Variability in Wave Energy Capturing From Triboelectric Nanogenerator

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Problem Definition and Background

The escalating global climate crisis emphasizes the urgent need to develop clean energy sources to replace the global reliance on nonrenewable sources like fossil fuels. With approximately 70% of the earth’s surface covered with water, this project aims to convert the movement of water into usable electrical energy. A Triboelectric Nanogenerator (TENG), an energy conversion technology that works through electrostatic induction and triboelectrification, will be used. The development of this Wave Energy Converter (WEC) will consist of designing a device shape, as well as the best TENG configuration, that when deployed in an optimal wave environment, maximizes energy conversion. Designing and utilizing a forced oscillation device to simulate the motion of ocean waves will allow for the study certain wave characteristics, such as amplitude and frequency, for their effect on power generation.

Design Requirements

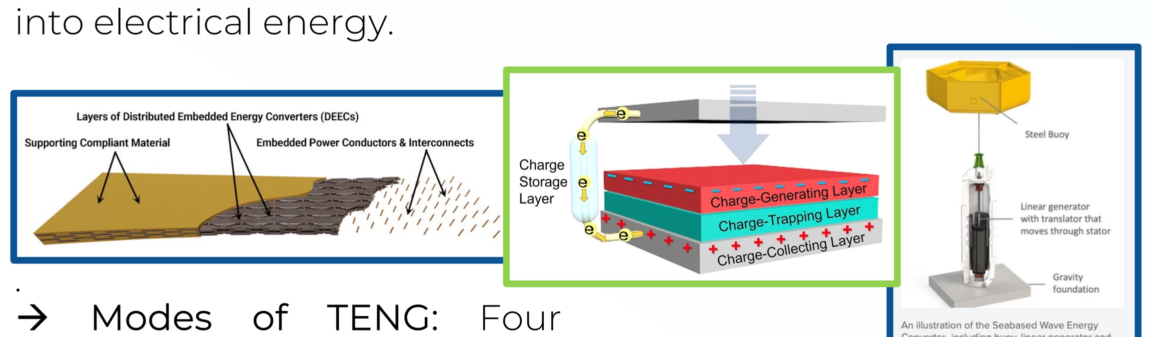
Constraints:
The device has two main components: the TENG and the power management system (PMS). The TENG can be made from a variety of materials, but the materials for this device must be commonly found and relatively affordable. The housing of the TENG, being implemented in an ocean environment, should be waterproof and corrosion-resistant. In addition to withstanding environmental elements, housing materials should not be conductive to preserve efficiency and decrease the risk of emitting electrical shocks to marine life and personnel. The chosen location should be easily accessible for maintenance and the electricity generated can be utilized by nearby infrastructure. 3D printers will be utilized to manufacture the housing for affordable and precise prototypes. The PMS’s purpose is to convert the variable output of the TENG into a usable output for energy storage. This component will also need to withstand the environment and be easily accessible.

Standards Applied:
→ NEC(NFPA 70): used to determine wire gauge for circuit connections based on the power output (voltage and current) of TENG at this scale and full-scale; also used to wire the stepper motor and micro-step driver based on spec-sheet
→ RoHS 2 Directive 2011/65/EU
→ Low Voltage Directive 2014/35/EU
→ Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF

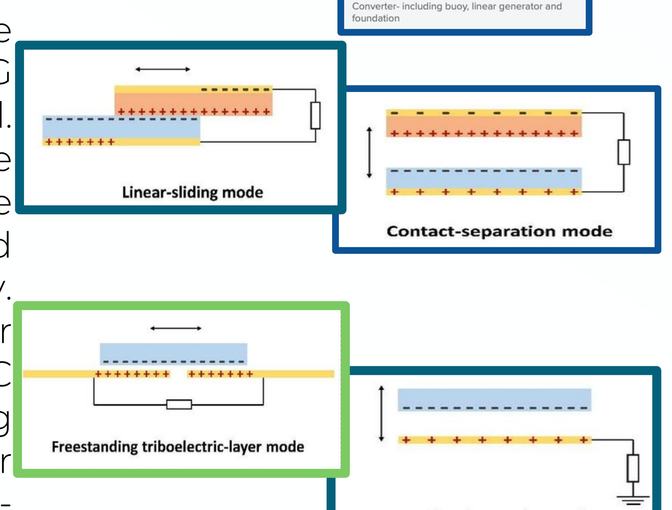
Standards to be Applied if Deployed:
→ 30 CFR 77.701-1: approved methods of grounding equipment connected to an AC power system
EC 62600/TC 114: Marine energy - Wave, tidal, and other water current converters
→ UL 9540: Energy Storage System (ESS) Requirements

Design Alternatives

→ **Power Takeoff Systems (PTO):** Converts mechanical motion into electrical energy.



→ Modes of TENG: Four modes of TENG that are commonly used in TENG devices were considered. These modes are distinguished by how the materials interact and generate electrical energy. Based on the curvilinear shape of the selected WEC design, the Freestanding Triboelectric Nanogenerator was chosen due to its non-rigid and flexible structure.

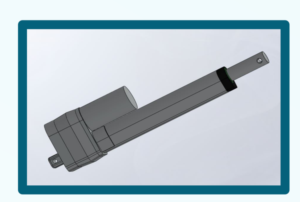


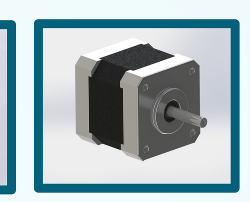
Design Evaluation and Iterative Process

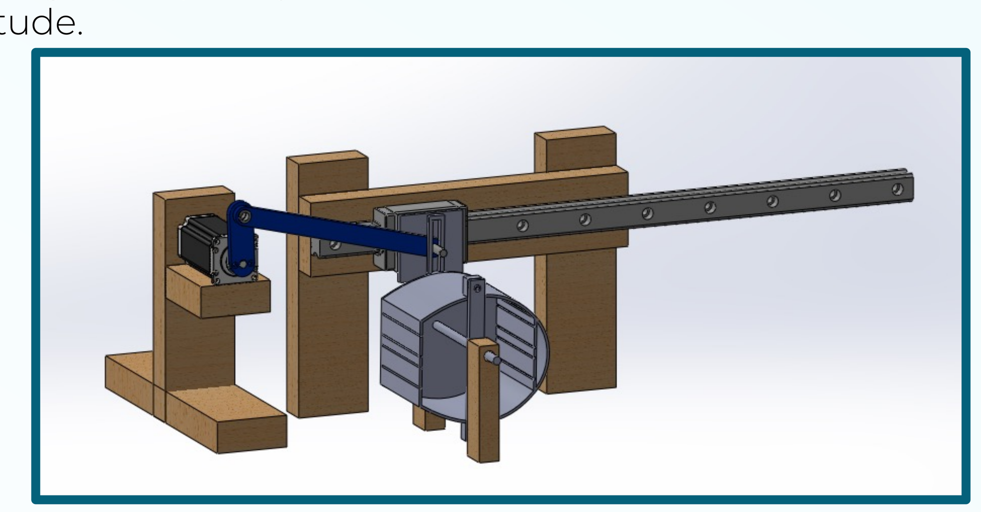
Forced Oscillation Device

The initial iteration of this project entailed the use of a physical wave tank to simulate ocean waves. The setup parameters for the tank and data validation was to be done using a series of tests, including computational fluid dynamics (CFD) simulations and a forced oscillation device. However, due to the complexity of building the tank, size restraints, and the high possibility of confounding results due to reflected waves, data collection was chosen to be simplified and done through forced oscillation and CFD alone.

A linear actuator and a stepper motor were considered for creating motion in the device. The stepper motor alternative was selected due to the flexibility it offered in operating frequency and drive amplitude.

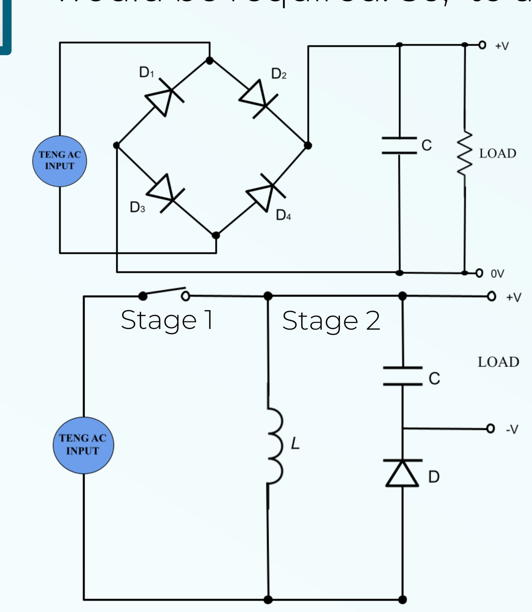






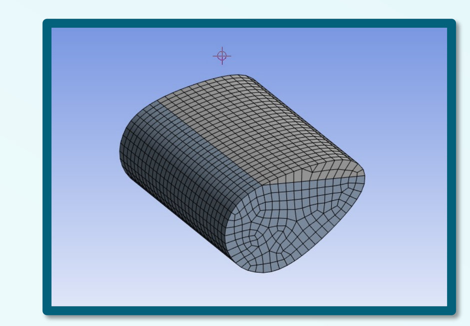
Power Management System

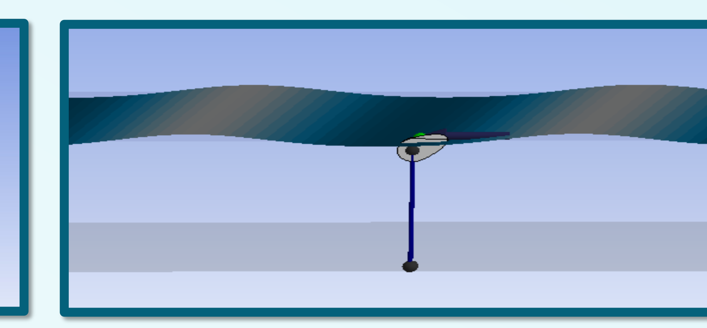
Due to the oscillatory nature of the Duck, the TENG has an unstable AC output. A Power Management System (PMS) can be implemented to modify the output to a stable DC voltage. The initial approach to creating the PMS was to use a bridge rectifier to switch the AC input to DC and smooth the signal with a capacitor. When tested with a function generator at varying frequencies (200 Hz - 1.5 kHz) and amplitudes (> 2 Vpp), the circuit produced a desirable output. However, the scale of the TENG prototype limits the output to less than 1.5V. The voltage drop of the diode bridge is ~1.4V, thus most of the energy harvested was lost. A non-inverting op-amp was considered to amplify the signal before going through the rectifier, but an external power supply would be required. So, to avoid a total loss in voltage, a passive switch circuit was configured. The passive switch parallelly connects an inductor to a diode in series with a capacitor. When the TENG outputs a positive voltage in stage 1, the diode enters reverse bias, and magnetic energy is collected in the inductor. As the TENG output declines, the diode enters forward bias, and the capacitor begins to charge in stage 2. The equation $\tau = RC$ determines the optimal capacitor value, as a slower capacitor discharge rate best smooths the output.

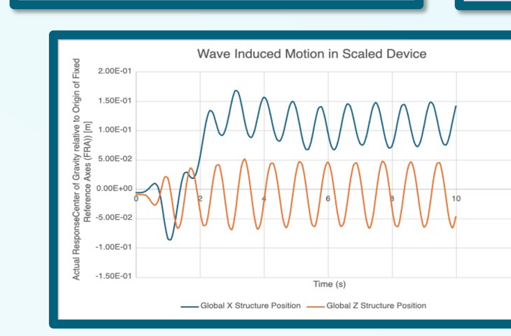


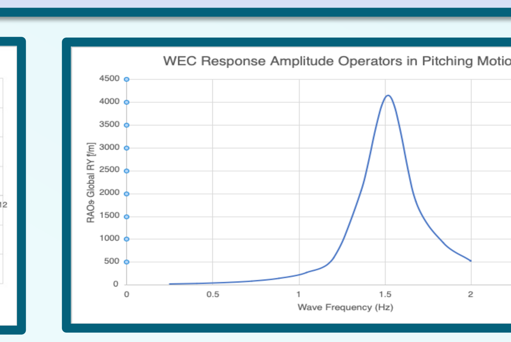
Simulations and Testing

The device shell was modeled in SolidWorks and sized to scale. The natural buoyancy of the device was solved using the SolidWorks plugin *Floatsoft* and the solved model was imported into ANSYS Workbench to be used by the Hydrodynamic Diffraction and Response Modules of ANSYS AQWA. AQWA also requires input of model and environment parameters, such as mass properties and wave frequency and amplitude. The diffraction module calculates coefficients in the frequency domain, with the most important of these coefficients for this project being the response amplitude operators (RAOs). RAOs determine the effect that a sea state at a given frequency has on the device and are very useful for determining the ideal frequencies for the device to be deployed in for generating the most power. The response module works in the time domain and can be used for determining the motion response of the device.





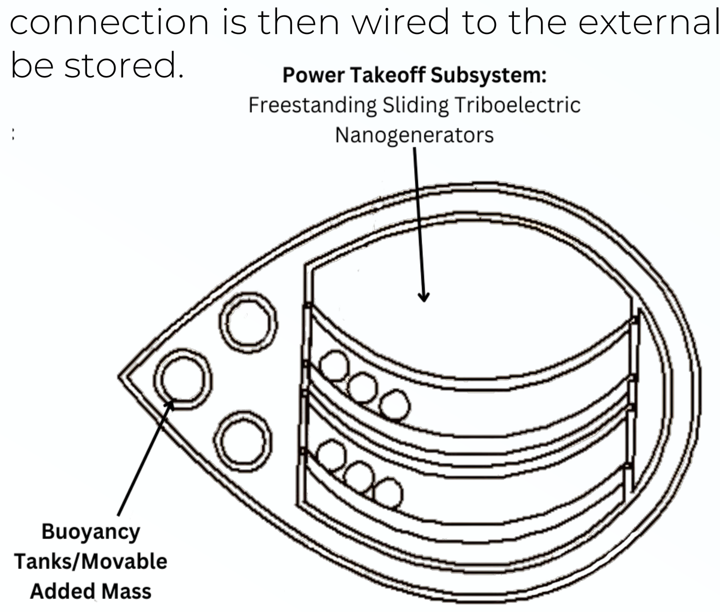


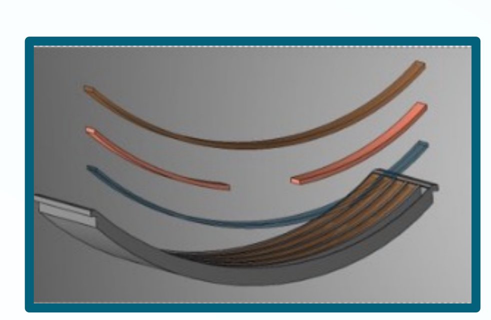


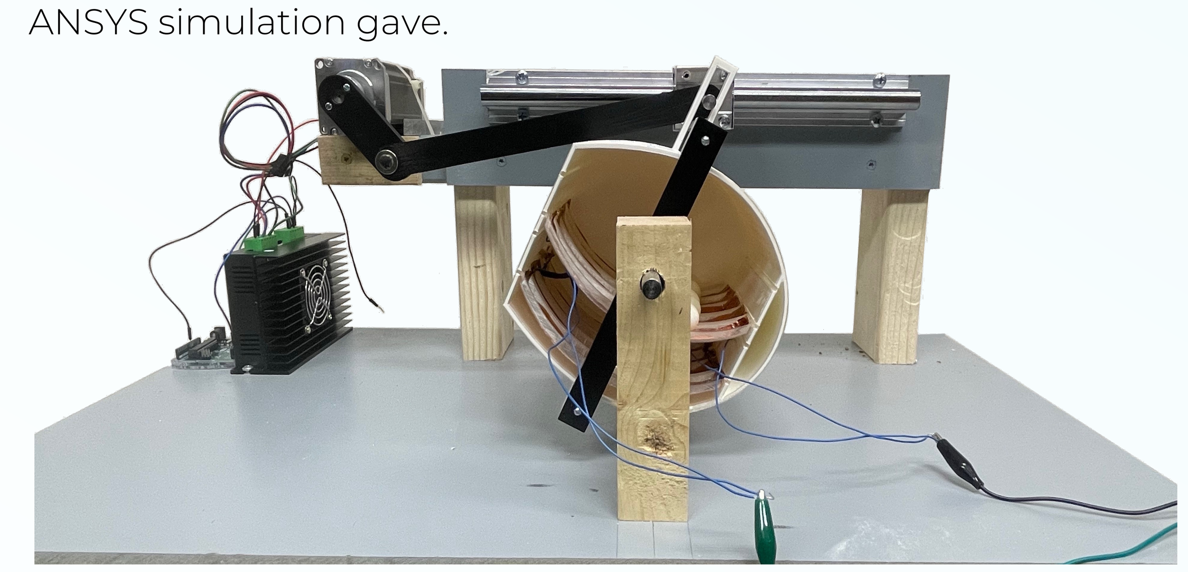
Final Design and Implementation

The final design consisted of a pear-shaped outer shell and a multi-tiered TENG power takeoff system (PTO). Since the physical testing device was not deployed in water, the outer shell was disregarded. The TENG PTO was completely 3D printed with PLA filament at a 1:55 scale. The device has two shelves, each with five channels that house a single TENG system. Kapton tape and nylon spheres were chosen as the triboelectric pair and copper electrodes were placed at the bottom of each channel to enable charge transfer. Each channel was connected in parallel, and tiers are also in parallel. The connection is then wired to the external PMS where the energy can be stored.

Forced Oscillation tests were performed to mimic the pitching motion the device would experience in ocean waves. The system functions as an inline slider crank and consists of a stepper motor controlled by an Arduino Uno and microstep driver. The mounting of the TENG converts the linear motion of the slider to the rotational motion of the housing. The rotational speed of the motor is designed to match wave frequency, and the inner crank arm length is equal to wave amplitude. The output voltage and current is monitored and compared at the varying frequencies that the ANSYS simulation gave.







Discussion

This model experiment demonstrates the proposed relationship between forced wave oscillation and free-standing TENG energy generation. With optimal values for wave frequency and amplitude, coastal locations for TENG WEC deployment can be specified based on a region's typical sea state.

References

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Acknowledgments

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