Portable Vertical Axis Wind Turbine

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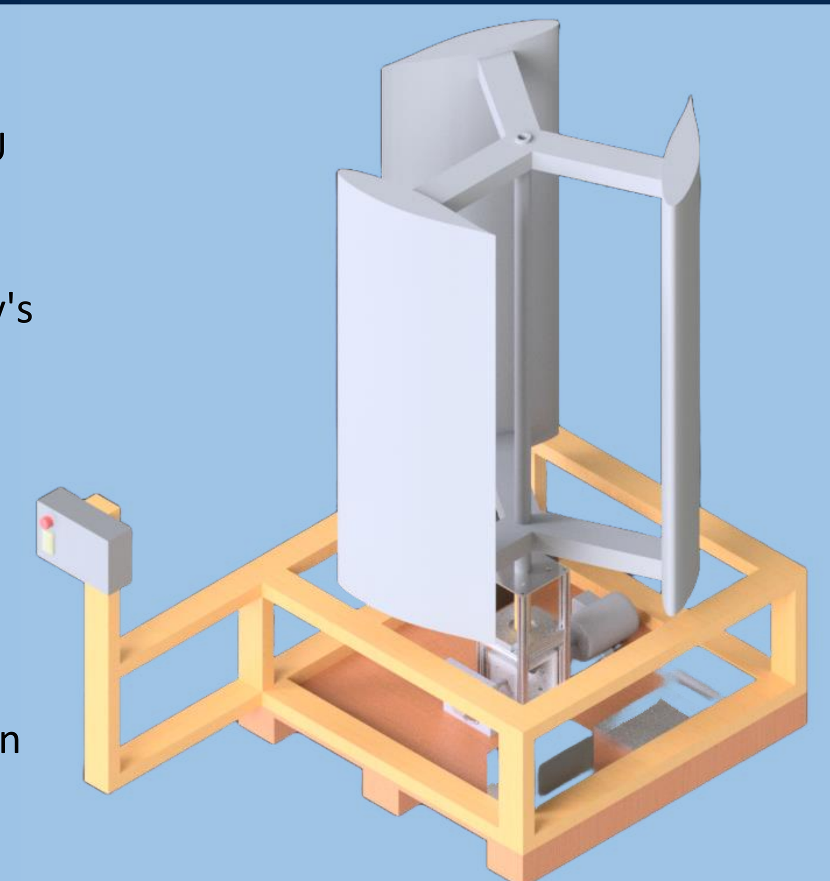
MOTIVATION & BACKGROUND:

PROBLEM:
Wind is an under-utilized method of generating electrical energy on the SNHU campus. This is a missed opportunity to harness a sustainable and renewable resource that could reduce the university's carbon footprint and energy costs



APPROACH:
A Vertical Axis Wind Turbine (VAWT) is designed to harness wind power and provide renewable electricity for low-wattage devices, promoting sustainable energy use and raising awareness of clean technology on campus.

Why a VAWT?
Two popular options for wind generation are vertical (VAWT) and horizontal axis wind turbines (HAWT). The VAWT was selected due to its smaller blade size, increased efficiency at low wind speeds, and omnidirectional capabilities. HAWTs in comparison require large diameter blades, fast and constant wind speeds, and directional air currents.

How does a VAWT generate electricity?
Force from the wind is converted to rotational force on the shaft by the blades. This rotation is transferred through the gearbox, to the generator. The generator converts the mechanical rotation into a 3-phase AC current. This is converted into 24V DC and stored in the batteries until power is required at the output, at which point the inverter provides 120V AC to the user.

How were the optimal RPM and blade angle of attack calculated for the VAWT to achieve 500W at 25mph wind speeds?
Knowing the necessary RPM to generate 500W at 25mph wind speeds is critical for the system design. This equation is used to calculate RPM:

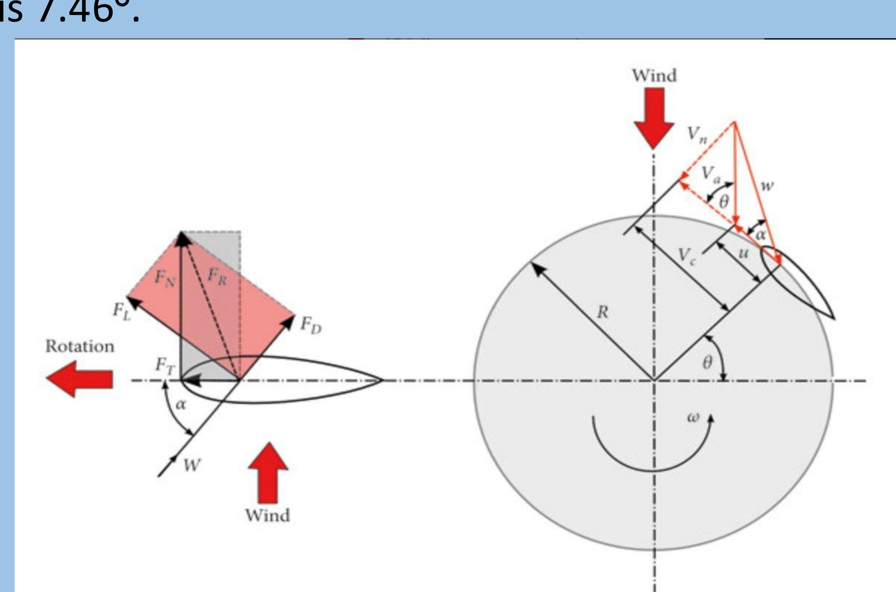
$$RPM = 60 * V_{wind} * \frac{\lambda}{\pi * d_{rotor}}$$

Where λ is the tip speed ratio (TSR), V_{wind} is the velocity of the wind, and d_{rotor} is the diameter of the rotor. The TSR was determined to be 2.95 through aeronautical analysis, the wind speed was 25 mph, and a rotor diameter of 2" was calculated through mechanical analysis. The necessary blade RPM calculated is 516 revs/min.

After the TSR was chosen, an airfoil angle of attack (A) could be calculated. The equation used is:

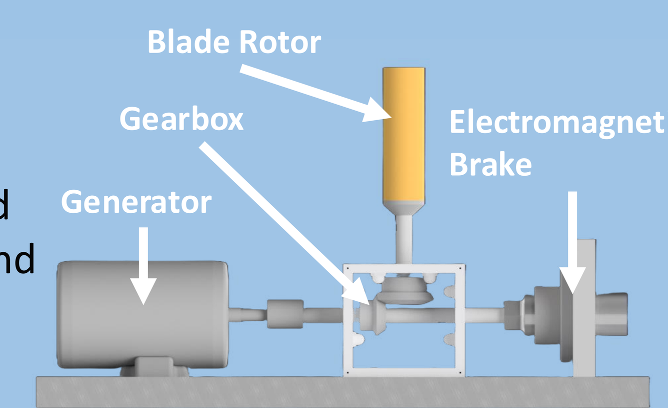
$$A = tan^{-1}\left(\frac{sin\theta}{\lambda + cos\theta}\right)$$

Where θ is the azimuth angle. The azimuth angle for the H-Rotor blades is 30°. The angle of attack calculated is 7.46°.



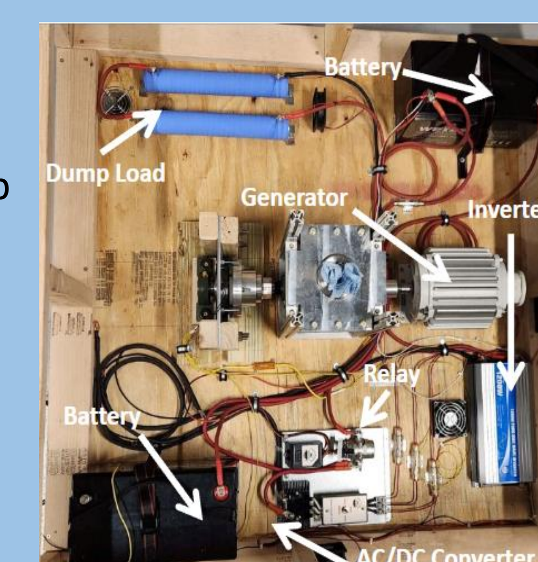
SYSTEM DESIGN:

MECHANCIAL SUBASSEMBLY:
A single-input, dual-output gearbox with bevel gears was chosen to be the centerpiece of the system. The input is the rotation of the blades, and connected to the two outputs are the generator and brake. The RPM of the blades correlates to the wattage produced by the generator



To meet the safety requirements an electromagnetic brake was added to the system. This brake was installed on one of the two output shafts of the gearbox and has two means of activation. The first means of activation is by hitting the emergency stop (e-stop) which is located on the UI and the second is via the installed encoder, which will trigger the brake when a pre-programmed RPM threshold is reached.

ELECTRICAL SUBASSEMBLY:
The image to the right shows the electrical components and their located within the system.



The 3-phase permanent magnet generator can produce up to 1.5kW of power. The output is 3-phase 24V RMS waveform is then efficiently converted to 24V DC by the AC/DC converter in the MPPT and stored in the batteries. Two 12V deep-cycle, lead acid batteries provide up to 200AHrs of storage.

The low passive consumption of the electronics ensures that the stored power is supplied to the user via the 1.2kW rated inverter. This ensures a long operating window for users to access the power stored in the batteries

USER INTERFACE SUBASSEMBLY:
The user interface enhances system safety by incorporating an e-stop to stop the blades in the case of an emergency.

A GCFI-controlled outlet allows users to plug devices into the system while maintaining a safe distance from the blades.

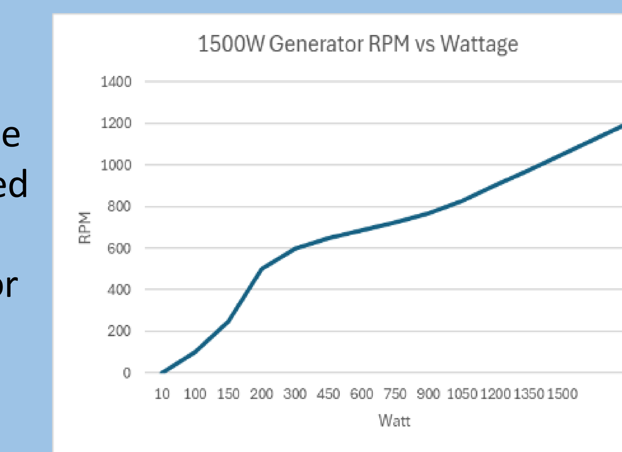
The power inverter output can be controlled by the user to disable and enable the output with the press of a button.

AERONAUTICAL SUBASSEMBLY:
The NACA0012 symmetrical airfoil was selected due to its higher maximum tip speed ratio than comparable airfoils. A symmetrical airfoil is used due to its generation of positive lift at both positive and negative angles of attack. The aspect ratio $\left(\frac{Blade\ Height}{Rotor\ Diameter}\right)$ for the airfoil was designed to be 1.25, which is a tradeoff of the higher surface area produced by low aspect ratios and the increased aerodynamic performance displayed in higher aspect ratios. The interior structure for the blades features wooden ribs and aluminum spars that are evenly spaced to distribute applied loads and prevent structural failure. The exterior structure includes a poster board shell covered in MonoKote that is wrapped around the inner structure to provide weather protection and produce the shape of the airfoil.

Airfoil	σ_{cpmax}	λ_{cpmax}	c_{pmax}
NACA 0012	0.3	2.95	0.43
NACA 0015	0.4	2.5	0.45
NACA 0018	0.4	2.54	0.51
NACA 0021	0.4	2.5	0.45
NACA 0024	0.5	2.2	0.51

EVALUATION & EVOLUTION:

TESTING:
RPM / Power Test
Verify the power module can produce the required output current to produce 500W at a rotor shaft speed of 516RPM



- Data Sheet
  - Low power generation credited to missed RPM requirement
  - The power generated at the acquired RPM lines up with the given data sheet

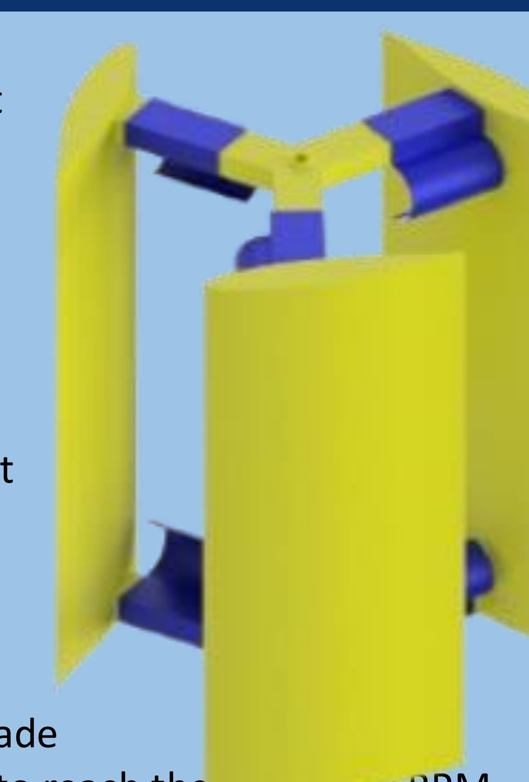
Wind Speed/RPM Calibration Test Results

Wind Speed	Expected RPM	Measured RPM
~25 MPH	516	105

Scan to see video of the modified blades

- Leaf blowers produced a more turbulent flow than wind
- Modifications to the blades were necessary to allow for the blades to spin with the leaf blowers
- Suboptimal blade design wouldn't allow the blades to achieve the proper RPM

FUTURE WORK:
A drawback of H-Rotor blades is their inability to self-start at low wind speeds. To alleviate the issue, a hybrid design that incorporates Savonius blades can be added. Savonius blades utilize drag, which will enable the system to rotate at low wind speeds. By adding these additional blades to the current design, the system will gain the ability to self-start at lower wind speeds while still maintaining the H-Rotors optimal power production at increased speeds.



With the current gearbox setup, a 1:1.5 gear ratio was initially sufficient to achieve the RPM required for the power generation targets. However, due to the original blade design not operating as intended, the system was unable to reach the necessary RPM. Increasing the gearbox ratio would help alleviate the issue by allowing the gearbox to translate slower blade RPM to faster generator RPM. The generator would then be experiencing higher rotational speeds at slower wind speeds.

The optimal angle of attack for the blades was not produced during the fabrication process and can be improved. While initial calculations called for an attack angle of 7.46°, the constructed angle of attack is currently 0 degrees, which produces less lift than the optimal angle of attack. Adjustments to the blade and connecting rod system could be made, with the front and rear connecting rods being cut to different final lengths before the welding process to produce the desired angle of attack. Another fix would be to redesign the wooden ribs to attach to the interior structure of the blades at the desired angle.

A redesign of the airfoil's outer structure can be improved to reduce skin friction drag. The poster board shell did not adhere well to the spruce ribs which caused bowing and poor skin quality. Future designs would include laser-cut slots on the exterior edge of the ribs for stringers to be mounted. This design change would increase the surface area at which the MonoKote skin can bond and produce a cleaner finish than the current design.

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