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COMPUTATIONAL APPROACH FOR COMPARATIVE ANALYSIS OF ENERGY GENERATED FROM ASSOCIATED TURBINE MODEL SPECIFICATIONS USING ANNUAL BONNY WIND SPEED.

[1]R.E. AKPODEE; [2]A. ZUKBEE; [3]B.NKOI

[1]Department of Mathematics, Faculty of Science, Rivers State University. [2,3]Department of Mechanical Engineering, Faculty of Engineering, Rivers State University.

ABSTRACT

Qualitatively, on the comparative analysis of energy generated from associated turbine model specifications using annual Bonny wind speed, numerical simulation approach was used on a diffusion model equation computationally with Matlab ODE45 numerical scheme software. In this study the results show that from

Introduction

The world's attention has been drawn to the use of renewable energy by a number of factors, including the population boom, the constant rise in energy demand, the desire for a better standard of living, the threat of acid rain, the dangers of global warming caused by the greenhouse effect, the environment, and the depletion of fossil fuel resources (Jafari *et al* 2011). If carefully studied, renewable energy sources like wind might be exploited to lessen the reliance on fossil fuels for the production of power (Buhari *et al* 2013).

A wind is an airflow resulting by the unequal heating of the earth caused by solar radiation and the spinning of the globe. Differential atmospheric temperature, density, and pressure are produced by variations in solar radiation

the 60th day to the 360th day of our experimental time we observed a fluctuating (non-sequential) pattern on the coordinates of the Bonny wind speed with its optimal values ranging from 8.7953002m/s to a saturated value of 8.7071175m/s. The corresponding energy generated for Polaris P15-50 ranges from 3682037.91271854 Watts on the 60th day to a saturated value of 22092227.47631127 Wattson the 360th. Similarly, for Polaris P19-100 with 5813904.35369085 Watts on the 60th day which increases monotonically down the trend to a saturated value of 34883426.12214510 Watts on the 360th experimental days. This shows that Polaris P19 – 100 has a relative advantage over Polaris P15 – 50 in power generation under the same conditions and time interval. Furthermore, from the 60th day to the 360th day of our experimental time we observed a fluctuating (non-sequential) pattern on the coordinates of the Bonny wind speed with its optimal values ranging from 8.7953002m/s to a saturated value of 8.7071175m/s. The corresponding energy generated for Polaris P15-50 ranges from 57372474.4017779 Watts on the 60th day to a saturated value of 344234846.4106673 Watts for WWD-1-60 on the 360th. Also, for Polaris P50-500 with 39841996.1123458 Watts on the 60th day which increases consistently to a saturated value of 239051976.6740745 Watts on the 360th experimental days. This shows that Polaris WWD-1-60 has a relative advantage over Polaris P50 – 500 in power generation under the same condition and time interval. The full results of this noble contribution are presented and discussed as well.

Keywords: Random Perturbation, Numerical Simulation, Wind Speed, Wind Energy, Turbine Power, Mathematical Modeling, Comparative Analysis.

absorption at the earth's surface and how that radiation is reflected back into the atmosphere. These variations in turn produce forces that transport air from one location to another in form of local winds and planetary wind. Trade winds, westerlies, easterlies, subtropical and polar jets are a few examples of semi-permanent global wind patterns that are caused by the earth's rotation. Of course, not all of the wind energy produced by the sun's uneven heating can be used to generate electricity because it is very difficult, if not impossible, to do so with air currents over water or at high elevations. However, a sizeable portion of wind energy is accessible close to the Earth's surface. It would make a major contribution and eliminate the need to produce electricity using fossil or nuclear fuels, even if just a small portion of the available wind power is converted to electricity.

On Earth's land surface, nature produces around 1.67x103 kWh of wind energy each year. The global average is 10 times this amount (Rajput, 1999). Utilizing devices like wind turbines, wind mills, and sails, one may transform the kinetic energy of the wind—a resource that is found in nature—into useable mechanical energy.

The average power generated by the wind within a given time period, usually one year, is the quantity of energy that is available in the wind (the wind energy resource). The windspeed, air density, temperature, and height all affect and propel the wind power. As a result, while determining the resource, the site wind speed distribution or the relative frequency of occurrence for each wind speed is crucial.

Between 2004 and 2030, it is anticipated that global energy consumption would rise by 57% (Oyedepo *et al* 2012). However, a large portion of the world's energy is typically produced and used in ways that the amount of consumption is unsustainable at the state of technology (Kukukali and Baris, 2009). A fifth of the population, or roughly 51%, is thought to live in sub-urban areas with inadequate, rationed, or non-existent access to electricity (Ohunakin et al., 2013). Due to the Niger Delta's unique physical location as a coastal region, the situation is significantly worse. In order to achieve sustainable national development, it is crucial to fully utilize the country's abundant renewable energy resources. These resources can be used to supplement traditional energy sources, prevent energy crises, and increase access to electricity.

In 2005, liberalized the power industry by the Federal Government of Nigeria establishing the Nigeria Electricity Regulatory Commission, the Electricity Power Sector Reform Acts (EPSR), and the Rural

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Electrification Agency (REA). These are some government initiatives meant to end the industry monopoly and enable for the construction and operation of power plants by private operators who fully incorporate renewable energy into their energy offerings. Both Sambo (2005) and Buhari et al. (2013) stated that the Energy Commission of Nigeria's predicted electricity supply by fuel-mix showed a good contribution from wind energy among renewable energy sources. When compared to other renewable energy sources, wind energy ranks among the most widely used due to its high efficiency, power, and economics.

Mathematical formulations

First order logistics ordinarily differential equation for wind speed numerical simulation.

Wind is air in motion (aerodynamics) which evolves over time, following (Hariji *et. al.,* 2011 and Akpodee, 2019), in the absence of an inhibiting factor, wind speed follows an exponential growth model which is counter intuitive in meteorological reasoning. This is stated mathematically as:

$$\frac{dN}{dt} = \alpha N(t)$$

Where N represents wind speed

The solution trajectory of the above equation is mathematically tractable since $N(t) = N_0 e^{\alpha t}$ is an exponential growth model which implication is hazardous and does not make meteorological sense as steady increase in the wind speed will cause serious damage to the ecosystem functioning. Hence, we consider an intra-competition coefficient in the model equation which is the contribution of the wind speed that will inhibit the growth of itself hence the need for a logistic first order ordinary differential equation which will be used to study the dynamical system of the wind speed that evolves over time.

In the formulation of a logistic ordinary differential equation model of first order that will be used for possible prediction and impact analysis of the wind speed using NIMET data set and field data set covering a duration of 12 months from April 2019 to March 2020 for Portharcourt,Yenagoa, Bonny and Warri location, the key parameters

that will be used in this study will be the carrying capacity, the intrinsic growth rate of the wind speed and the intra-competition coefficient that inhibit the growth of the wind speed.
Therefore, the required logistics model (Hariji *et. al.,* 2011, Shaikh and Ji, 2016 , Akpodee, 2019, Akpodee and Ekaka-a,2019) is stated as:

$$\frac{dN}{dt} = N(t)[\alpha - \beta N(t)], \quad N(0) = N_0 > 0$$

In other to obtain the general solution trajectory of this model, we resolve it analytically before computational approach which is more efficient and precise will be used for our various analysis.

Therefore, from the equation

$$\frac{dN}{dt} = N(t)[\alpha - \beta N(t)], \quad N(0) = N_0 > 0$$

Where:

$\frac{dN}{dt}$ represents the rate of change of wind speed with respect to time.

N represents the wind speed.

α represents the intrinsic growth rate of the wind speed.

β represents the intra-competition coefficient of the wind speed.

N (0) represents the initial value of the wind speed at the base year here called the initial condition.

t represents time.

Using analytical approach to obtain the solution map from the given equation:

$$\frac{dN}{dt} = N(t)[\alpha - \beta N(t)]$$

$$WLOG\ N(t) = N$$

$$\frac{dN}{dt} = N[\alpha - \beta N] = \alpha N - \beta N^2$$

$$\frac{dN}{dt} = \alpha N \left[1 - \frac{\beta N}{\alpha}\right]$$

Let $M = \frac{\alpha}{\beta}$ be the saturated value (carrying capacity)

So that $\frac{I}{M} = \frac{I}{\frac{\alpha}{\beta}} = \frac{\beta}{\alpha}$

Substituting into the logistics equation we have:

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$\frac{dN}{dt} = \alpha N\left[1 - \frac{N}{M}\right]$

Separating variables,

Dividing through by $N\left[1 - \frac{N}{M}\right]$ we have:

$$\frac{dN}{N\left[1 - \frac{N}{M}\right]dt} = \alpha$$

Multiplying through by dt, we have:

$\frac{dN}{N\left[1-\frac{N}{M}\right]} = \alpha dt$

Integrating both side of the equation

$\int \frac{1}{N\left[1-\frac{N}{M}\right]} dN = \alpha \int dt$

$N = Ae^{\alpha t}\left[1 - \frac{N}{M}\right]$

$N = Ae^{\alpha t} - \frac{ANe^{\alpha t}}{M}$

$N(0) = N_0$

$N(0)\left[M + Ae^{\alpha(0)}\right] = AMe^{\alpha(0)}$

$N_0[M + A] = AM$

$N_0M + N_0A = AM$

$AM - N_0A = N_0M$

$A[M - N_0M] = N_0M$

$A = \frac{N_0M}{M-N_0}$

$N(t) = \frac{MAe^{\alpha t}}{M+Ae^{\alpha t}}$

Substituting A into the equation

$N(t) = \frac{M\left[\frac{N_0M}{M-N_0}\right]e^{\alpha t}}{M+\left[\frac{N_0M}{M-N_0}\right]e^{\alpha t}}$

Dividing both the numerator and the denominator by $e^{\alpha t}$, we have

$N(t) = \frac{M\left[\frac{N_0M}{M-N_0}\right]}{Me^{-\alpha t}+\left[\frac{N_0M}{M-N_0}\right]}$

dividing through by $\frac{N_0M}{M-N_0}$ we have

$N(t) = \frac{M}{\frac{M}{\frac{N_0M}{M-N_0}}e^{-\alpha t}+1}$, Here we $let\ k = \frac{M(M-N_0)}{N_0M} = \frac{(M-N_0)}{N_0}$

$N(t) = \frac{M}{Ke^{-\alpha t}+1}$

Thus the qualitative behavior of the solution trajectory of the wind speed over a longer duration of time will be the limit of $N(t)\ as\ t \rightarrow \infty$

$$limN(t) = lim\left(\frac{M}{Ke^{-\alpha t}+1}\right) = Mlim\left(\frac{1}{Ke^{-\alpha t}+1}\right)$$

as t approaches infinity the wind speed (N(t)) converges to $M = \frac{\alpha}{\beta}$ which is wind speed carrying capacity over time.

In other words, as time gets larger and larger, the wind speed will respond by converging to a positive constant M which specifies a positive unique saturation value.

This phenomenon is consistent with meteorological and mathematical modeling and its applications.

Method of solution

Model equation for wind speed on-site data at 10m height in Port Harcourt location

Using the monthly averaged of the on-site wind data set at 10m height obtained from Port Harcourt location, the value of k and the growth rate α can be computed using the predicted carrying capacity M=1.73, the initial wind speed at the base month January t=0, $N_0 = 1.36$ and the Wind Speed at February t=1 $N_1 = 1.60$ using the solution map,

We have;

$$let\ k = \frac{(M - N_0)}{N_0} = \frac{(1.73 - 1.36)}{1.36} = 0.272$$

and $N(1) = \frac{1.73}{0.272e^{-\alpha(1)}+1} = 1.60$

$$1.73 = (0.272e^{-\alpha} + 1) \times 1.60$$

$$1.73 = 1.60 + 0.4352e^{-\alpha}$$

$$0.13 = 0.4352e^{-\alpha}$$

$$e^{-\alpha} = \frac{0.13}{0.4352} = 0.298713235$$

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Taking $\log_e$ of both sides, we have

$$-1.208271246 = -\alpha$$

$$\alpha = \frac{-1.208271246}{-1} = 1.208271246$$

Thus on simplifying the equation further, the intrinsic growth rate is obtained as $\alpha = 1.208271246$.

In computing the intra-competition coefficient β, we use the existing relationship between the intrinsic growth rate α, the carrying capacity cc and the intra-competition coefficient β stated as:

CC $= \frac{\alpha}{\beta}$ and

$$\beta = \frac{\alpha}{CC} = \frac{1.208271246}{1.73} = 0.698422685$$

Thus the required logistics first order ordinarily differential model equation for Port Harcourt location is stated as:

$$\frac{dN}{dt} = N(t)[1.208271246 - 0.698422685N(t)],$$

$$N(0) = 1.60 > 0$$

Model equation for wind speed on-site data at 10m height in Warri location

Using the monthly averaged of the on-site wind data set at 10m height obtained from Warri location, the value of k and the growth rate α can be computed using the predicted carrying capacity M=2.0, the initial wind speed at the base month January t=0, $N_0 = 1.63$ and the Wind Speed at February t=1, $N_1 = 1.76$ using equation.

We have;

$$let\ k = \frac{(M - N_0)}{N_0} = \frac{(2.0 - 1.63)}{1.63} = 0.226994$$

and $N(1) = \frac{2.0}{0.226994e^{-\alpha(1)}+1} = 1.76$

$$2.0 = (0.226994e^{-\alpha} + 1) \times 1.76$$

$$2.0 = 1.76 + 0.39950944e^{-\alpha}$$

$$0.24 = 0.39950944e^{-\alpha}$$

$$e^{-\alpha} = \frac{0.24}{0.39950944} = 0.600736743$$

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Taking $\log_e$ of both sides, we have

$$-0.5095985 = -\alpha$$

$$\alpha = \frac{-0.5095985}{-1} = 0.5095985$$

Thus on simplifying the equation further, the intrinsic growth rate is obtained as $\alpha = 0.5095985$

In computing the intra-competition coefficient β, we use the existing relationship between the intrinsic growth rate α, the carrying capacity cc and the intra-competition coefficient β stated as:

CC =$\frac{\alpha}{\beta}$ and

$$\beta = \frac{\alpha}{CC} = \frac{0.5095985}{2.0} = 0.2547992$$

Thus the required logistics first order ordinarily differential model equation for Warri location is stated as:

$$\frac{dN}{dt} = N(t)[0.5095985 - 0.2547992N(t)],$$

$$N(0) = 1.76 > 0$$

Model equation for wind speed on-site data at 10m height in Yenagoa location

Using the monthly averaged of the on-site wind data set at 10m height obtained from Yenagoa location, the value of k and the growth rate α can be computed using the predicted carrying capacity M=1.75, the initial wind speed at the base month January t=0, $N_0 = 1.27$ and the Wind Speed at February t=1, $N_1 = 1.59$ using equation,

We have;

$$let\ k = \frac{(M - N_0)}{N_0} = \frac{(1.75 - 1.27)}{1.27} = 0.377952755$$

and $N(1) = \frac{1.75}{0.377952755e^{-\alpha(1)}+1} = 1.59$

$$1.75 = (0.377952755e^{-\alpha} + 1) \times 1.59$$

$$1.75 = 1.59 + 0.600944881e^{-\alpha}$$

$$0.16 = 0.600944881e^{-\alpha}$$

$$e^{-\alpha} = \frac{0.16}{0.600944881} = 0.266247379$$

Taking $\log_e$ of both sides, we have

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$$-1.323329406 = -\alpha$$

$$\alpha = \frac{-1.323329406}{-1} = 1.323329406$$

Thus on simplifying the equation further, the intrinsic growth rate is obtained as $\alpha = 1.323329406$

In computing the intra-competition coefficient β, we use the existing relationship between the intrinsic growth rate α, the carrying capacity cc and the intra-competition coefficient β stated as:

CC =$\frac{\alpha}{\beta}$ and

$$\beta = \frac{\alpha}{CC} = \frac{1.323329406}{1.75} = 0.756188232$$

Thus the required logistics first order ordinarily differential model equation for Yenagoa location is stated as:

$$\frac{dN}{dt} = N(t)[1.323329406 - 0.756188232N(t)],$$

$$N(0) = 1.27 > 0$$

Model equation for wind speed on-site data at 10m height in Bonny location

Using the monthly averaged of the On-site wind data set obtained from Bonny location in 2022, the value of k and the growth rate α can be computed using the predicted carrying capacity M=8.61, the initial wind speed at the base month January t=0, $N_0 = 1.97$ and the Wind Speed at February t=1, $N_1 = 4.05$ using equation,

We have;

$$let\ k = \frac{(M - N_0)}{N_0} = \frac{(8.61 - 1.97)}{1.97} = 3.370558376$$

and $$N(1) = \frac{8.61}{3.370558376e^{-\alpha(1)}+1} = 4.05$$

$$8.61 = (3.370558376e^{-\alpha} + 1) \times 4.05$$

$$8.61 = 4.05 + 13.65076142e^{-\alpha}$$

$$4.56 = 13.65076142e^{-\alpha}$$

$$e^{-\alpha} = \frac{4.56}{13.65076142} = 0.3340473$$

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Taking $\log_e$ of both sides, we have

$$-1.096472679 = -\alpha$$

$$\alpha = \frac{-1.096472679}{-1} = 1.096472679$$

Thus on simplifying the equation further, the intrinsic growth rate is obtained as $\alpha = 1.096472679$

In computing the intra-competition coefficient β, we use the existing relationship between the intrinsic growth rate α, the carrying capacity cc and the intra-competition coefficient β stated as:

CC $=\frac{\alpha}{\beta}$ and

$$\beta = \frac{\alpha}{CC} = \frac{1.096472679}{8.61} = 0.127348743$$

Thus the required logistics first order ordinarily differential model equation for Bonny location is stated as:

$$\frac{dN}{dt} = N(t)[1.096472679 - 0.127348743N(t)],$$

$$N(0) = 1.97 > 0$$

Analytical computation of Energy Obtained from Turbine Models

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt}V_w^2$$

$$where \quad \frac{dm}{dt} = \rho A V_w$$

$$P = \frac{dE}{dt} = \frac{1}{2}\rho A V_w^3$$

where V_w represents average wind speed for Bonny simulated. Vw = 8.2035;

the density for Bonny $\rho = 1.2235 \cong 1.22$

A represents area of model specification Bonus 1000-54

A = 2290.518 square meters.

The optimal energy required to drive the turbine specification can be obtained by integrating both side of Equation (iii).

$$\frac{dE}{dt} = \frac{1}{2}\rho A V_w^3$$

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$$dE = \frac{1}{2}\rho A V_w^3 dt$$

$$\int d(Eu - y) = \frac{1}{2}\rho A V_w^3 \int dt$$

$$E(t) = \frac{1}{2}\rho A V_w^3 t + c$$

Using the initial condition for optimal energy

$$E(0) = 0$$

$$E(0) = \frac{1}{2}\rho A V_w^3 (0) + c$$

$$C = 0$$

Thus $E(t) = \frac{1}{2}\rho A V_w^3 t$

Inputting values stated earlier

$$at\ t = 0$$

$$E(0) = \frac{1}{2}(1.225)(2290.518)(8.2035)^3(0) = 0$$

$$at\ t = 30$$

$$E(30) = \frac{1}{2}(1.225)(2290.518)(8.2035)^3(30)$$

$$= 23235852.13\ watts$$

Having computed the energy generated by the turbine using Bonny wind speed, numerical simulation approach of generating turbine energy is the core of this study and is been presented in our results and discussion.

Results and Discussions.

Table 1: Wind Energy (Watts) Simulated for Turbine Model Specification Bonus PolarisP15-50 and Polaris P19-100 Using Annual Average Wind Speed of Bonny Location

1.0e+007 *

Time (Days)	Polaris P15-50	Polaris P19-100
0	0	0
0.000003000000000	0.184101895635927	0.290695217684542
0.000006000000000	0.368203791271854	0.581390435369085
0.000009000000000	0.552305686907782	0.872085653053627
0.000012000000000	0.736407582543709	1.162780870738170
0.000015000000000	0.920509478179636	1.453476088422713

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0.000018000000000	1.104611373815563	1.744171306107255
0.000021000000000	1.288713269451491	2.034866523791798
0.000024000000000	1.472815165087418	2.325561741476340
0.000027000000000	1.656917060723345	2.616256959160883
0.000030000000000	1.841018956359273	2.906952176845425
0.000033000000000	2.025120851995200	3.197647394529968
0.000036000000000	2.209222747631127	3.488342612214510

Comparatively, results were obtained for Turbine Model Specification Polaris P15-50 and Turbine Model Specification Polaris P19-100 for an experimental time interval of 0-360 days (Table 1). On the base day it was at initial value which is zero as usual. On the 30thday of our experimental time, it recorded as 1841018.95635927 Watts for Polaris P15-50 and Polaris P19-100 with 2906952.17684542 Watts indicating Polaris P19-100 with high energy potential to generate power at that point. From the 60th day to the 360th day of our experimental time we observed a fluctuating (non-sequential) pattern on the coordinates of the Bonny wind speed with its optimal values ranging from 8.7953002m/s to a saturated value of 8.7071175m/s.The corresponding energy generated for Polaris P15-50 ranges from 3682037.91271854 Watts on the 60th day to a saturated value of 22092227.47631127 Wattson the 360th. Similarly, for Polaris P19-100 with 5813904.35369085 Watts on the 60th day which increases monotonically down the trend to a saturated value of 34883426.12214510 Watts on the 360th experimental days. This shows that Polaris P19 – 100 has a relative advantage over Polaris P15 – 50 in power generation under the same conditions and time interval.

Table2: Wind Energy (Watts) Simulated for Turbine Model Specification WWD-1-60 and Polaris P50-500 using Annual Average Wind Speed of Bonny Location

1.0e+008 *

Time(Days)	WWD-1-60	Polaris P50-500
0	0	0
0.000000300000000	0.286862372008889	0.199209980561729
0.000000600000000	0.573724744017779	0.398419961123458
0.000000900000000	0.860587116026668	0.597629941685186
0.000001200000000	1.147449488035558	0.796839922246915

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0.000001500000000	1.434311860044447	0.996049902808644
0.000001800000000	1.721174232053337	1.195259883370373
0.000002100000000	2.008036604062226	1.394469863932101
0.000002400000000	2.294898976071115	1.593679844493830
0.000002700000000	2.581761348080005	1.792889825055559
0.000003000000000	2.868623720088894	1.992099805617287
0.000003300000000	3.155486092097784	2.191309786179017
0.000003600000000	3.442348464106673	2.390519766740745

Comparatively, result was obtained from Turbine Model Specification Polaris WWD-1-60 and Turbine Model Specification Polaris P50-500 for an experimental time interval of 0-360 days (Table 2). On the base day, it was at initial, so the result was taken to be zero (0). Furthermore, with an optimal Bonny wind speed value of 8.6686932m/s simulated on the 30th day of our experimental time, we observed a gain in the wind energy simulated for WWD-1-60 which is recorded as 28686237.2008889 Watts and Polaris P50-500 with 19920998.0561729 Watts indicating Polaris WWD-1-60 with high energy potential to generate power at that point. From the 60th day to the 360th day of our experimental time we observed a fluctuating (non-sequential) pattern on the coordinates of the Bonny wind speed with its optimal values ranging from 8.7953002m/s to a saturated value of 8.7071175m/s. The corresponding energy generated for Polaris P15-50 ranges from 57372474.4017779 Watts on the 60th day to a saturated value of 344234846.4106673 Watts for WWD-1-60 on the 360th. Also, for Polaris P50-500 with 39841996.1123458 Watts on the 60th day which increases consistently to a saturated value of 239051976.6740745 Watts on the 360th experimental days. This shows that Polaris WWD-1-60 has a relative advantage over Polaris P50 – 500 in power generation under the same condition and time interval.

Conclusion

This study revealed that as time increases with an optimal wind speed, the associated wind energy of the turbine specification Polaris WWD-1-60 has a relative advantage over Polaris P50 – 500 in power generation under the same condition and time interval. Similarly, Polaris P19 – 100 has a relative advantage over Polaris P15 – 50 in power generation under the same conditions and time interval.

Recommendations

This study will recommend the following extended research work mainly:

1.) Carrying out similar research on other turbine model specifications using Bonny wind speed.
2.) Carrying out similar research on these turbine model specifications using Yenagoa wind speed.
3.) Carrying out similar research on these turbine model specifications using Warri wind speed.
4.) Carrying out similar research on these turbine model specifications using Port Harcourt wind speed.

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