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Abstract

The characteristics of the Vertical Axis Wind Turbine make it possible to use generating techniques not suitable for Horizontal Axis Wind Turbines. Methods for converting mechanical energy into electrical energy are presented and discussed for vertical turbines of the 250 KW to 2500 KW size. This paper will also look at the present status of Vertical Axis Wind Turbine research in the United States.

1. INTRODUCTION

A Vertical Axis Wind Turbine, abbreviated as VAWT, has its axis of rotation in the vertical position as shown in Figure 1. The rotating airfoils need not have any type of pitch control in order to obtain satisfactory aerodynamic performance.

The turbine shown in Figure 1 is a Darrieus type VAWT. Its blades are symmetrical airfoils fastened in a bow shape to the top and bottom of a rotating vertical shaft. The torque produced by these rotating blades is a result of the component of aerodynamic lift in the direction tangent to the rotational path minus the component of drag in that direction. If the blade speed is four times the speed of the wind, a single blade will produce torque during 80% of its circular path regardless of the wind direction.

Figure 2 illustrates how the wind velocity as seen by the blade $V_{w/b}$ is obtained from adding vectorially the velocity V_b. The aerodynamic lift is proportional to the angle of attack α up to stall conditions. For the tip-speed ratio shown here ($V_b/V_w = 4$) the maximum angle of attack is 14 degrees so that flow separation is completely avoided during each revolution. Therefore, the component of lift in the direction of motion is greater than the component of drag except in the shaded region indicated in Figure 2. Here the angle of attack is small which reduces the magnitude of the lift as well as reducing the inclination of the lift force. In this case, the drag component is equal or greater than the lift component resulting in a small negative torque. When more than two blades are used it is possible to produce a net positive torque that is nearly constant for all rotational positions.

The cost of the blades and the tower accounts for around half of the cost of a VAWT. Presently efforts are underway to reduce this cost.(1) Power conversion equipment accounts for nearly 25% of total cost. This paper will look at two methods which may reduce the cost of power conversion equipment for VAWT's.

A comparison of the VAWT of Figure 1 with a Horizontal Axis Wind Turbine, HAWT, of Figure 3 shows it is possible to mount energy conversion equipment for VAWT's on the ground. There is little doubt that installing and servicing equipment at ground level is more desirable than working on a 100-foot tower. Weight and size restrictions do not constrain the design of this energy conversion equipment as it would with horizontal axis machines. The necessity of mounting the energy conversion equipment for the HAWT on the tower limits the size of the conversion equipment due to tower load and wind blockage.

Two of the energy conversion schemes possible with a

VAWT are shown in Figure 4. The gear box and generator system is presently being used in the operational 17-meter VAWT at Sandia Laboratories in Albuquerque and by NASA's HAWT at Plumbrook, Ohio. The second scheme is not possible on a horizontal axis machine but may have a future on a vertical axis turbine. It changes the approximately 20 rpm's of the VAWT directly to electrical energy and eliminates the gear box. A recent study[2] for Sandia Laboratories indicates that speed increasers other than gear boxes are not feasible for large wind turbines.

2. DIRECT DRIVE SYSTEMS

Since a 500 KW VAWT operating at 20 rpm's appears to be capable of producing more kilowatt-hours per dollar[3] than larger sizes, it will be used as a data point for considering the direct drive systems. In order to obtain an idea of the cost of standard power conversion equipment for VAWT's, a gear box and induction machine combination for a 500 KW VAWT costs $120,000[2] with 80% of the cost assigned to the gear box. If a direct drive electrical machine could be produced at a lower cost, the ¢/kWh for wind energy will decrease.

2.1. DIRECT DRIVE AC MACHINES

The use of direct drive synchronous AC machines for VAWT power conversion would require a machine of large diameter in order to accommodate the required poles and windings. For example, a 20-rpm machine would require 360 poles and 480 sets of windings. A machine with these specifications is not a standard product. However, hydro-generators turning at 80 rpm indicate that such a machine should be given consideration.

Based on the sizes of existing generators, a machine of the size given in Figure 5 would produce the required power at the 20-rpm speed of the VAWT.

The electrical machine that is used as a generator for a VAWT is generally used as a starting motor since VAWT's are not self-starting. Since a synchronous machine does not have good starting torque, the use of a low-rpm induction machine should be considered.

The induction machine stator windings are identical to those of the synchronous machine, but instead of rotating poles as on the synchronous machine, an induction machine could use the simpler squirrel-cage rotor. Besides being able to provide starting torque, the induction machine allows for some variation in turbine speed and should cost less to construct. The induction machine does not need the field control equipment required of a synchronous machine which is another indication of a possible cost savings.

2.2. DIRECT DRIVE DC MACHINES

The torque developed by a DC motor with permanent magnets (PM) depends on the flux, number of windings, armature current, and the physical dimensions of the machine. If the flux and armature current are constant, the torque, T, produced can be expressed as:

$$T = K_{PM} R^2 \ell$$

where R is the radius of the armature and ℓ is its length as shown in Figure 6. The constant K_{PM} for a PM-DC motor can be calculated from manufacturer's data and can have values exceeding 130,000 n/m². A machine to be used with a 500 KW VAWT is required to have a speed of 2 radians/sec in order to have an optimum value for the turbine's power coefficient. Based on the construction of present low-rpm machines and the above K_{PM}, a machine with a radius of 2.0 m and a length of .5 m turning at 2 radians/sec could be rated at 500 KW.

An illustration of this machine is shown in Figure 7. It is understood that many of the details of building such a machine must be worked out. Voltage and current levels must be determined, heat transfer problems solved, and shaft and armature mechanical stresses considered in the development of a direct drive DC machine.

3. CONCLUSIONS

Although the VAWT is not as efficient as a HAWT,[4] present research indicates it may produce electricity at a lower cost. The development of four identical 100-KW VAWT's by Alcoa[1] indicates that these machines will be able to produce electricity at around 5¢/kWh. The 17-meter VAWT at Sandia Laboratories has shown that the VAWT can operate successfully over a wide range of wind velocities.[5] With the current successes in hardware development and cost reduction, the VAWT is becoming an attractive wind energy conversion device.

REFERENCES

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5. Akins, Robert E., Performance Evaluation of Wind Energy Conversion Systems Using the Methods of Bins-Current Status, Technical Report SAND77-1375, Sandia Laboratories, available at NTIS.

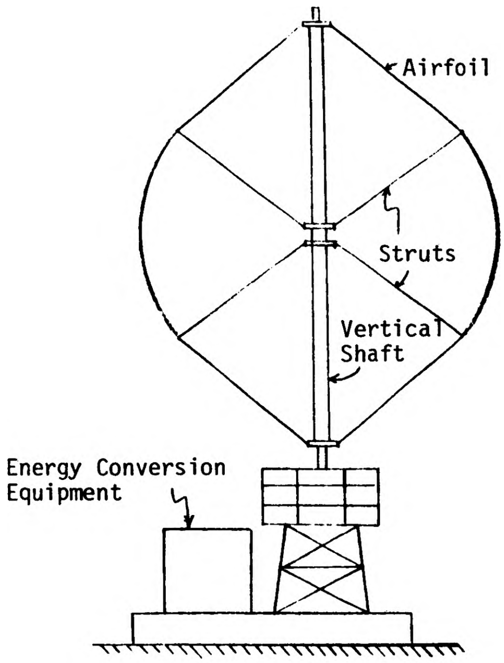

Figure 1. Vertical Axis Wind Turbine

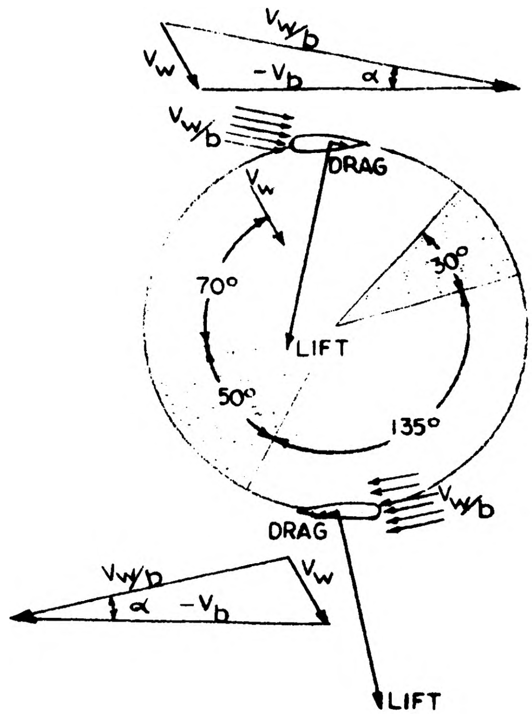

FIGURE 2

AERODYNAMIC FORCES ON A ROTATING AIRFOIL

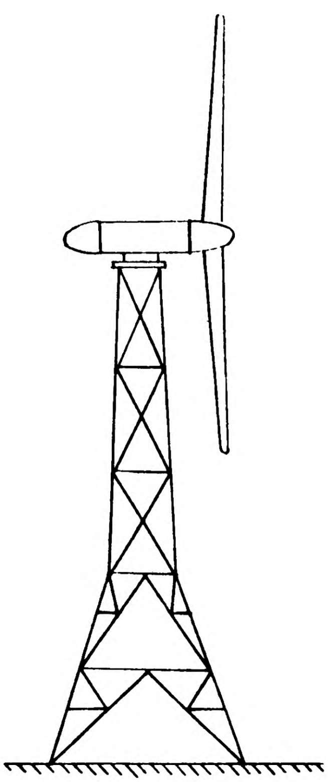

Figure 3. Horizontal Axis Wind Turbine

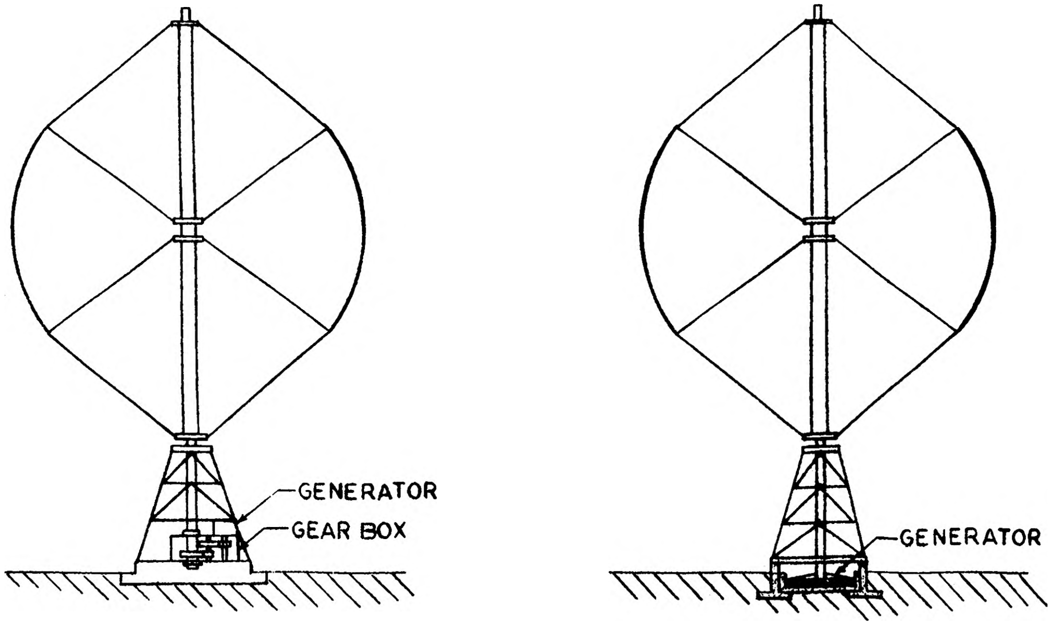

FIGURE 4

ENERGY CONVERSION SCHEMES

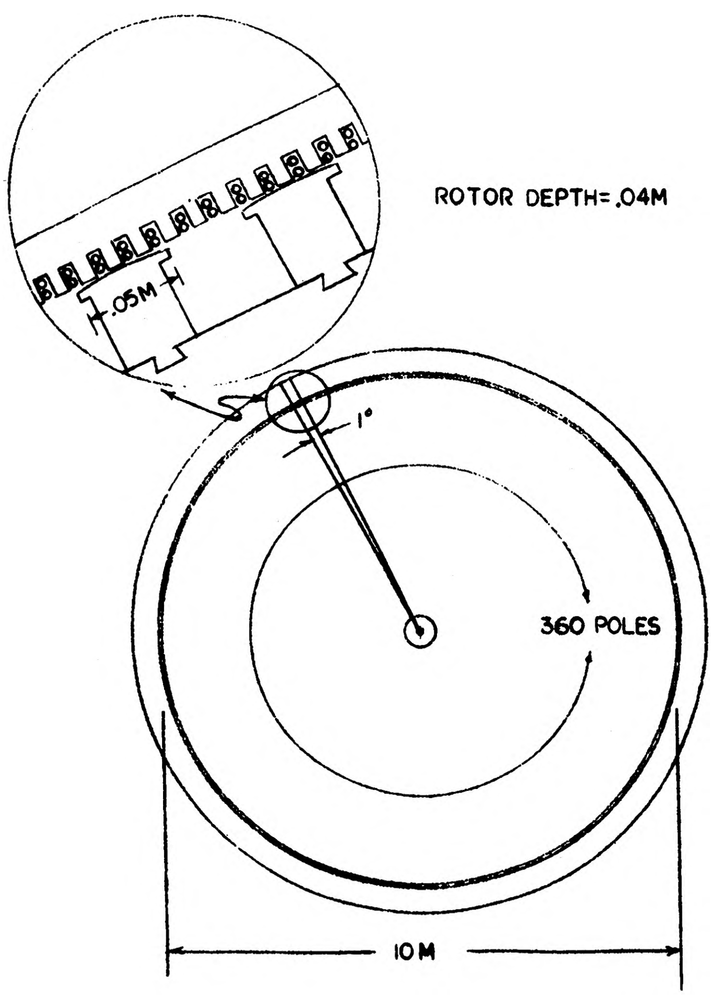

FIGURE 5

A C MACHINE DIRECT DRIVE

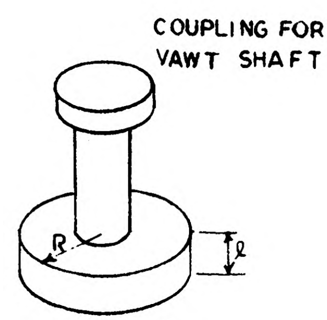

FIGURE 6

ROTOR DIMENSIONS OF PM-DC MACHINE

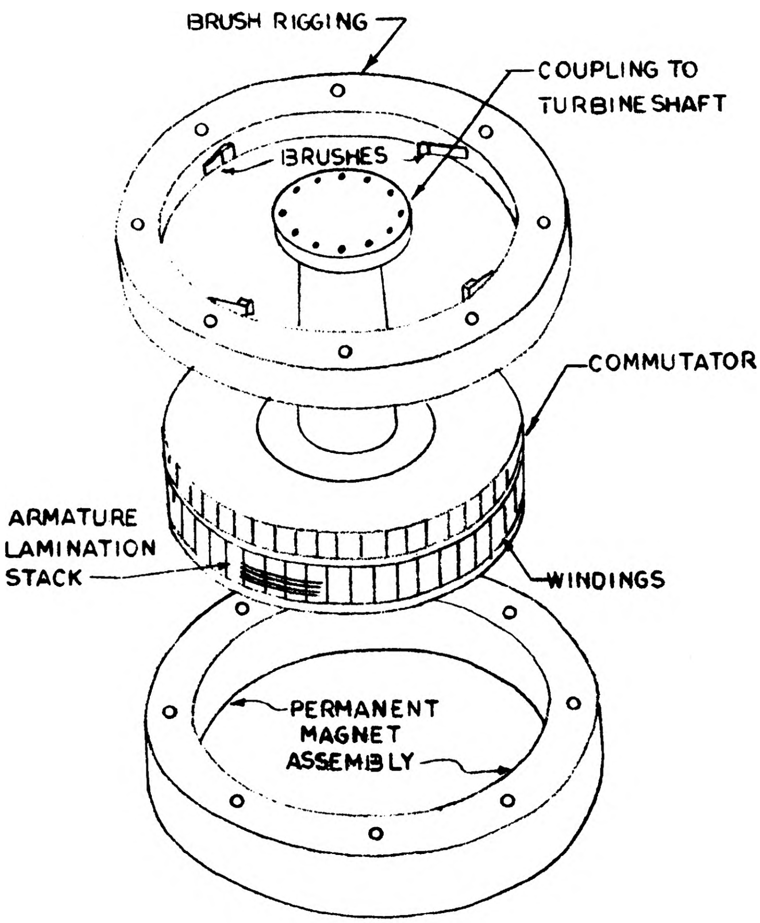

FIGURE 7

PERMANENT MAGNET DIRECT DRIVE
DC MACHINE