Wind Energy Conversion System for Electrical Power Generation in UNIPORT and UPTH, Port Harcourt, Rivers State, Nigeria

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Abstract- As one of the fifth major urban cities in Nigeria, high demand for electricity in Port Harcourt, Rivers State, Nigeria is evident, and hence, requires high installed capacity for steady conventional energy source. At present this is hardly met, coupled with its attendant risk of undesirable emissions and other identified disadvantages. This paper considers that the conventional energy source may be supported or entirely replaced by the alternative or renewable sources to meet demands for electricity as well as minimize risks of undesirable emissions including other limitations of the conventional sources. It therefore presents a study of wind energy conversion system to be installed along the Choba banks of the New Calabar River. The system should be capable of serving electricity need of the University of Port Harcourt and the University of Port Harcourt Teaching Hospital all in Port Harcourt. The study is focused on the horizontal axis wind farm turbine rotor aerodynamic performance analysis, using the blade element momentum theory, and economic evaluation of the wind energy conversion system. It showed that, to meet with the total power requirement of 21 [MW] in the University and its Teaching Hospital for a projected period of 20 years, rotor blades of each of the wind farm turbines, which are optimally designed for capacity of 1.5 [MW], wind velocity of 17.5 [m/s], and for airfoil shape of NACA 2412, are desired. The power and torque of the designed turbines, using these blades and having positive non linear relationship with wind velocity, were achieved. Besides, an economic study of the system revealed savings in costs of ₦8, 633,032,101.98 in comparison with the existing diesel plant.

Keywords- Port Harcourt, Nigeria, Wind Energy Conversion System, Horizontal Axis Wind Turbine, Blade Element Momentum Theory, Turbine Rotor Blade, Aerodynamic Performance

1. Introduction

Port Harcourt, the capital city of Rivers State, Nigeria, lies along the Bonny River, and is located in the Niger Delta region [1]. Its area taken as at 1980s is 360 km^2, and population taken as at 2012 is 1,947,000, and as a result, it is known as the fifth major urban areas in Nigeria. It is highly congested, as it is the only major city of the state. It features a tropical monsoon climate, with lengthy and heavy rainy seasons, and very short dry seasons. It experiences dry season only in the months of December and January, with harmattan being less pronounced. It experiences the heaviest rainfall in September, with an average rainfall of 370 mm, and the driest weather in December, with an average rainfall of 20 mm. Its temperatures are relatively constant, with an average temperature typically in the range between 25 and 28 ^{0}C. As a major industrial centre, the city has a large number of multinational firms in addition to other industrial concerns, more especially, business related to the petroleum industry. It is known as the chief oil-refining city in Nigeria. Besides, Rivers State is one of the wealthiest states in Nigeria in terms of gross domestic product and foreign exchange revenue from oil industry, crude oil being its main export earner. These historical, geographical, climatic and economic features coupled with the identified economic, social and environmental benefits of the renewable energy resources have motivated investigation and assessment of its wind energy resource for wind energy utilization reported in Izelu et al [2], with the obtained results showing that it is a potential site for installation of wind energy conversion system (WECS) meant for electricity generation.

As one of the major urban areas and industrial center in Nigeria, high demand for electricity is evident, and would require high installed capacity for steady conventional or hydropower energy resource, which at present is hardly met by the Power Holding Company of Nigeria (PHCN), coupled with its attendant risk of undesirable greenhouse emissions and many other identified disadvantages [2]. Consideration for support or provision by a non-conventional, alternative or renewable energy resource is therefore justified. Hence, interest in wind energy resource conversion is demonstrated in this work to apply the results of wind resource assessment reported in Izelu et al [2] with target installed capacity enough to support, in hybrid with the conventional system, or provide, on its own, the electricity need in Port Harcourt, Rivers State, Nigeria.

Wind energy conversion technology is not entirely new, however more efforts are required from, and has been exerted by, numerous researchers to further its development and applications. Some of the major developments are discussed in the works of Johnson [3] and Munteanu et al [4] on wind energy conversion systems; Stiebler [5] and Abarzadeh et al [6] on wind energy conversion systems for electric power generation; Ragheb and Ragheb [7] on wind turbine theory based on the Betz aerodynamic actuator disc concept; Ingram [8, 9], Cowgill et al [10], Schubel and Crossley [11], Tenguria et al [12], Shateri [13], Rathore and Ahmed [14], Leisshman [15], Bak et al [16], Zhang [17] and Claessens [18] on vertical and horizontal axis wind turbine blade design, analysis and performance evaluation based on the blade element momentum theory; Ahlstrom [19] on wind turbine dynamics; Martens and Albers [20], Khemiri et al [21] and Belfedhal et al [22] on wind energy conversion systems drives, generators and controls; and Website [23], Jacob et al [24] and Moran [25] on wind turbine blade airfoils. These works are quite relevant in the present study to aid understanding, and subsequently, to establish criteria and relations required for the assessment of wind characteristics, wind farm turbine design and layout, and for economic evaluation of the system.

This work therefore concerns the utilization of the wind resource in Port Harcourt to meet the electric power requirements of the University of Port Harcourt (UNIPORT), Port Harcourt, and that of the University of Port Harcourt Teaching Hospital (UPTH), Port Harcourt, through the study of a WECS to be installed along the Choba banks of the New Calabar River, Port Harcourt, Rivers State, Nigeria. It involves brief description of the system and detailed analysis of the wind turbine rotor using the results of wind resource assessment reported in Izelu et al [2] and the blade element momentum (BEM) theory reported in [8, 9] to establish the optimal wind power coefficient, wind power output, turbine rotor torque and the axial thrust, and to finally, propose a wind farm based on standard layout and determine the economic value of the conversion system.

2. Wind Energy Conversion System

2.1. Anatomy and Configurations

A wind energy conversion system (WECS), also known as wind turbine (WT), performs the function of wind energy capture or extraction, and its subsequent direct conversion into mechanical energy achieved through its capacity to cause rotational motion of the turbine rotor. The mechanical energy may be used either for electric power generation, or for numerous other purposes. The various components of WECS designed for power generation are schematically depicted in Fig 1 [7]. As shown in Fig 2 [27], its main alternative configurations, based on the rotor design and its shaft orientation, are the vertical-axis wind turbine (VAWT) and horizontal-axis wind turbine (HAWT).

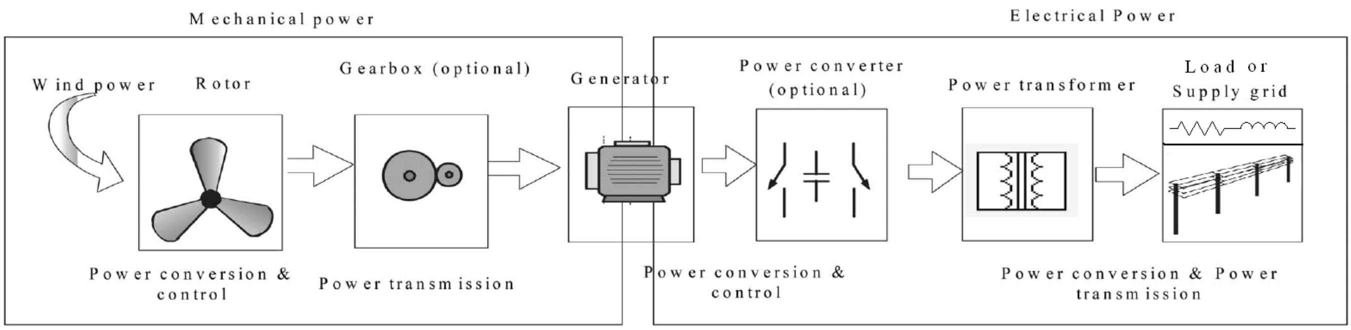

Figure 1: Components of a Wind Energy Conversion system (Source: Abarzadeh et al [7])

Figure 2: Alternative Configurations of WECS (Source: Bureau of Energy Efficiency, India)

The HAWT is lift driven, and therefore, largely dependent on wind direction. It has been the most preferred of the two because of its variable blade pitch, tall tower base, high efficiency and low blade fatigue. Most HAWT have two or three blades, which may be oriented upwind or downwind of the tower [28]. They may also be actively or passively yawed to face the rotor in the wind direction. The actively yawed wind turbines use wind direction sensor and yaw motor to position the rotor. They are usually very large machines capable of converting greater percentage of energy of the wind as well as being predictable. Downwind wind turbines usually do not require a yaw-drive system because they are dynamically stable when the rotor is against the wind.

The VAWT may be lift or drag driven, and therefore, independent of wind direction. Lift driven VAWT is the main focus of research in wind power generation today because its maximum possible efficiency is larger when compared to that of the drag driven turbines. As documented in Martens and Albers [20], other configurations based on the type of drives and output current include the constant speed wind turbine (CSWT), variable speed wind turbine (VSWT) with inverter and the variable-speed wind turbine (VSWT) with inverter and continuous variable transmission (CVT)

The rotor of a wind turbine, which consists of blades and hub assembly mounted on a low speed shaft, performs the function of wind energy conversion into mechanical energy most often at low speed and high torque sometimes enough to drive the generator. However, if a high speed generator is used, a suitably power transmission gear box will be required to transmit the produced mechanical energy from a low speed shaft to a high speed shaft so coupled to drive the generator. If a generator, specifically designed for direct drive, is used, there would be no need for a power transmission gear box. Generally, generators perform the function of mechanical energy conversion into electrical energy, and therefore, are conventionally referred to as electrical machines of either electromagnetic or electrostatic design. The electromagnetic machines may be of the asynchronous A.C. or induction type, or of the synchronous A. C. type. The D.C. machines are no longer of practical interest as generators because they require more maintenance effort, have an unfavourable power to mass ratio and are not suitable for high voltage windings [5]. Most unconventional electrical machines are of the direct driven generators. Such designs include the axial field machines, transverse flux machines, modular magnetic machines and the variable reluctance machines. Electrical equipment for both control and distribution of the generated electrical power are equally critical components of WT. Due to lack of space, this study reserves, for further communications, the performance assessment of the wind turbine drives, generators and electrical equipment, but considers, in greater details, only rotor design of the HAWT and its performance assessed on the basis of the Blade Element Momentum (BEM) theory, wind farm details based on standard layout of the project site and economic evaluation of the system.

2.2. Wind Turbine Performance

The performance of a WECS depends essentially on its capacity to extract or capture greater percentage of the available wind energy, and hence, on the rotor blades design. According to Ingram [8, 9] the Blade Element Momentum (BEM) theory for the HAWT equates two methods of examining how a wind turbine operates. The first method uses a momentum balance on a rotating annular stream tube passing through a turbine. The second examines the forces generated by the airfoil lift and drag coefficients at various sections along the turbine blade. These two methods give rise to a series of equations referred to as the fundamental blade element momentum equations that can be solved iteratively for a finite number (N) of blade elements to determine the optimal blade design. These equations are given as follows:

$$\tan\beta = \frac{\lambda_r(1+a')}{(1-a)} \tag{1}$$

$$\frac{a}{1-a} = \frac{\sigma'[C_L\sin\beta + C_D\cos\beta]}{4\cos^2\beta} \tag{2}$$

$$\frac{a'}{1-a'} = \frac{\sigma' C_L\cos\beta - C_D\sin\beta}{4\lambda_r\cos^2\beta} \tag{3}$$

Note that, in (1) to (3) and for the different blade elements, $\beta = \gamma - \alpha$ [0] is the direction of the relative wind velocity; γ [0] is the twist angle of the blade; α [0] is the incident angle or angle of attack of the blade on the wind; v [m/s] is the free stream wind velocity; $a = (v_1 - v_2)/v_1$ [--] is the axial induction factor; v_1 [m/s] is the wind velocity some way upstream of the turbine; v_2 [m/s] is the wind velocity just before the turbine blade; $a' = \omega/2\Omega$ [--] is the angular induction factor; ω [rad/s] is the angular velocity of the turbine blade wake rotation; Ω [rad/s] is the angular velocity of turbine rotor rotation; $\lambda_r = \Omega r/v$ [--] is the local tip speed ratio(TSR); r [m] is the local tip radius; $\sigma' = \beta c/2\pi r$ [--] is the local solidity of the blade; $c = 8\pi r\cos\beta/3B\lambda_r$ [m] is local chord length; B [--] is the number of turbine blades; C_L is the blade lift coefficient; C_D is the blade drag coefficient; and $w = v(1-a)/\cos\beta$ [m/s] is the relative wind velocity.

The initial guesses for iterative solution of the above system of equations are obtained from the following equations.

$$\beta = 90^0 - \frac{2}{3}\tan^{-1}\left(\frac{1}{\lambda_r}\right) \tag{4}$$

$$a = \left[1 - \frac{4\cos^2\beta}{\sigma' C_L\sin\beta}\right]^{-1} \tag{5}$$

$$a' = \frac{1-3a}{4a-1} \tag{6}$$

The solution steps to establish the optimum values of β, a and a' are given in Ingram [8, 9]. The performance parameters, such as the power coefficient, power output, developed torque and axial thrust, are then computed by numerical integration over the blade span. The integral equations involved are given as follows:

$$C_p = \frac{P_{wt}}{\eta P_w} = \frac{8}{\lambda^2}\int_{\lambda_h}^{\lambda} Q\lambda_r^3 a'(1-a)\left(1-\frac{C_D}{C_L}\tan\beta\right)d\lambda_r \quad (7)$$

$$F_x = \pi\rho v^2 \int_0^R Q[4a(1-a)]rdr \quad or$$

$$F_x = \pi\rho v^2 \int_0^R \frac{\sigma'(1-a)^2}{\cos^2\beta}(C_L\sin\beta + C_D\cos\beta)rdr \quad (8)$$

$$T = \pi\rho v\Omega \int_0^R Q[4a'(1-a)]r^3dr \quad or$$

$$T = \pi\rho v^2 \int_0^R \frac{\sigma'(1-a)^2}{\cos^2\beta}(C_L\sin\beta + C_D\cos\beta)r^2dr \quad (9)$$

Note that, in (7) to (9), C_P [--] is the wind turbine power coefficient; $P_w = \frac{1}{2}\rho\pi R^2 v^3$ [W] is the wind power; $P_{wt} = C_p\eta P_w$ [W] is the wind turbine power output; η [--] is the electrical and mechanical efficiency; ρ [kg/m3] is the air density; R [m] is the turbine blade length; F_x [N] is the axial thrust on the turbine blade; T [Nm] is the torque developed by the turbine; and Q [--] is the tip loss correction (TLC) factor for the turbine blade.

Light and Robinson [26] derived the following formula for computing the optimal chord length of any blade element at a radial distance of r [m] from the hub center.

$$c = \frac{16R}{9\lambda^2 B}\left(\frac{R}{r}\right) \quad (10)$$

As in Ingram [7, 8], the aerodynamic performance of wind turbine rotor blades has also been studied in Tenguria et al [12], Shateri [13], and Rathore and Ahmed [14] using the BEM theory, amongst numerous other theories, such as used in Munteanu et al [4], Abarzadeh et al [6], and in Ragheb and Ragheb [7]. The same BEM theory is adopted in this study to establish the optimal performance of the turbine rotor blades.

2.3. Wind Turbine Blade Airfoil Section

NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA) a predecessor of the National Aeronautics and Space Administration (NASA) in the United States of America (USA). The NACA 4-digit series convention for designating airfoils is adhered to in this study. Under this convention the airfoils are designated using a four-digit numeric series following the word "NACA". The parameters in the numeric code can be entered into equations to precisely generate the cross section of the airfoil and calculate its properties [23]. According to Jacobs et al [24] the NACA 4-digit wing sections define the profile by the first digit, which gives the maximum camber m [m] as a percentage of the chord; the second digit, which gives the distance of the maximum camber from the leading edge p [m] in terms of percents of the chord; and the last two digits gives the maximum thickness of the airfoil t [m] as percents of the chord.

The turbine blade surface profile coordinates are defined by the standard NACA 4-digit series formulae. Moran [25] gives one of such formulae for symmetrical NACA 4-digit series airfoils as,

$$y = \frac{ct}{0.2}\begin{bmatrix} 0.2969\left(\frac{x}{c}\right)^{1/2} - 0.1260\left(\frac{x}{c}\right) \\ -0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 \\ -0.1015\left(\frac{x}{c}\right)^4 \end{bmatrix} \quad (11)$$

Note that, in this equation, x [m] is the position on the interval, $0 \le x \le c$; y [m] is half of the thickness at each x [m]; and c [m] is the blade camber length. Also, at $(x/c)=1$, the trailing edge of the airfoil, the thickness is not quite zero, but if so desired, one of the coefficients say the last can be modified to - 0.1036 such that they sum to zero. The leading edge approximates a cylinder with a radius, $r = 1.1019t^2$ [23]. For the case of symmetric NACA 4-digit series airfoils, the coordinates (x_U, y_U) of the upper surface and (x_L, y_L) of the lower surface are defined as, $x_U = x_L = x$ [m], $y_U = +y$ [m] and $y_L = -y$ [m] [25]. For the case of asymmetric NACA 4-digt series airfoils, the coordinates are defined as, $x_U = x - y\sin\theta$ [m], $y_U = y_c + y\cos\theta$ [m]; $x_L = x + y\sin\theta$ [m] and $y_L = y_c - y\cos\theta$ [m] [25], where the angle θ is defined as, $\theta = \arctan(dy_c/dx)$ [0] and the mean camber is define as, $y_c = m(x/p^2)[2p-(x/c)]$ [m] on the interval $0 \le x \le pc$ [m] and $y_c = m[(c-x)/(1-p)^2][1+(x/c)-2p]$ [m] on the interval $pc \le x \le c$ [m]. As in Jacob et al [24] and Moran [25], the performance of wind turbine rotor blades with NACA 4-digit series airfoils has also been studied in Tenguria et al [12], Shateri [13], and Rathore and Ahmed [14]. The same series of airfoils, more especially, NACA

2412 airfoil is adopted in this study to establish the rotor blade section and its performance.

2.4. Wind Farm Layout

A wind turbine farm is required if the desired capacity would be achieved. The ultimate goal in searching for the optimal arrangement of wind turbines on the site is to obtain the highest possible energy yield of the entire wind farm over its service life. The prescribed distances to buildings, environmental regulations, maximum building heights, and conditions and costs of installation, such as construction of power lines right from the turbine to the transformers and interconnection stations and provision of roads for assembly, maintenance and service vehicles, are also major considerations in the arrangement of the wind turbines in a farm. According Stiebler [5], the importance of the following in wind turbine layout must be emphasized. That is, the spacing of the wind turbines is affected by factors such as terrain, wind speed, wind direction, turbine size and access to the electric grid; the optimum orientation and spacing is considered to be in an east-west direction with about 305 [m] between each turbine and about 915 [m] between North and South rows; and the optimum location for a wind farm is one with a steady wind speed that averages at least 6 [m/s], which generally equates to a wind capacity factor of about 35 – 45 [%].

These are important practices meant to ensure that the project is viable, that is, deliver power efficiently and cheaper compared to a diesel engine generating system of the same installed capacity. It involves determination of the projected power consumption, capital and operating expenses of the two alternatives over a number of years, performing economic analysis, and then, selecting the best based on results of the analysis. Besides, power consumption data is required for performance analysis and determination of wind farm capacity. Its computation involves the use of an equation such as:

$$P = V_L I_L \cos\phi\sqrt{3} \quad (12)$$

Note that, in equation (12), P [MW] is the required electrical power; V_L [volt] is the line voltage; I_L [ampere] is the line current; and ϕ [o] is the phase angle.

Energy Demand and Economic Evaluation of the System

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3. Wind Turbine Design and Analysis

Wind turbine installation along the Choba banks of the New Calabar River, Port Harcourt, Rivers State, Nigeria, designed for wind power utilization in UNIPORT and UPTH, is desired. Wind resource assessment reported in Izelu et al [2], using the Weibull probability distribution function in the form of Rayliegh probability distribution function for the site, gives an optimum average wind velocity of 17.75 [m/s] at an hub height of 50 [m] corresponding to an optimum power density of 1370.13 [W/m^2]. It goes further to give the maximum average wind velocity of 35.25 [m/s] at the same height of 50 [m] corresponding to a maximum power density of 10731.08 [W/m^2]. With these results, the site was confirmed potential for wind energy utilization, and hence, required for further study, such as presented in this work.

The data on current consumption for each power station and the corresponding line voltage in UNIPORT obtained from the Department of Works is given in Table 1 (see appendix). The average line current and voltage obtained from this data are used in equation (12), with allowance for 10 [%] anticipated load over a period 20 years, to obtain a total power consumption in UNIPORT given as 7.11 [MW]. A physical point to point observation of infrastructures is used, and also, with allowance for 10 [%] anticipated load over a period 20 years, to obtain a total power consumption in UPTH given as 13.5 [MW]. An electrical power of 20.61 [MW], therefore, is the overall demand or requirement for UNIPORT and UPTH. Hence, a WECS or wind turbine farm (WTF) of not less than 20.61 [MW] installed capacity is required to meet the electricity needs of UNIPORT and UPTH for the next 20 years. An individual WT power output of 1.5 [MW] is therefore selected, and fourteen (14) such WTs are proposed for the WTF. Performance analysis of one of the WT is undertaken using the data reported in Izelu et al [2], and the procedure is based on BEM theory of Ingram [8, 9] the algorithm of which is highly modified, and the statements presented for completeness as follows:

Start

Input the desired power output (P) for the wind turbine and the rated wind velocity (v).

Select the desired number of blades (B) for the wind turbine.

Determine and input the blade radius (R) using the site condition, and divide the blade into N blade elements, that is, either 10 or 20.

Choose the type of design desired. The choice is between a normal design in which the airfoil shape that would yield the optimal design is selected from the software data base of NACA airfoil shapes, and a custom design in which the user specifies the NACA aerofoil shape desired along with its aerodynamic characteristics of lift (L), drag (D) and angle of incidence (α).

Steps (f) to (k) are repeated, irrespective of the type of airfoil design selected, for the following range of the tip speed ratio, $\lambda \geq 4$ [--].

Compute the blade angular speed using the formula, $\Omega = \lambda v / R$ [rad/s].

Compute the optimal cord length, c [m], from (10). The thickness, t [m], the maximum camber, m [m], and its location relative to the leading edge, p [m], and each blade element are computed as discussed in section 2.3.

Compute the local tip speed ratio (LTSR), λ_r [--], and the local solidities, σ' [--], at each blade element using the formulae, $\lambda_r = \Omega r / v$ and $\sigma' = \beta c / 2\pi r$, respectively.

Compute the initial guesses for iterative solution and the blade twist angle at each blade element γ_i [0] using (4) to (6).

Perform the BEM design iteration on each blade element. The fundamental BEM equations, that is, (1) to (3) should be solved iteratively.

Perform rotor performance analysis on the designed turbine rotor blade. That is, calculate its coefficient of power, C_P [--] using Equation (7), and then, power output, developed torque, axial load and thrust force.

Compare the result obtained for each value of the tip speed ratio (TSR) and display the performance parameters for the TSR, which yields a coefficient of performance closest to a value of 0.45 [--] suitable for most modern wind turbines.

Compute and plot the power and torque characteristic curves for the designed rotor blade.

Compute the surface profile coordinates and plot the surface profile for the designed rotor blade.

Make full engineering drawing of the optimally designed wind turbine rotor blade.

Stop

A program was developed to implement the above wind turbine blade design algorithm. The program was written with the high level, event-oriented programming language known as the Microsoft Visual Basic 6.0 (MS-VB6.0) and it incorporates various advanced features of the programming language, such as Visual Basic for Applications (VBA), Object Linking and Embedding (OLE) and Automation. The features of the program include: optimization of the blade design by implementing the BEM blade design iterations; generation of the elemental surface plots for the blade element showing effects of the blade twist; generation of the power and torque characteristics of the designed wind turbine blade; drawing of the final optimized wind turbine blade; and simulation of the designed wind turbine blade in varying aerodynamic conditions.

The program uses Graphic User Interfaces (GUIs). GUIs are the visual touchable platforms or interactive environments through which the program users interact with it. Each user action or event triggers implementation of specific lines of code and each GUI is displayed only as a result of an event in the preceding GUI. The program has five GUIs, namely input data, custom design, output data, blade characteristics curve, and blade element surface plot GUIs. Each GUI is decorated with various GUI elements called controls or objects such as forms, labels, combo boxes, grids, command buttons, etc. Due to space constraints the program details are omitted. However, some results of computation using the program are presented and discussed in the appropriate section.

4. Conclusion

The benefits implementing the project would confer compared to the cost it would impose on the University is evaluated. The aim is to determine the best alternative for powering the UNIPORT and UPTH. The choice is between the existing diesel power plant (Alternative A) and a WECS (Alternative B) to be installed with a nameplate capacity of 21MW.

This is adequately pursued by obtaining the capital and operating expenses of alternative A, such as given in Table 2 (see appendix), which on yearly basis is converted to the form presented in Table 3 (see appendix); obtaining the capital and operation expenses of alternative B from the Foshan Ouyad Electronic Company Limited, Guangdong, China (Mainland); performing economic analysis of alternative A projected to a period of 20 years, which yields a total project cost of N 13,463,032,101.98; performing economic analysis of alternative B also projected to a period of 20 years, which yields a total project cost of N4, 830,000,000; and then, by selecting the best alternative based on the results of the economic analysis. Note that, the inflation rate in Nigeria was obtained from the Central Bank of Nigeria and the power used was as computed earlier. Also, at present the UNIPORT and UPTH runs on four diesel engine power plants, which are not sufficient source for electricity supply. In 20 years time, therefore, the university and hospital will require about 21 MW. Again, for alternative B, the purchase and delivery costs for a single 1.5 [MW] turbine is N 270,000,000, while the installation cost was estimated at N75,000,000 [27]. Hence, for fourteen such wind turbines, the total project cost was estimated as N4, 830,000,000 since the operating costs are almost non-existent.

5. Results and Discussion

A NACA-2412 airfoil shape for the blade was selected. Running the program for this shape, turbine power output of 1.5 [MW], and a wind velocity of 17.5 [m/s] yielded the results shown on Table 4 (see appendix). The sample blade surface profiles plotted by the program for each blade element are presented in Figs 3 to 8. The designed turbine is three-bladed with a swept area of 1269.3124 [m2], swept diameter of 40.1931 [m], with the resulting power and torque characteristic shown in Figs 9 and 10. The results of economics evaluation, by applying the benefit and cost (B-C) measure of worth analysis, are summarized in Table 5 (see appendix). From Fig 9, it is seen that, the velocity at which the turbine begins to deliver power (cut-in velocity) is 4 [m/s] at which it produces 40 [KW] and the wind velocity at which the speed control kicks in (rated wind speed) is 16 [m/s] at which the turbine generates 1.2 [MW]. In Fig 10, it is shown that, at cut-in velocity of 4 [m/s], the torque on the rotating machinery is about 25 [KN-m], while at rated wind velocity of 16 [m/s], it is 42 [KN-m].

The swept diameter of the designed rotor is 40.1931 [m] which results in a reduction of about 20 [m] when compared with a wind turbine of the same capacity available in the market which has a swept diameter of 60.25 [m] [27] .This results in large savings in material cost for both the blades and the tower, since the larger the blade size the larger the tower. The minimum geographical area required when the market turbine is used is 2851.044 X 920 [m2] when compared with that required when the designed turbine is used, which is only 1265.392 X 920 [m2]. It is seen that the land area required has been reduced by 1585.652 X 920 [m2].

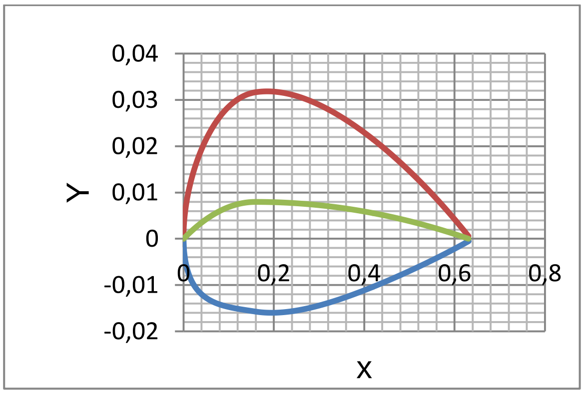

Figure 3: Surface Profile for Un-twisted 0th NACA -2412 Blade Element (S/N =0)

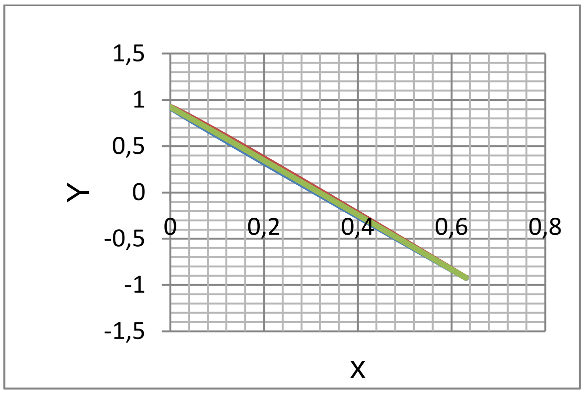

Figure 4: Surface Profile for Twisted 0th NACA-2412 Blade Element (S/N = 0)

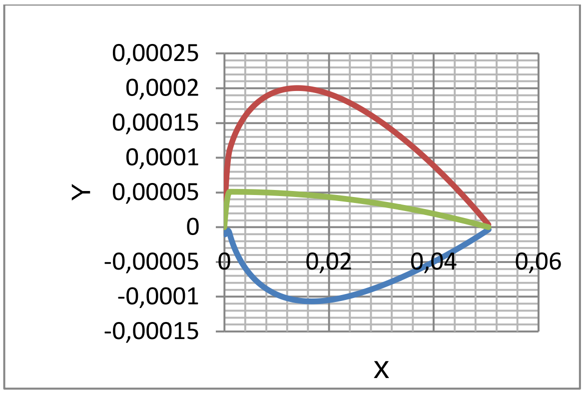

Figure 5: Surface Profile for Un-twisted 10th NACA-2412 Blade Element (S/N =10)

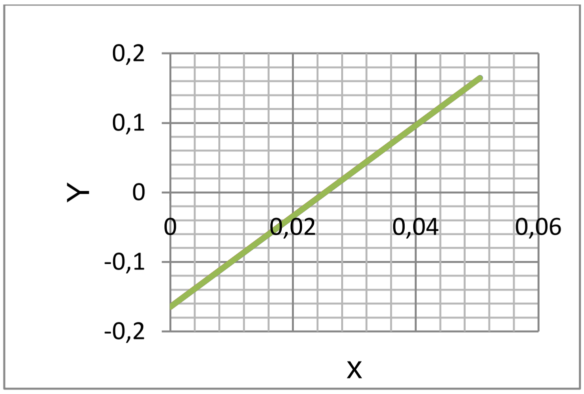

Figure 6: Surface Profile for Twisted 10th NACA-2412 Blade Element (S/N =10)

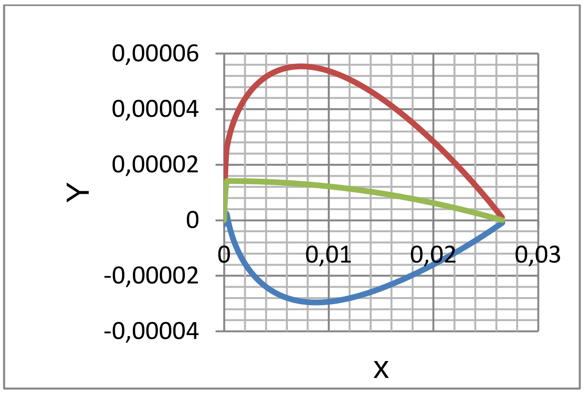

Figure 7: Surface Profile for Un-twisted 19th NACA-2412 Blade Element (S/N =19)

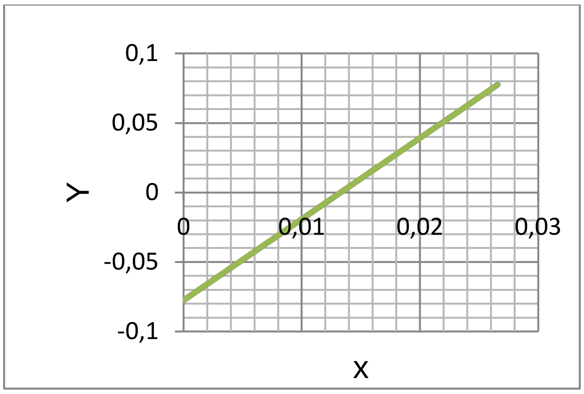

Figure 8: Surface Profile for Twisted 19th NACA-2412 Blade Element (S/N =19)

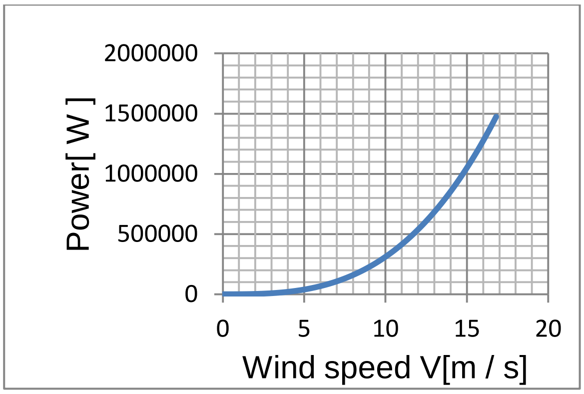

Figure 9: Power characteristic of the designed blade

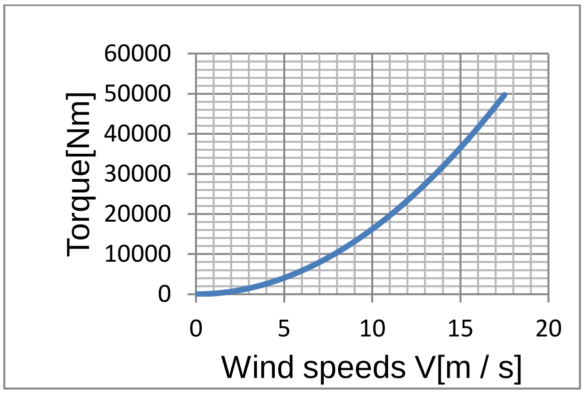

Figure 10: Torque characteristic of the designed blade

Table 5 (see appendix) revealed that, by implementing alternative B, the power requirement of UNIPORT and UPTH will be met while saving about N8.6 billion. Research in renewable energy needs plenty of subsidies, the most important of which stems from the "green credits". Electricity consumers in the commonwealth, of which Nigeria is a member, must buy the growing proportion of their electricity need from renewable sources, requiring them, in practice, to pay a premium for their power [28]. Nigeria pays no attention to the advancement of knowledge and innovation, were she the opposite, the amount of subsidies that would have been given to this project would have made the project almost of no financial cost.

6. Conclusion

According to the great physicist, Albert Einstein, "the significant problems we have cannot be solved at the same level of thinking with which we created them". The current level of thought along the lines of fossil fuel utilization have created such problems as global warming, pollution of atmospheric air and water bodies, health hazards, and world and national politico-economic rancor. Renewable energies are the new level of thought with which these problems can be solved. In this work, wind energy, utilized to supply the power requirements of the University of Port Harcourt (UNIPORT), and the University of Port Harcourt Teaching Hospital (UPTH), is considered. The significant findings are itemized as follows:

1. The total power requirement for the University and its teaching hospital is 21 [MW] for a projected period of 20 years.
2. The wind turbine rotor blades are optimally designed for capacity of 1.5 [MW]; wind velocity of 17.5 [m/s], airfoil shape of NACA 2412.
3. The power and torque of turbine using the designed blades have positive non linear relationship with the wind velocity.
4. Economic study revealed savings in costs of ₦8, 633,032,101.98 as compared with the existing diesel plant.

Based on these findings it is concluded that, a wind energy system or wind farm, having fourteen 3-bladed horizontal-axis wind turbines with power extraction capacity of 1.5 [MW] each, due to wind speed of 17.5 [m/s] at hub height of 50 [m], should be installed along the Choba banks of the New Calabar River to supply electric power to the University of Port Harcourt and its teaching hospital (UPTH). This system is adjudged to be technically and economically more effective than the existing diesel power plant. It is therefore recommended, for further investigation, as follows:

1. A cost analysis to express emissions and greater energy independence in monetary terms should be performed.
2. The cost imposed by grid integration and environmental effects should be performed.
3. The indirect and induced effects on tourism spending should be determined.
4. An ecological impact analysis of the wind turbine should be performed.
5. More NACA 4 digit airfoil shapes should be added to the software database. And other types of airfoils such as the 5, 6, modified 6 digits NACA airfoils should be included in the software database to diversify its application.
6. Final blade drawing and simulation capability should be added to the software. OLE automation with AutoDesk's AutoCAD drafting software package is a possible path for this feature.

References

[1] Website: http://en.wikipedia.org/wiki/Port_Harcourt, Extracted on 2013, pp 1 – 7

[2] Izelu, C. O., Agberegha, O. L. and Oguntuberu, O. B, Wind Resource Assessment for Wind Energy Utilization in Port Harcourt, River State, Nigeria, Based on Weibull Probability Distribution Function, International Journal of Renewable Energy Research, Vol. 3, No. 1, 2013, pp 180 – 185

[3] Johnson, G. L., Wind Energy Conversion Systems, Electronic Edition, 2006, pp 1 – 449

[4] Munteanu, I., Bratcu, A. I., Cutululis, N. A. and Ceanga, E., Wind Energy conversion System, Optimal Control of Wind Energy Systems Towards a Global approach, 2008, XXII, 283 p. 203 illus, Chapter 2, pp 9 – 27

[5] Stiebler, M., Wind Energy Conversion Systems Electric Power Generation, Springer Series in Green Energy and Technology, Springer-Verlag Berlin Heidelberg, 2008, pp 1 – 201

[6] Abarzadeh, M., Kojabadi, H. M. and Chang, L., Small Scale Wind Energy Conversion Systems, Wind Turbine, in Tech, 2011, pp 639 – 652

[7] Ragheb, M and Ragheb, A. M., Wind Torbine Theory – The Betz Equation and Optimal Rotor Tip Speed Ratio, Fundamental and Advanced Topics in Wind Power, 2011, In Tech, www.intechopen.com, pp 19 – 38

[8] Ingram, G., Wind Turbine Blade Design using the Blade Element Momentum Method, Version 1.0, School of engineering, Durham University, 2005, pp 1 – 21

[9] Ingram, G., Wind Turbine Blade Design using the Blade Element Momentum Method, Version 1.1, School of engineering, Durham University, 2011, pp 1 – 21

[10] Cowgill, R. T., Fouts, J., Haley, B. and Whitham, C., Wind Turbine Rotor Design: Final Design Report, College of Engineering, Boise State University, 2006, pp 1 – 36

[11] Schubel, P. J. and Crossley, R. J., Wind Turbine Blade Design, Energies, 2012, Vol. 5, pp 3425 – 3449

[12] Tenguria, N., Mittal, N. D. and Ahmed, S., Investigation of Blade Performance of Horizontal Axis Wind Turbine based on Blade Element Momentum Theory (BEMT) using NACA Airfoils, International Journal of Engineering, Science and Technology, Vol. 2, No. 12, 2010, pp 25 – 35

[13] Shateri, A. R., A New Evolutionary Algorithm for Aerodynamic Design Optimization of Axis Wind Turbine, Advances in Natural and Applied Sciences, Vol. 6, No. 2, 2012, pp 147 – 152

[14] Rathore, A. S. and Ahmed, S., Aerodynamic Analysis of Horizontal Axis Wind Turbine By Differential Blade Airfoil Using Computer Program, IOSR Journal of Engineering, Vol. 2, Issue 1, 2012, pp 118 – 123

[15] Leishman, J. G., Challenges in Modeling the Unsteady Aerodynamics of Wind Turbines, American Institute of Aeronautics and Astronautics, 2002, pp 1 – 28

[16] Bak, C., Fuglsang, P., Sorensen, N. N., Madsen, H. A., Shen, W. Z, and Sorensen, J. N., Airfoil Characteristics for Wind Turbines, Information Service Department, Riso National Laboratory, Roskilde, 1999, pp 1 – 51

[17] Zhang, J., Numerical Modeling of Vertical Axis Wind Turbine (VAWT), MSc Thesis, Department of Mechanical Engineering, Technical University of Denmark, 2004, pp 1 – 88

[18] Claessens, M. C., The Design and Testing of Airfoils for Application in Small Vertical Axis Wind Turbines, MSc Thesis, Faculty of Aerospace Engineering, Delft University of Technology, 2006, pp 1 – 113

[19] Ahlstrom, A., Aeroelastic Simulation of Wind Turbine Dynamics, PhD Thesis, Royal Institute of Technology, Department of Mechanical Engineering, 2005, Sweden, pp 1 – 154

[20] Martens, A. H. J. A and Albers, P. H. W. M., Wind turbine Study: Investigation into CVT Application in Wind Turbines, Technische Universitiet Enidhoven, 2003, pp 1 – 31

[21] Khemiri, N., Khedher, A., and Mimouni, M. F., Wind Energy Conversion System using DFIG Controlled by Back-stepping and Sliding Mode Strategies, International Journal of Renewable Energy Research, Vol. 2, No. 3, 2012, pp 421 - 434

[22] Belfedhal, S. A., Berkouk, E., Meslem, Y. and Soufi, Y., Modeling and Control of Wind Power Conversion System with a Flywheel Energy Storage System and compensation of Reactive power, International Journal of Renewable Energy Research, Vol. 2, No. 3, 2012, pp 528 – 534

[23] Website:http://en.wikipedia.org/wiki/nasa_airfoil, Extracted on 2013, pp 1 – 6

[24] Jacob, E. N., Ward, K. E. and Pinkerson, R. M., the Characteristics of 78 Related Airfoils Sections from Tests in the Variable-Density Wind Tunnel, NACA Report No. 460, 1935

[25] Moran, J., An Introduction to Theoretical and Computational Aerodynamics, Dover, 2003, p 7

[26] Light, T. and Robinson, J., Aerodynamic Design of a Large Horizontal-Axis Wind Turbine, London, 2003, p 5

[27] Website: www.alibaba.com/windturbinemanufacturers, Extracted on 27/11/2009.

[28] Barrett, J., Giuffre, D., Haughton, J. and Tuerck, D. G., an Economic Analysis of a Wind Farm in Nantucket Sound, Beacon Hill Institute, Suffolk University, Suffolk, 2004.

Appendix

Table 1: Current Consumption for each Power Station and the Corresponding Line Voltage

		Current Consumption for Seven (7) Days Average of Red-Yellow-Blue (Amperes)						
S/N	**Power Station**	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	Day-7
1	Delta/Choba Park	1700	2000	1800	2000	1700	1500	1500
2	Abuja	1200	900	1000	900	1000	900	900
3	Ghana-Ama/Gambia-Ama	900	800	800	900	900	1000	1100
Average line Voltage: 415 [volt], 3-phase supply								

Source: Department of Works, UNIPORT, 19/06/2009

Table 2: Data for analysis of Alternative A

COST ELEMENT	QUANTITY	UNIT
Diesel price per litre as @ 01/01/2010	120	[N /litre]
Inflation rate in Nigeria	9	[%]
Engine oil cost per 3 months	83,200.00	[N]
Diesel consumption rate of 3 plants per week	33000	[litres]
Maintenance cost of 3 plants per 2 weeks	700,000.00	[N]
Purchase price of a diesel generator	70,000,000.00	[N]
Power capacity of a diesel generator	1.5	[MW]
Cost of installation for 3 plants	200,000,000.00	[N]
Required power capacity	21	[MW]

Source: Department of Works, UNIPORT

Table 3: Data for Analysis of Alternative A on Yearly Basis

COST ELEMENT	QUANTITY	UNIT
Number of diesel generators needed	14	[-]
Diesel cost per year	205,920,000.00	[N]
Maintenance cost per year	18,200,000.00	[N]
Purchase price of all the generators	980,000,000.00	[N]
Installation cost for all generators	1,000,000,000.00	[N]
Engine oil cost per year	332,800.00	[N]

Table 4: Results of BEM design for the wind farms turbines

S/N	**RADIUS [m]**	**CHORD [m]**	**THICKNESS [m]**	**LTSR [-]**	**CAMBER [m]**	**LOCATION [m]**	**TWIST [^{0}]**
0	0.80	0.6313	0.0758	1.54	0.0126	0.2525	71.17
1	1.00	0.5050	0.0606	1.93	0.0101	0.2020	77.48
2	2.01	0.2525	0.0303	3.85	0.0051	0.1010	89.89
3	3.01	0.1683	0.0202	5.78	0.0034	0.0673	93.69
4	4.02	0.1263	0.0152	7.70	0.0025	0.0505	95.53
5	5.02	0.1010	0.0121	9.62	0.0020	0.0404	96.61
6	6.03	0.0842	0.0101	11.55	0.0017	0.0337	97.32
7	7.03	0.0721	0.0087	13.48	0.0014	0.0289	97.83
8	8.04	0.0631	0.0076	15.40	0.0013	0.0253	98.21
9	9.04	0.0561	0.0067	17.32	0.0011	0.0224	98.51
10	10.05	0.0505	0.0061	19.25	0.0010	0.0202	98.74
11	11.05	0.0459	0.0055	21.18	0.0009	0.0184	98.94
12	12.06	0.0421	0.0051	23.10	0.0008	0.0168	99.10
13	13.06	0.0388	0.0047	25.02	0.0008	0.0155	99.23
14	14.07	0.0361	0.0043	26.95	0.0007	0.0144	99.35
15	15.07	0.0337	0.0040	28.88	0.0007	0.0135	99.45
16	16.08	0.0316	0.0038	30.80	0.0006	0.0126	99.54
17	17.08	0.0297	0.0036	32.72	0.0006	0.0119	99.62
18	18.09	0.0281	0.0034	34.65	0.0006	0.0112	99.69
19	19.09	0.0266	0.0032	36.58	0.0005	0.0106	99.75
20	20.10	0.0253	0.0030	38.50	0.0005	0.0101	99.81

Table 5: Summary of economic evaluation of alternatives

ECONOMIC PARAMETERS	**VALUE (N)**
Total cost of diesel power (Alternative A)	13,463,032,101.98
Total cost of wind power (Alternative B)	4,830,000,000
Benefits of Alternative B over Alternative A:	
Fuel cost Saved	10,534,891,836.68
Engine oil cost saved	17,026,087.82
Maintenance Cost Saved	931,114,177.48
Emission Reduced	-
Greater Energy Independence	-
Total savings accrued by implementing Alternative B	8,633,032,101.98