Harnessing Wind Energy to Solve Nigeria's Energy Crisis

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Abstract: Nigeria is a nation largely composed of a rural economy and the need for sustainable energy development arises, which is pertinent in ensuring that the desire to make Nigeria one of the best twenty economies in the world by the 2020 is realized. Nigeria cannot achieve meaningful development without solving the prevailing energy crisis. The current situation of the power supply in Nigeria reveals that <20% of rural dwellers have access to electricity and as such, it calls for a pragmatic approach in resolving this imbalance between energy supply in the urban and the rural centers. This study describes, how a renewable and sustainable energy source, wind energy, can be applied by virtue of its conversion to electricity through wind turbines, for use for rural electrification in Nigeria. The study also highlight the prospects, technical details, policy proposals and challenges to harnessing of wind energy for rural electrification are also presented. The study however, concludes that Nigeria can emerge stronger from the current energy crisis if the principles of sustainable development in terms of economic, energy and environmental policy and if international support is mobilized to meet Nigeria's needs.

Key words: Nigeria, power supply, renewable energy, rural electrification, sustainable energy, wind energy, wind turbine

INTRODUCTION

Efforts at extending electrification in Nigeria has proved abortive, there is still a rural population of approximately 18% (Awogbemi and Asaolu, 2008). In Nigeria who do not have access to electricity. Extending grid connection to many dispersed communities, who have little capacity to pay for significant electrical energy, is not economic. In an effort to obtain a cost-effective means of bringing power to the rural population, Mini-grids, particularly those powered by small-scale renewable energy sources, are now recognized as being the most cost-effective. Technologies, such as solar photovoltaic, are suitable for individual household supplies. Others are more cost-effective when implemented as a village scheme based on a mini-grid. This is the case for biomass generators, micro-hydro and wind turbines. The major energy consumption in Nigeria includes agricultural sector, household sector, industrial sector, transport sector and service sector (Sambo, 2005).

Rural electrification programs should include renewable energy technologies, especially decentralized options, as an important part of a portfolio of technologies that can provide rural people with cost-effective electricity services. Moreover, major government targets for development of rural renewable energy technologies can stimulate the use of decentralized systems in remote rural communities, which at present continue to expect grid connections in the near future and are thus, resistant to accepting renewable energy systems. Renewable energy sources are increasingly being utilized for electrification mainly because they are freely available, pollution free and they have low maintenance cost. However, this energy has not been exploited fully mainly due to the relatively high costs associated with the energy conversion technologies (Sambo, 2005).

Rural loads are characterized by low load factor, which has a negative influence on plant operating costs and makes it less cost effective to supply them from the grid (Ijumba *et al.*, 1999). In such cases, renewable energy sources become the best alternative despite the high installation costs. The sustainable technologies are to be adopted for the conversion of these renewable energy sources to electric power. The technology aspect of building a sustainable energy capacity encourages the implementation of improved alternative options such as renewable and off-grid solutions (Akinbami, 2001). The renewable solutions include wind energy, solar energy, geothermal systems, nuclear energy and biomass. This study focuses on the use of wind energy for electric power generation via the use of wind turbines.

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Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth surface. Wind energy, a renewable energy source is an alternative form of energy, which has stood out as the most valuable and promising choice. This is not only due to the fact that wind energy has a decentralized mode of operation that reduces transmission and distribution failures, but also because it is cheap, environmentally friendly, inexhaustible, price stable, free from control and is virtually available in every part of the nation in some amount. If the mechanical energy is used directly by machinery, such as a pump or grinding stone, the machine is usually called a wind mill. If the mechanical power is converted to electricity, the machine is called a wind generator, wind turbine, Wind Power Unit (WPU) or wind energy converter. The wind turbines can be installed in a wind farm (an array of wind turbines) creating a wind power station, with hunderds of megawatt. Wind energy conversion systems are available in a wide range of sizes and can fit almost any application where, power is needed (Akinbami, 2001).

The various wind generator projects in Nigeria were neglected in the last decade due to increasing popularity and low price of crude oil. In recent times, the high price of Petroleum products lead to attempt at restructuring these wind turbines. However, difficulties in obtaining spare parts for models, which were no longer being manufactured hindered the restoration. Also, some other factors that led to the failure of past wind generators are the assessment of wind energy potentials, feasibility studies on wind energy utilization, inadequate wind data base used as the bases for designing and building different prototypes that need be considered in reducing locally manufactured windmills (Ojosu, 1989).

Prospects of wind energy in Nigeria: A study by Ogbonnaya *et al.* (2007) shown that the annual wind mean speed at a height of 10 m above the ground ranges between 2.3-3.4 m sec^{-1} for sites along the costal areas and 3.0-3.9 m sec^{-1} for high land areas and semi-arid regions. The analysis carried out on the data shows that the monthly average wind power can be as high as 50.1 W m^{-2}. Small wind energy conversion systems for pumping water, irrigation and small agricultural industries are recommended for small communities living in isolated areas around the selected sites. It was also, discovered that the wind turbine can generate up to 97 MWh year^{-1} in Sokoto, a site in a high wind speed regions (Awogbemi and Asaolu, 2008). Therefore, using wind energy conversion systems for electric power generation and supply in Nigeria, especially around the

Sokoto axis will be cost effective. Similarly, after analysis of wind potential of a town near Jos, it was discovered that the maximum power intensity, which could be extracted from the wind in the area was found to be 14.23 W m^{-2} out of the estimated available wind power intensity of 24.00 W m^{-2}. The amount of energy density available in the wind has also been estimated to be 1126.28 kWh year^{-1}. These results suggest that Heipany, a town in Jos, is an ideal location for construction of wind mills (Ojosu, 1989; Ojo and Bamigbetan, 2008).

In remote or rural areas, where purchased electricity is simply unavailable, wind energy may well be the only alternative. The use of wind energy will be suitable for rural farming companies that require lighting and some limited supply of electricity, which will be costly to get due to the location of farms. The use of wind power for the supply of electricity broadens the energy base and reduces environmental pollution. It is particularly practical if it can be made economically competitive with conventional energy sources. It has been shown that in areas with annual mean wind speed of 3.5-4.0 m sec^{-1} or greater, wind power systems can usually deliver electricity or pump water at costs lower than photovoltaic, diesels, or grid-extension (Ojo and Bamigbetan, 2008).

For the past 10 years, the Federal government of Nigeria has embarked on aggressive rural electrification projects across the country. This laudable project is aimed at providing electricity to the rural dwellers where, about 64% of the entire populations live. By this program also, the Federal government hopes to minimize, if not curb the rural-urban migration-thereby forcing young school leavers and graduates to remain in the village self-employed rather than moving to the urban areas seeking white-collar jobs (Ojo and Bamigbetan, 2008; Fagbenle, 1991). The National Rural Electrification Program was started in 1981 with the aim of connecting all the country's local government headquarters and some important towns to the national grid. The program is managed by the Federal Ministry of Power and Steel. The Rural Electrification Program is facing several structural constraints. Nigeria's current electricity demand is put at over 5,000 MW, with supply still hovering between 1,500 and 2,000 MW. Secondly, the much-awaited institutional reforms-setting out a national regulator, unbundling PHCN and privatizing the new business units have yet to be fully implemented. Third, the rural electrification program has been driven by political considerations rather than social and economic considerations. This has led to unnecessarily high costs and government has done little to control the mismanagement and corruption. Fourth, funding is a constraint as almost all funding for rural electrification comes from the federal and state budgets.

It is clear that grid extension alone will not meet universal rural electrification coverage cost-effectively within a reasonable timeframe but major barriers to market development for off-grid options such as renewable energy technologies remain (Leithead and Connor, 2000).

In order to enable the creation of wind farms for the wind power schemes for rural areas of Nigeria, it is pertinent to note that the scheme is capital intensive and as such a the role the government has to play comes to light in order to actualize the objectives of rural electrification. In the area of private participation to increase generating capability, Nigeria has begun to implement several Independent Power Projects (IPPs), but also the private sector can be encouraged to venture into creation or construction of wind farms.

In implementing rural electrification projects, several components such as concrete poles, wooden cross-arms, stay blocks, etc. are locally provided. However, many of the capital intensive components consisting of conductors, insulators, cables, transformers, etc. are imported. Attempts have been made in the past to develop manufacturing capacity for several of the imported components. Nigeria has a vibrant electricity sales and service industry. This ranges from contractors, equipment vendors, consulting engineers, etc. Rural electrification has therefore in most cases been carried out by local contractors. However, capacity utilization within these companies is low as job orders are constrained by government budgets (Ojo and Bamigbetan, 2008).

MATERIALS AND METHODS

Power in the wind: The power in the wind is proportional to:

- The area of rotor blade being swept by the wind
- The cube of the wind speed
- The air density, which varies with altitude

Kinetic energy of a portion of the flowing air of mass δm is $\frac{1}{2}\delta mV^2$ and the rate of energy flow (i.e., power) P for the whole flow is:

$$p_w = \frac{1}{2} \times \rho \times A \times V^3 \qquad (1)$$

Where:
P_w = Power in watts (W)
ρ = The air density (kg m^{-3})
A = The swept rotor area (m^2)
V = The wind speed (m sec^{-1})

$$\text{Power coefficient } Cp = \frac{P_r}{P_w} \qquad (2)$$

Where:
P_r = Mechanical power to drive the wind turbine gears
P_w = Wind power (W)

Blade design for a small capacity (50-3000 W) wind turbine: The rotor blade is the most important and most visible part of the wind turbine. It is through, the rotor that the energy of the wind is transformed into mechanical energy that turns the main shaft of the wind turbine. It is expedient to start by describing why the blades are shaped the way that they are and what really happens, when the blades rotate. The front and rear sides of a wind turbine rotor blade have a shape roughly similar to that of a long rectangle, with the edges bounded by the leading edge, the trailing edge, the blade tip and the blade root. The blade root is bolted to the hub. The radius of the blade is the distance from the rotor shaft to the outer edge of the blade tip. If a blade were sawn in half, one would see that the cross section has a streamlined asymmetrical shape, with the flattest side facing the oncoming air flow or wind. This shape is called the blade's aerodynamic profile. The shape of the aerodynamic profile is decisive for blade performance. Even minor alterations in the shape of the profile can greatly alter the power curve and noise level. Using a single unit wind turbine of 2 kW capacity as a study for rural electrification, the following parameters can be duly obtained.

Rotor diameter: In choosing, the rotor diameter for the any required output, the following procedures are taken into consideration. A generator of capacity of the required amount or more will have a RPM of a specific value that corresponds to its output power P_o. As such, the rotor diameter D_r will be given by the Eq. 3 (Hugh, 2008).

$$D_r = \left[P_O \left(\frac{47\lambda}{RPM} \right)^3 \right]^{0.2} \qquad (3)$$

For a wind turbine of capacity 2 kW, it is thus, apparent to choose a rotor diameter, D as 5 m so as to make effective use of the wind available by providing a large swept area. This implies that the radius is 2.5 m for the purpose of generating up to 2 kW (Hugh, 2008).

Tip speed ratio: The tip speed ratio will affect the rpm (revolution/min) of the main shaft connecting the hub to the gearbox as shown in the relation (Hugh, 2008).

$$C = \frac{4D}{(\lambda^2 B)} \qquad (4)$$

The value of the tip speed ratio is chosen from between 5 and 8. Any value can be selected. The tip speed ratio (λ), is usually chosen as 5.

Number of Blades (B): Using the relation

$$C = 80/\lambda^2 \qquad (5)$$

Number of Blades ($\lambda = 5$)
Therefore, number of blades = 3

Width of the blade: The width of the blade in the outer portion, will be obtained from the relation (Hugh, 2008).

$$C = 4D/(\lambda^2 B) \qquad (6)$$

Therefore, for a 2 kW wind turbine, taking D = 5 m, λ = 5 and B = 3

$$C = 0.267 \text{ m}$$

It should be noted that the outer part of the blade is the most important than the inner part. But, the inner part should be made wider to help with starting torque.

Blade setting angle (β): The blade setting angle will be obtained along the section of the wind turbine blades. This is also, obtained together with the Chord length, pitch along the section. Radius R = 2.5 m. Table 1 can be generated for the design in this project using the formulas obtained for chord Width, pitch and Blade setting angle

The pitch is given by Philip (2004).

$$\text{Pitch}\,\varphi = \arctan \frac{2}{3}\left(\frac{r}{R}\right)\lambda \qquad (7)$$

Chord width, C_w given by Hugh (2008)

$$Cw = \frac{16\pi R\left(R/r\right)}{9\lambda^2 B} \qquad (8)$$

Blade setting angle β,

$$\beta = \arctan \frac{2}{3}(r/R)\lambda \qquad (9)$$

The blade root is tapered out wide to improve the starting and the tips are tapered down to reduce the noise. Starting torque can be estimated from the formula (Philip, 2004).

Table 1: Design parameters for blade

Sections	0.2	0.4	0.6	0.8	1
Chord width (C_w (m))	0.93	0.47	0.31	0.23	0.19
Pitch (φ, (°))	34	19	13	10	8
Blade setting angle (β (°))	29	14	8	5	3

Ojo and Bamigbetan (2008)

$$\text{Torque} = \frac{V(Z)^2 R^3}{\lambda^2} \qquad (10)$$

Where:
V = The average wind speed
R = The rotor radius
λ = The tip speed ratio
V(z) = Obtained from the expression (Philip, 2004):

$$V(Z) = V \ln \frac{z}{z_0} \qquad (11)$$

Where:
Z = Taken at Hub height of 10 m
Z_0 = Taken as 0.5 m for a forest region (Philip, 2004)

To calculate the shaft speed and power coefficient

$$\text{Shaft rpm} = 60\,\lambda\,V(z)/(D\pi) \qquad (12)$$

It is generally reported that modern wind turbines operate at a slightly lower practical non ideal performance coefficient as:

$$C_{p.prac} \text{ approx.} = 0.4 = 40\% \qquad (13)$$

RESULTS AND DISCUSSION

Developing a wind power scheme: In order to have a well efficient system of wind turbine arrayed in a wind farm to form a mini-grid system for rural electrification, one of the main factors, which will determine the economic viability of such a wind power project is the annual mean wind speed at a site. These wind speed data are provided by the Nigerian Meteorological Agency (NIMET) and several researchers have ventured into the field for provide updated wind parameters for a particular site. The power produced by a wind turbine depends on several parameters including the wind speed (the main factor), the area swept by the blades and the efficiency of the rotor and generator (Ragheb, 2008). The power output can be doubled by increasing the rotor blade length by 40%, or by an increase in wind speed, for example from 6-7.5 m sec^{-1} (Ojo and Bamigbetan, 2008). Wind speeds vary enormously from region to region and from valley floor to hill-top, so wind speed measurements will usually be needed for virtually all proposed developments, other

than those for only a few kilowatts. For schemes larger than about 10 kW, on-site, wind measurements will usually be required, with results being correlated to longer term, local meteorological data of average wind speed in the region. For smaller schemes, meteorological data may be all that is required, even though there will be some discrepancy between the data and the actual wind speed at a given site. A full wind speed assessment will normally involve:

- Erecting a mast, preferably of similar height to the proposed turbine, with a recording anemometer
- Monitoring the wind speeds and direction over an extended period
- Correlating the data with long term records from local meteorological stations

A data collection period of 6 months is generally thought to be minimum time to obtain reasonably reliable results, but a 12 month collection period will reduce the uncertainty in the estimates as all seasonal weather patterns will have been recorded (Ogunleye and Emehelu, 2007).

The development process that needs to be followed for a wind power scheme is highly dependent on the size of the schemes. Larger schemes will require the involvement of specialist wind power consultants. It is important to investigate the site's geological conditions, determine the optimum turbine positions and check on access routes for construction vehicles and for maintenance of the turbines and power lines.

The following factors are essential to be duly considered before embarking-on or building a wind farm for a wind power scheme (Legeton *et al.*, 2004).

Understand the sites wind resource: The most important factor to consider in the construction of a wind energy facility is the site's wind resource. Local weather data available from airports and meteorological stations may provide some insight as to averages.

Determine proximity to existing transmission lines: A critical issue in keeping costs down in building a wind farm is minimizing the amount of transmission infrastructure that has to be installed. Whenever, possible availability and access to existing lines should be considered in selecting a site.

Secure access to land: Landowners, both private and public will expect to be compensated for any wind energy development that occurs on their land. Royalty or lease agreements will need to be discussed with all parties

involved. Roads, transmission equipment, maintenance infrastructure, turbines and the likes need to be considered. Moreover, the construction of a wind farm necessitates the use of heavy industrial equipment. Developers will need to invest in roads capable of accommodating significant weight. To do so will require the cooperation of landowners and in some cases, the local community.

Establish access to capital: Building a wind farm is not cheap and as being earlier noted, it is a scheme that can be facilitated by the government or can be facilitated by private organizations. To take advantage of economies of scale, wind power facilities should be in excess of 20 MW.

Identify reliable power purchaser or market: To date, wind energy is the most cost competitive renewable energy option on the market (Legeton *et al.*, 2004). In fact, wind energy's cost has declined so much that it rivals many traditional power generation technologies. However, utilities will tend to purchase power from what they consider to be the cheapest and most reliable technology. In most cases today, that is natural gas. That does not mean there is not a market for wind, though. Demand for green power (electricity from clean sources like wind that is sold to customers at a premium price) and environmental requirements are creating buyers for wind energy and competitive rates.

Address sitting and project feasibility considerations: The fact that a site is windy does not mean it is suitable for wind power development. A developer needs to consider many factors in sitting a project. Is there high raptor activity in the area? Are there endangered or protected species that could be jeopardized by the presence of the facility? Is the site's geology suitable and appropriate for industrial development? Will noise and aesthetics be issues for the local community? Will the turbines obstruct the flight path of local air traffic? (Legeton *et al.*, 2004). There are quite a few environmental and social issues that will need to be addressed in the sitting of a wind power facility.

Understand wind energy's economics: There are many factors contributing to the cost and productivity of a wind plant. For instance, the power a wind turbine can generate is a function of the cube of the average wind speed at its site, which means that small differences in wind speed mean large differences in productivity and electricity cost. Additionally, the swept area of a turbine rotor is a function of the square of the blade length (the radius of the rotor's swept area). A modest increase in blade length

boosts energy capture and cost-effectiveness. Financing methods can make a major difference in project economics as well. Securing significant investment capital or joint ownership of a project can cut costs significantly. Furthermore, there are federal and state incentives, for which a project may qualify and which could reduce costs and encourage more favorable investment.

Establish dialogue with turbine manufacturers and project developers: Every wind turbine is different despite seemingly similar power ratings. Some machines are designed to operate more efficiently at lower wind speeds while, others are intended for more robust wind regimes. A prospective wind power developer would be wise to investigate all the various considerations and compare the performance to existing machines. Moreover, anecdotal information and even the professional services of wind power developers may prove helpful.

Secure agreement to meet operation and maintenance (O and M) needs: Turbine availability (reliability) is a major factor in project success and the services of professional familiar with the operation and maintenance of wind turbines can prove to be invaluable.

Policy proposal and challenges in using wind energy for rural electrification: While, this study discusses the existence of an economic and reliable renewable energy, wind energy, application to address rural electrification needs in Nigeria, there are important barriers preventing the commercialization of these decentralized technologies. Barriers ranging from high initial cost to lack of loan service can prevent the realization of the full potential of Wind energy in Nigeria. To remove these barriers and to take full advantage of the opportunities identified above, policies and institutional strategies for rural renewable energy development are needed. The policy proposals offered here seek to facilitate the development of a viable off-grid renewable energy market where, wind energy can be effectively harnessed. Some of the policy proposals include:

Building an institutional framework: Nigeria needs to build an effective institutional framework to promote renewable energy use, especially in its rural areas where, conventional grid connections are not feasible. Renewable energy options should be integrated into the government's overall rural development plans. Rural electrification programs should include renewable energy technologies, especially decentralized options, as an important part of a hodgepodge of technologies that can provide rural people with cost-effective electricity

services. Reform of existing organizational structures in order to increase governmental coordination in rural renewable energy development would also, contribute positively to a renewable energy future for Nigeria.

Increasing financial support: To foster self-sustaining rural renewable energy markets in Nigeria, greater financial services to rural users will be needed. Financial resources for wind power schemes could be mobilized by issuing renewable energy development bonds, creating green energy investment funds and using taxes on the production and use of fossil fuels. Nigeria should consider the adoption of incentive policies to attract early investment in renewable energy technologies. Sliding-scale investment tax credits to manufacturers and developers and tax incentives offered to individual customers can spur early adoption of renewable energy technologies. Successful incentive programs in other countries include:

- Tax credits for the first-time renewable energy system buyers
- Tax exemptions on the interest earned from renewable energy development bonds
- Tax deductions in interest payments for renewable energy loans

Recognition of the social and environmental benefits of renewable energy justifies reducing tax rate on renewable energy producers and consumers. Such incentive policies can facilitate early adoption of renewable energy technologies. In addition to incentive policies, Nigeria can examine market transformation strategies to help the market for renewable energy technologies to flourish.

Rural financing programs should include low-interest loans provided by governments to low-income families. If low-income customers can pay less in the beginning and increase payments later, when their businesses grow (or they are able to borrow money at a lower rate in the beginning years and a higher rate in later years), the twin purposes of rural economic development and electrification can both be served. Furthermore, to give customers more financing choices, the government should also explore other effective financial tools such as manufacturer financing, retailer financing, cooperative financing, as well as lease and rent-to-buy agreements.

Creating renewable energy markets: The commercialization of renewable energy in Nigeria requires the establishment of energy markets for rural populations. To nurture such a commercial market, there is a need to increase investment in renewable energy development.

Improving services and training for the utilization of renewable energy technologies: The success of commercialization efforts depends also upon its social acceptability. There is a need to improve service and maintenance arrangements for renewable energy technologies. Rural users need to be provided with adequate repair and preventive maintenance services locally. There is also, a need for training consumers in basic operation skills such as correct appliance connections and battery usage, as well as in routine maintenance procedures such as filling batteries with water and cleaning wind turbine blades. User training should also, include load control skills that can help end-users manage their daily energy uses efficiently and reduce the need for large storage requirements in renewable energy systems.

Global cooperation: Finally, Nigeria could seek capacity-building and institutional support from multilateral development organizations as well as bilateral aid and development agencies in the areas of energy planning, regulatory reform, market transformation and policy intervention. Nigeria can take action, as well, to clearly define the institutional basis for cooperation with other countries to foster the transfer of renewable energy technologies. Furthermore, Nigeria can explore greater renewable energy development opportunities through participation in global information exchanges on energy and the environment that focus on wind energy.

CONCLUSION

In view of the erratic supply of electricity in Nigeria and the near non-existence of power supply in the rural centers, the need for alternative energy source cannot be neglected and as such, wind turbine technology plays a vital role in contributing to the search as an alternative source. The wind turbine is a machine that converts the power in the wind into mechanical power in order to drive a generator for the production of electricity.

Rural electrification is now and will remain an essential element for rural development in Nigeria. Wind power scheme, can provide an economical and environmentally sustainable option for meeting energy needs of rural households in Nigeria. Adoption of effective policies-the building of an institutional framework to support wind energy development, the establishment of effective financial mechanism to provide capital for renewable energy development, the adoption of incentive based actions to spur renewable energy development, the implementation of market transformation

strategies to encourage renewable energy development and the enhancement of international cooperation to promote wind energy technologies-will create the level playing field needed to enable renewable energy technologies to compete with conventional options such as fossil fuel.

Certainly, the challenges faced by Nigeria are great. However, these challenges can be met if principles of sustainable development inform of economic, energy and environmental policy and if international support is mobilized to meet Nigeria's needs. Together, Nigeria's government and the world community can produce the new ideas and enact the innovative polices that will realize a sustainable future under the framework of vision 2020 of Nigeria.

However, the success of wind power schemes for rural electrification can be viewed as a stepping stone for Nigeria's development into the wind turbine technology. It will form the basis for large-scale installations of wind turbine, which would facilitate energy production using Wind, the inexhaustible source of energy, thereby reducing the emission of greenhouse gas and also combat global warming. Nigeria can benefit from the use of this alternative source of energy production as is the case with that obtainable in Denmark.

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