

FESC Phase 2 Technology Commercialization

Development of a Low Cost Concentrating Solar Energy System Using Solar Sausages

PI: David Van Winkle, Sean Barton - Florida State University

Industry Partner: Hunter and Harp Holdings (HHH)

Beginning in late 2010, weekly meetings have been held at HHH offices in Tallahassee that include representatives of the several entities involved in deploying the “Solar Sausage” concentrating system at the Yulee St. site in Tallahassee. The entities include Pro Solar Inc., Barkley Consulting Engineers Inc., Winton Engineering PA, and Applied Research and Design Inc. A series of 50-foot long prototype sausages were made and inflated on site. Many issues were identified that needed to be resolved before manufacturing and deploying several hundred solar sausages on site including methods of constructing, mounting, and operating the balloons, distribution of air and electricity, and removal of heat.

Specific accomplishments:

- We have identified the correct adhesives for bonding the PET polyester films to each other and the correct bond geometry for minimizing the peeling stresses on the adhesive.
- We have designed and partially built the actuation system for rotating the balloons to track the sun.
- We have streamlined the process of producing the balloons such that a team of 16 workers can produce about 1 balloon per hour. Currently 150 of 336 balloons have been produced. While our current manual process produces balloons of 50-foot length, HHH is investing in machinery that will produce balloons of continuous length, to be cut to the length desired. This will reduce the number of "balloon ends" in the final application. Balloon ends are undesirable from the standpoint of electrical distribution, air distribution, solar-tracking actuation, and optical end effects.
- We have designed and are generating the software required to control absolute pressure in the balloons, to control differential pressure between the compartments of the balloon to maintain the optic, and to make astronomical predictions and control the rotation of the balloons. (Specifically, an FSU led portion of the project – resulting in an in-kind cash match from HHH to FSU to purchase instrumentation from National Instruments for this part.)
- We have developed procedures for mitigation of damage during high-wind and catastrophic-wind events which include increasing the pressure in the balloons, securing the photovoltaic modules with a tensioned retainer cable, and (if time allows) removing the photovoltaic modules.
- We have identified the need for photovoltaic material with greater concentration ratios.
- We have identified a variety of alternative methods by which the balloons could be rotated to track the sun.
- We have identified several of these scenarios that eliminate the need for counterweights.
- In the future, with higher concentration PV material and longer balloons, costs may be scientifically reduced using the centralized-elevated-receiver concept.

As can be seen in the accompanying photographs, the project is well along in terms of deployment of the technology on the Yulee St. site.

The project has involved full and part-time employment of approximately 100 individuals over the last 8 months doing construction, site development, and manufacturing.



VIEW OF THE YULEE ST. SITE FROM THE NORTH EAST CORNER



FIRST FULL-SIZED INFLATABLE MIRROR



PLANT STREET FACILITY FOR PRODUCTION OF THE BALLOONS



GLUE MACHINE APPLYING GLUE TO REFLECTIVE MEMBRANE



REHEATING THE GLUE TO BOND THE MEMBRANES TOGETHER



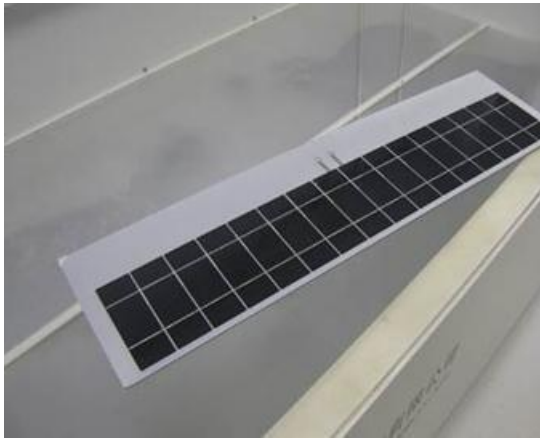
THE SOLAR SAUSAGE FORMING AND GLUE MACHINE



LOAD-ADHESION TESTING OF A 50-FOOT BALLOON



A 50-FOOT BALLOON



ENCAPSULATED PHOTOVOLTAIC CELLS



STREET VIEW OF THE YULEE ST. SITE FROM THE EAST

Stress Evolution in Solid State Li Ion Battery Materials

PI: Kevin S. Jones – University of Florida

Student: Nick Vito (Ph.D.)

Industry Partner: Planar Energy

The goal of this work is to understand the structure property relationship of cathodes being developed for solid state Li ion batteries. In conjunction with Planar Energy, various cathodes were supplied with the compositions of $\text{LiMn}_{1-x-y-z}\text{Co}_x\text{Ni}_y\text{Al}_z\text{O}_2$ ($x+y+z \leq 0.30$) using the streaming protocol for electroless electrochemical deposition (SPEED). SPEED is a non-vacuum fabrication technique that enables the development of nano-particle based materials at low cost.

All cathodes received have a crystal structure based off the $R\bar{3}m$ space group. The space group is shared by LiCoO_2 and is described as alternating layers of Li and transition metals (Mn, Ni, Co, and Al) separated by oxygen layers in a close packed lattice. The crystal structure was revealed by x-ray diffraction using a Philips Xpert MRD and selected area diffraction (SAD) using JOEL 2010F TEM with the results shown in figure 1. Energy dispersive x-ray spectroscopy (EDS) confirmed the elemental composition of the cathodes with respect to the transition metals. Each cathode of the type $\text{LiMn}_{1-x-y-z}\text{Co}_x\text{Ni}_y\text{Al}_z\text{O}_2$ varied by less than 10% in Mn, Co, Ni, and Al from the theoretical composition.

The result of spraying the cathode onto a steel surface leaves a film that is 2 - 5 μm in thickness with occasional mounds reaching heights of 30 μm . The film and mounds are porous, allowing the electrolyte to reach a larger surface area of the cathode. A cross sectional secondary electron (SED) image reveals three phases. The phase with the darkest contrast relates to the porosity, which was back-filled with an epoxy in order to isolate a single plane. The remaining phases relate to the cathode. The evolution of the cathode from the steel surface to the height of the film is shown in figure 2. The porosity of the sample, $\text{LiMn}_{0.7}\text{Al}_{0.3}\text{O}_2$, is approximately 50% throughout the film. Using transmission electron microscopy (TEM), the structure of the cathode includes both nanoparticles on the order of 5 - 10 nm in size and larger crystalline grains greater than 250 nm in size from figure 3. These different particle sizes are thought to make up the regions of varying contrast in the cathode which are otherwise chemically identical.

The electrochemical properties of the $\text{LiMn}_{1-x-y-z}\text{Co}_x\text{Ni}_y\text{Al}_z\text{O}_2$ cathodes were tested in half-cell configurations. Figure 4 shows the efficiency of the half-cell batteries along with the capacity fade over 50 cycles between 3 – 5 V at 75 $\mu\text{A}/\text{cm}^2$. This sample is $\text{LiMn}_{0.7}\text{Ni}_{0.1}\text{Co}_{0.2}\text{O}_2$ and was sintered under O_2 at 923 K for 10 minutes. While the efficiency of the charge/discharge times of the cells vary between 80-100%, the capacity fade follows a more consistent pattern. After 50 cycles, 70-75% of the total capacity is accessible at a charge rate that varies between 1.5C and 2C. Improvements in the capacity fade are being sought through varying the composition of the film and alternate annealing cycles.

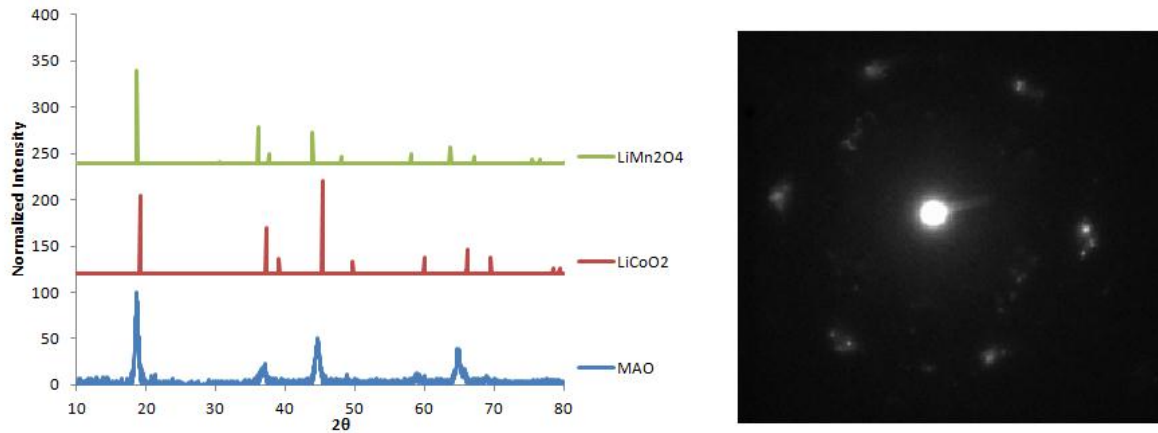


Figure 1. (Left) XRD pattern of LiMn_{0.7}Al_{0.3}O₂ (MAO) compared to LiCoO₂ and LiMn₂O₄, (Right) SAD pattern of a MAO crystal showing hexagonal symmetry

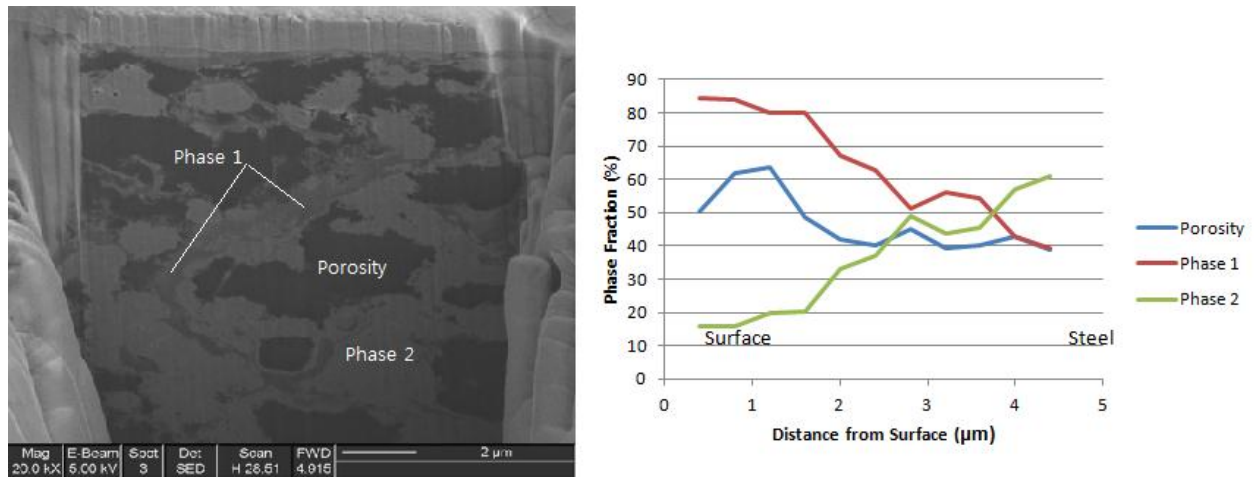


Figure 2. (Left) Cross-sectional SEM image depicting three phases in LiMn_{0.7}Al_{0.3}O₂, (Right) Phase fractions mapped from surface to steel substrate interface

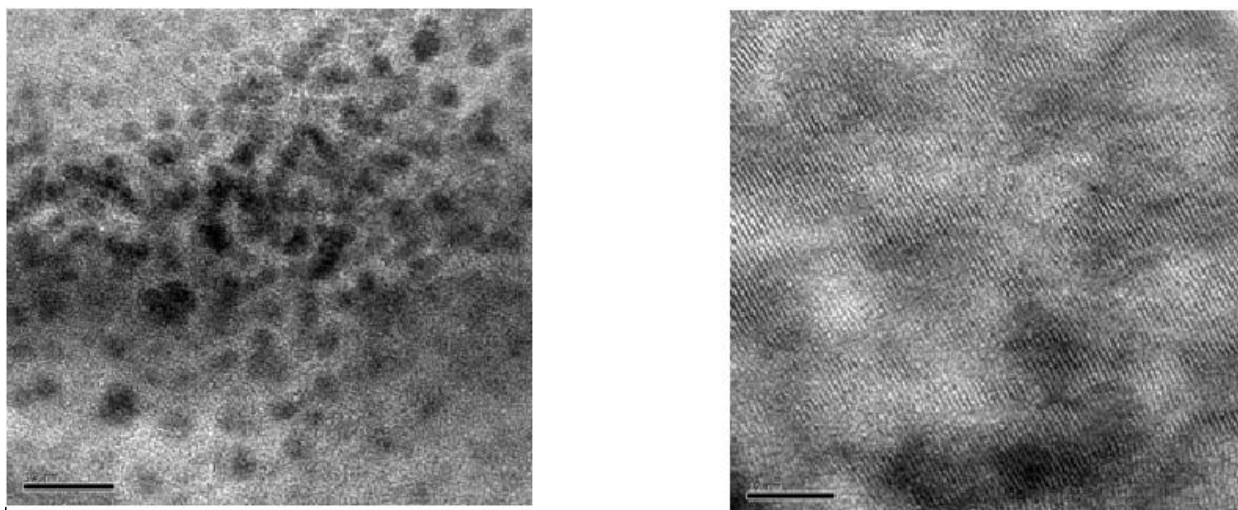


Figure 3. TEM images showing nanoparticles (left) and larger single crystal regions (right)

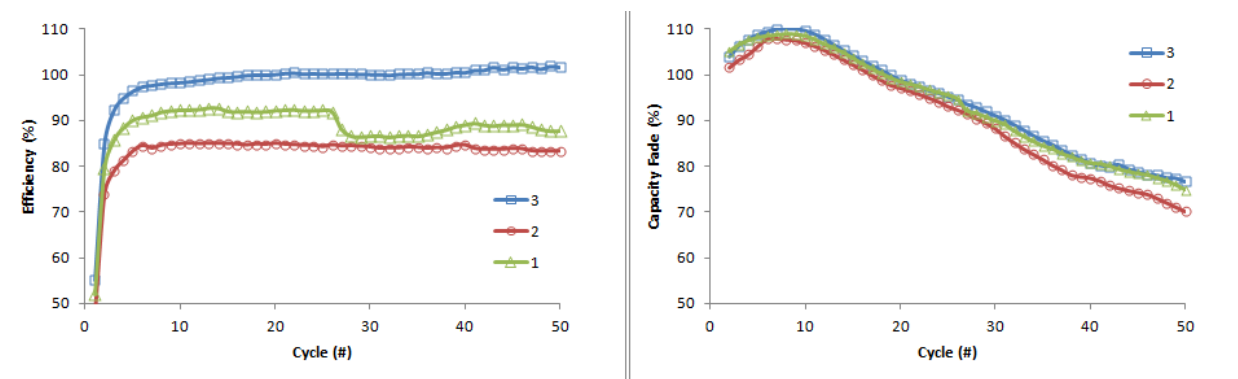


Figure 4. Plots showing discharge/charge efficiency (left) and capacity fade (right) over 50 cycles for 3 samples of $\text{LiMn}_{0.7}\text{Ni}_{0.1}\text{Co}_{0.2}\text{O}_2$



Nick Vito constructing a battery in the Glove Box at UF

SWNT Based Air Cathodes for Fuel Cells & Metal Air Batteries

PI: Andrew G. Rinzler – University of Florida

Industry Partner: nRadiance LLC

The goal of this project is to develop and use novel gas diffusion oxygen reducing electrode (air cathode) based on single wall carbon nanotube (SWNT) films in zinc-air batteries and fuel cells. Metal-air batteries, utilizing surrounding air as an inexhaustible cathode material have the highest specific and volumetric energy density of any primary battery system available. Gas diffusion oxygen electrodes, where molecular oxygen is electrocatalytically reduced, are vital to battery and fuel cell performance. The air cathode should be permeable to air or another source of oxygen, but must be substantially hydrophobic so that electrolyte will not leak through it, and have an electrically conductive element connected to external circuitry. Generally, conventional air cathode is a thick multilayer film comprising carbonaceous powder mixed with nanoscale metal catalyst to promote oxygen reduction and hydrophobic polymer additive pressed onto electrically conductive layer. While noble metals such as platinum that are commonly used as catalysts in conventional air cathodes offer the advantages of intrinsic catalytic activity, their deficiency in resource, high costs, and susceptibility to catalyst poisoning, have become a serious concern for commercial applications. An optimized SWNT based air cathode catalyst that would constitute a significant improvement in existing technologies is being developed. This new system avoids precious metals, is not poisoned, is thin, light-weight, and resists electrolyte flooding.

Findings to date indicate that the catalyst being developed is competitive with platinum in terms of its oxygen reduction activity in alkaline and neutral pH environments. This makes it suitable for a broad range of power generating devices including alkaline fuel cells, enzyme based biofuel cells, microbial fuel cells, micro-fuel cells, small direct methanol fuel cells and advanced metal-air batteries.

Our findings will contribute to making fuel cells economically viable and permit broader implementation of long lived sources of portable power. Platinum is costly because of its actual scarcity on Earth versus its importance and utility in many chemical processes. It has been estimated that if the world's fleet of 500 million internal combustion vehicles were converted to fuel cell power plants using platinum catalysts (what is used in today's fuel cells) the world's supply of platinum would be exhausted in only 15 years (even with recycling). This is perhaps the biggest roadblock to a viable hydrogen economy.

Our work involves single wall carbon nanotubes which are themselves costly in today's market. The difference compared to platinum however is that this is not due to any scarcity of carbon from which nanotubes are made but rather because the motivation for their bulk manufacture (and attendant economy of scale) has been lacking. Our finding may change that equation.

Since patent is pending on this work, detailed report will not be provided.

Examples of applications: Metal-air batteries and fuel cells generate clean, reliable energy for transportation, stationary and portable applications such as:



Low/zero-emission vehicles, spacecraft etc.



Portable electronics



Residential/business back-up power generators

Uni-Directional Impulse Turbine for the Powering of Offshore Monitoring Systems

PI: Zhihua Qu **Co-PI:** Kuo-chi Lin – University of Central Florida

Student: Carlos Velez (Masters)

Industry Partner: Harris Corporation

Description: Numerical modeling and experimental testing of turbine for wave energy conversion. The University of Central Florida and Harris Corporation have joined efforts to design, build and analyze a wave powered abandoned oil well monitoring system for use in the Gulf of Mexico. This system proposes a fully automated oil leak detection system which is self-powered by the local ocean energy which is converted to electricity, conditioned and sent from the surface buoy to the ocean floor to supply power for an abandoned oil well monitoring system.

Progress Summary

The University of Central Florida and Harris Corporation have joined efforts to design, build and analyze a wave powered abandoned oil well monitoring system for use in the Gulf of Mexico. This system proposes a fully automated oil leak detection system which is self-powered by the local ocean energy which is converted to electricity, conditioned and sent from the surface buoy to the ocean floor to supply power for an abandoned oil well monitoring system.

This project was split into four different components which were completed by four UCF senior design teams; three of the teams were chosen from last year's Mechanical Materials and Aerospace Department (MMAE) senior design class and the fourth team was chosen from the electrical engineering senior design class. The project was split into two major components, the first one being the design, construction and testing of a fully automated and battery powered oil well monitoring system. The second component focuses on the conversion of wave motion into electrical energy which is used to power the sensor battery system. Each of these two major components has been undertaken by two teams. In order to summarize the joint efforts contributed by each team a brief description of each team's goals and accomplishments is given below. A more indebt description of each team is provided after this summary.

In order to provide a monitoring system for abandoned oil wells a mechanical senior design team designed, tested, and built a fully powered and automated oil detection system for end users such as the EPA. The system acts like a cap to be installed on the top of all abandoned oil wells. The cap is shaped like a nozzle, which forces any leaking oil from the well to flow out through the nozzle and through a channel were a series of sensors detect for the presence of oil.

Since ocean waves provide an intermittent and inconsistent source of energy a smart energy converter was needed to convert, condition, and supply consistent power to the sensor system. For this purpose an electrical engineering team created a black box electrical unit which was made in four parts: Input Circuit, DC-DC Converter, Battery Charge Controller, and Microcontroller.

In order to provide electrical energy for the monitoring system a unique uni-directional impulse turbine was designed, built and tested. The team made the design schematics which were built by the HARRIS Corp. through the use of their rapid prototyping machine. The experimental testing resulted in 44% turbine efficiency for the optimal flow coefficient.

In order to house the turbine and generator system a mechanical engineering senior design team designed, built and tested a floating buoy which was acted as the link between the ocean wave motion and the impulse of air flow through the turbine section. A quarter scaled buoy was constructed and was hydrodynamically stable in all of the field tests.

2011 Annual Report

Along with the work of the senior design teams, graduate student Carlos Velez has conducted research in the modeling of a uni-directional impulse turbine for wave energy conversion. He has created a analytical model and a 3-dimensinal viscous CFD (computational fluid dynamics) simulation to predict the performance of the turbine for a range of flow coefficients. An illustration of turbine is shown below in figure 1.

The CFD simulations and numerical model are in agreement with the findings in the literature and experimental results. The validated simulations are used to find the key losses in the turbine passage in an attempt to increase the efficiency over a larger range of flow coefficients. Since this turbine is used in an oscillating wave column there exists no set design point, this requires the turbine to function efficiently in a large range of flow coefficients. For most of the non-ideal flow coefficients large flow separation can be seen at the trailing edge of turbine. To counter this affect the use of injection jets on the rotor blade has been used to create regions of low pressure on the rotor surface. This process is energy friendly as it uses the pressure difference which already exists in the oscillating wave column chamber to drive air through the turbine blades through small holes at large velocities. The results of the injection simulations are very promising.

The injection system considerably reduces the amount of flow separation occurring across the rotor blade and an increase in efficiency is encountered across the entire flow regime. The results show an average of 6% increase across the entire range of flow coefficient with highest increases in efficiency (12%) occurring at flow coefficients above unity. A comparison plot of efficiency with and without injection is show below in figure 2.

To extend the research beyond simulations a new set of senior design projects have been initiated with the construction of a full scale uni-directional impulse turbine and bi-directional wind tunnel which will replicate the air flow encountered in an oscillating wave column.

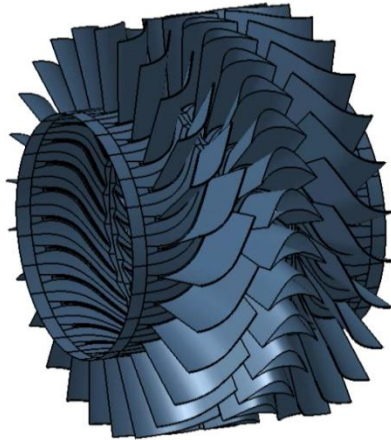


Figure 1. Turbine Schematic

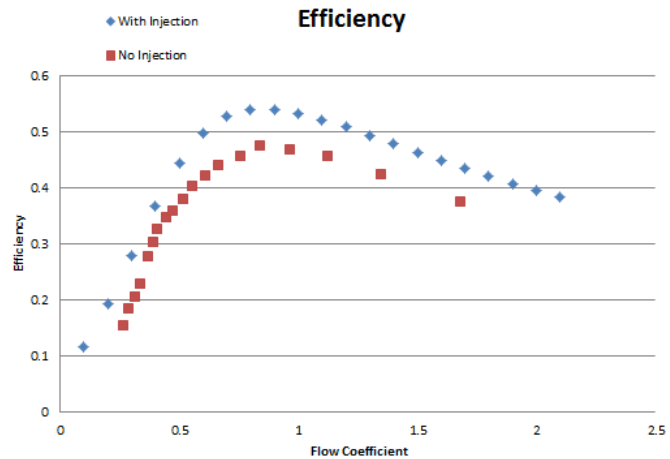


Figure 2. Turbine efficiency with and without injection

To detail the work contributed by each of last year’s senior design teams the following section will describe the process and findings for each senior design project.

Sensor Team Summary

In order to provide a monitoring system for abandoned oil wells a mechanical senior design team designed, tested, and built a fully powered and automated oil detection system for end users such as the EPA. The system acts like a cap to be installed on the top of all abandoned oil wells. The cap is shaped like a nozzle as seen in figure 1, which forces any leaking oil from the well to flow out through the nozzle and through a channel where a series of sensors detect for the presence of oil.

Various sensors were considered for this task, the team concluded that the use of a fluorometer and pressure sensor would work best for detecting the presence of oil. The fluorometer is an electronic sensor which can detect the presence of oil in water through the use of the luminescent properties of oil. The second sensor is a pressure transducer which can detect the presence of oil in the configuration designed by this group by detecting a pressure drop. Minimal power is consumed by each of these sensors with total power consumption equal to about 360 mW. The final requirement to be able to wirelessly transmit the signal produced by the fluorometer and pressure transducer was accomplished through the use of a product called a Wi-Ranger. The actual oceanic design consists of the two sensors and a data acquisition system which would be attached to the funnel design which would encapsulate any leaking oil from an abandoned oil well. The data acquisition system, which is housed in a hermetic electronics enclosure, would convert the signal from the sensors into a useable and interpretable signal. A wire from the data acquisition system would be connected to the buoy, which also provides the power for the sensors, on the surface of the water where the signal could be transmitted wirelessly.

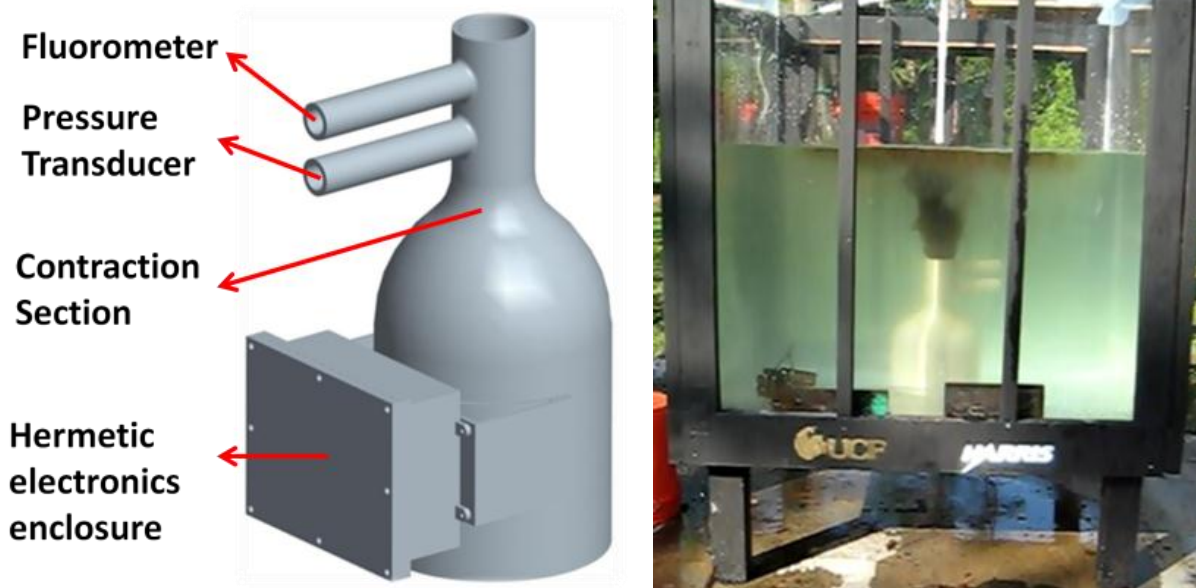


Fig 3. Illustration of funnel design and experimental testing of funnel prototype

Electrical Team Summary

Since ocean waves provide an intermittent and inconsistent source of energy a smart energy converter was needed to convert, condition, and supply consistent power to the sensor system. For this purpose an electrical engineering team created a black box electrical unit which was made in four parts: Input Circuit, DC-DC Converter, Battery Charge Controller, and Microcontroller.

According to the specs given by the turbine team, the generator would produce about 0VAC (assuming no wave conditions) to 60VAC. This input was rectified by the Input Circuit via a full wave bridge rectifier. A large smoothing capacitor was then used to convert this full wave rectified signal to a DC signal. The output of this circuit was 0VDC to 56VDC. The DC signal then needed to be stepped down using a buck converter. A circuit for this purpose was used to convert the input DC voltage to a steady 15.6VDC for the Battery Charge Controller. A few components such as resistance and capacitance in the circuit can easily be changed in order to change the output voltage. It was decided to use a battery in order to provide constant power to the sensors. Hence, to charge the battery, a Battery Charge Controller circuit was made. This circuit ensured a high charging efficiency for the battery under various load conditions. The 15.6VDC from the DC-DC Converter Circuit was used as an input to the battery charge controller. The output of this circuit was a 13.8VDC which was then used to charge a 12V lead-acid battery. In order to maximize the power for any kind of wave conditions (heavy or calm), a PIC microcontroller was used to control the load distribution in the circuit for large or small power extraction based on the past history of the input signal. This smart system was designed to optimize overall power production and conversion efficiency. The control hysteresis is defined and controlled using C code which manages the charging conditions. The charging of the battery only takes place between 15VDC and 55VDC for undercharging and overcharging protection. This protects the battery by allowing the input signal to operate within safe parameters for the battery. Future work would involve implementing a power factor correction system which would optimize the generator load to reach optimal ranges of rotor RPM.



Fig 4. AC-DC converter and battery charging system

Turbine Team Summary

A mainly aerospace team was constructed to design, build and test a bi-directional turbine for use in a water medium. The team chose this turbine design based on its unique capability of rotating in a single direction independent of the fluid direction. This has obvious advantages in the ocean environment as the oscillating motion of waves can be a difficult motion to harness with typical mechanical systems. The team then sought out to design the turbine blade based on the previously documented dimensions. The blade number and arrangement was designed by the team based on several CFD simulations and analytical numerical models which simulate the performance of the turbine under various flow conditions. The team designed the blades through the use of the software SolidWorks and the design schematics were built by the HARRIS corp. through the use of their rapid prototyping machine. The first prototype consisted on the essential single rotor and double stator blade design along with a converging diverging nozzle which would help to accelerate the flow at the turbine and there for increase the power. The prototype was tested through the use of a 6 DOF motion platform located on campus, the turbine channel was submerged in a water tank and was rigidly fixed to the table. This allowed for the turbine to be plunged up and down inside the water tank to simulate the oscillating motion of the waves. The experimental data showed that the turbine was successful in spinning in a single direction regardless of the table/wave motion. The first prototype had an efficiency of 22%, which was low but agreed with the prediction found in the numerical model which was very important. Now that the numerical model had been validated an optimization scheme was implemented by the team. The team found that using the same turbine blades a new channel could be designed with a larger area ratio which would double the speed of the fluid at the turbine. Thus, the second channel prototype was built with a RPM with an inlet to channel area ratio of approximately four. The nozzle worked as expected by the model and the efficiency of the system increased to 44%. This was a very important factor which showed the designs capability to withstand and harness a wide variety of loads. The conclusion of the experimental and numerical analysis resulted in a system with high adaptability and large power consumption with minimal stresses acting on the system.

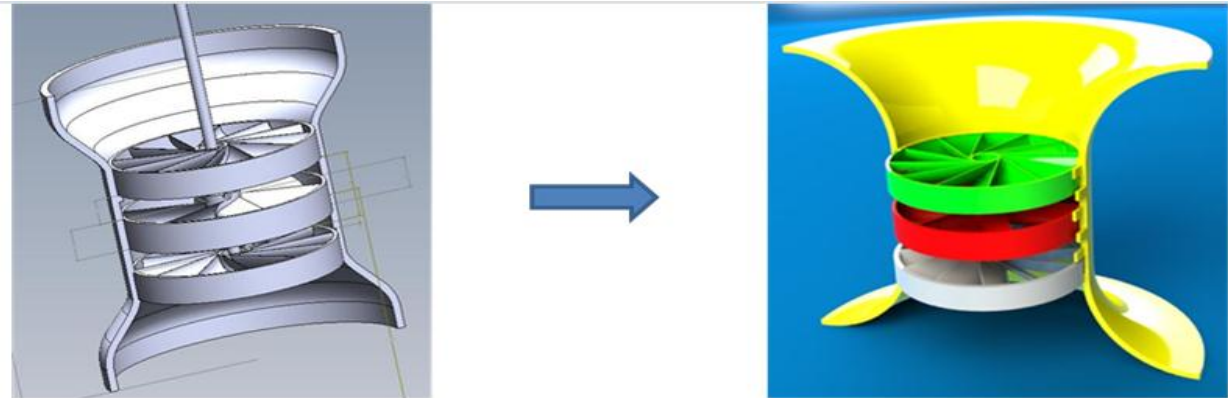


Fig 5. Illustration of two prototypes of the bi-directional turbine and nozzle design

Buoy Team Summary

As described in the turbine team summary, a turbine can transfer bi-directional translational motion very efficiently to rotational motion. This team set out to determine if more energy can be harnessed by creating a buoy which would produce a larger relative velocity between the turbine and the water than what is normally found between the wave and buoy. This concept is based on the non-synchronies relative motion between the buoy and wave. The team found that if the buoy were perfectly out of phase with the wave motion the relative velocity between the turbine and the wave can be theoretically doubled. This would allow for water which is rising to drive the turbine faster since the turbine itself is dropping relative to the water. With this motivation the team set out to build a consistent, stable, water proof, buoy which would house the generator, electrical system and turbine safely while producing the highest potential power. Three major experiments were conducted to test the performance of various components of the buoy along with fluid simulations which were created to optimize the buoy geometry.

The main components of the design are as follows:

1. **Buoy**- Geometric design promotes a lag between wave and buoy.
2. **Swivel**- Keeps turbine held vertically so that any pitching of the buoy will still produce vertical fluid motion through the turbine.
3. **Generator Housing**-Water tight enclosure provides a dry environment for the generator
4. **Turbine Housing**- Turbine is held in place by the “swinging” shaft
5. **Shaft Assembly**- A dual shaft system is used to separate the shaft from the wet environment to a dry environment where the generator is driven.

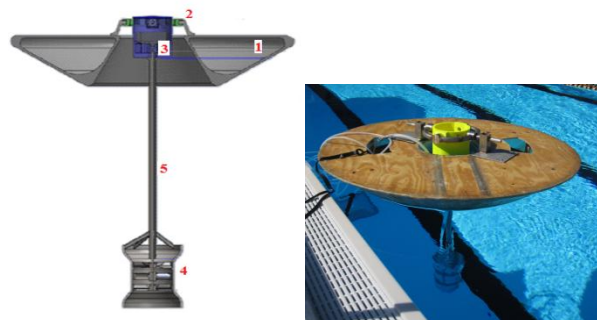


Fig 6. Illustration of buoy components and buoy experimental prototype