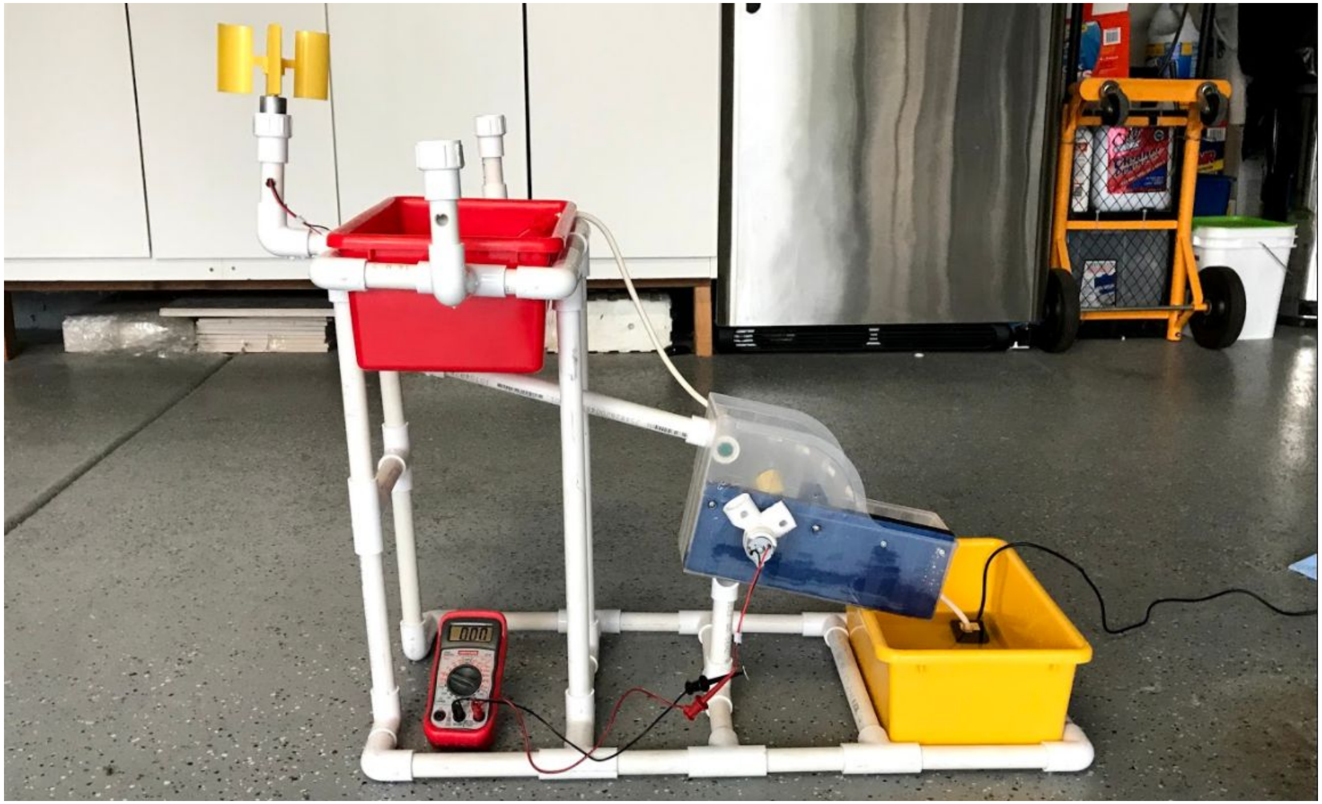
An Alternative Choice for Alternative Energy



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Introduction/Statement of the Problem/Purpose

Mankind is searching for methods to start using and improving renewable energy sources, but why not improve on ones already found? Renewable energy is making its way into everyday life thus, providing energy for tasks of varying levels. For example, any consumer of energy can be "fed" by the installation of renewable energy sources. This is happening in several households, which are now powered by renewable energy. As renewable energy becomes more widespread, creating a new plant from combining wind and hydro energy intro one structure can offer a way to deliver clean energy. Unlike burning one-time use fossil fuels, renewable energy plants can take advantage of the surrounding environment to create energy. Renewable energy promotes anti-pollution of the globe. Fossil fuels highly contribute to global warming, rising water levels, and health problems due to air pollution. Unlike several other structures, hydro-wind plants could be installed in areas not suitable for other renewable energy plants and instead supply a steady amount of eco-friendly produced energy.

There are several methods of harnessing renewable energy, but there have been very few innovations to them. Therefore, the objective of this experiment is to create a combination of wind power and hydroelectricity, while finding out the optimal format of the design. Several setups can provide energy, and this can negatively affect the overall outcome of energy. Another issue is that energy may not able to be produced due a region's geography. The design's subunits, such as the wind turbines, can be affected by the geographical features of the location it has been placed in. Using only one type of renewable energy source is not always reliable, and may not provide energy at all in unsuitable conditions. Overall, the experiment aims to create a reliable and clean energy plant, which can be built and function properly in various conditions of the surrounding area.

The purpose of this experiment is to design and test a scale model combining wind and hydroelectric power, while producing the maximum amount of energy possible. Individual renewable energy sources, such as wind turbines and hydroelectric dams, may not be able to satisfy the demand for energy due to environmental factors. Neither of these structures can function efficiently on their own. For example, producing energy from a hydroelectric dam requires too much time to pump water from the lower reservoir to the upper reservoir. Energy is used daily in society, and renewable energy structures cannot meet the demand of energy needed; therefore, energy sources such as fossil fuel power plants continue to damage the environment. Reliable clean energy plants are vital to mankind, because they serve the same purpose as fossil fuel power plants, while preventing the damage in Earth's environment from worsening.

Previous Experiments

The University College, Dublin combined wind and hydro energy to create a new source to gather energy from the two renewable sources. During testing, students conducting the experiment found a way to combine the two by using wind energy when possible, but also use a pumped hydro plant as backup. The basic requirements for the turbine were that it must have a one hundred meter hub height, and upper and lower reservoirs for the hydro plant. If there were insufficient turbine cycles per second (less than 6.2 kilohertz) to meet the minimum energy demand or if the energy demand suddenly rose, water from the upper reservoir would be released to the lower reservoir. From here, the energy would be collected with a hydro plant from the water's kinetic energy traveling downwards. Once all of the water reached the lower reservoir, it would then be pumped back to the upper reservoir. This study shows that both sources of renewable energy can be combined, to create a reliable structure providing near constant energy. Applying this structure can provide energy for several areas with no water sources, or ones with no energy (or any major movement) in those water sources. This is because the water reservoirs can be installed almost anywhere, and no water is required beforehand. Further research on the overall structure would be done with modifications to the original structure to attempt to gather more energy.

John Dabri, a former professor at Caltech, and several workmates organized a method minimize the size of wind farms. In the Field Laboratory for Optimized Wind Energy, Dabri tested VAWTs, or vertical axis wind turbines. With this type of turbine, he was able to create another type of wind farm, which was less costly and required less space for blade length. In fact, positioning each VAWT closer together was beneficial, because it prevented aerodynamic interference. By putting more turbines in one space, the amount of watts per square meter increased by 20 to 40 watts. This experiment shows that rather than having one large horizontal turbine, several smaller VAWTs should be used instead. This brings several benefits, as less money is spent, but more energy is gathered. The design is highly portable, allowing this to be used in several areas, as long as the VAWTS are in the correct formation. Therefore, the design using VAWTs can collect more energy despite taking up less space. Overall, this design would allow more turbines to be used in one space, in order to efficiently capture wind energy. This would be beneficial to the current experiment to attempt to produce a larger amount of energy.

Studies conducted by Stanford University conducted in Southern Norway's pumped hydro plant have found how to increase the amount of balance power capacity. In a pumped hydro plant, water in an upper reservoir is transferred to a lower reservoir. The energy is collected when the water stream is close to reaching the lower section. Since the water source did not provide a constant downward flow like a river, the water had to be pumped back up from the lower reservoir, creating the term "balance power". Balance power is how the amount of energy produced compensates with the amount of energy consumed to pump the water. The Stanford researchers planned on creating two parallel paths for the water, optionally installing more hydro plants. After the upper reservoir was filled, water would be released when demand for energy was high. This meant that the energy could be directly transferred to consumers, and be used to power communities and households. This study shows that energy hydroelectricity could be the solution to when the demand for electricity raises. The research done in the experiment supplies a source of clean energy, which can be almost constantly used whenever the demand for energy was high. This example of a hydro plant in Southern Norway can be implemented to other areas, especially because it does not need a starting water source. This could be applied to the experiment, to attempt to lose less power during pumping.

Core Science

Renewable energy, including turbine systems and hydroelectric plants, is currently on the rise. Yet, individual renewable energy sources do not always work efficiently due to the environment around them. For example, wind turbines would not function without wind, and hydroelectric plants cannot function without water activity. A solution to this is combining the two renewable sources, to create a pumped water plant with support from wind turbines. Several variables must be accounted for with the use of this design, such as when to drop water to meet demand or from little wind activity. This would be taken care of with the use of the hydro plant, and the two renewable energy sources would support each other to provide energy. This structure could provide energy reliably, because it would be able to provide it whenever there is high demand. For example, the maximum amount of energy can be achieved once the water is released from the upper reservoir. The action of releasing the water would only happen when the demand was at its highest points, or when there was a lack of wind. Overall, this would act as a battery, with the water holding all of the energy at the highest point. Yet, after the water is released, it must be "recharged," with an electric pumping system powered by the wind turbines. The two structures would continuously create energy, and would support each other to provide the maximum amount of energy possible.

Wind turbines are structures that take advantage of the wind, and produce energy out of wind movement. Wind turbines function with the use of wind speeds, to rotate the rotors and create energy. The energy is created in a generator that is connected to the rotor through a shaft. Often times wind turbines include a gearbox, which can either increase the amount of revolutions, and thus, creating more energy from the generator. Also, wind turbines can be orientated in either horizontal of vertical axes, and are called either HAWTs or VAWTs. To find the maximum efficiency of a wind turbine, the equation $P=1/2\rho av^3$ is used to find the highest wind power output (where "P" represents power, "ρ" represents air density, "a" represents the total area covered by rotor, and "v" represents the speed of the wind"). In order to calculate "ρ" the equation $\rho\ dry\ air = p/R \times T$ would be used (where "ρ dry air" represents the density of dry air, "p" represents the air pressure, "R" represents the specific gas constant for dry air (287.05 J/kg.K, and "T" represents the temperature in K°). This would represent the maximum output, assuming that conditions of the environment are desired. In order to test this, the use of wind testing rooms is required.

Pumped hydroelectric plants function by utilizing the downward motion of water. Usually, hydroelectric plants can be found by natural water sources such as rivers or man-made sources similar to reservoirs. In a pumped hydroelectric plant, the structure is similar to regular hydroelectric plants, except this would have two reservoirs and a pumping system to transfer water upwards. In order to measure the efficiency of a hydroelectric dam, the equation (net head × flow) ÷ 10 = P must be used (where P represents power, flow is in gallons per minute, and net head is in feet). Each of these systems use the downward force of water to power a large turbine, which could also use a gearbox to increase the amount of energy created. Overall, hydroelectric plants can be efficient, and pumped plants can be built in several areas and not require a starting water source.

The current experiment attempts to measure the efficiency of the scale model with the introduced modifications. To do this, the efficiency equation must be used: $efficiency=energy\ output-energy/\ input \times 100\%$. The energy output shall be represented by W_{out}, which would be measured in joules. The energy input shall be represented by W_{in}, which would be measured in joules. This would be beneficial to find the efficiency of the overall structure, because the pumping system requires for energy to be used, or would be the energy input. Using the efficiency equation could show how well the scale model performs, and how it may perform in realistic situations.

Hypothesis/Materials

Hypothesis

Recently, the University College, Dublin created a new type of renewable energy plant, combining both wind and hydroelectricity. The design comprised of wind turbines, and a hydroelectric power plant. The wind energy was collected whenever possible, and the energy would be harnessed to be used in other areas. If there were not optimal conditions and the turbines could no longer produce electricity, the main power source would then be the pumped hydro plant. A pumped hydro plant consists of higher and lower reservoirs of water. To gather the energy from the pumped hydro plant, the water would need to be transferred to the lower reservoir, then be pumped back up again to continue gathering energy. The overall design of this structure can provide energy for several areas not suitable for other types of renewable energy.

The current experiment will attempt to find out how to produce the most energy out of this design with scale model testing, by determining the times to drop the water, to making the design more efficient. This relates to the current experiment because the same overall structure will be used. The purpose of the experiment was to combine hydroelectricity and wind energy, and the same idea shall be used. This experiment will consist of a new design, but still consist of the same hydro plant, and same wind turbine idea. The idea of combining the two renewable sources will be kept, but the way of collecting the energy will be changed. Overall, the main ideas of the structure shall be used in the scale model, but the design will have several modifications to efficiently and reliably gather the most amount of energy possible.

Based on prior research, a hypothesis can be formed stating that: **the scale model of the proposed design will have an 75% efficiency, the VAWT unit will have 55% efficiency, and the hydroelectric unit will have a 60% efficiency.** From here, the energy from the design would be able to provide electricity for the basic needs of a household. The experimenter will test the scale model with a realistic environment. Each section of the structure, including the amount of energy produced, will have the same scale, to find the most accurate efficiency. In conclusion, a scale model will be produced with several modifications to the original design, and several tests shall be done to find the efficiency and how much energy is produced.

Materials

2 identical watertight containers
2 9’ PVC Pipes
PVC connectors
PVC cap
Glue
Plastic book holder
Wood
Waterproof spray paint
2 VAWT turbines
5 Screws
Thin metal rod
Spacers

2 Generators
Small Rubber Connector
Plugs
Epoxy
Pump
Hammer
Drill
Room without any windflow
Multimeter
Stopwatch
Paper or Notebook
Writing Utensil

Procedures

Part I: Building the Frame for the Reservoirs

1. Designate an area large enough for an upper and lower reservoir to be built.
2. Build two identical frames from PVC pipes, slightly larger than the dimensions of the two reservoir containers.
    a. Modify one frame by adding PVC tee connectors (facing downwards) to the edges, then cut PVC pipes to desired heights to the connectors.
    b. Use PVC pipes and connectors to connect the upper reservoir base to the lower reservoir, with a connector piece facing upwards in the middle..

Part II: Building the Hydroelectric Turbine System

1. Move a Vertical Axis Wind Turbine (VAWT - Now the turbine) to one side of the plastic book holder, and determine how much excess space is present.
2. Measure and cut a piece of wood 0.5 cm less than the excess space.
    a. Cut a second piece of wood that is half of the height of the book holder, and the same width as the book holder.
3. Determine where the center of the turbine must be in order to be approximately 0.25 cm from the bottom of the book holder base, and 1 cm away from the back.
    a. Attach the two pieces of wood together based on the position of the turbine, and coat with waterproof spray paint.
4. Drill a hole through the turbine hub measuring to the same size as the metal rod.
5. Place the metal rod through the wooden piece and the book holder.
    a. Attach the metal rod to a generator with a rubber tube (Melt the rubber to connect the pieces together if necessary).
6. Cut a PVC pipe to the length of the generator, then cut the piece into two half tubes, and attach to the side of the book holder in order to hold the generator.
7. Create the “head” for releasing the water onto the turbine, using a tee connector.
    a. Take two plugs, and place into 2 cm long PVC pieces. Cover the piece with epoxy to seal and to make watertight.
    b. Drill holes in the bottom of the connector to allow water to exit the head.

Part III: Attaching the Vertical Axis Wind Turbines (VAWTs)

1. Modify the upper reservoir frame by adding PVC tee connectors to the side and back edges, placing the connector parallel to the ground.
2. For each tee connector, connect a 90° connector facing upwards.
3. Measure and cut a PVC pipe approximately 4 cm longer than the PVC connector.
    a. Drill a hole in the center of the PVC pipe
4. Place generators onto the open pipes, and pull wiring through the hole, then attach VAWT

Part IV: Testing and Observations

1. Determine how much energy each unit could potentially create.
    a. In order to find the amount of energy that the hydroelectric dam can produce, use the equation (net head × flow) ÷ 10 = P must be used (where P represents power, flow is in gallons per minute, and net head is in feet). Convert the dimensions of the scale model from cm to satisfy this equation.
    b. In order to find the amount of energy that the VAWTs can produce, use the equation P=12 ρav3, where *P* represents power, ρ represents air density, *a* represents the total area covered by rotor, and *v* represents the speed of the wind
2. Test each unit separately, starting with the hydroelectric unit then finishing the the VAWTs.
    a. Connect the multimeter to the generator wiring in the hydroelectric turbine system, and set the multimeter to measure the amount of volts produced.
    b. Release water from the upper reservoir, while starting a timer for thirty seconds.
    c. Every 5 seconds, record the voltage until thirty seconds pass, or until no more water can be released from the upper reservoir.
    d. Repeat steps 2b-2c for a total of 6 trials.
    e. Repeat steps 2b-2d again while measuring current, then repeat again while measuring hertz.
3. Repeat steps 2a-2e while testing the VAWT. Instead of releasing plug and starting the timer, turn on wind source and begin timer
4. Once data has been obtained, determine the efficiency of each section by using the equation *efficiency*=energy outputenergy inputx100%, where energy output represents the data from each trial (volts).
5. Determine the efficiency of the scale model by combining the data from the hydroelectric unit with the VAWT unit data, and dividing by how much energy potentially could be created.

Observation/Results

This scale model experiment was conducted to design and test a scale model combining wind and hydroelectric power, while performing at the desired efficiencies. Two different units were tested for voltage and current over 6 trials each. Data was recorded every five seconds within a thirty second time frame while providing wind to the vertical axis wind turbine (VAWT) or releasing water from the hydroelectric unit. Each of these individual units served as the control, without either units providing energy for the other. The overall scale model was the experimental, with each unit providing energy in order to compensate for power shortages. Numerous trials were conducted on each unit and the overall scale model, showing the similar trends in the energy output.

The materials used to provide potential energy sources consisted of a hairdryer for the VAWT unit and water for the hydroelectric unit. Once the plug of the upper reservoir was released, the water quickly drained out because of the force provided by the water on the top. Yet, as the water level of the upper reservoir lowered, there was not enough water pushing down on the plug, causing the speed of the water exiting from the upper reservoir to exponentially decay. This resulted in the voltage to diminish at the end of each trial, decreasing the amount of energy from the start by approximately 425 millivolts. Despite this, the same pattern of exponential decay is present in throughout each trial.

Two different types of digital multimeters, or DMMs, were used in order to measure the voltage and current of each unit. A more sophisticated DMM was required to measure the current due to the inability of the other DMM measuring the voltage. The exponential decay trend in the voltage occurred in the current as well, due to the same reasons. On the other hand, the VAWT voltage and current was near constant due to the constant exposure to the wind source. This may have been caused because the hydroelectric reservoirs do not have a infinite capacity of water, while the hair dryer can provide wind to the VAWT for the whole thirty second time period. Once the overall scale model was tested, the same voltage and current trends were present in the hydroelectric unit, while the VAWT unit provided a near constant voltage and current.

At the end of experimentation, each unit seemed to perform as efficiently as every other trial. There were no major variations in the data, except for an outlier at the end of each hydroelectric trial. Despite this, the hydroelectric data produced similar results in the voltage, having a range of only 0.16 millivolts at the end of the thirty second time range. The VAWT unit by itself was able to power the pump, where the input was required to range from 4.5-10 volts. The overall scale model was able to perform efficiently because of the VAWT power, allowing several reservoir releases to be conducted in a short time frame. With each energy source providing for the other, the scale model was able to perform efficiently with no issue in the compliance of each unit.

Data Tables/Graphs

Trial 1		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.754	2.42	3.17	0.01236	0.0318	0.041	0.0093	0.0769	0.1299
0:10	0.730	2.39	3.12	0.01214	0.0317	0.0438	0.0088	0.0757	0.1366
0:15	0.673	2.38	3.05	0.01205	0.0314	0.0434	0.0081	0.0747	0.1323
0:20	0.688	2.39	3.07	0.01195	0.0316	0.0435	0.0082	0.0755	0.1335
0:25	0.698	2.34	3.04	0.01161	0.0315	0.0431	0.0081	0.0737	0.1310
0:30	0.231	2.37	2.58	0.00544	0.0313	0.0367	0.0012	0.0741	0.0946

Trial 2		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.739	2.49	3.18	0.01278	0.0321	0.0438	0.0094	0.0799	0.1392
0:10	0.702	2.47	3.16	0.01248	0.0312	0.0432	0.0087	0.0770	0.1365
0:15	0.725	2.46	3.11	0.01267	0.0317	0.0437	0.0091	0.0779	0.1359
0:20	0.723	2.48	3.15	0.01205	0.0309	0.0436	0.0087	0.0781	0.1373
0:25	0.680	2.45	3.15	0.01208	0.0315	0.0437	0.0082	0.0771	0.1376
0:30	0.379	2.44	2.80	0.00811	0.0318	0.0398	0.0030	0.0775	0.1114

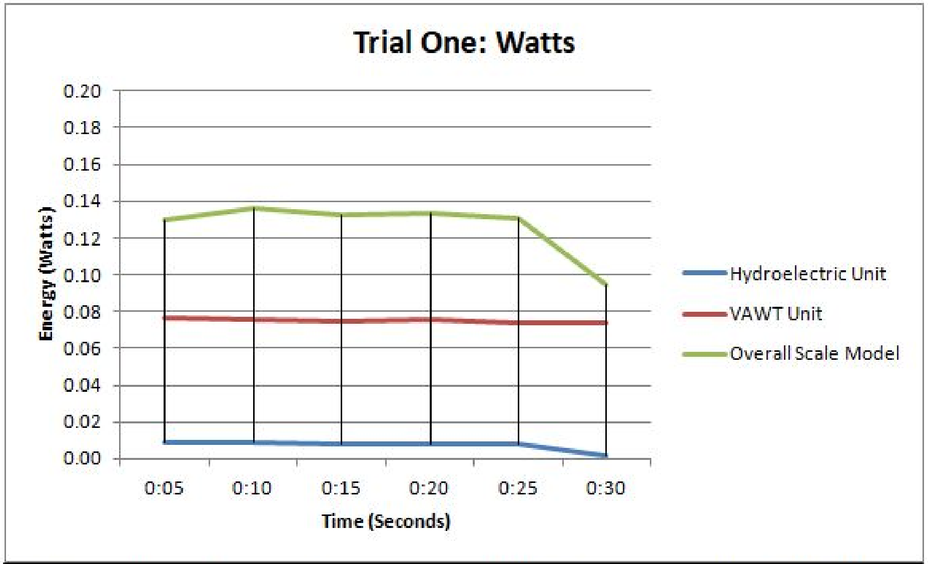
Trial 3		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.761	2.42	3.24	0.01269	0.0316	0.0436	0.0096	0.0764	0.1412
0:10	0.738	2.41	3.25	0.01237	0.0317	0.0436	0.0091	0.0760	0.1417
0:15	0.754	2.45	3.24	0.01180	0.0314	0.0425	0.0088	0.0769	0.1412
0:20	0.705	2.49	3.14	0.01233	0.0312	0.0437	0.0086	0.0776	0.1372
0:25	0.682	2.43	3.18	0.01212	0.0319	0.0434	0.0082	0.0775	0.1380
0:30	0.327	2.44	2.77	0.00498	0.0312	0.0441	0.0016	0.0761	0.1221

Trial 4		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.734	2.45	3.22	0.01314	0.0311	0.0452	0.0096	0.0761	0.1455
0:10	0.744	2.46	3.21	0.01227	0.0308	0.0434	0.0091	0.0757	0.1393
0:15	0.732	2.39	3.19	0.01232	0.0311	0.0440	0.0090	0.0743	0.1403
0:20	0.720	2.43	3.20	0.01222	0.0316	0.0431	0.0087	0.0767	0.1379
0:25	0.709	2.47	3.15	0.01228	0.0317	0.0437	0.0087	0.0782	0.1332
0:30	0.311	2.42	2.75	0.00681	0.0318	0.0386	0.0021	0.0769	0.1061

Data Tables/Graphs

Trial 5		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.741	2.48	3.16	0.01358	0.0310	0.0451	0.0100	0.0760	0.1425
0:10	0.736	2.41	3.14	0.01328	0.0313	0.0479	0.0097	0.0754	0.1504
0:15	0.719	2.49	3.17	0.01320	0.0307	0.0446	0.0094	0.0764	0.1413
0:20	0.698	2.44	3.19	0.01301	0.0314	0.0450	0.0090	0.0766	0.1425
0:25	0.703	2.50	3.13	0.01250	0.0313	0.0444	0.0087	0.0782	0.1389
0:30	0.219	2.45	2.66	0.00442	0.0301	0.0356	0.0009	0.0737	0.0946

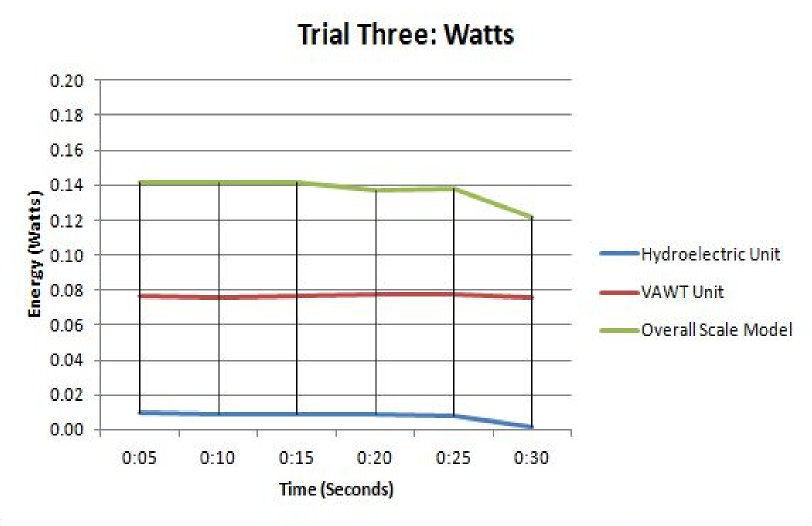
Trial 6		Date: 12-12-17						Overall Scale Model	
Time (Seconds)	Hydroelectric Unit	VAWT Unit	Overall Voltage (Volts)	Hydroelectric Unit	VAWT Unit	Overall Current (Amps)	Hydroelectric Unit	VAWT Unit	Overall Energy (Watts)
0:05	0.753	2.46	3.21	0.01354	0.0308	0.0443	0.0101	0.0757	0.1422
0:10	0.726	2.40	3.12	0.01304	0.0316	0.0446	0.0094	0.0758	0.1391
0:15	0.752	2.43	3.18	0.01231	0.0309	0.0432	0.0094	0.0750	0.1373
0:20	0.740	2.44	3.18	0.01230	0.0313	0.0436	0.0091	0.0763	0.1386
0:25	0.698	2.42	3.12	0.01252	0.0315	0.0440	0.0087	0.0762	0.1372
0:30	0.328	2.39	2.71	0.00772	0.0314	0.0321	0.0025	0.0750	0.0869



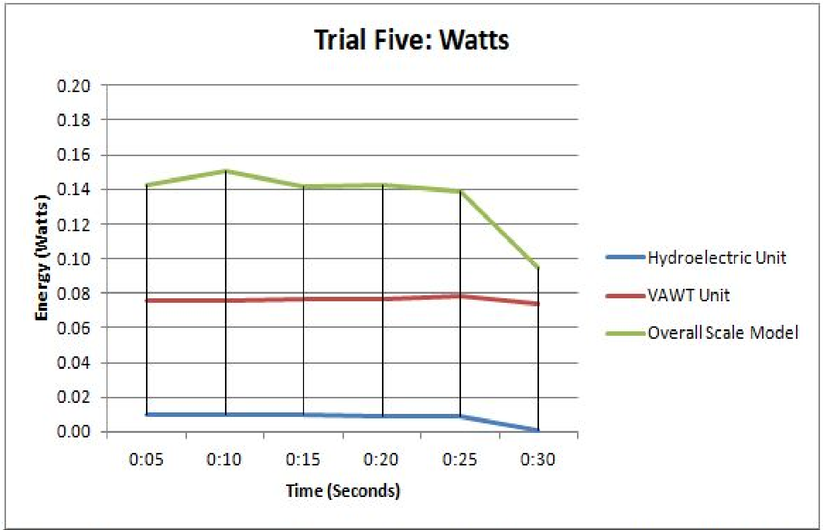
This graph shows the amount of energy produced in the three groups in trial one. The highest amount for the hydroelectric unit was 0.0093 watts at 5 seconds, VAWT unit was 0.0769 watts at 5 seconds, and the overall scale model was 0.1366 watts at 10 seconds.

This graph shows the amount of energy produced in the three groups in trial two. The highest amount for the hydroelectric unit was 0.0094 watts at 5 seconds, VAWT unit was 0.0799 watts at 5 seconds, and the overall scale model was 0.1392 watts at 5 seconds.

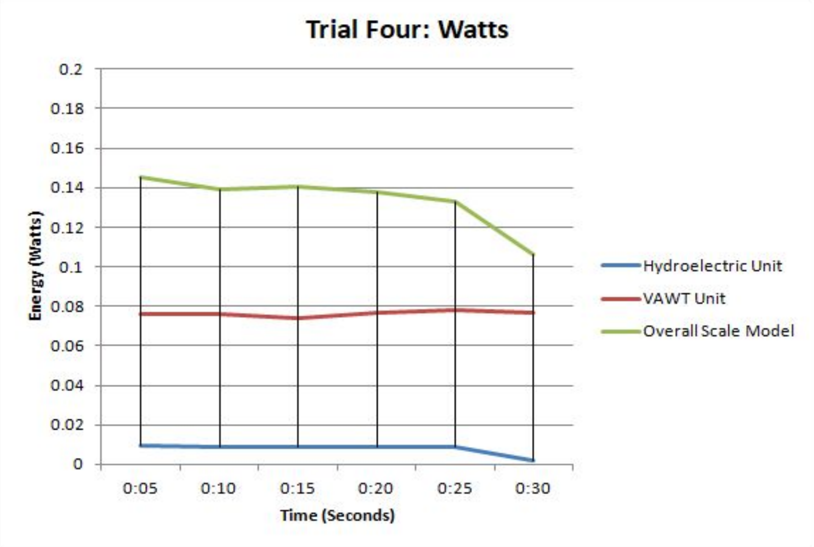
Data Tables/Graphs



This graph shows the amount of energy produced in the three groups in trial three. The highest amount for the hydroelectric unit was 0.0096 watts at 5 seconds, VAWT unit was 0.0776 watts at 20 seconds, and the overall scale model was 0.1417 watts at 10 seconds.



This graph shows the amount of energy produced in the three groups in trial five. The highest amount for the hydroelectric unit was 0.01 watts at 5 seconds, VAWT unit was 0.0782 watts at 25 seconds, and the overall scale model was 0.1504 watts at 10 seconds.



This graph shows the amount of energy produced in the three groups in trial four. The highest amount for the hydroelectric unit was 0.0096 watts at 5 seconds, VAWT unit was 0.0782 watts at 25 seconds, and the overall scale model was 0.1455 watts at 5 seconds.

This graph shows the amount of energy produced in the three groups in trial six. The highest amount for the hydroelectric unit was 0.0101 watts at 5 seconds, VAWT unit was 0.0758 watts at 10 seconds, and the overall scale model was 0.1422 watts at 5 seconds.

Conclusions/Recommendations

Conclusion

In this experiment, a renewable energy source was proposed consisting of a hydroelectric dam and several vertical axis wind turbines (VAWT). By combining these two energy sources, a more reliable design could be created to satisfy the demand for energy. The original hypothesis was that the **the scale model of the proposed design will have an 70% efficiency, while the Vertical Axis Wind Turbine (VAWT) unit will have 55% efficiency, and the hydroelectric unit will have a 60% efficiency.** With similar trends between each data results, the hypothesis is quite accurate, having **the proposed design performing at a 73.62% efficiency, and the VAWT unit performing at a 46.52% efficiency, and the hydroelectric unit performing at a 54.52% efficiency**.

Each trial, the hydroelectric unit typically performed worse in the last five second time frame, possibly because there is no more weight from water forcing the water to leave the upper reservoir. When graphing these results, it was shown that the voltage and current would typically drop as less water was in the upper reservoir. Despite this, the voltage and current did not vary significantly until the last five seconds. Even though there was a falter at the end of each trial, the results were proven to be within 6% of the hypothesis for the efficiency. This was likely caused due to the benefit provided by the VAWT, which prevented any energy from being used in order to pump the water back to the upper reservoir.

The VAWT performed surprisingly well, managing to produce more energy than the hydroelectric unit. This is probably caused due to the constant supply of wind, unlike how the upper reservoir could provide water for they hydroelectric dam. Throughout the thirty second time frame, the wind source could constantly provide wind, while the hydroelectric unit lost energy in the last five seconds. Despite providing accurate results in the graphs, the generator may have limited the voltage and current by being unable to reliably convert the movement from the VAWT provided by the wind. Even so, the VAWT unit was still able to provide energy to pump water from the lower reservoir to the upper reservoir, which raised the efficiency and reliability of the overall scale model.

This experiment provided crucial information to the growing field of renewable energy. Combining renewable energy sources would allow the efficiency and amount of energy to rise, which would mean that less non-renewable energy structures would be used. If the efficiency of the scale model were to rise above the scale model efficiency of 73%, the effects of fossil fuel or coal plants would halt, thus making the issues of pollution and global warming smaller. Energy is crucial for the everyday human life, but clean energy could improve the pureness and cleanliness of the environment of Earth.

Recommendations

The scale model created improved efficiencies for each unit working together, but the environment around the scale model may have caused the results to be inaccurate and unrealistic. For example, when an actual VAWT is exposed to the wind, the airflow may not always go the same direction, such as how the air source only pointed to one blade. Also, the efficiency of the hydroelectric dam may have been higher depending on how the energy collection was performed. If one were to perform this experiment, the scale model should be placed outside to expose the scale model to realistic situations. Different environments shown to the scale model can show how well the proposed design may perform when actually built in a similar environment. While testing the scale model outside, the proper efficiency should be tested, because this would provide a more realistic situation for if the design was actually built.

Bibliography

1. Coburn, Alice, Eilín Walsh, Patrick J. Solan, and Kevin P. McDonnel. "Combining Wind and Pumped Hydro Energy Storage for Renewable Energy Generation in Ireland." Journal of Wind Energy. Hindawi, 21 Aug. 2014. Web. 12 June 2017. <https://www.hindawi.com/archive/2014/415898/>.

2. Dabri, John. "Wind-turbine Placement Produces Tenfold Power Increase, Caltech Researchers Say | Caltech." The California Institute of Technology. Caltech, 13 July 2011. Web. 16 June 2017. <http://www.caltech.edu/news/wind-turbine-placement-produces-tenfold-power-increase-caltech-researchers-say-1700>.

3. Davis, Scott. Microhydro: Clean Power from Water. Gabriola Island, B.C.: New Society, 2003. Print.

4. Gillman, Patrick. "Offshore Wind Energy." Bureau of Ocean Energy Management. Bureau of Energy Management, 12 Aug. 2016. Web. 19 June 2017. <https://www.boem.gov/Offshore-Wind-Energy/>.

5. Johnson, Gary L. Wind Energy Systems. Manhattan, KS: Gary L. Johnson, 1994. Print.

6. Martin, Heather Rae. "Development of a Scale Model Wind Turbine for Testing of Offshore Floating Wind Turbine Systems." The University of Maine Library. The University of Maine, Dec. 2011. Web. 19 June 2017. <https://library.umaine.edu/theses/pdf/MartinH2011.pdf>.

7. Murphy, Tom. "How Much Dam Energy Can We Get?" Do the Math. UCSD, 20 Dec. 2011. Web. 24 June 2017. <https://dothemath.ucsd.edu/2011/12/how-much-dam-energy-can-we-get/>.

8. Murphy, Tom. "Pump Up the Storage." Do the Math. USCD, 15 Nov. 2015. Web. 24 June 2017. <https://dothemath.ucsd.edu/2011/11/pump-up-the-storage/>.

9. Navqi, Syed Kazim. "Scale Model Experiments on Floating Offshore Wind Turbines." WORCESTER POLYTECHNIC INSTITUTE. N.p., May 2012. Web. 22 June 2017. <https://web.wpi.edu/Pubs/ETD/Available/etd-052312-133921/unrestricted/knaqvi1.pdf>.

Bibliography

10. Solvang, Eivind, Atle Harby, and Anund Killingtveit. "Increasing Balance Power Capacity in Norwegian Hydroelectric Power Stations." Stanford. SINTEF, 20 Feb. 2012. Web. 21 June 2017. <http://large.stanford.edu/courses/2012/ph240/doshay1/docs/tr-a7195.pdf>.

12. US Department of Energy. "Pumped Storage and Potential Hydropower from Conduits." Report to Congress. US Department of Energy, Feb. 2015. Web. 23 June 2017. <https://energy.gov/sites/prod/files/2015/06/f22/pumped-storage-potential-hydropower-from-conduits-final.pdf>.

14. Wind Power Wind Power Fundamentals, Alex, and Katherine Dykes. "Wind Power Fundementals." Massachusetts Institute of Technology. MIT Wind Energy Group & Renewable Energy Projects in Action Renewable Energy Projects in Action, n.d. Web. 25 June 2017. <http://web.mit.edu/windenergy/windweek/Presentations/Wind%20Energy%20101.pdf>.