Horizontal Axis Wind Turbine with Electrolyzer for Hydrogen Energy Storage

by

Michael Rybalko

WIND POWER SYSTEMS
NPRE 475 – SPRING 2010
Prof. M. Ragheb

My contribution to the class project was with the Horizontal Axis Wind Turbine (HAWT) team. The main goal of this project was to utilize the pre-existing wind turbine constructed and improved upon by previous classes and demonstrate the implementation of an electrolyzer and fuel cell. In doing so, a viable solution to the intermittency of wind power could be demonstrated, with energy storage for subsequent use or transport with hydrogen serving as the energy carrier. Additionally, an improved, more nacelle-like generator housing was desired to improve the appearance, aerodynamics, and protection from the elements of the generator and associated cables. I participated in all three aspects of the project, but my main contribution was the generator housing sub-task. The majority of this work was performed with a fellow Aerospace Engineering graduate student, Adam Ragheb.

Given the time constraints for this project the hand-building of a nacelle was quickly rejected. Instead, the prefabricated fiberglass cowlings of radio-controlled model aircraft were deemed the optimal solution. Three such cowlings were purchased at a local hobby shop following measurement of the relevant wind turbine dimensions. Upon return to the lab all three were fitted and the optimal one quickly selected. The selected cowling offered the best fit and most complete coverage and protection of the rotor mount and generator. Also, the large air intake ports on the front and ample clearance around the generator offered sufficient cooling airflow and the cowling's appearance was deemed most appropriate – resembling that of a utility-scale wind turbine nacelle.

Installation of the nacelle was relatively straightforward but required modification to the existing design in order to ensure sufficient clearance and a secure mounting system. The original configuration is shown in Fig. 1, with the generator protected by a curved metal plate and secured with a mounting bolt and two nuts. These features would be retained and the housing mounted in addition to the metal mounting/cooling plate and restraint. Necessary modifications included chamfering of the steel frame along its front edges and drilling of bolt holes in the sides of the frame for securing the new housing. Chamfering was done with a hand saw and holes drilled with a power drill. In both cases, modifications were made away from critical welds for structural integrity and safety reasons. These steps are shown in Figs. 2 and 3. The generator was also moved slightly forward of its existing mounting position to further improve clearance. This was undertaken with great care to ensure the generator remained mounted securely and would not vibrate excessively or shift during operation. At this time the wind turbine was taken to the Engineering Quad for its first test run (without the cowling) and the generator mount was found to perform as expected with no evidence of shifting or loosening following over a half hour of run time.

Following the test run the housing installation was completed. It was secured to the frame with nuts and bolts on both sides of the frame, and fit snugly over the chamfered front edges. Some material had to be trimmed from the underside of the cowling to ensure proper clearance around the metal support. Care was taken to ensure the housing's rotor shaft hole was centered relative to the rotor shaft and sufficient clearance provided to mount and remove the rotor and secure its two set screws (this can be done with a ball-hex key). The sleeve bearing on which the frame is mounted had to be moved up by roughly ½ inch to resolve clearance issues between the underside of the housing and the wooden pole and ensure unimpeded yaw motion. Both locking collars were moved and secured in the new positions. The finished assembly is shown in Fig. 4.

I also participated in the remaining two aspects of the project. First, the aforementioned test of the turbine at the Engineering Quad (before the housing was fitted) was intended to obtain data regarding turbine and generator performance as a function of wind speed. An anemometer and multimeter were used to acquire generator output voltage as a function of wind speed. These are illustrated in Figs. 5 and 6. During this testing I performed the role of the yaw mechanism via the chain attached to the turbine's rudder – ensuring everyone's safety by keeping the rotor perpendicular to the wind direction until everything was ready and everyone had stepped back and away from the rotor arc, where debris from a potential blade ejection or other failure could have been thrown. Given the variable and gusting wind a rather large range of voltage values were readily obtained, with a peak around 33-35 V. These "voltage curve" data were recorded by another student for plotting and further analysis. It was determined that a transformer would be required since the electrolyzer (selected and ordered in the meantime by the team leader, Pi Zonooz) required an input voltage of only 12 V.

During another meeting the electrolyzer was assembled (Figs. 7 and 8) and filled with NaOH electrolyzer solution. A solution strength of 10% the recommended value was given in the manual was used due to concerns about the extremely high concentration recommended. Also, NaOH was utilized rather than the suggested KOH due to availability. Neither of these modifications were found to be an issue. Since a transformer to step down the wind turbine generator's voltage was not yet obtained, and there was no wind regardless, a 13 V battery was used to test the electrolyzer, using a breadboard and several resistors to reduce the voltage to the recommended 12 V. (In the spirit of the project and an implicit completion of the circuit this battery was also charged by a wind turbine, the VAWT team's Savonius.) Following some trial and error with correctly identifying and securing the hydrogen and oxygen output lines a small plastic water bottle was used to collect hydrogen gas. This was subsequently ignited with a lighter to verify that hydrogen was indeed present, and a loud pop confirmed the assertion. At this point both the wind turbine/generator and battery/electrolyzer have been successfully tested. In order to connect the systems, however, an as-of-yet unavailable transformer was required and so only this disjoint mode of operating the components could be demonstrated.

A small hydrogen/oxygen fuel cell (Fig. 9) was also ordered by the team leader, Pi Zonooz. The last component in the setup, the aim of the fuel cell was to recombine hydrogen and oxygen produced by the wind turbine-powered electrolyzer and recover the energy in the form of electricity. The fuel cell was hooked up to the electrolyzer output and ran in oxygen mode, where pure oxygen is supplied from the electrolyzer as opposed to using atmospheric oxygen. This allowed for power production of 0.62 V across the fuel cell terminals at steady state. Again, the electrolyzer was powered by a battery during this test due to the lack of a suitable transformer. It was unfeasible to create a step-down voltage circuit because too much power would need to be dissipated, which could not only lead to overheat but would also waste a large portion of the power produced. No suitable transformer was found given the time constraints.

The project was successful in achieving all but on goal – the direct coupling of the turbine/generator with the electrolyzer/fuel cell. All other links in the system were tested successfully: the wind turbine delivered measurable voltage, and electrolyzer hooked up to a battery generated hydrogen and oxygen which in turn powered the fuel cell and generated usable voltage. The obvious next step is to construct or purchase a suitable transformer to complete the link. Alternatively, an electrolyzer with a higher voltage tolerance may also be a viable solution. Also, it is important to note that in a real application the hydrogen would be stored for later use rather than used directly, so the natural break in the chain is between the electrolyzer and fuel cell, allowing the hydrogen to be used as an energy carrier. These issues may be addressed by a future class project. Given the ambitious goals of the project the successful operation of all requisite components (except the transformer linking the generator to the electrolyzer) is still a worthwhile achievement and proves the viability of the underlying concept.

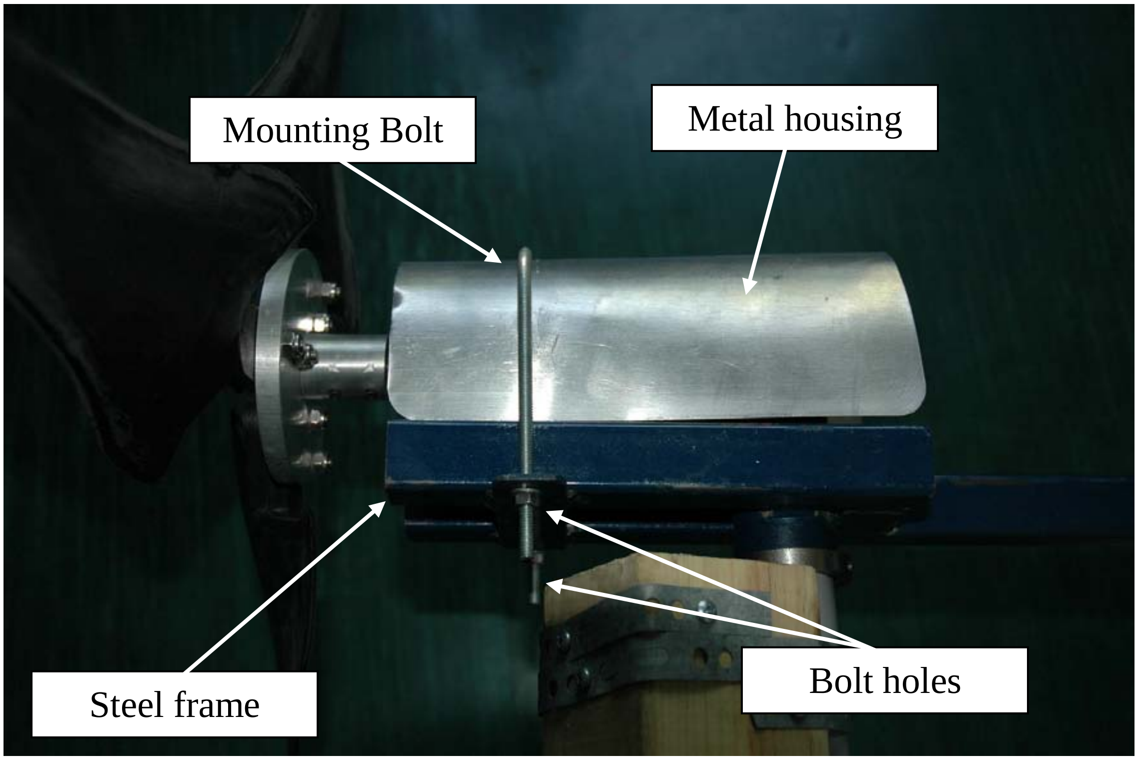

Fig. 1: Unmodified generator mount and housing.

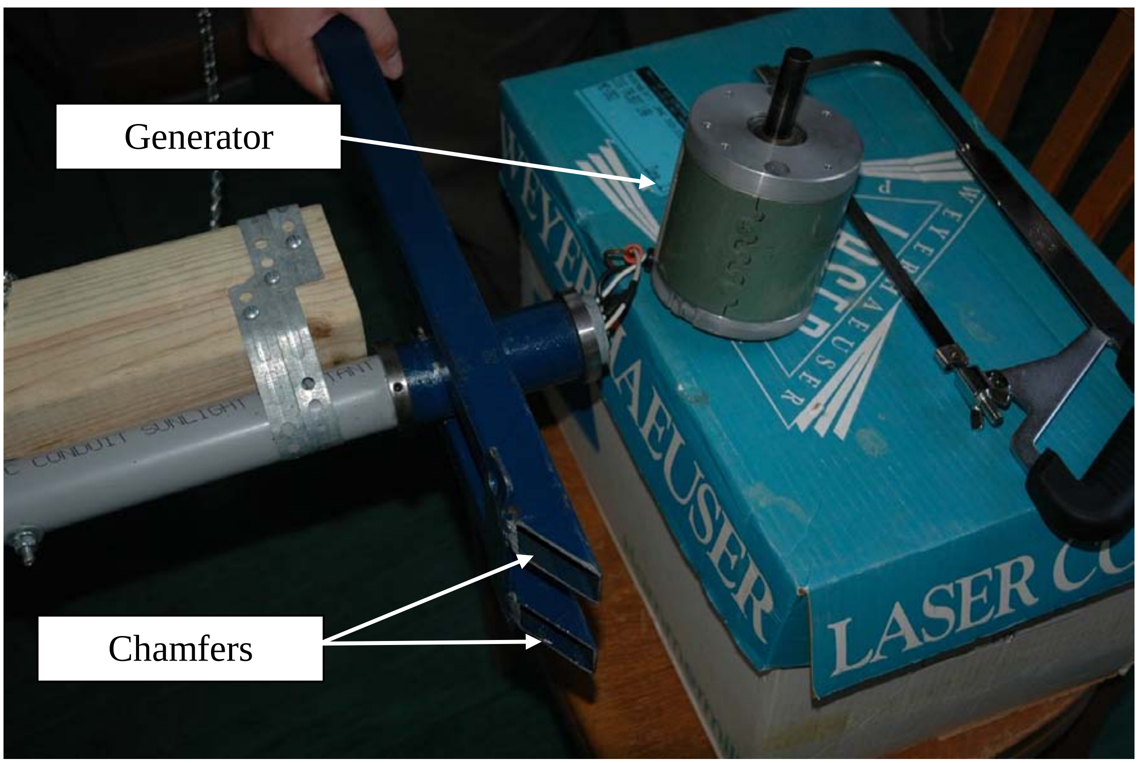

Fig. 2: Chamfer modification for nacelle clearance.

Fig. 3: Drilling of nacelle mounting bolt holes in frame.

Fig. 4: Finished nacelle installation.

Fig. 5: Installed turbine and anemometer for wind speed vs. generator voltage measurements (I'm holding the "yaw mechanism" chain).

Fig. 6: Multimeter used for generator output voltage readings.

Fig. 7: Electrolyzer system prior to assembly.

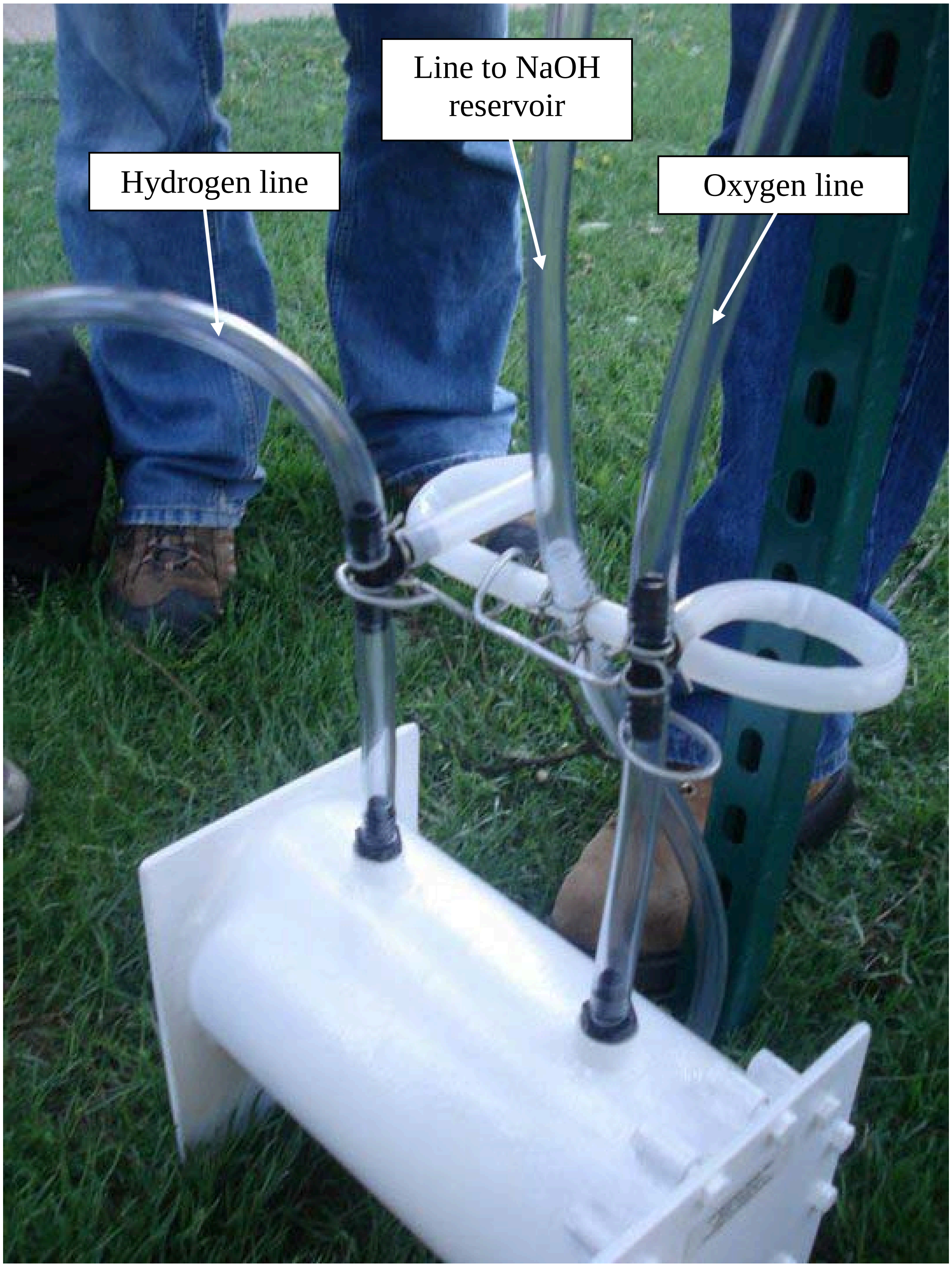

Fig. 8: Assembled electrolyzer filled with NaOH electrolyte solution.

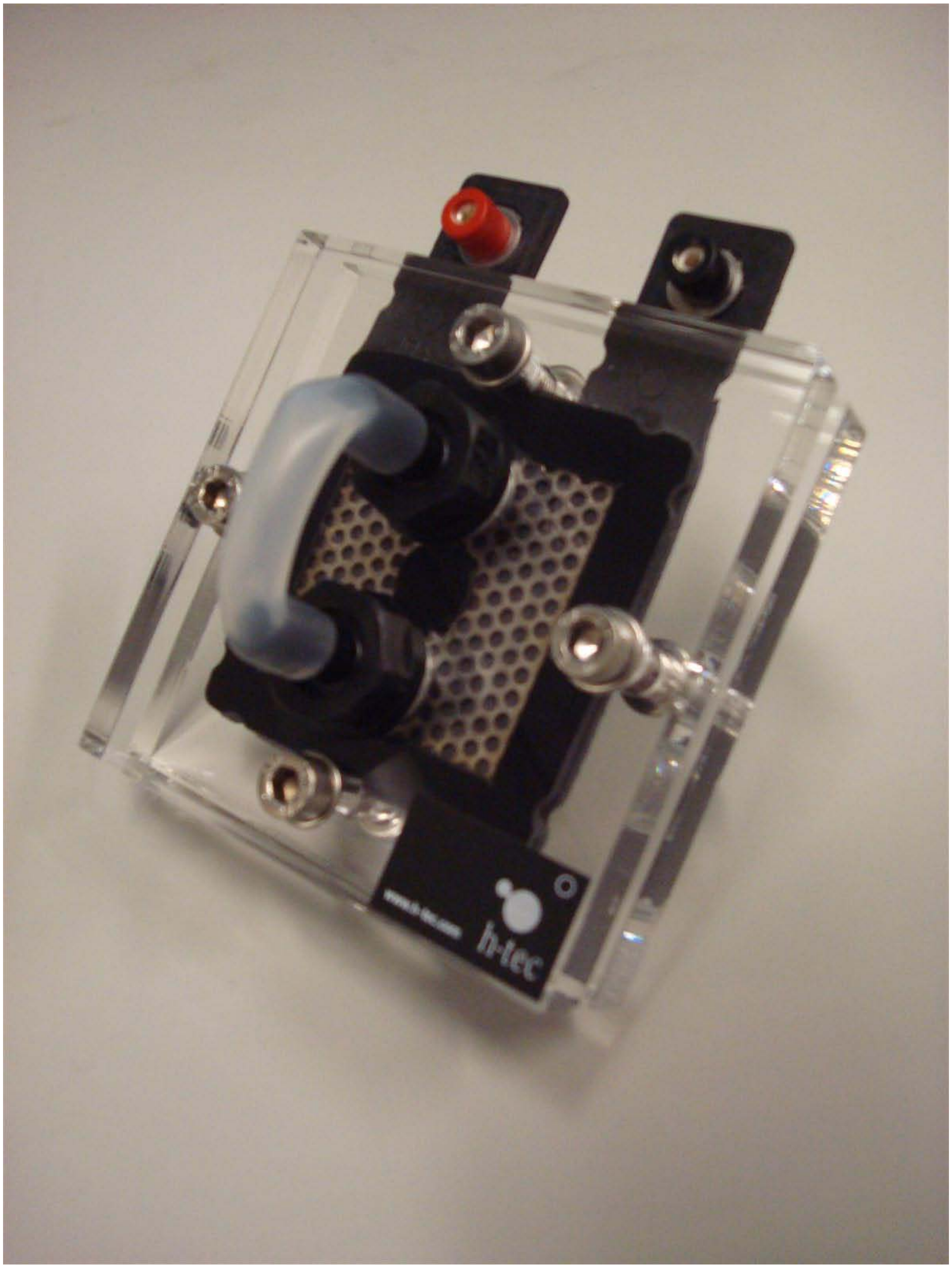

Fig. 9: h-tec hydrogen/oxygen fuel cell.

Component Summary:

Blades:
Three blades, each 24 in long.

Generator:
Ametek
Technical Motor Division based in Kent, Ohio
Serial Number - 965922-102 Rev. 10
01A (E110195) 116868-00
38 V.D.C. Nominal
Peak Current Rating: 12 Amps MAX
The generator is 4.5 in long, 4 in diameter.

Electrolyzer:
Electrolyzer purchased from Hydrogen Wind Inc.
No model number or serial number.
Capable of peak output of 0.5 gallons of hydrogen in 1 hour.

Fuel Cell:
F107 PEMFC Kit (Proton exchange membrane fuel cell)
Dimensions: Height of 90 mm, width of 80 mm, depth of 78 mm
Weight: 225 g
Electrode Area: 16 cm2
Power: Air mode - 200mW
Oxygen mode - 600mW
Generated Voltage: 0.4 to 0.96 VDC