Generation of Electricity from Wind Energy for a Home Using Qblade Software

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ABSTRACT---This work presents generation of electricity from wind energy for a home. There exists a huge shortfall in the reliability of power supply for residents in Ghana. Due to this, the objective of this work is to design and cost a small-scale wind energy generation system to meet the electricity demands of a 5kW home. This system would serve as an alternative power supply which is cleaner and in more abundant supply when there are power outages. The main technique used in this design was a simulation of the ideal WEGS using the Qblade software. With the results obtained we fine tune the design and estimate a cost for the system. It was found that using the direct drive system devoid of the gearbox was a more viable option in the component selection and although it reduced the cost of the system and improved the efficiency, the WEGS was still generally very costly.

***Index Terms*—**Electricity, Qblade software, Wind Energy Generation System, Power Supply, Reliability

I. INTRODUCTION

In recent years, Ghana has encountered insufficient electricity supply. This is predominantly a result of inadequate rainfall leading to reduced power generation and thus supply–at the hydroelectric power plants. Globally, a projected 1.2 billion people – 17% of the world population – did not have access to electricity in 2013. Many more suffer from supply that is of reduced quality. More than 95% of those living without power are in nations in sub-Saharan Africa and emerging Asia, and they are mostly in rural areas (around 80% of the world total). While still far from complete, development in providing electrification in urban areas has outstripped that in rural areas two to one since 2000 [1]. The satellite images of the earth at night from NASA support assertion. Also, it is projected that approximately 72% of the Ghanaian populace has access to electricity. Numerous studies have recognised a robust relationship between real GDP growth rate and electricity consumption [1], [2]. Other variables comprise the population growth rate and the Government of Ghana's (GoG) program to intensify access to electricity in the country as well as initiatives to improve effectiveness in energy use. With Ghana's population growth at 2.3 per cent per annum and GDP growth at 2.10 per cent per annum, electricity demand is projected to grow by more than 6 per cent per annum over the next 10 years [2].

Thus, if we are unable to meet our electricity demands now, then in a few years we would still be unable of doing so. The country's present total installed generating capacity needs to be increased to 5,175 MW by 2023 in order to address the current electricity shortfalls, meet the country's forecast growth in demand requirements, safeguard an adequate supply of power, and improve the quality of service and reliability of the electricity system. For this reason, there has been the need to consider forms of renewable power supply. Most countries are moving to Renewable energy because it is a practical and cheap solution to power needs. By accelerating renewable energy, they can:

i. Cut global warming emissions
ii. Decrease air pollution
iii. Reduce dependence on coal and other remnant fuels
iv. Diversify our power supply
v. Produce new jobs and industries

It is a marvel that we are still burning remnant fuels at all. With the present accessible technology, we can access 5.9 times the world demand of energy, all from natural sources. Wind energy is the second largest available form of available renewable energy and with current technology can deliver half the world's energy requirements [3]. All-natural energy sources combined provide 3078 times the present global energy needs.

Additionally, wind energy is a green energy source**.** Harnessing wind energy does not pollute the environment nearly as much as fossil fuels, coal and nuclear power do. It is true that the manufacturing, transportation and installation of a wind turbine contributes to global warming slightly, but the electricity production itself does not involve any emissions of climate gases whatsoever. Also, the potential of wind power is absolutely unbelievable. The global potential of wind energy when the wind turbine is placed on the Earth's surface is more than 400 terawatts [3]. Harnessing wind power can be done almost anywhere. Whether or not this resource is financially viable is another question we would answer for a typical home in Ghana. Similarly, wind energy is a renewable source of energy; naturally occurring and there is no way we can empty the energy resources. Wind power actually originates from the nuclear fusion methods that take place on the sun. As long as the sun keeps shining (according to scientists it will for another 6-7 billion years), we will be able to harness wind energy on earth**.** This is not the case for remnant fuels (e.g. natural gas and oil), which our society

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relies deeply on today. The wind turbines cannot be placed too close to each other, but the land in-between can be used for other things**.** This is why many would benefit more from installing wind turbines as opposed to solar panels [4]**.** The main feature of a small wind energy system is the wind turbine. A wind turbine is a machine that converts the wind's kinetic energy into rotary mechanical energy, which is then used to do work.

Though improving in production capacities, Africa signifies the least advanced in terms of installed wind power and wind energy adoption. North Africa, with Egypt (550 MW) and Morocco (286 MW) lead the way. Tunisia (54 MW), South Africa (10 MW) and Kenya are other promising countries. Besides, forecasts expose that in the near future wind power capacities up to few GW will be attained in places like Egypt, Morocco and South Africa. In sub-Saharan Africa, chiefly the West African region, no country has yet generated grid electricity from wind despite the known prospects. Thus, our research extends to some of these countries to examine how they progress using wind energy as their source of energy generation.

The remainder of the paper is organised as follows: Section II presents the theoretical background of small wind turbine; Section III presents the energy needs of the home and also on the design; component selection and installation of the small wind turbine, power generated and losses and siting of the wind turbine to harness greater wind; Section IV presents an economic study of the project estimate and its economic feasibility analysed; Section V evaluates the approach and discusses the simulation results; Section VI concludes the paper.

II. THEORICAL BACKGROUND

Wind Energy: The energy that can be extracted from the wind is directly proportional to the cube of the wind speed, so an understanding of the characteristics of the wind (variation velocity, direction) is critical to all aspects of wind energy production, from the identification of suitable sites to predictions of the economic viability of wind farm projects to the design of wind turbines themselves, all is dependent on the characteristic of wind.

The most outstanding characteristic of the wind is its randomness or stochastic nature. The wind is highly variable, both temporally and geographically. Additionally, this variability exists over a very wide range of scales, both in time and space. This is significant because extractable energy from wind varies with the cube of wind velocity. This variability is due to different climatic conditions in the world. Again, the tilt of earth on its axis and its own spinning results in different wind distributions across the globe. Also, within any climatic region, there is a great deal of difference on a smaller scale, which is dictated by several factors such as ratio of land and water, presence of mountains etc. The type of vegetation also affects wind distribution through temperature moderation, absorption of moisture, and reflection of sun's energy. Typically, more wind is observed on the tops of hills and mountains than in low level areas. Even more locally, wind velocities are altered by obstacles such as buildings or trees. For any location there is variation of wind pattern, wind speed may vary from year to year, also wind distribution will change from decade to decade. Major factors that have accelerated the wind-power technology development are as follows:

i. Improved plant operation, pushing the availability up to 95 percent.
ii. Development of high-strength fiber composites for constructing large low-cost blades.
iii. Variable-speed operation of electrical generators to capture maximum energy.
iv. Decrease in prices of the power electronics components such as converters.
v. Accumulated field experience (the learning curve effect) improving the capacity factor.
vi. Economy of scale, as the turbines and plants are getting larger in size.

Power in a wind stream

A wind stream has total power given by:

$$P_t = \dot{m}(K.E\ W) = 0.5\ \dot{m}V_i \qquad (1)$$

Where: m is the mass flow rate of air, kg/s and V_i is the incoming wind velocity, m/s.

Air mass flow rate is given by:

$$\dot{m} = \rho A V_i \qquad (2)$$

Where: ρ is the density of incoming wind, kg/m^2 = 1.226 kg/m^2 at 1 atm, 15^{o}C and A is the cross-sectional area of wind stream,m^2**.**

Substituting the above and accounting for the constants, we arrive at the following:

$$P_W = 0.5 \times \rho \times \pi \times R^3 \times V_W^3 \times C_P(\lambda\beta) \qquad (3)$$

Where: P_W is the extracted power from the wind; ρ is the air density, (approximately 1.2 kg/m^3 at 20 ^{o}C at sea level); R is the blade radius (in m), (it varies between 40-60 m): V_W is the wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s); C_P is the power coefficient which is a function of both tip speed ratio (λ), and blade pitch angle, (β) (deg.)

Power coefficient (Cp) is defined as the ratio of the output power produced to the power available in the wind.

Betz Limit: Betz limit is the theoretical limit allotted to efficiency of a wind turbine. It states that no turbine can convert more than 59.3 % of wind kinetic energy into shaft mechanical energy. Thus, the value of Cp is limited to Betz limit. For a well-designed turbine the efficiency lies in the range of 35-45 %.

Capacity Factor: Capacity factor is a term used to denote the utilization rate of a wind turbine or any power generating source for that matter. It is the ratio between power produced to the power that could have been produced if the generation source operated at 100% efficiency.

A conventional plant utilizing fossil fuels will naturally have a larger capacity factor as it is a continuous process. If the plant is laid idle or under maintenance then only will the capacity factor drop down. For a Wind turbine however, it is more of a question of the availability of the wind, as the wind is random in speed and direction, therefore a wind turbine may not always operate at maximum output condition. Also, there lies a cut-in and furl in speed which means the turbine only acts within a specific window. The capacity factor of turbines is typically low around 40 %.

Also, for a fuel powered plant capacity factor denotes the reliability of the plant, but in case of wind turbines it encompasses the design aspects of wind turbines.

III. WIND ENERGY SYSTEMS

Stand-Alone Systems: Stand-alone systems (systems not connected to the utility grid) involve batteries to store excess power generated for use when the wind is still. They also need a charge controller to keep the batteries from overcharging. Deep-cycle batteries, such as those used for golf carts, can discharge and recharge 80% of their capacity hundreds of times, which makes them a good option for remote renewable energy systems. Automotive batteries are shallow-cycle batteries and should not be used in renewable energy systems because of their short life in deep-cycling operations.

Grid Connected Systems: In grid-connected systems, the only additional equipment required is a power conditioning unit (inverter) that makes the turbine output electrically compatible with the utility grid. Usually, batteries are not needed.

IV. ENERGY NEEDS OF THE HOME AND DESIGN CONSIDERATION

How much energy will my system generate?

The wind speed, V, has an exponent of 3 applied to it. This means that even a small increase in wind speed results in a large increase in power. That is why a taller tower will increase the productivity of any wind turbine by giving it access to higher wind speeds. The formula for calculating the power from a wind turbine is as follows:

$$P = KC\rho^{\frac{1}{2}}V^3A\rho \tag{4}$$

Where: P is the Power output, kilowatts; C_P is the Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59); ρ is the density of air, kg/m^3; A is the Rotor swept area; V is the Wind speed, mph; K a constant to yield power in kilowatts; and A is rotor swept area. The bigger the rotor, the more wind energy it can harness, this makes the swept area of the rotor, A, a very noteworthy part since it is the portion of the wind turbine the harnesses the wind energy. The air density, ρ, has two main parameters that bring about its variation, which are the air temperature and elevation. Acceptable conditions of about 15℃ at sea level influences the ratings for the various wind turbines. Regarding higher elevations, density corrections should be made as shown in the Air Density Change with Elevation graph. Forecasting the long-term use of a wind turbines does not require a correction for the temperature. In spite of the fact that the calculation of wind power depicts relevant facet of wind turbines, the finest measure of wind turbine performance is based on the annual energy output.

The dichotomy between energy and power is that energy (kilowatt-hours [kWh]) refers to the quantity consumed whilst power in kilowatts (kW) is the rate at which electricity is consumed. A good estimation of the annual energy output obtained from a wind turbine, kWh/year, is the most appropriate way to predict whether or not a particular tower and wind turbine will generate enough power to match your demands. A preliminary estimation of the performance of a particular wind turbine can be calculated using the equation:

$$AEO = 0.01328D^2V^3 \tag{5}$$

Parameter of equation: AEO refers to the annual energy output in kWh/year; D is the Diameter of Rotor; and $V$is the annual average wind speed in mph.

Is There Enough Wind on My Site?

The quality of your wind resource is an important determining factor for predicting whether or not erecting a wind turbine in your farm or home is economically viable. For a small wind turbine to generate enough power to be cost-effective, an average annual wind speeds of at least 4.0–4.5 m/s (14.4–16.2km/h; 9.0–10.2 mph) is required. A wind resource potential map is a significant tool for evaluating a site for its wind Energy potential. It is used for checking the wind speed measurements that have been measured at a local weather station. Siting factors at these weather stations, such as nearby trees and buildings, may have significant influence on any wind speed measurements. In addition, noting that the equipment at these stations is usually located a bit closer to the ground, and that weather stations sited at airports are usually shielded from the wind. With this, it portrays that wind speed measurements recorded at these stations may under represent the wind potential at your site. Thus, it is necessary to have a wind resource evaluation system.

How Do I Select the Most Appropriate Site for My Wind Turbine?

Siting refers to the process involved in selecting the site for setting up a wind turbine. The duration and regularity of wind flows over the course of the day and the year are key parameters that affect the suitability of a particular site. A number of rules of thumbs used in setting up small wind turbines listed below:

i. Be polite. Keep a reasonable distance between the turbine and the neighbors. About 250–300 m away from the neighbors is typical.
ii. Gently sloping in the prevailing direction of the wind tends to increase the wind speed but a very steep slope leads to turbulence that can impact the lifespan of the turbine.

iii. Elevated areas such as hilltops experience much more wind.
iv. The bottom part of the rotor should at least be 10 rotor lengths higher than any obstacle within the surrounding.
v. Zoning is a very important parameter which should be through the local government for any other bylaws and regulations about it.
vi. Local vegetation may be symptomatic of the existence of a wind resource and the prevailing trajectory of the wind.
vii. Keep neighbours posted on your plans to prevent futuristic conflict.
viii. Preferably, within a distance of about 100 times the rotor diameter, there should be no obstruction to the flow of wind about the turbine.

IV. ECONOMIC STUDY OF THE PROJECT

The installation costs of wind turbines differ greatly based on permitting, local zoning, and utility interconnection costs. As stated by the American Wind Energy Association, “small wind energy systems cost from $3,000 to $5,000 for every kilowatt of generating capacity” [4]. Comparing to solar electric systems, it is much cheaper but the payback period can still be longer. Wind energy becomes more cost effective as the turbine’s rotor increases in size. The cost of the energy produced by small (<10 kW) wind turbines over their lifespan has been estimated to vary from $0.07/kWh, for a low-cost turbine constructed in a windy area, to $0.96/kWh, for a high cost turbine constructed in a low wind area. Figure 1, depicts the wind turbine installation cost.

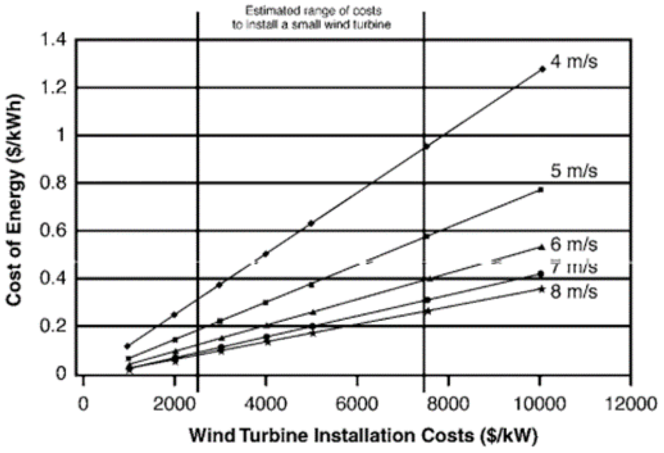

Fig.1 Wind turbine installation cost

$$\text{Saving}_{\text{annual}} = \text{Cost of energy} \times \text{Total annual energy production} \tag{6}$$

The simple payback (SPB) time will therefore be:

$$\text{SPB} = \frac{\text{Installed Cost}}{\text{Savings}_{\text{annual}}} \tag{7}$$

Note that the average wind speed utilized will need to match up the average wind speed at the turbine hub height, that is, the height of the generator. The wind energy produced will likely be noticeably less, if the turbine is located at a lower height than the wind speed was estimated at.

Estimate of cost of Wind Energy Generation System
Generally, the cost of the Wind Energy Generation system has 64% of the cost being from the wind turbine. With the components selected a cost estimate was made using current prices on the market.

Components	**Estimated Cost**
Wind Turbine cost	**¢ 57000**
Miscellaneous	¢3420
Lead acid Battery Bank	¢3230
Wind tower	¢1520
Disconnect switch	¢ 247
Charge controller	¢289
Total	**¢66,584**

V. SIMULATION RESULTS AND DISCUSSION

Factors such as determination of application, review of previous experience and topology plays a vital role in wind turbine design for used as an electricity producing turbine for a home.

Choice of the number of blades: Choosing the number of blades of a wind rotor is critical to the operation as well as its construction. A larger number of blades is known to cause turbulence in the system, and a lesser number would not be capable enough to harness the optimum amount of wind energy. Three (3) blades were chosen due to the aesthetic appeal and efficiency of the turbine.

Power control: Stall, variable pitch controllable aerodynamic surfaces and yaw control

Rotor Position: This can be Downwind or Upwind. A graphical method was used to determine the power coefficient of 0.4. From figure 2, we deduce that TSR =6

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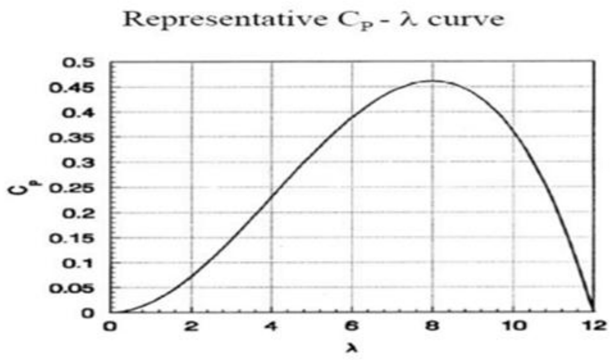


Fig 2 Graph of Power coefficient and TSR

The topology was selected based on a few improvements on existing designs and various calculations and simulations using the Q-blade software. Other parameters for determining the design of the wind turbine are as following:

Diameter of the Rotor: Forasmuch as the wind power produced is directly proportional to the square of the diameter of the rotor, it makes it a valuable parameter. The relation between the mean wind speed of the area and the optimum power required to be generated basically determines it.

$$P_{avail} = \frac{1}{2}\rho A V^3 C_P \qquad (8)$$

Given the wind energy power equation, P is power output in kW = 5 kW; C_P is the maximum power coefficient = 0.4; A is the swept area; ρ is air density = 0.9936kg/m^3; and V is the average annual wind speed = 5 m/s

We calculate the swept area and thus the ideal rotor diameter can be calculated as follows:

$$A = \pi r^2 \qquad (9)$$

Where: the radius is equal to the blade length as shown in Figure 3.

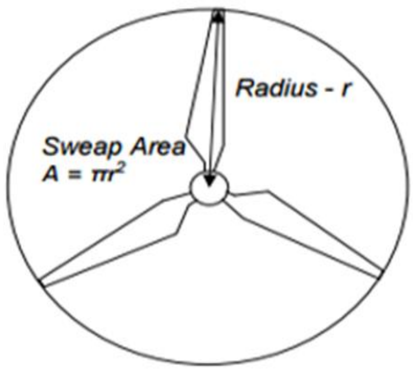


Fig. 3 Radius and Blade Length

Using a power coefficient value C p of 0.4 as the Betz limit is 0.59, and solving for A, A = 116.486 metres square and r = 6.089m.
Where: r is the blade length.

Coefficient of Power: The coefficient of power of a wind turbine basically signifies the conversion efficiency of the wind energy of the wind into mechanical energy, which in turn is used to drive the generators. Since it does not include the losses in transmission (mechanical) and in electrical power generation it differs from the overall system efficiency. Betz limit is known as the theoretical limit in horizontal axis machines, which is investigated to be around 0.593 (16/27 or 59.3%). For a good turbine, it within the range of 35-45%.

Cp= (Output Power of a Wind Machine)/ (Power Content of the wind stream). We use a general value of 0.4.

A tentative design was developed and results were obtained and compared. Once an overall design layout had been determined, the preliminary turbine design was developed. It was necessary to develop a power curve of the turbine that depicted the performance of the turbine at several speeds. And using the blade length derived we simulated two possible designs. This was achieved using the Qblade software as shown in Figure 4 and Figure 5.

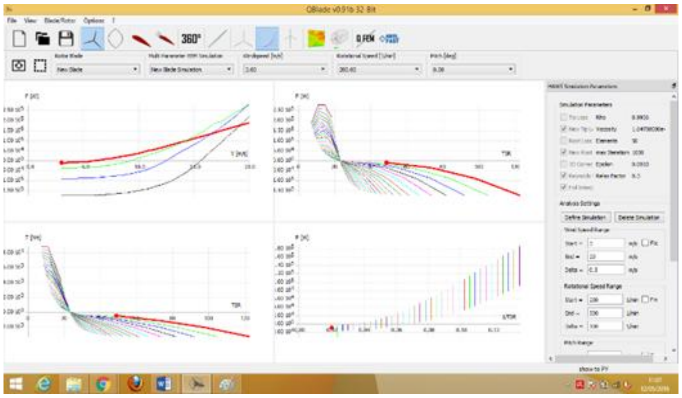
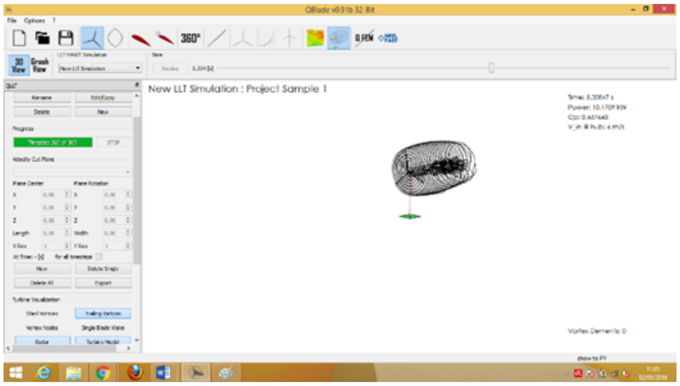


Fig. 4. Results obtained from UPWIND turbine design



New LLT Simulation : Project Sample 1

Fig. 8. Results obtained for downwind turbine design using same parameters

From our design simulations we realised that given the same parameters of wind speed and tower height, the upwind turbine functions with a better output than the downwind turbine. We deduce that this is because of the tower shading of the downwind turbine and the turbulence that was experienced by the rotor for that design. Also, the upwind turbine has a capacity factor that is higher than the downwind turbine and as stated earlier, capacity factor is a term used to denote the utilization rate of a wind turbine or any power generating source for that matter. It is defined as the ratio between power produced to the power that could have been produced if the generation source operated at an efficiency of 100%. Thus, describing a better efficiency for the upwind turbine than the downwind turbine.

VI. CONCLUSION

We have presented generation of energy from wind for a home in this study. Our system is estimated to produce about 5kW required by a typical household. It was found that the optimum combination of the WEGS with the battery storage depends upon the individual subsystems' economics. Also, it is not very viable as yet to have a wind energy generation system for individual homes in Ghana as the cost is very high for individuals to finance. Also, from our research upwind turbines are better suited to our climate than downwind turbines and are more efficient. Future work of study will consider the possibility of using aerodynamic turbines which could rise higher into the atmosphere independent of the tower to harness less turbulent and higher wind speeds for better energy production.

REFERENCES

[1] E. N. Kumi, "The Electricity Situation in Ghana: Challenges and Opportunities," *Centre for Global Development Paper,* no. September, p. 28, 2017.

[2] F. Doe and E. S. Asamoah, "The Effect of Electric Power Fluctuations on the Profitability and Competitiveness of SMEs: A Study of SMEs within the Accra Business District of Ghana," *Journal of Competitiveness,* vol. 6, no. September, p. 17, 2014.

[3] K. Marvel, B. Kravitz and K. Caldeira, "Geophysical limits to global wind power," *Nature Climate Change,* no. September, p. 4, 2012.

[4] U. S. D. o. Energy, "Small Wind Electric Systems: An Oklahoma Consumer's Guide," no. August, p. 9, 2007.