Locally Manufactured Small Wind Turbine For Rural Home Electrification
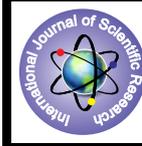
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ABSTRACT   *The main objective of this work is to determine and design a suitable wind turbine which could be employed for rural homes. A variety of horizontal and vertical axis wind turbines exist, each possessing a number of advantages and disadvantages which needed to be taken into account before a basis for the design is selected. A small healthy design which is relatively simple and cheap to construct is in essence the main criteria for wind turbine selection. A Savonius type rotor, which is a rotor based on a modification of the 'S' rotor, is selected as it best fitted the design criteria. A small prototype 1.5 m tall with a rotor diameter of 0.65 m is designed and built. The finished prototype is used to estimate the power obtainable under normal operating conditions*

Introduction

There is a tremendous amount of free energy in the wind which is available for energy conversion. The use of wind machines to harness the energy in the wind is not a new concept and can be dated back as far back as the Chinese in 2000 B.C. These early machines were used for pumping water for irrigation purposes and later developed as windmills for grinding grain. It has only really been in the last century that intensive research and development have gone into the use of wind energy for electricity generation [1, 2].

A number of different types of wind machines, or wind turbines, exist today. Horizontal axis wind turbines, or HAWTs, have blades mounted radially from the rotor. Vertical axis wind turbines, or VAWTs, are not as common and only recently have they been used for large scale electricity generation. Simple construction and cost of materials was a major driving factor in the decision but there was also a need for a design which was healthy.

The Savonius rotor, designed by the Finnish inventor S. J. Savonius in 1925, is a VAWT which has been based around a modification of the 'S' rotor [1]. It operates on the principle that a drag differential is created between the concave and the convex surface which induces rotation. Efficiencies of the Savonius rotor are generally low when compared with those other VAWTs, such as the Darrieus rotor [1], but fabrication time, cost and the fact that the rotor blades do not have to be designed and tested to complex precision meant that it was a suitable choice for the project. The impellers/rotors were designed so as the turbine could start from any wind direction. Suitable bearings, rotor shaft and frame were carefully selected and fabricated. All materials used had to be fit for the purpose intended with the main criteria being robustness from loads imposed from wind and other forces and also being able to withstand the elements of nature such as rain.

A generator and means for energy transmission from the shaft to the generator were the next step. Once a generator was found it was tested to determine its effective operating range. A pulley-V-belt configuration set up for energy transfer from shaft to generator. With the basic design built measurements were taken, such as the area of the rotor blades swept by the wind, to determine the estimated power output which would be obtainable from the finished model [3].

The power in the wind

The wind systems that exist over the earth's surface are a result of variations in air pressure. These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. Significant areas of the world have mean annual wind speeds of above 4-5 m/s which makes small-scale wind powered electricity generation.

By using formula to calculate the power in the wind:-
Power = density of air × swept area x velocity cubed / 2
$P = \frac{1}{2}.\rho.A.V^3$ .... (1)

Where,P is power in watts (W)
ρ. is the air density in kilograms per cubic metre (kg/m3)
A is the swept rotor area in square metres (m2)
V is the wind speed in metres per second (m/s)

Average of basic usage of power/day for individual.

Refrigerator : 0.7 kWh/day
Electric ranges and cooking : 1.6 kWh/day
Lighting : 0.4 kWh/dav
Total : 2.7 kWh/dav

Wind turbine selection and evaluation

There are two main types of wind turbines. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) [8]. The advantages of the HAWT are that it can obtain a relatively high efficiency up to 47% that because they are typically tower mounted they have access to the higher undisturbed wind flows above ground level. There is an increased capital cost incurred in the need for the tower and also the rotor and generator are more difficult to attend to for maintenance and repair than if the wind turbine was mounted on the ground.

The other type of wind turbine, the VAWT, has rotors which move in the direction of the wind. A Darrieus VAWT named after the French inventor George Darrieus. VAWTs can obtain efficiencies of up to 37% of the power obtainable from the wind. There is no requirement for a tower therefore there are lower capital costs and also the fact that the generator is mounted at ground level means that it is easy to access [9, 10].

Choosing a suitable wind turbine

It was decided to design and build a Savonius VAWT. The Savonius rotor, proposed by the Finnish inventor S.J. Savonius in 1925, is a vertical axis rotor shown in Fig. 1. driven by drag forces [1, 7]. The design is essentially a modification of the 'S' rotor comprising of two semicircular rotor blades. From Fig. 2 it can be seen that the surfaces move with the wind for half a revolution and against it for the other half. The differences in drag between the concave and the convex surfaces creates a pressure differential and induces rotation. One of the important things to note is the path of the streams through the rotor. The horizontal displacement of the rotor blades increases the pressure difference by diverting wind upstream to effectively push the top blade into the wind. This aids in the rotation of the rotor and increases torque.
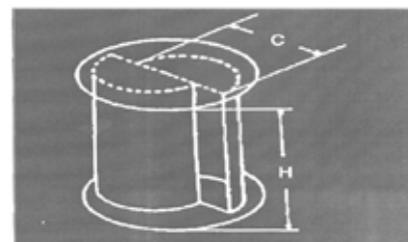

Fig. 1. Rotor blade configuration & Aspect ratio.
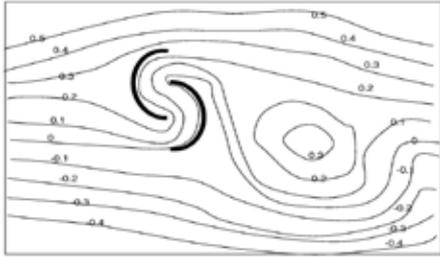
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Fig. 2. Velocity stream diagram.

This type of rotor is capable of obtaining efficiencies of up to 24% of the energy in the wind but typically a figure of 20% is more a realistic value [10]. Despite the Savonius rotors low efficiency it is simple and less expensive to fabricate on a small scale than complex vertical axis machines.

Advantages over the horizontal axis machines

• Simple construction
• Lack of necessity for over-speed control
• Acceptance of wind from any direction
• Relatively inexpensive to fabricate on a small scale

Mechanical design considerations
For a wind turbine the main design characteristics stem from the choice of rotor. Different types of rotors have different characteristics such as speed, power, robustness and overall design appearance. Once the Savonius rotor had been selected, there were a number of elements which needed to be considered. These include:

• Aspect ratio
• Overlap ratio
• Separation gap
• Cross-section profile
• Number of buckets/rotors
• Stacks of buckets/rotors
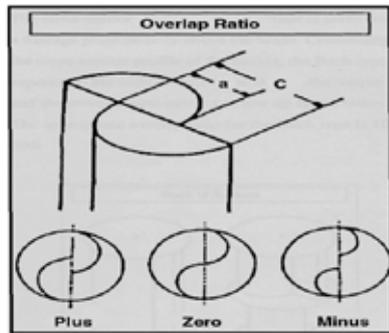• Bucket/rotor endplates

Fig. 3. Overlap ratio.

The double-stack rotor is slightly superior to the corresponding single-stack rotor in both torque and power characteristics.
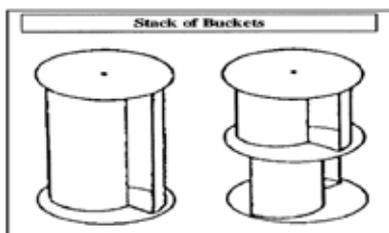

Fig. 4. Stack of buckets.

Finalised design of Savonius rotor
With the Savonius rotor selected as the most appropriate de-

sign. The drums were to be the basic building block to build the design around and this method has been very popular in the past for the likes of rural applications such as irrigation water pumps. A rotor of this size would not be feasible to build for the following reasons [11]:

• Cost
• Building environment
• Time

All of the above problems being minimized or eliminated and a new smaller scale design drafted. A maximum height of 1.5 m with a length of 1.5 m and a width of 0.8 m would ensure that the working environment, with respect to space, wouldn't be a problem and also that the wind turbine could readily be moved as required [12].The next step was to decide upon suitable materials quotes from different suppliers to obtain the best prices.

Impellers
For impellers (or rotor blades) PVC plastic was selected because it comprised of the following favorable properties:

1) Lightweight
2) Ductile
3) Readily formed
4) Resistant to the elements
5) Resistant to work hardening
6) Relatively inexpensive

Each impeller was designed and built as a separate entity so as it could readily be removed from the rotor if required. The PVC plastic was affixed with a series of screws and washers.

Bearings
The bearings selected for the design were flange mounting, self-aligning easy to replacement. They needed to be strong enough to provide for the axial and radial loading from the wind itself and tension from the pulley-V-belt connection linking the shaft to the generator.

Rotor shaft
The design incorporates what is termed a 'live-shaft'. This means that the shaft rotates as part of the rotor. One of the main design aspects of the shaft was mainly for assembly and disassembly purposes.

Support frame
A support frame was required to house the rotor, bearings and the generator.

• Able to take the full weight of the rotor.
• Withstand forces induced upon it from the wind.
• Able to disassembled, easily to handle.
• Provide for the mounting of the generator.
• Able to withstand the elements of nature.

Finished prototype
With all of the above criteria taken into account a working model was constructed shown in Fig.5 there are two stacks of impellers. This was to provide for starting from any wind direction and produce a more uniform torque.

To estimate the power output of the system using Eq. (1), (taking average wind speed to be 10 m/s), gives power output of 27 W. It's around 0.65 kWh/day.
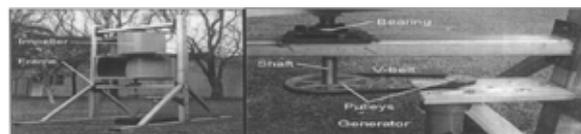

Fig. 5. The complete prototype model.

Practical applications
Applications for the model designed and built are very limited due to the fact that it has been built on such a small scale. To put

things into perspective, with an average output of 0.65 kWh/day it would be able to run a small refrigerator. In order to be suitable for more practical applications the scale or size of the wind turbine would have to be increased. For an individual living with many of the modern luxuries such as t. v. the average usage of power per day is around 5 kWh/day. An individual living in an isolated environment and only requiring the basics should be able to get away with using around 2.7 kWh/day. There would realistically be a need for refrigeration, cooking and lighting at night.

Doubling the width and the height of the rotors active area would increase the power output by a factor of four i.e. from 0.65 kWh/day to 2.7 kWh/day which would appear at face value to be satisfactorily close. This would be the case if the energy was used at the time that it was generated but in reality there will be times of high and low demand. This scenario creates the need for some form of energy storage. The use of lead acid batteries is a feasible solution but these generally only have efficiencies of around 80%. Realistically the active surface area would need to be around six times larger than the original model in order to be suitable for this application as there is a need to take account of energy losses at all stages of the energy conversion, transfer and storage [13, 14].

Conclusion
In this paper, a small design which was relatively simple and cheap to construct was in essence the main criteria for wind turbine selection. A Savonius type rotor was selected as it best fitted the design criteria. The overall size of the wind turbine and its supporting structure was limited to a maximum height of 1.5 m, length of 1.5 m and width of 0.8 m. These specifications were set at the start to ensure that it would be of a suitable size for the workshop in which it was to be fabricated and also provide for ease of relocation and storage. The impellers/rotors were designed so as the turbine could start from any wind direction. Suitable bearings, rotor shaft and frame were carefully selected and fabricated. All materials used had to be fit for the purpose intended with the main criteria being robustness from loads imposed from wind and other forces and also being able to withstand the elements of nature such as rain. Tests were also performed on the turbine rotor to find how fast that it rotated under rated operating conditions. From the difference in operating speed between the generator and the turbine rotor a gearing ratio was determined and a pulley-V-belt configuration set up for energy transfer from shaft to generator. With the basic design built measurements were taken, such as the area of the rotor blades swept by the wind, to determine the estimated power output which would be obtainable from the finished model. The results provided as a power output enabled suitable applications to be suggested.

The Savonius rotor vertical axis wind turbine definitely has a place in electricity generation. It has many advantages despite its relatively low efficiency. On other hand; small scale it is cheap, simple to design and construct and is also very robust. There are a number of small-scale applications for which it would be suitable especially for tin likes of a small isolated homestead. As it is easily repairable and maintainable there would be little need for the services of a technician as almost any individual with an understanding of basic mechanics would be able to service it.

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