Assessment of Potential for Wind Farm Development in Olomoro Town, Isoko South Local Government Area of Delta State, Nigeria

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Abstract

The challenge of supplying electricity, yet not jeopardizing the environment, or rather, producing electricity while ensuring sustainability is required if man is to save the environment from its current state of decline and environmental decadence. The work seeks to access and develop a wind energy system for a rural community. The methodology adapted in this study, is basically modeling; with its objective being the estimation of the highest possible Power Available to be harnessed by the wind resource of the study area. The mathematical models where developed using the works of other authors. Codes were developed in Matlab to generate random numbers, and simulations were subsequently performed in minitab.

I. INTRODUCTION

The industrial revolution brought in its wake man's drive to provide fuel for powering the industrial machines. The Industrial man has been able to use the knowledge of nature for energy exploration so as to solve his energy supply needs. However, in solving his energy needs, man has almost irredeemably jeopardized his environment – earth. This energy is of different sources . Millions of literatures abound on the extent of damages caused by man. [13],[3].

However, one of the most detailed work on man's damage to his environment was [17]. The environmental problems associated with the use of fossil fuels or non-renewable energy sources can as well be mitigated with the use of non-renewable energy sources like, solar, wind, geothermal, tidal and the rest [3].

The massive growth of the oil and gas industries has created significant environmental challenges, and have been a source of much concern for the people. Challenges such as gas flaring, oil spills from pipeline, deforestation and waste mismanagement have been made serious by federal laws which centralize control of the rich land and allow local government relatively little control over activities. It has been reported that the local government had joined ICLEI – Local governments for sustainability.

These efforts are commendable, however, they do not seek a long term solution to the devastation caused by climate change, and other environmental hazards. The best solution is renewable energy that has the capacity to keep the environment green while providing jobs for youths and employables. [4],[12],[5].

The present work seeks to develop a wind energy farm for Olomoro town.

The challenge of producing sufficient energy to meet the ever increasing global energy consumption, the rapidly depleting fossil fuel reserves, and the serious environmental problems associated with the use of fossil fuels have motivated considerable research attention on clean energy sources. Wind energy is one of the several energy sources that are both environmentally preferable and renewable. Moreover, wind energy is abundant in nature, inexhaustible, fuel-free, can generate power near load center, and thus eliminates energy losses associated with transmission network [14].

Small wind farms can provide electricity, making a significant contribution to our nation's energy needs. The criteria for the use of wind electric system has been noted [18]: (i) if there is enough wind in the town (ii) if tall towers are allowed in your neighborhood or town (iii) if you have enough space (iv) if you can determine how much electricity you need or want to produce (iv) if it works for you economically.

Wind energy systems are one of the most cost-effective home-based renewable energy systems. Depending on your wind resource, a small wind energy farm can lower your electricity bill by 50% to 90%, help you avoid the high costs of having utility power lines extended to remote locations, prevent power interruptions, and it is not a source of concern to the environment [18]. The advantages and disadvantages of the wind turbine are [5], respectively, are advantages:

renewable energy, low maintenance cost, medium (not high) price, few residual waste materials; disadvantages: volatile production, hard to estimate (precisely), noise, disturbs the environment, birds are in danger, drying of the soil.

II. STUDY AREA

Figures 1: showing the map of Olomoro town (source: Google images)

Olomoro is situated in Isoko south local government area, delta state, Nigeria. Its geographical coordinates are 5^0 25' 0'' North, 60 9' 0'' East and its original name is Olomoro (with diacritics). Olomoro is a part of a low-lying section of the larger Niger Delta basin, intercepted with streams, canals and rivers. It is located in a region of deciduous and ever green forests, with patches of mangrove forest, as well as a forest reserve along the Aviara clan [20].

III. METHODOLOGY

The methodology adapted in this study, is basically modeling; with its objective being the estimation of the highest possible Power Available to be harnessed by the wind resource of the study area. The mathematical models where developed using the works of other authors. Codes were developed in Matlab to generate random numbers, and simulations were subsequently performed in minitab. In general, the cycle of (mathematical) modeling consists of the following steps:

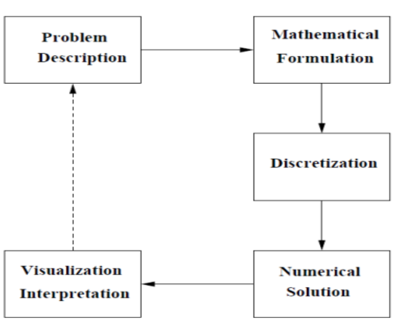


Figure 2: Methodology for the mathematical modeling [19]

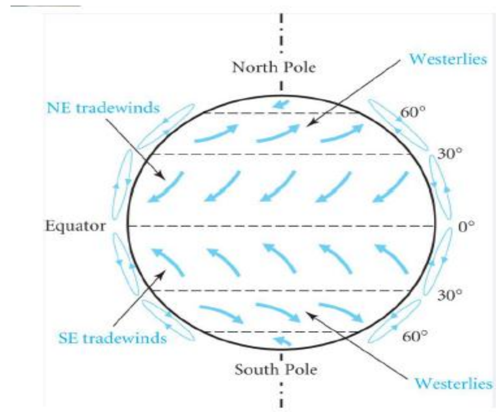
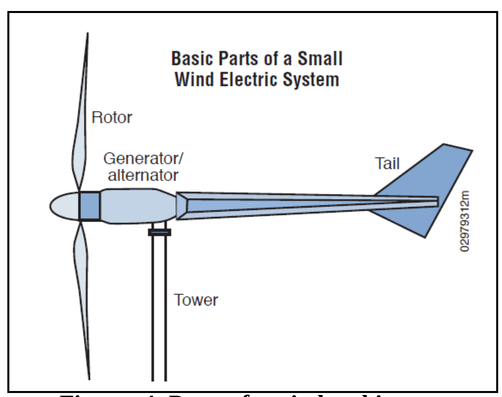


Figure 3: A simplified map of global wind patterns [19]

IV. MATHEMATICAL MODELING

Wind is created by the unequal heating of the Earth's surface by the sun. When the sun unequally heats the surface of the earth, the density of air varies; and the denser air settles down, while the less dense air rises. It is this reciprocating movement of air –less dense and denser – that causes the wind. The wind turbine was created to leverage this free energy resource by converting the kinetic energy in the wind into mechanical power that runs a generator to produce clean electricity. The blades of the turbine are aerodynamically designed to capture the maximum energy from the wind. The wind, generated by uneven heating of the earth's surface, turns the blades which spin a shaft connected to a generator that produces electricity.



Figures 4: Parts of a wind turbine

A. Modeling the size of the wind turbine

The size or installed capacity of any energy system is dependent on the estimated load the system is supposed to carry. Olomoro is a rural community with its inhabitants being farmers and fishermen and couple of civil servants. Since no industry is in Olomoro, the community requires a small-scale wind farm to power the domestic energy needs. Experts have defined a small wind turbine to be within 20 to 500Watts. The Community energy needs are, basically, charging phones, lighting their homes, pumping water, in very rare occasions.

1. Basic parts of the wind turbine

A wind turbine comprises of a rotor, or generator or alternator mounted on a frame,a tail, a tower and a ‘‘ balance of system’’ components: controllers, inverters and/ or batteries (figure 4).

B. Modeling the power output of the wind turbine

The mathematical model that estimates how much energy a wind turbine can generate [18].

$$Power = \frac{1}{2kc_p\rho AV^3} \quad (1)$$

Where P= Power output, kW.
c_p =Maximum power coefficient; $0.25 \geq c_p \leq 0.45$, maximum is 0.59
ρ = air density,lb/ft^3
A = Rotor swept Area, Ft2 or $\pi D^2/4$ $(D\ is\ the\ rotor\ diameter\ in\ ft, \pi = 3.142)$
V = wind speed; vary it from; $0 \geq V \leq 100$
K = 0.060133. a constant to yield power in kilowatts(multiplying the above kilowatts answer by 1.340 converts it to horsepower [ie 1kW = 1.340hp]

C. Modeling the annual energy output from the wind

To determine whether a wind turbine and tower will produce enough to meet the needs of clients or customers(www.nrel.gov/wind

$$AEO = 0.01328D^2V^3 (2)$$

Where AEO = Annual energy output,kwh/year
D = Rotor diameter, feet
V = annual average wind speed,mph

D. Modeling the amount of power available in the wind

[6] gave a model for the amount of power available in the wind; and from the model, this power available is dependent on the velocity of wind. This velocity, in turn, could be affected by obstructions, trees, buildings. Also, geological formations could be a cause of worry for the wind speed. Similarly, possible future source of obstruction should be planned for and prevented.

Furthermore, the turbine needs to be cited upwind of buildings, trees and obstructions; it also needs to be 30 feet above anything within 300ft. one also need enough room to raise and lower for maintenance, and if ones tower is guyed, one must allow room for the guy wires [18].

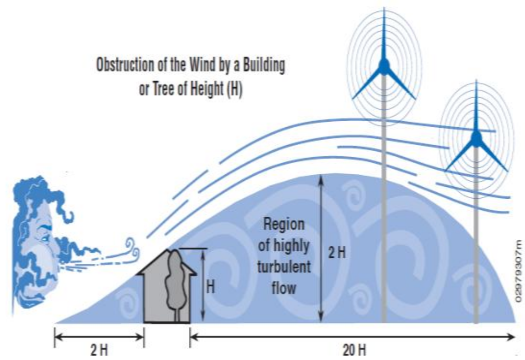


Figure 5: Model for situating wind turbine [18]

E. Modeling the urban flow pattern and the characteristic urban geometry parameters

By the interaction between the blades of the turbine and the surrounding fluids, a fluid field results creating below the schematic represented.

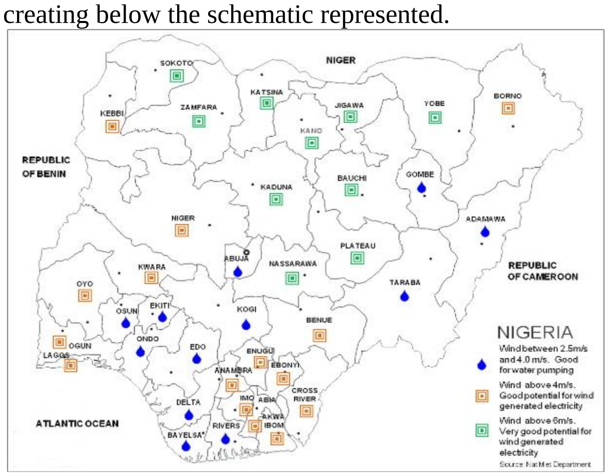


Figure 6: Wind resource map of Nigeria (NIMET)

1. Modeling Wind Energy Output

To estimate the wind energy potential, it is expedient that a statistical model be used to model the mean wind velocity at the given location. Widely used model for the variations in wind speed is the two-parameter Weibull distribution, which describes the variation of the average velocity magnitude *U* through the scale parameter *c* (related to the mean velocity) and the shape parameter *k* (related to the location where the wind is analyzed). Adopting this model, the 3rd rawmoment of the Weibull distribution defines the effective wind energy flux [9]

$$v_{eff} = \frac{v_p}{\psi} \frac{\ln\left(\frac{h_1}{z_{op}}\right)\ln\left(\frac{z-d}{z_{OR}}\right)}{\ln\left(\frac{z_p}{z_{op}}\right)\ln\left(\frac{h_i-d}{z_{OR}}\right)} (3)$$

$$\exists_{eff} = \frac{1}{2}\rho\left\{c^3\Gamma\left(1+\frac{3}{k}\right)\right\} (4)$$

$$\exists_{eff} = \frac{1}{2}\rho\left\{\left[\frac{v_{eff}}{\Gamma\left(1+\frac{1}{k}\right)}\right]^3 \Gamma\left(1+\frac{3}{k}\right)\right\} (5)$$

Where v_{eff} is effective velocity, v_p is reference wind velocity, z_p is reference wind height, z_{OP}Reference surface roughness, k is Weibull shape parameter; h is Building height;

2. Random number generation for the temperature and diameter of the rotor blades:

The temperature of Olomoro and rotor diameter used in the simulation were generated using

$$\begin{cases} \frac{dV}{dt} = a_0 V, \ \ t \geq \tau_1 \\ \frac{dV}{dt} = a_1, \ \ t \leq \tau_2 \\ V(t=0) = V_0 \end{cases} (6)$$

Where, the coefficient a_0 is the fraction of proliferative cells times $\ln 2/T_c$, where T_c is either the constant cell cycle length or the mean cell cycle length. The coefficient a_1 drives the linear phase [2].

To adopt this model for the present study, we assume that the solution to the problem of equation 1 is continuously differentiable uniquely and further assumed equation 1 to be a linear equation. Where t is temperature in Kelvin, and $\tau_1 \& \tau_2$ are numerical values whose range lies between 0 and 400.

Alternatively, to generate random number sequence, the Levenshtein-Damerau distance d of the pattern to the corresponding part of the random sequence was computed [11]

$$s(m,z) = \frac{1}{l}\sum_{i=n}^{l}\frac{1}{di+1} (7)$$

Where s gives a sequence and a pattern as input

F. Modeling the urban flow pattern and the characteristic urban geometry parameters

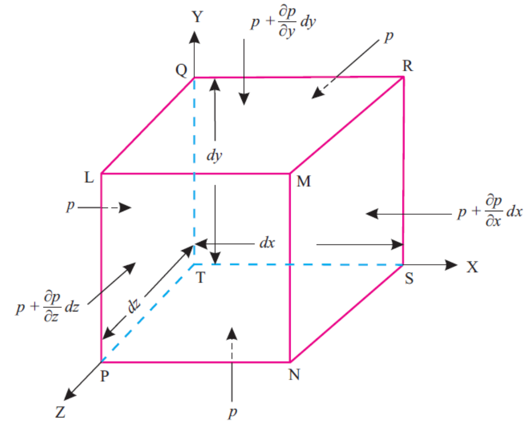


Figure 7: An infinitly small mass of fluid (air) enclosed in an elementary parallelepiped [21]

By the interaction between the blades of the turbine and the surrounding fluids, a fluid field results creating below the schematic represented.

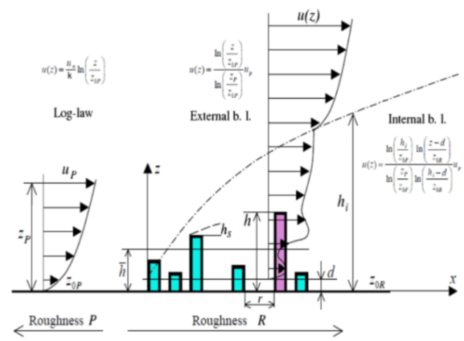


Figure 8: Modeling the urban flow pattern and the characteristic urban geometry parameters [9].

The blades of the turbine are assumed to cause an aerodynamic wake on an infinitely small mass of air. In the cause of modeling, this air is assumed to be an elementary parallelepiped of sides

$$dx, dy, and \ \ dz$$

This fluid element, enclosed in an arbitrary parallelepiped, has been modeled by [21]; White, (1999) to be subjected to four forces:

1. Normal forces due to pressure, modeled with a net pressure force in the X- direction thus:

$$F_N = pdydz - \left[p + \frac{\partial p}{\partial x}dx\right]dydz = -\frac{\partial p}{\partial x}dxdydz \ \ (3)$$

2. Gravity or body forces

If we assume G to be the body force per unit mass of the fluid having Gx, Gy and Gz in the x, y and z coordinates, we can write the force to be

$$F_g = G_x \rho dxdydz \qquad (4)$$

3. Inertia forces
The inertia force acting on the fluid mass, along the X-coordinate is given by

$$F_I = \rho dxdydz \frac{du}{dt} \qquad (5)$$

4. Shear force: the blades of the wind turbine while turning exerts shear force on the surrounding air(fig 7)
Of shear force per unit mass set up by viscous effects in the x, y and z direction respectively:

$$F_S = S_x \rho dxdydz \qquad (6)$$

Applying Newton's second law of motion to the parallelepiped fluid element of air, we have

$$F = ma \qquad (7)$$

Considering the net force exerted on the fluid element, air and substituting these four forces (1 to 4) into the modified Newton's second law of motion

$$F_g + F_I + F_S + F_N = ma \qquad (8)$$

A further simplification yields

$$\left.\begin{aligned} G_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \\ G_y - \frac{1}{\rho}\frac{\partial p}{\partial y} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \\ G_z - \frac{1}{\rho}\frac{\partial p}{\partial z} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] \end{aligned}\right\} \qquad (9)$$

In more implicit form, these Navier-Stokes equation may be written thus:

$$\frac{DV}{Dt} = G - \frac{1}{\rho} grad.p + \upsilon \nabla^2 V \qquad (10)$$

Equations 9 or 10 shows or have the capacity to describe fluid flow in its most beautiful form as it shows complex, yet complete mechanics of the flow of air as the blades of the wind turbine exerts shear stress on the fluid element, air. The wake and force dynamics of the dynamic interplay and interphase between the blades of the wind turbine and air, the former slices. [21] gave the number of unknowns in equations 9 to be:

$$u, v, w \text{ and } p$$

The Navier- Stokes equation, equation 9 plus the continuity equation, equation 11 for an incompressible flow in three dimensions are sufficient to conditions for determination of the flow characteristics.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (11)$$

Equation 9 is a second order non-linear differential equation, whose general solution has not been found out yet. However, equation 9 as well as equation 11 may be reduced to solvable form by simplifying the complex physics to simple physics using the following algorithms:

The solution to the algorithm depicted in figure 8 gives a complete step by step solution, 1-D, 2-D or 3-D space, to understanding the aerodynamic interaction between the wind turbine blades.

Start

If we consider 1-D flow along the x-axis, then

$$G_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right]$$

Else, consider 1-D flow along the y-axis, then

$$G_y - \frac{1}{\rho}\frac{\partial p}{\partial y} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right]$$

Else, consider 1-D flow along the z-axis, then

$$G_z - \frac{1}{\rho}\frac{\partial p}{\partial z} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right]$$

Else if , consider 2-D flow along the x and y- axis, then

$$G_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right]$$

and

$$G_y - \frac{1}{\rho}\frac{\partial p}{\partial y} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right]$$

Else, consider 2-D flow along the x and z-axis, then

$$G_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right]$$

$$G_z - \frac{1}{\rho}\frac{\partial p}{\partial z} = \frac{du}{dt} - \upsilon\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right]$$

If, considering 3-D flow along the x, y and z-axis, then

$$\left.\begin{aligned} G_x - \frac{1}{\rho}\frac{\partial p}{\partial x} &= \frac{du}{dt} - \upsilon\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \\ G_y - \frac{1}{\rho}\frac{\partial p}{\partial y} &= \frac{du}{dt} - \upsilon\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \\ G_z - \frac{1}{\rho}\frac{\partial p}{\partial z} &= \frac{du}{dt} - \upsilon\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] \end{aligned}\right\} \quad (9)$$

Stop

Figure 9: algorithm for the solution of the three dimensional flow analysis using Navier-Stokes Equations

V. RESULTS AND DISCUSSION

A. Power Available

Figure 8 shows the power available for the wind energy resource. This power is not constant, but varies or undulates as the ambient air condition – temperature, pressure and humidity varies. While air density is constant, the power available to the wind undulates, peaking and troughing at different peaks with the zenith at 17500MW. From the study, it has been shown that with a varying wind speed of 3.25m/s to 4.25m/s prevalent in Olomoro town, the maximum Power available is 17500MW. It can also be observed that the effective power, the effective energy and the available power is heavily or strongly dependent on the wind speed.

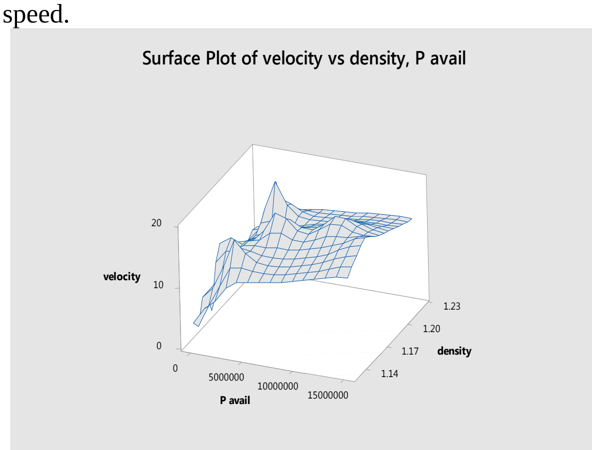


Figure 10: Surface plot of velocity vs density, Power available

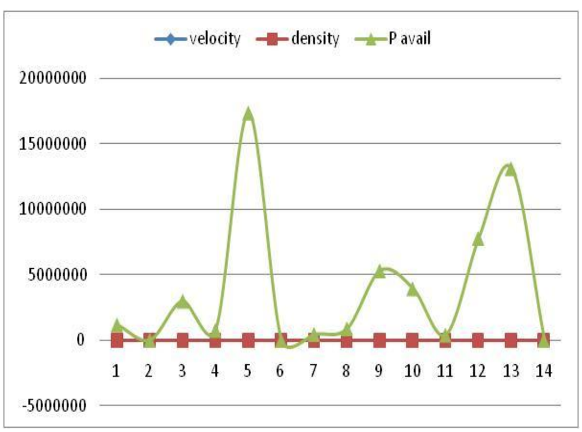


Figure 11: Plot of available power Vs Air density

B. Distribution Plot

The distribution curve (figure 8) depicts a normal curve.

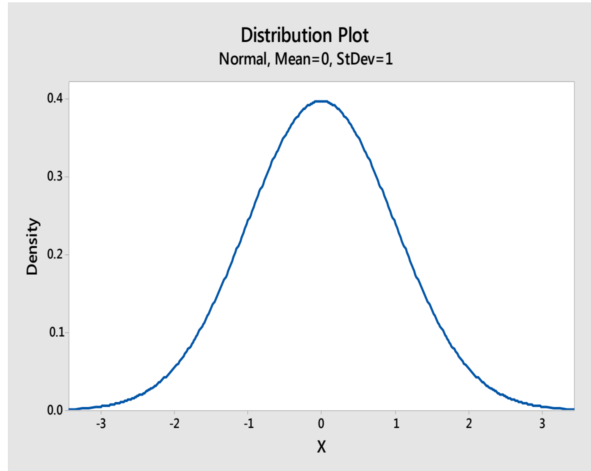


Figure 12: Power distribution curve

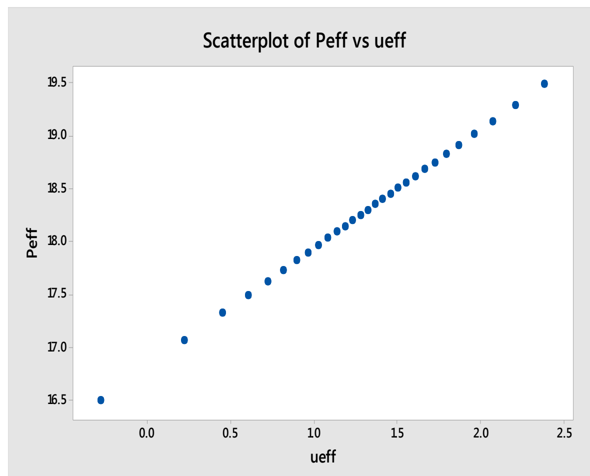


Figure 13: Surface plot of Effective power vs effective velocity

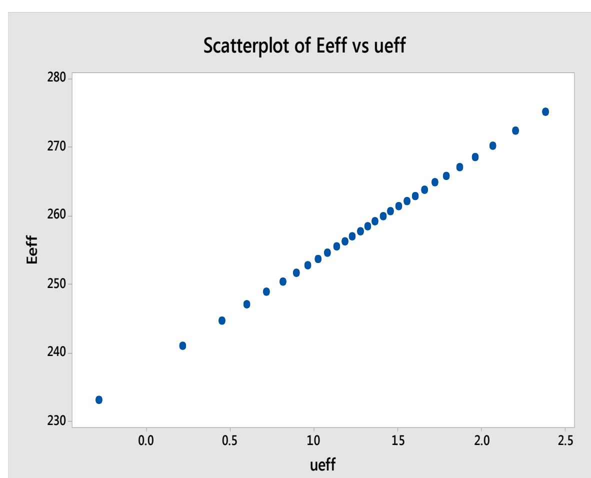


Figure 14: Surface plot of Available power vs effective velocity

As can be seen the Effective Power varies linearly as the effective velocity (figure 14). In the same token, the effective energy varies linearly as the effective velocity.

VI. RECOMMENDATIONS

The following recommendations are made based upon the work performed:

1. The ministry of energy mayreview this work for possible implementation to provide energy supply for the state.

2. Olomoro town may seek for funding as well as incentives to develop its wind energy resource.

3. Meet with town officials to establish a public outreach program to provide public education on the project and the anticipated benefits/impacts, develop and evaluate/address the concerns of any neighborhood opposition to the project (Atlantic Engineers Project, 2009)

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