Development and Performance Evaluation of a Windmill for Pumping Water
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Abstract:
The need for the development of windmill for pumping water which can be used in rural areas and for irrigation purpose where sources of energy is a challenge was identified. A six (6) blade horizontal windmill was developed to convert wind energy of minimum speed of 3.75 rad/sec to mechanical energy for pumping water using a displacement pump of 0.2 m stroke. The slider crank mechanism was adopted for the development of the windmill, various materials were used for the development of components such as mild steel, aluminum alloy, stainless steel, galvanized sheet. These materials were locally sourced. The maximum rated power of the windmill is 8.41 Kilowatt with an extraction efficiency of 18.5 percent and system efficiency of 79.5 percent.

Keywords: Displacement, Hub, Shaft, Slider-Crank, Strain, Stress, Windmill.

1. INTRODUCTION
The high price of electricity and fossil fuel in Nigerian necessitate the research into alternative source of fuel. The wind energy is of high significance and if properly harness is of great importance. Wind energy is equal in content among all alternative source and renewable sources of energy. Wind on the earth surface are produced primarily by the uneven heating of the land and water by sun.

The changes in temperature gradients prompt the circulation of air from one zone to another [1]. It has been assessed that approximately 10 million MW’s of energy are always available in the earth’s winds. The exploitation of some of this energy through various conversion devices has contributed a decisive role in the economic development of many countries where wind is strong and stable.

[1] Clean water is important to sustain life and thus many societies of remote areas and underdeveloped countries have concentrated on designing easier and cheaper ways to assure water availability. Many countries in Africa face problems in reaching reliable water sources due to the weather condition and geographic location. Water is directly consumed for drinking purposes, but also used for irrigation schemes, farming, and for sanitation purposes. Communities that do not have access to clean water face problems such as illness, starvation, and other health problems. The idea of exploiting energy from wind power and using it as a renewable energy source was first established in the 1970’s. As the knowledge became available, entrepreneurs began to develop prototypes and establishments to continue the research on the new renewable resource.

The reduction in the world energy is predicted to grow by 50% from 2005 to 2030 [2]. Everyday solution is being found to lessen our reliance on petroleum, whether it is via biofuels, solar cells, or wind power. This evolution to greater clean energy output has caused an increase in energy that is being created by wind power. Many are acquainted with the customary steel wind turbines, however recently the idea of utilizing wind power from kites and other forms of airborne wind turbines has come to realization [2]. Like vitality, the requirement for water is rising quickly as supplies of standard assets keep on reducing because of abuse, waste, and contamination.

In any case, the capability to utilize neighborhood vitality assets to get access to water supplies that would some way or another be difficult to reach is acquired. This water is either found underground in profound aquifers or in surface lakes, waterways, and streams. By and large, the absence of accessible, shabby vitality makes accessing this water costly, tedious, and possibly risky. The best possible utilization of any of various alternatives accessible today can make accessing this water a reality in numerous ranges not beforehand considered [3].

2. MATERIALS AND METHOD
The materials to be used for the development of windmill for pumping water for irrigation use are based on material selection criteria. The criteria used include;

(i) Availability: the material to be selected for the fabrication must be readily available at the local market for easy accessibility.

(ii) Performance: also the material used for the windmill should be able to perform optimally and also meet all the design specifications.

(iii) Cost: economic of material selected for a particular purpose is often an over-riding factor which normally dictates the choice of material. The cost of materials to be used for the design should be relatively inexpensive.

2.1. Methodology
The general methodology adopted for the project design comprises of; problem identification/problem definition, data collections/information gathering (that is, wind speed), analysis, criteria development, synthesis of possible solution, optimization and decision step, test evaluation and production of performance.
3.0. DESIGN ANALYSIS AND CALCULATIONS

3.1. Design Requirement & Design Criteria
The design requirement for the windmill for pumping water include:

i. The mean wind speed of 2.25m/s
ii. Min pumping power of 8.41 watt
iii. Pump head of 0.2m (positive displacement pump)

3.2. Efficiency of power system
The efficiency of power system is a function of the coefficient of power \((C_p)\) where \(C_p\) is the ratio of power extracted by the windmill to the total power contained in the wind resources. According to Betz theory, the Betz limit is the maximum possible value for the coefficient of power which is \(0.59\) but the optimum possible for a multi-blade wind ranges from 15-45%.

Coefficient of power or the efficiency of the windmill is calculated from

\[
C_p = \frac{C_T \cdot \lambda}{15} \times 100
\]

From equation, \(C_T_{\text{interm}} = 0.1814\)
\(C_p = 0.1814 \times 1\)
\(C_p = 0.18\)

Hence, the efficiency of the windmill is 18.14%.

3.3. Efficiency of the system
The efficiency of the system can be calculated from

\[
\text{efficiency} = \frac{\text{input}}{\text{output}} \times 100
\]

Using the input force and output force,

\[
\text{efficiency} = \frac{165.9}{210} \times 100 = 79\%
\]

Hence, the efficiency of the Windmill is 79%.

3.4. Simulation and Flow Analysis
3.5. Solid works Simulation
The following are the steps carried out to run simulation on any component:

(i) Open a new motion study
(ii) Add a material
(iii) Add a fixed geometry
(i) Add external loads
(ii) Create mesh
(iii) Run study (Time-based Motion Analysis _ SOLID WORKS, 2015)

3.6. Flow Analysis
The following steps were followed during the flow analysis:

i. A rotating part was picked first, that is the blade
ii. A plane was selected and a cylinder was created which contains the part to be rotated.
iii. Extrusion was done without merging result; this is the volume that was rotated.
iv. A transparency change was done in other too see the part clearly
v. the flow simulation command was initiated in Tools->Add-ins->Flow simulation
vi. A wizard was selected in other to create a new study
vii. Click on the arrows on the right side and click on analysis type.
vi. Choose external flow and check both boxes on the right side and click on rotation analysis (the blades will be rotating)
The fluid used is air (Time-based Motion Analysis _ SOLID WORKS, 2015)

3.7. Design Optimization
Optimization is the act of obtaining the best result under given circumstances. The ultimate goal of optimizing is either to minimize the effort required or to maximize the desired benefit. Optimization was done for the blades and all movable/rotating parts.

3.8. Performance Evaluation
Once the water pumping system is designed and installed, it was monitered and its performance evaluated to determine the operating efficiency. Performance evaluation helps to check whether the pumping system functions as per design. Depending on the data requirements, the system can be monitored with simple discrete-time measurements or real-time measurements such as a strain gauge for measuring strain, and an anemometer for measuring the wind speed. However, if detailed information is needed, it is better to use data acquisition systems and data transmitter/receiver devices such as modems, to measure performance in real time.

4.0. RESULT AND DISCUSSION

4.1. Result
Summary of Results from components design: The result obtained during the development of the windmill for pumping water is summarized in table 4.1 below;
Table.1. Dimensions/Results of the Blade Design

<table>
<thead>
<tr>
<th>Description of Parameter</th>
<th>Calculated Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Length</td>
<td>60mm</td>
</tr>
<tr>
<td>Top length</td>
<td>120mm</td>
</tr>
<tr>
<td>Height of blade</td>
<td>800mm</td>
</tr>
<tr>
<td>Minimum Thickness</td>
<td>1mm</td>
</tr>
<tr>
<td>Area of blade</td>
<td>1.2 $\text{m}^2$</td>
</tr>
<tr>
<td>Diameter of blade</td>
<td>1.2mm</td>
</tr>
<tr>
<td>Tip speed</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Shaft

| Diameter of shaft         | 16.5mm            |
| Maxumum bending Moment    | 20.1Nm            |
| Maximum Torsional moment  | 31.22Nm           |
| Length of Shaft           | 500mm             |

3. Flywheel

| Diameter                  | 300mm             |
| Thickness                 | 15mm              |
| Mass of Disc              | 2.88Kg            |
| Torque required to rotate disc | 210.2N |

4. Link 1

| Mass                      | 0.06$\text{m}^2$+Kg |
| Force                     | 203.61N            |
| Area                      | 0.03 $\text{m}^2$  |

4.1.1. Stress, Strain and Displacement analysis results

Some of the components were analyzed for stress, strain and deflection limits using solid works simulation software. These components include the Blade hub and shaft, flywheel and the shaft alone.

Figure.4.1. Graph of Radius of the Blade against Blade

Figure.4.2. graph of wind speed (m/s)

4.1. Stress, Strain and Displacement analysis results

Some of the components were analyzed for stress, strain and deflection limits using solid works simulation software. These components include the Blade hub and shaft, flywheel and the shaft alone.

Figure.4.3. shaft and blade hub stress model (von mises) with deformation scale: 63.4288

Figure.4.4. Shaft and Blade Hub Displacement Model (Ures) With Deformation Scale: 63.4288

Figure.4.5. Shaft and Blade Hub Strain Model (Estrn) With Deformation Scale: 63.4288

Figure.4.6. flywheel stress model (von mises) with deformation scale: 249.305
Figure 4.7. Flywheel displacement model (ures) with deformation scale: 249.305

Figure 4.8. Flywheel strain model (estrn) with deformation scale: 249.305

Figure 4.9. Shaft stress model (Von Mis) with deformation scale: 374.843

Figure 4.10. Shaft displacement model (Von Mises) with deformation scale 374.843

Figure 4.11. Shaft strain model (Estrn) with deformation scale: 374.843

Figure 4.12. Flow analysis

5.0. CONCLUSION

It has been confirmed by this project that renewable energy is a good source of energy and very important to human life because of the benefits it provides such as environmental benefit. The development of windmill for pumping water was manufactured successfully in the workshop through the concept of slider crank mechanism. A minimum speed of 3.75 rad/sec was required to turn the blades and a maximum force of 210N is required to turn the flywheel. Out of the power of the wind, the windmill was able to extract 18.14% of it. The force and other parameters on each component were calculated. The modelling of slider crank mechanism was numerically modeled in MATLAB and the result shows the maximum and minimum velocity of a crank mechanism of 2.61 m/s and -2.61 m/s respectively, maximum and minimum acceleration of 9.11 m/s$^2$ and -2.47 m/s$^2$ respectively. Also, the maximum and minimum of the plunger velocity is 1.18 m/s and -0.74 m/s, acceleration of 6.8 m/s$^2$ and -4.6 m/s$^2$ respectively and displacement of 0.4 m. In the same vein, the simulation of flywheel, blade hub and shaft was carried out by SolidWorks, the result shows that each component was safe and did not stress beyond the limit. The material used are efficient, available and cheap, most of the material such as mild-steel angle iron, are readily available in the local market. Component like bearing, bolt were purchased to suit the design specification which makes it easy to fabricate. In conclusion from the result obtained from previous chapters, the aim and the objectives were achieved. That is, energy from the wind was used to perform a required task to pump water with the help of displacement pump which create suction and...
water was delivered through the discharge tube so it can be useful to human life thus promote technology.

6.0. REFERENCES

