Ocean Wave Energy Converter

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We hereby recommend that the dissertation prepared under our supervision by: NAME AND REGISRATION NUMBER. Titled: "Ocean Wave Energy Converter" be accepted in partial fulfillment of the requirements for the award of BE Mechanical degree with (___ grade).

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ABSTRACT

A novel energy conversion apparatus intended to convert the mechanical energy of a source of cyclic motion to unidirectional rotational kinetic energy by means of a unidirectional vertical axis turbine that is submerged in the ocean and is subjected to cyclic motion under the influence of the source i.e. ocean waves where the cyclic motion of the ocean waves is transferred to the turbine via a connecting means in the form of a rectangular frame. When in motion, the turbine experiences a relative flow of fluid across its rotor blades and therefore rotates in a single direction producing useful shaft power. The shaft work can then be utilized in various applications such as electricity generation, pumps etc.

PREFACE

Ocean Waves are an abundant form of clean energy available throughout the day. In fact, this form of energy alone can cater to the requirements of the whole world. It is estimated that the global energy requirements amount up-to 18 TW whereas ocean wave energy potential is around 900 TW. For this reason, numerous efforts have been made to utilize the resource in an effective manner. However, none of them could effectively present a method to tap on the random cyclic nature of the ocean waves as well the harsh ocean environment.

This project aims to validate a novel mechanism experimentally as a solution to harnessing the random cyclic ocean wave energy. The main feature or component of this mechanism is a unidirectional that receives a relative flow of fluid and converts it into rotational motion of its shaft in a single direction.

ACKNOWLEDGMENTS

First of all, we would like to express our deep appreciation to our supervisor Dr. Muhammad Sajid and co. supervisor Sir Majid for their valuable and constructive suggestions as well as constant supervision which really helped us completing our project well in time. Also we would like to extend our sincere thanks to Col. Naveed for his assistance in material selection, Sir Imad ud Din for providing us with the technical resources and Sir Hafiz Abd Ur Rehman for his valuable guidance. Lastly we would like to mention the staff of MRC especially Sir Faisal really co-operated with us with the manufacturing of our prototype.

ORIGINALITY REPORT

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ABBREVIATIONS

OWEC Ocean Wave Energy Converter

VAT Vertical Axis Turbine

NOMENCLATURE

Input speed, Speed of turbine w.r.t fluid	V_{in}
Rotor Swept/Projected Area	A_s
Input RPM	$N_{in} = \frac{V}{r}\left(\frac{60}{2\pi}\right)$
Input power	P_i
Density of Water	ρ_w
Drag Coefficient	C_D
Input Volume	V_{in}
Output RPM	N_{out}
Output Torque	τ_{out}
Output Power	P_o
Power Co-efficient	C_p

CHAPTER 1

INTRODUCTION

Scope:

To demonstrate and validate a novel OWEC mechanism through prototyping, experimenting and quantifying it.

Aims and objectives:

Following objectives are to be achieved in order of their importance

1. Appropriate turbine design
2. Development of a working prototype
3. Development of a testing facility including wave simulator
4. Quantification of the energy efficiency

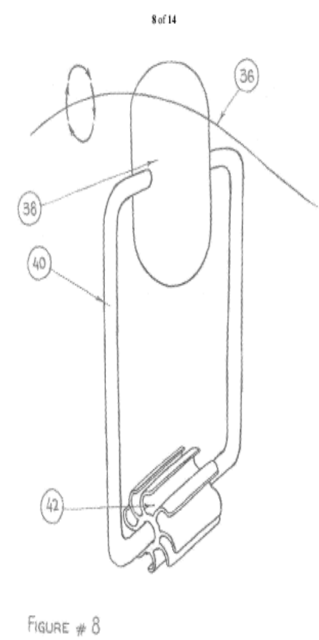

Figure 1. Schematic diagram of OWEC

Components of OWEC:

The OWEC apparatus consists of following components

1. **Unidirectional VAT:**

A unidirectional turbine (42) is one which rotates in a single direction regardless of the direction of the flow of fluid across it. A number of vertical axis turbines are used for wind applications particularly and are unidirectional in nature such as Savonius turbine, Darrhieus turbine etc.

2. **Connecting means:**

The purpose of connecting means (40) is to transfer the cyclic motion of the ocean waves to the turbine which is submerged in the water. It consists of a rectangular frame on which both the float and the turbine are mounted at the top and bottom respectively.

3. **Float:**

The purpose of float (38) is to keep the whole assembly floating in the ocean as well as to force the assembly to follow the circular path of ocean waves. However for the purpose of laboratory experiment, we have replaced the float by a wave simulator to replicate the wave motion as it is.

4. **Generator:**

The purpose of generator is to convert the rotational motion of the turbine shaft into electrical energy which can be measured. The generator is mounted on the connecting frame or placed on top of float.

5. **Spring & Belt:**

The purpose of spring and belt system is to apply braking force to the shaft thus quantify the amount of torque produced by the turbine.

6. Testing bench:

The testing facility comprises of a water tank of dimensions 3*2.5*2.5 and a paddle wheel system, on which the entire assembly is mounted, for simulating ocean wave motion.

Working principle:

Ocean waves are progressive in nature and travel on the surface of water bodies. When a wave passes by a particle of water resting on the surface, it undergoes a circular motion almost about its mean position with a slight horizontal displacement. Thus the OWEC assembly when placed in the ocean with float on the surface and turbine submerged, it would follow a similar path. The turbine undergoing a similar motion while submerged in water, would experience a relative flow of fluid across its blades and therefore rotate in a single direction producing useful work.

The shaft work output of the turbine can be converted into electrical energy through a generator mounted on the connecting frame or placed on top of the float. However for the purpose of measurement of output parameters, a calibrated spring belt system is used instead. The spring applies a braking force on the turbine and the point at which rotating shaft reaches static equilibrium gives the amount of force or torque required to bring the shaft to rest which is the same as torque produced by the turbine.

CHAPTER 2

LITERATURE REVIEW

Introduction:

The basic motivation for this project was to solve the energy crises faced by Pakistan and then the whole world. The global energy requirement as of 2012 is 18.0 TW and this demand is ever increasing. Fossil fuels that are widely used in the world right now have the capacity of providing the energy for about 50 years in the future on the current rate. This give rise to the need of Renewable energy sources. Renewable energy resources are the answer to the energy problem and from the past century a lot of work has been done to utilize and harness energy from these resources.

Renewable Energy:

Energy collected from renewable resources. And these resources replenish naturally on a human timescale such as waves, rain, tides etc. Following are the sources of renewable energy

1. Solar Energy
2. Wind Energy
3. Ocean Wave Energy
4. Tidal Energy
5. Geo Thermal Energy
6. Nuclear Energy

Ocean Wave energy:

Ocean Wave energy is a major part of renewable energy as its potential throughout the world is 2 – 3 Million Megawatts. This energy is more than enough to provide all the energy requirement of the world if harnessed properly and effectively. Some of the advantages of ocean wave energy are:

1. It is a form of Renewable energy
2. It is environment friendly
3. It is abundant and widely available
4. Less damaged is done to land during harnessing it.
5. More consistent and sustainable form of renewable energy as it is available all the time.
6. More dense form of energy

Although ocean wave energy has many advantages over other renewable energy resources. However, it has also some cost associated with it in the form of disadvantages. Some of the disadvantages are:

1. It is available at certain places only (with ocean)
2. It effects marine ecosystem if not harnessed properly.
3. Noise and visual problem when the systems are installed near to the ocean

Wave Motion:

Waves are generated by the circular motion of a water particle and this energy is transferred to the neighboring molecule and hence the wave is formed. So, the basic motion and the source of energy is the circular motion of water molecule that could be harnessed. The exact motion of wave particle is explained in the picture below:(1)

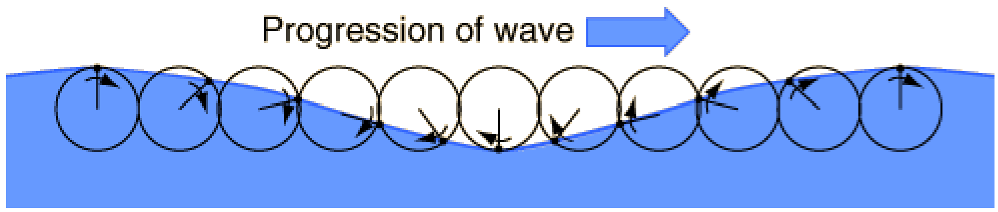

Figure 2. Wave particle motion

Each particle of the wave follows this circular motion and the magnitude of this wave is felt up-to the half of wavelength down the wave. After that point, the wave tends to become weak and the magnitude of circular motion drops gradually to the point where it becomes zero.

Selection of Wave:

The wave most suitable for the harnessing of energy from the apparatus is the swell wave. Swell waves are also called as surface waves or gravity waves. They are generated by distant water weather systems. Since, these waves are hardly affected by local wind so they are consistent and they have a long wavelength. They are also smooth and the water particle in these waves follow a complete circular motion.

Existing Ocean Wave Energy Conversion Devices (OWECs):

The potential of ocean wave energy has been recognized since a very long time and since then many ocean wave energy conversion devices have been developed to harness the energy of waves and convert them into useful energy (mechanical or electrical). Some of these devices are as follows:

1. Pelamis wave energy converter
2. Attenuator
3. Point Absorber
4. Oscillating water column

5. Submerged Pressure Difference

Since out of these devices only Pelamis Wave energy converter is a commercial success so it is introduced briefly.

Pelamis Wave energy Converter:

Pelamis uses the ocean surface waves to generate electricity. The device is made up of connected sections containing semi-submerged cylindrical sections hinged to each other. When the wave passes the sections move relative to each other and this relative motion is converted into hydraulic motion via hydraulic motors and accumulators. These motors drive generators to produce electricity and it is then transferred through cables.

Cyclic to Rotary motion converter:

The Cyclic to Rotary motion converter designed, developed and tested in this project also targets the waves for energy conversion. The device has four major components

1. Float
2. Connecting means
3. Unidirectional Turbine
4. Power Transmission – Cables, motors, generators

The basic principle is that float rides the waves and the due to relative motion of turbine and water the turbine blades rotate in unidirectional manner during upward and downward motion of waves.

The basic element of the device is the unidirectional turbine and for this purpose savonius turbine is selected.

Conclusions:

The energy demand of world is ever increasing and the fossil fuels will no longer be able to fulfill the energy requirement of the world. So, renewable energy is the future of energy world. Ocean wave energy is a sustainable form of energy and many devices have been developed to harness the energy from waves. The ocean wave energy converter developed in this project has the potential to harness the wave energy easily and efficiently.

CHAPTER 3

METHODOLOGY

Understanding of Novel Mechanism:

Having a project completely related to Ocean Waves, we had to understand the complete naval mechanism. We needed to understand the mechanics of waves and the energy they carry.

To experimentally understand the very basics, we had come up with an idea to use squirrel cage mechanism. We simply took the blower of the car. It is light in weight and it has tilted blades all around it. We passed the shaft from its central axis of rotation. To make up an assembly, we took two PVC pipes and by keeping them in vertical parallel position, we joined them with the help of shaft perpendicular to both of them.
At one end of the shaft, pulley was installed so that it can transfer mechanical power of shaft to the generator. We installed generator above the blower attached to PVC pipes. A belt has been rounded over the pulley of the shaft and generator's pulley.

With the help of water jet, we tried to give the input power to the turbine. Turbine started rotating and due to shaft rotation, belt transferred the mechanical power to the pulley of generator. So we actually measured the efficiency and came to know the method of doing calculations for our upcoming future work.

This prototype development was our very first step towards the design analysis and calculations.

To measure efficiency, we were required to have the known values of input power of water jet and output power being generated from the generator. Through Digital multimeter, we measured the output power from the terminals of generator. Below is the figure

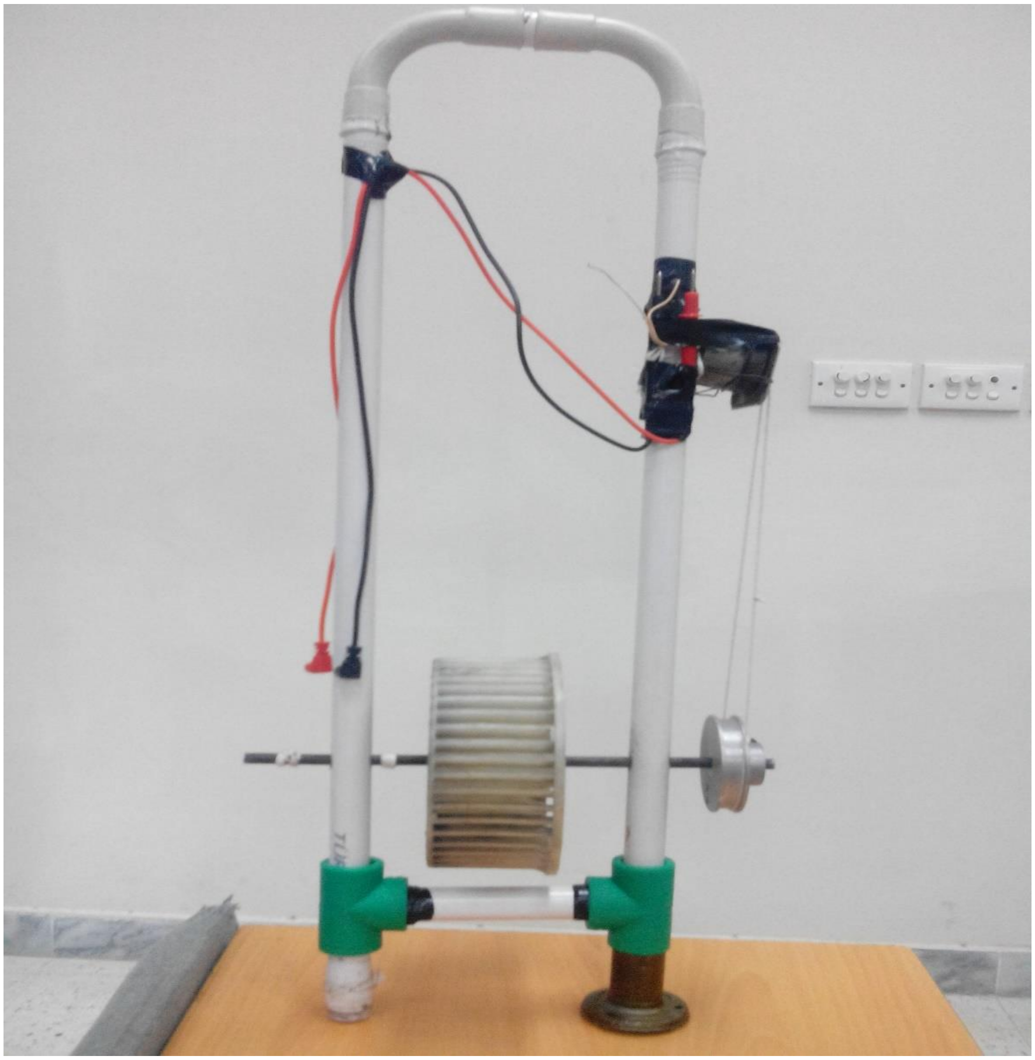

Figure 3. First prototype incorporating squirrel cage turbine

Here complete calculations has been shown:

Calculations:

- Input Power:

$P_{in} = Force_{waterjet} \times Velocity_{waterjet}$

Where

$$Force = Density \times Flow\,rate \times velocity$$

$$Force = 1000 \times 2.797 \times 10 - 4 \times 1.1$$

$$Force = 0.3\ N$$

Now

$$Power = 0.3 \times 1.1$$

$$Power = 0.33W$$

Efficiency

$$Efficiency = \frac{Output\ Power}{Input\ Power} = \frac{0.1}{0.33} = 0.\ 303$$

Or $$Efficiency = 30.3\%$$

Results:

I. Average Output Voltage = 2.5 V

II. Average Output Current = 0.04 A

III. Average Power Output = 0.1 W

IV. Average RPM = 250

Unidirectional Turbine:

We are in phase 2 now. We have the complete understanding of novel mechanism. When waves will hit the prototype, they will make it to move in a circular motion like to and fro as well as up and down. Due to this circular motion of prototype, turbine in the structure will also get the same circular motion.

We have to convert the cyclic motion of waves to rotary motion of turbine i.e., turbine should rotate continuously as the structure moves due to influence of waves. During this cyclic motion, turbine will go up for the half cycle and it will go down during the next half cycle.

Turbine is not stationary with the respect to the surrounding. So during the first half cycle, forces will act in one direction and during the next half cycle, same forces equal in magnitude but opposite in direction will act over it.

We need to have a turbine which should be unidirectional. Like either structure goes up or down, turbine should move in one direction only. It will result in harnessing useful output. So we had to design a unidirectional turbine, its blades should be such that, it should behave unidirectional in water.

We have come up with an idea to design a simpler unidirectional turbine. We took a PVC pipe and cut it at 120 degree into three pieces. These three curves pieces are three blades of the turbine. We took another pipe of smaller diameter and label three fringe spaces over it. Now we joined those three blades over this rotor. Turbine is ready.

This was our second phase and second prototype development. Similar to 1st prototype structure, we hold this turbine between mild steel pipes and a pulley over the shaft of turbine. We tested it manually by giving circular motion to the structure in the water with the help of our hands. And what we saw was that turbine is behaving unidirectional. Turbine design was like savonius wind turbine. Its blades were similar to those of savonius wind turbine.

Optimization:

The final step is to optimize the complete mechanism. Unidirectional turbine is ready. We need to optimize the complete structure, measurements and testing to reach to the final prototype. To make it more efficient, turbine needed an attention to be considered of some specific material. (2)

Aspect ratio, number of blades, radius of blades, curved angle of blades and stages of turbine needed to be considered for the better efficiency.

- To have a maximum efficiency, aspect ratio of turbine should be 0.7. Aspect ratio is length of turbine blade to the diameter of rotor. We kept it 0.7(3)
- If 3 blades are used in a turbine, it gives the maximum output torque, se we kept 3 blades. (4)
- Angle of blades should be 124 degree for the maximum output power. (5)
- Two stage turbine is better than the single stage turbine. Also its efficiency gets enhances if end plates are used.(6)

By keeping all the above factors under consideration, we have come up with completely unique design of turbine which ought a reasonable efficiency.

Testing Bench:

Here comes one of the main domain of ocean wave energy converter which is to measure efficiency. Of course we needed a complete naval environment or either its alternative somehow having resemblance to it. We have come up with an idea of installing a mechanism that can give a circular motion to the prototype structure.

Since we had to give this input power manually that should not be consistent because waves are also not consistent. We involved the similar axle and pedal mechanism of a bicycle to give it a circular motion. A transparent water body just like a fish aquarium has been taken to make the process visible to us.

Since the whole structure is moving in a cyclic motion, it is not feasible to measure rpm of turbine. We could have installed generator to convert mechanical power of shaft to electrical output of generator, but that also would have resulted in maximum loses. What we did was to use the brake horse power mechanism.

Final/Working Model:

Complete working model is shown in following figures

Figure 4. Double stage savonius rotor with three blades each

Figure 5. Working Model

Figure 6. Water Tank

Conclusions:

Due to the novel mechanism, the project was experimental and different prototypes were developed before reaching the final optimized prototype.

CHAPTER 4

RESULTS

The outcomes of this project include successful demonstration of a working prototype together with the measurement system (spring & belt mechanism) and a testing facility. Measurements include the input and output parameters required for the quantification of energy efficiency of this system.

Following is a summarized experimental and theoretical analysis of our OWEC device.(7)

Input Parameters:

The input parameters account for the input energy available to the turbine at any instant of time. These parameters provided below are either properties of ocean waves or the geometry of turbine.

Input speed = V_{in} = Speed of turbine w.r.t fluid

Rotor Swept/Projected Area = A_s = $Rotor\ diameter\ \times Rotor$ length

Input RPM = $N_{in} = \frac{V}{r}\left(\frac{60}{2\pi}\right)$

Input Power:

For a two stage Savonius turbine, the power available to the turbine is given by the formula

$$P_i = \frac{1}{2} \times \rho_w \times A_s \times V^3 \times C_D$$

Where

$$\rho_w = density\ of\ water = 1000\,\frac{kg}{m^3}$$

$$A_s = swept\ area = 0.3\ \times 0.21 = 0.063\ m^2 =$$

$$C_D = drag\ coefficient = 0.35$$

$$(V_{in})^3 == (1.32)^3 = 2.30\ \frac{m^3}{s^{-3}}$$

Therefore substituting values in above equation, we get the input power i.e.

$$P_i = 25.25\ Watts$$

Output Parameters:

The output parameters account for the output power produced by the turbine as well as the quantification of energy efficiency of the system and development of parametric model for future systems. These parameters include

Output RPM = N_{out}= Number of revolutions of turbine shaft per shaft

Output Torque = $\tau_{out} = r * F =$ Torque produced at the turbine shaft

Theoretical Output Power:

The theoretical output power produced by the savonius rotor is calculated using the power coefficient i.e. Percentage of input power converted into output. We have

$$P_o = P_i \times C_p$$

$$C_p = 0.30$$

$$P_o = 25.35 \times 0.30$$

$$P_o = 7.6\, Watts$$

Experimental Output Power:

The experimental output power produced at the turbine shaft is calculated by using a spring belt mechanism which applies braking force on the shaft. When the shaft reaches to the point of static equilibrium, the two torques are balanced out. Using equation

Where

$$\tau_b = r \times F = 0.05 \times 10 = 0.5\ Nm$$

$N_{rpm} = 125$ Calculated using tachometer

Substituting values in the equation gives

$$P_0 = 6.54\ Watts$$

Experimental power coefficient:

Experimental power coefficient is calculated using experimental values of power output i.e.

$$C_p = \frac{P_o}{P_{in}}$$

$$= \frac{6.54}{25.5}$$

$$= 0.26$$

It is quite close to the actual power coefficient '0.3' of a two stage savonius rotor with three blades each. The small difference is due to limitations of the measurement apparatus used.

Scalability:

The main advantage of this mechanism is that it is highly scalable i.e. it can be scaled up, scaled down, adjusted according to the change in input parameters and therefore produce higher power output.

Integrative Nature:

Several such prototypes can be placed in an integrative array manner along the length of the wave to achieve higher power output.

Conclusion:

In this chapter the quantification scheme is presented and a comparison between experimental and theoretical output is made. Based on the comparative study, it can be concluded that the OWEC mechanism presented above is practical, efficient and in many ways better than its contemporaries because of its simplicity and scalability. It can, however be improved further by incorporating digital measurement system and performing experiments in actual ocean environment.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION:

As defined clearly in the introduction, the main aim of this project was to develop a working model, based on the said patented mechanism of harnessing ocean wave energy, in order to quantify and validate its practicality.

The methodology adopted in order to achieve the objectives is elaborated in chapter 3.

However certain limitations were associated with each undergone step. These were

1. The extreme ocean environment conditions as well as the complex wave dynamics is not incorporated in the mathematical and physical model due to resource and time limitations.
2. Due to lack of access to the ocean itself, a simple laboratory wave motion simulator was developed and attached with the OWEC via a connecting road as shown in figure 4. In this manner, the actual working conditions were simulated with for the OWEC device
3. The turbine selected for this purpose is approximated with savonius rotor, developed for wind application, with slight modification. The mathematical model of savonius rotor is therefore used by incorporating the density of water instead of air as given below

$$P_i = \frac{1}{2} \times \rho_w \times A_s \times V^3 \times C_D$$

This mathematical model describes the relation between input power and turbine geometry.

Similarly the output power is calculated using the following relation

$$P_o = \tau \times N_{rpm}$$

The experimental values were measured using a measurement system i.e. a calibrated spring belt system which was used to apply brakes to the rotating shaft. The amount of force or torque required to do so was calculated from the spring force. Alternatively, the electrical power output could be measured using a motor (operating in reverse) and multimeter.

The experimental power coefficient calculated for the savonius rotor was 28% against a theoretical maximum value of 30%. The slight difference is due to precision limitations of the measurement apparatus as well as the geometry tolerances.

The scale or size of the prototype was determined based on the available budget and testing facility as well as the handle ability and manageability. It can however be extrapolated according to the conditions and input parameters of the actual off shore environment of Karachi for instance.

RECOMMENDATION/FUTURE WORK:

The basic purpose of future work is to transform the prototype to product stage and to generate electricity through it so that it could be added into the national grid. For this purpose, following recommendations are suggested:

1. Detailed and comprehensive study of marine environment
2. Material selection for the product based on the marine data

3. Develop an empirical relation of the product with the ocean wave potential of world so that it could be used anywhere.
4. Accurate, flexible and precise measurement system for the determination of efficiency and other output parameters
5. Detailed Study of the floating mechanism
6. Anchoring mechanism for anchoring the device in the ocean
7. Transfer mechanism of electrical energy

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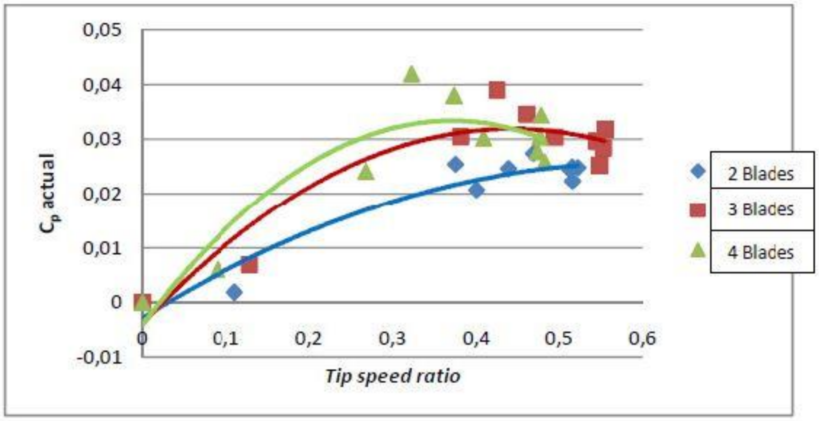
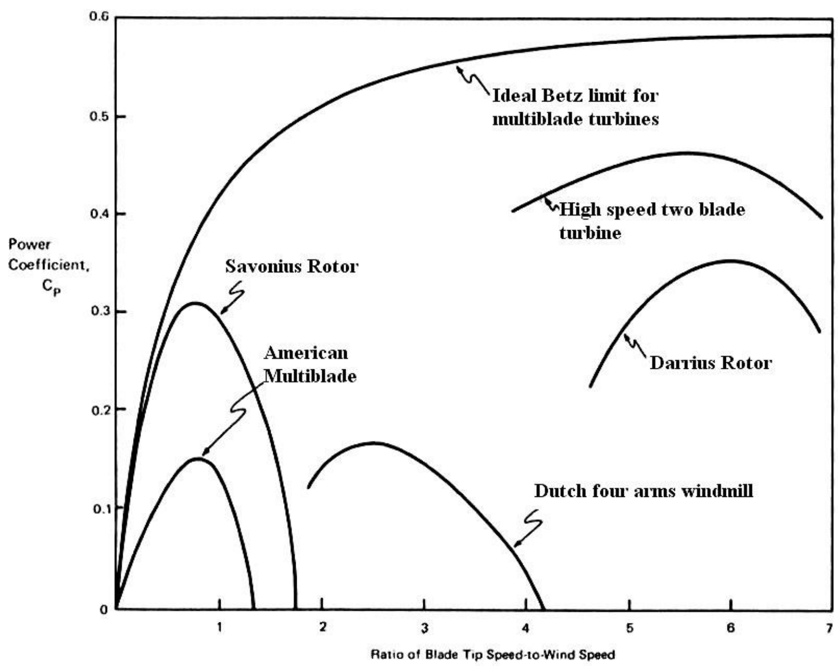
APPENDIX I: GRAPH FOR POWER CO-EFFICIENT



(3)

Figure 7. Power coefficient vs tip speed ratio for different number of blades



(8)

Figure 8. Power coefficient of different turbine rotors

APPENDIX II: 3D SAVONIUS ROTOR GEOMETRY

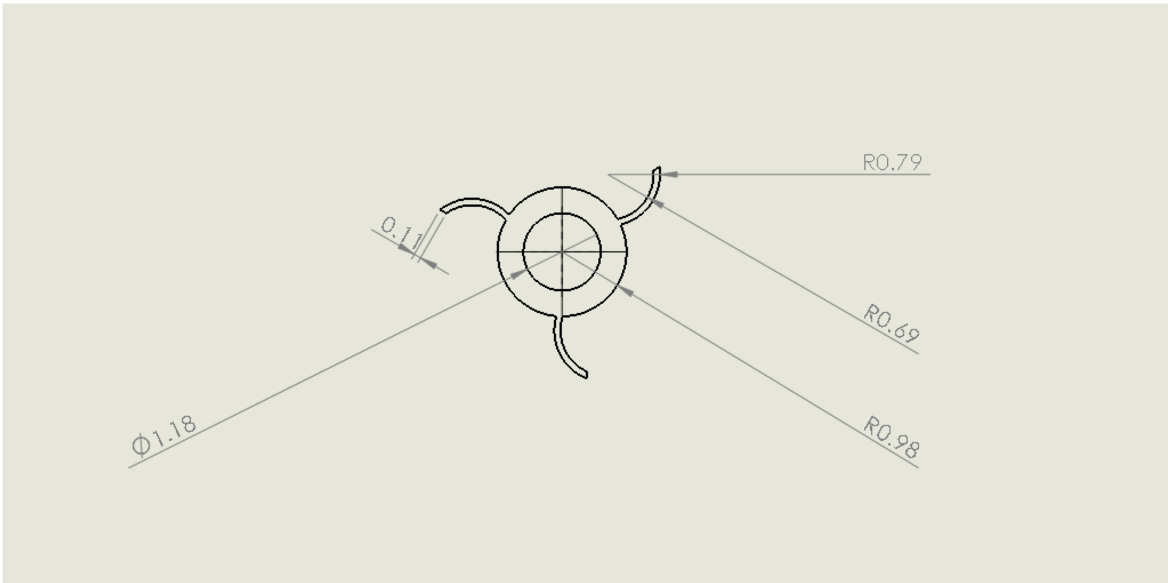


Figure 9. Top View

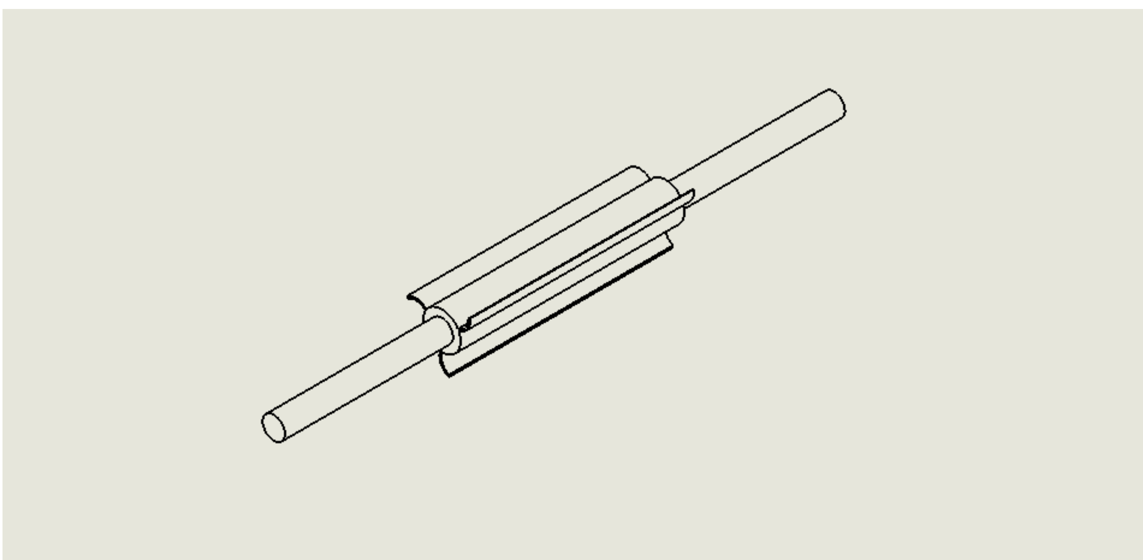


Figure 10. Isometric view

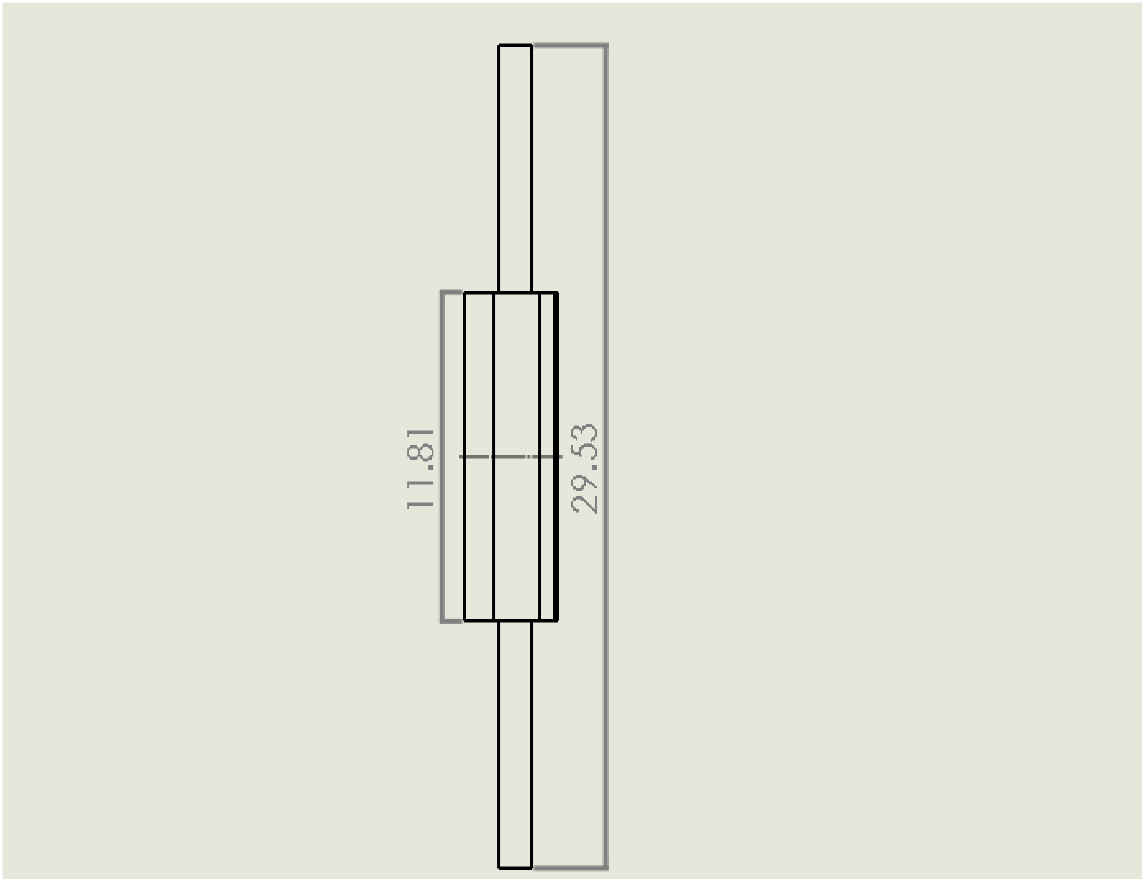


Figure 11. Front view

Units: Inches

Scale: 1:1