAS-V80	4	16	25	76	1.80	60
	ZEPHYROS-Z72	3	16	25	71.2	2.00	65
	BONUS	4	18	25	76	2.00	60
	GE-2.3	3	14	25	94	2.30	100

III. METHODOLOGY

As the speed of the turbine blades exceeds a certain minimum, the mechanical energy generated at shaft is converted to electrical energy by the generator. Furthermore, the electrical output power generated is related to the wind speed by the power curve as seen in the manufacturer's manual of every wind turbine.

For this research, wind speed data is measured using the anemometer at a hub height of 25m for a sample interval of 30 minutes between January 2018, to December, 2018. This data is used in determining the wind variability for the area under study.

A. The Case Study

Afe Babalola University is a private University located in the South-western region of Nigeria, Ado-Ekiti, which is the State capital of Ekiti State. Afe Babalola University lies between latitude 7.6110°N and longitude 5.2571°E, occupying a surface area of about thirteen (13) square kilometers at an elevation of 382 metres above sea level (a.s.l). The campus has an average temperature of 24.7°C. Two seasons are prevalent in Nigeria, the rainy season and the dry season. The geographical location of the site is depicted in Figure 3. The data used for this study are as obtained from the anemometer. It consists of the daily average wind speed, and wind power density(W/m^2) obtained at a hub height of 25m over a period of one year (January 2018 to December 2018).

Figure 3. Map showing an aerial view of Afe Babalola University.

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B. Data Collection

In this case study, the wind speed and wind power density (W/m^2) is measured using the anemometer in an interval of 30 minutes between the period of January 2018 and December 2018, (twelve months). The average monthly wind speed obtained at Afe Babalola Univeristy was 4.45 m/s. This data was taken at various locations on campus and the most consistent average value was recorded.

C. Weibull-Distribution estimation of the Wind turbine power Output

The Weibull distribution is a widely used statistical mathematical tool for analyzing and determining the most frequent wind speeds observed at a specific site. Furthermore, since wind speed is stochastic, in order to calculate the mean power delivered by a wind turbine from the manufacturers power curve, the probability density distribution of the wind speed is carried out. The yearly energy output(kWh/year) can therefore be calculated using the Weibull-distribution, probability density function(PDF) [13]. This can be expressed as in (9).

$$E_{weibull}(kWh) = \sum_{i}^{n} P_{i,output} F_i(V) T_i) \tag{9}$$

Where, T_i is the number of hours the wind turbine is in operation in a year, while Fi(V) is the number of days in a month the wind turbine is in operation, Pi is the mean output power of a specify turbine with rating of 66W to 300W for an average operating time of 2840hours per year.

D. *Modeling of the Hybrid Power System for Afe Babalola University*

Here, a hybrid Wind/PV/Diesel Power System was designed using HOMER, with system components comprising of the wind turbine, Diesel Generator, PV panel, Converter, and battery. The Wind turbine and the PV plant are to supplement the power from the Diesel generator, with the aid of the converter. The battery bank will therefore act as an energy storage System, as it will be brought into operation for critical loads during emergency, while it is being constantly charged at other times by the excess electricity produced by the hybrid system. Figure 4, shows the schematic diagram of the proposed hybrid PV/diesel Power System for the University campus, while Table IV shows the specifications of system components used for modeling the Hybrid (Wind/PV/Diesel) power system for ABUAD using HOMER.

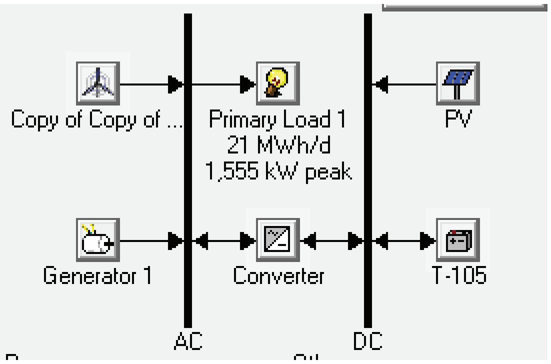


Figure 4. Schematic diagram of a hybrid Power System for ABUAD

TABLE IV. SPECIFICATION OF SYSTEM COMPONENTS USED IN THE HOMER DESIGN

COMPONENTS		SPECIFICATIONS
PV PANEL	Size	0-2000kW
	Capital ($)	946 per kW
	Replacement ($)	756 per kW
	O&M Cost ($/yr)	0.00
	Life time	20 years
	Derating(%)	80
ABUAD Diesel Generation	Size	0-2200kW
	Capital($)	124
	Replacement ($)	124
	O&M Cost ($/hr)	0.025
	Life time (hours)	15,000
	Fuel	Diesel
	Fuel price/litre ($)	1.26
	Efficiency	90%
Converter (Inverter)	Size	0-2000kW
	Capital($)	300
	Replacement ($)	300
	O&M Cost ($/yr)	0
	Life time (years)	20
	Efficiency (%)	90
Battery	Model	Trojan T-105
	Capital($)	1100
	Replacement ($)	1100
	O&M Cost ($/yr)	0
	Nominal Capacity	225Ah
	Nominal Voltage	6V
	Life time(years)	10
	Lifetime throughput(kWh)	845
	Battery per string	2
	State of charge	30%
Wind Turbine	Model	Vestas V82
	Capital($)	534
	Replacement ($)	427
	O&M Cost ($/yr)	5
	Life time(years)	20 years
	Hub Height	25m
	Size	1,650kW
	Rotor diameter	82m

IV. RESULTS

Table V shows samples of the average wind speed obtained from various test sites in Afe Babalola University campus at about 9am on 24th June, 2018. It further reveals that wind speed obtained at Wema Girl's hotel has the highest value of 2.50m/s while the wind speed obtained at the Talent Discovery Centre (TDC) has the least speed of 2.42m/s.

Furthermore, Figure 5 and Table VI shows the average monthly wind speed, while Table VII shows the average monthly wind power density of Afe Babalola University as obtained using the anemometer. It was also observed that the wind speed and the wind power density was highest during the month of July, 5.9365m/s and 37.40W/m^2 respectively, thus the wind turbine will be better utilized during this period.

TABLE V. SAMPLES OF WIND SPEED DATA OBTAINED FROM SELECTED AREAS IN ABUAD AT 9AM.

Locations	Wind Speed(m/s)
Wema Girl's Hostel	2.50
Alfa Belgore	2.46
Talent Discovery Centre	2.42
ABUAD Teaching Hospital	2.48
Average Wind Speed (m/s)	2.465

TABLE VI. SHOWING THE AVERAGE MONTHLY WIND SPEED OF ABUAD

Months	Wind Speed(m/s)
January	3.25
February	3.42
March	4.02
April	4.150
May	4.20
June	5.3456
July	5.9365
August	5.5254
September	5.6458
October	5.2121
November	3.80
December	3.45
Scale annual Average(m/s)	4.45

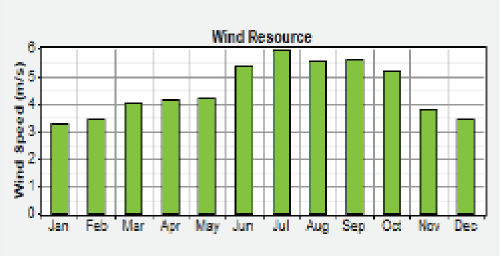


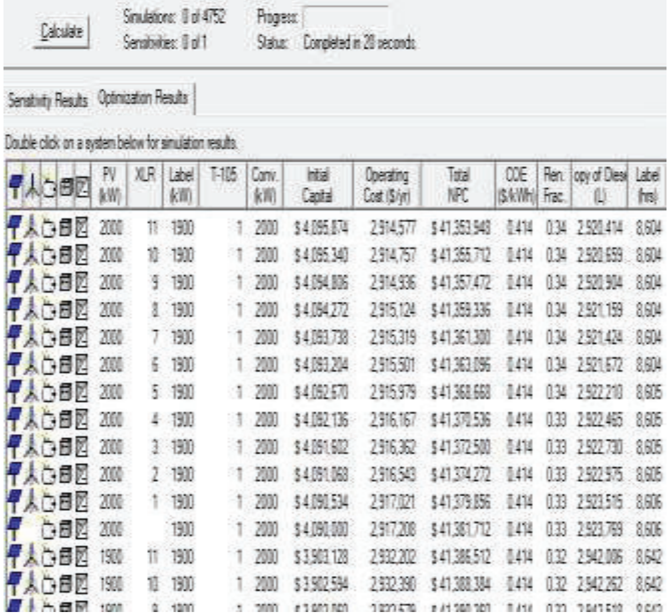
Figure 5. Monthly average wind speed at ABUAD

TABLE VII. MONTHLY AVERAGE WIND POWER DENSITY OF ABUAD

Months	Power Density(W/m^2)
January	20.475
February	21.546
March	25.326
April	26.145
May	26.46
June	33.677
July	37.40
August	34.776
September	35.564
October	32.823
November	23.94
December	21.735
Scale annual Average(m/s)	28.035

A. *Simulation Results From HOMER*

Simulations performed by HOMER software compared 4752 different system configuration considering the input variables, in order to obtain the most cost efficient and reliable system combination. The result showed an optimal system comprising of one, 1,650kW wind turbine, 2000kW PV panels, 1900kW Diesel generator, 2000kW Converter, and one Trojan T-105 battery having levelized cost of energy (COE) of 0.414$/yr, Net Present Cost(NPC) of $41,353,948, initial cost of $ 4,095,874 , operating cost of $/yr 2,914,577. Fig. 6 gives the various system configuration combination and their corresponding, Net present cost (NPC), and Cost of energy (COE). Furthermore, Table VIII gives a comprehensive analysis of the internal component of the Net Present Cost (NPC) for the various generators. It was further revealed that though the 1900KW diesel generator had a low initial installation cost, conversely, it had the highest cost of operation and maintenance. Also, the 2000 PV plant had the highest cost of installation but has a negligible running cost.



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Double click on a system below for simulation results.

PV (kW)	XLR	Label (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	opy of Dies (L)	Label (hrs)
2000	11	1900	1	2000	$ 4,095,874	2,914,577	$ 41,353,948	0.414	0.34	2,520,414	8,604
2000	10	1900	1	2000	$ 4,095,340	2,914,757	$ 41,355,712	0.414	0.34	2,520,659	8,604
2000	9	1900	1	2000	$ 4,094,806	2,914,936	$ 41,357,472	0.414	0.34	2,520,904	8,604
2000	8	1900	1	2000	$ 4,094,272	2,915,124	$ 41,359,336	0.414	0.34	2,521,159	8,604
2000	7	1900	1	2000	$ 4,093,738	2,915,319	$ 41,361,300	0.414	0.34	2,521,424	8,604
2000	6	1900	1	2000	$ 4,093,204	2,915,501	$ 41,363,096	0.414	0.34	2,521,672	8,604
2000	5	1900	1	2000	$ 4,092,670	2,915,979	$ 41,368,668	0.414	0.34	2,522,210	8,605
2000	4	1900	1	2000	$ 4,092,136	2,916,167	$ 41,370,536	0.414	0.33	2,522,465	8,605
2000	3	1900	1	2000	$ 4,091,602	2,916,362	$ 41,372,500	0.414	0.33	2,522,730	8,605
2000	2	1900	1	2000	$ 4,091,068	2,916,543	$ 41,374,272	0.414	0.33	2,522,975	8,605
2000	1	1900	1	2000	$ 4,090,534	2,917,021	$ 41,379,856	0.414	0.33	2,523,515	8,606
2000		1900	1	2000	$ 4,090,000	2,917,208	$ 41,381,712	0.414	0.33	2,523,769	8,606
1900	11	1900	1	2000	$ 3,903,128	2,932,202	$ 41,386,512	0.414	0.32	2,942,006	8,642
1900	10	1900	1	2000	$ 3,902,594	2,932,390	$ 41,388,384	0.414	0.32	2,942,262	8,642

Figure 6. Optimization results from HOMER Simulation Software

TABLE VIII. SHOWING THE OVERALL COST OF VARIOUS GENERATORS

Component	Capital ($)	Replacement($)	O&M($)	Fuel($)	Salvage($)	Total ($)
PV	5,853,947	1,204,149	0	0	-74,858	4,383,239
Wind turbine	5,874	1,960	703	0	-365	8,172
Generator	235,600	1,672,004	5,224,433	29,866,168	-36,230	36,961,980
Trojan T-105	148	104	0	0	-14	238
Converter	305	86	0	0	-48	343
Over-all System	4,095,874	2,878,302	5,225,136	29,866,168	-711,515	41,353,964

B. Environmental Assessment of the Hybrid Power System

Considering the increasingly damaging effect of the GHGs on our ecosystem. A critical environmental assessment was carried out to ascertain the degree of ecosystem friendliness of the proposed hybrid system. In view of this, the amount of GHGs emitted by the proposed Hybrid model is compared with that of the Standalone Diesel power System as presented in Table IX .The results clearly reveals that the amount of pollutant was greatly reduced. This further shows that the proposed hybrid system is more ecosystem friendly than that of the conventional standalone diesel generator, because of its reduced dependance on fossil fuel.

TABLE IX. COMPARATIVE ANALYSIS OF GAS EMISSIONS FROM THE HYBRID POWER SYSTEM

Pollutant	**Emissions(kg/yr)** **Hybrid System**	**Emissions(kg/yr)** **Standalone diesel**
Carbon dioxide	8,574,405	11,322,387
Carbon monoxide	21,165	27,948
Unburned hydrocarbons	2,344	3,096
Particulate matter	1,595	2,107
Sulfur dioxide	17,219	22,737
Nitrogen oxides	188,854	249,380

C. Renewable Energy Distribution Analysis

The monthly contribution of the PV and Wind turbine accounts for 39 percentages (%) of the total energy mix of the modeled ABUAD power system, as represented in Table X. This will significantly reduce the campus dependence on the conventional fossil fuel and will further reduce the resultant pollution. It was also observed that the wind turbine output is the least compared to the other energy sources because of the low wind speed of ABUAD.

TABLE X. SHOWING THE PERCENTAGE ENERGY CONTRIBUTION FROM THE VARIOUS ENERGY SOURCES IN THE PROPOSED HYBRID POWER SYSTEM.

Production	kWh/yr	Percentage (%)
PV array	3,081,522	31
Wind turbines	802,898	8
Generator1	6,122,099.7	61
Total	10,036,229	100

D. Validation of Wind Turbine Power Output Estimation

Table XI gives the wind turbine power output estimation from both Weibull distribution and that from HOMER. This further shows a good correlation between the estimated turbine output from both methods, however the output from the wind turbine is small compared to the energy requirement of Afe Babalola University campus.

TABLE XI. THE WIND TURBINE ESTIMATED POWER OUTPUT

HOMER		Weibull distribution	
		Lower limit	Upper limit
(kWh/month)	14,255	17,040	21,300

V. CONCLUSION

In this study, wind speed obtained at an interval of 30 minutes by the anemometer is used to investigate wind variability in Afe Babalola University for a short-term period of 12 months. This is also used to determine the economic viability of installing wind turbine at Afe Babalola University. It was observed that the average wind speed obtained using the anemometer at a height of 25m above sea level was 4.45m/s, which meets the minimum permissible wind speed for rotating wind turbines. This paper also provides seasonal variability analysis of wind speed in Afe Babalola University using the anemometer as wind speed was highest between the months of April and October. It was also observed that the month of July recorded the highest wind speed of 5.9365m/s during the period of the study, and a corresponding power density of 37.40W/m^2. The expected output power from the wind turbine ranges from 66W to 300W for an average operating time of 2840hours per year. Also, the estimated output energy (kWh/month) that can be harnessed from the wind turbines is about 17,040kWh/month to 58,590kWh/month as obtained from the Weibull distribution, this shows a good correlation the results obtained using HOMER (802,898kWh/year).

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