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DESIGN OF VAWT FOR POWER GENERATION

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ABSTRACT

Extracting the tidal wave power available in a creek or backwater can be a useful source of power generation in areas having no or poor grid connectivity. Our project aims at extracting power out of tidal waves in a creek and establishing the proof of concept for backwater power generation using VAWT (vertical axis water turbine). The power available in a tidal wave is proportional to the current velocity and this current velocity is dependent upon the tidal cycle. More the difference in heads during high tide and low tide, higher is the current velocity. Also this velocity follows the lunar cycle, meaning that the maximum velocity occurs during no moon day and minimum during full moon day. The velocity varies intraday also when the tide cycles change every six hours. Moreover the direction of flow of water reverses every six hours too. The aim of this project is to extract power just enough to power basic lighting equipment in remote areas along the coastal regions having favorable conditions. This is achieved using a vertical axis water turbine. The turbine can easily be coupled to a generator through a gearbox with suitable reduction.

1. INTRODUCTION

The coastal areas of India are the hub of fishing activities. They are home to both large scale commercial and small scale fishing industry. There are many remote areas in the coastal regions, where the docks for small fishing boats have no access to power and no provision for lighting. These docks called a jetty rely on diesel generators for power supply or carry out their activities in the dark. A possible source of energy to power these areas in the tidal current energy. The backwaters of a sea or ocean usually has a converging area that causes an increase in current velocity. If this velocity can be tapped and converted into electricity, many remote, grid inaccessible areas of India can be powered independently. This work aims to study the feasibility of such an independent standalone power generation system. For the purpose of the study the site selected is close to the small town of Harihareshwar, located in the western state of India, Maharashtra.

2. LITERATURE REVIEW

To get an idea about exactly how much power can be developed using the current velocity in a creek it is important to establish a model that relates the tidal current parameters to the maximum power that can be obtained in terms of measurable variables. The data about the tidal cycles for the study site and the velocity profiles over a sufficiently long time are to be acquired. Initially the data for current velocity and tidal cycles for areas around the study site was obtained from government organizations that work or have installed buoys for data logging. CWPRS located in Pune, is one such government organization which works that records the logged data for various sites around India. Useful information regarding the timing of tidal cycles, the variation patterns in velocity, previous attempts made to harness tidal current and other useful inputs were provided by the department with full co-operation extended by the employees. Seawater is 832 times as dense as air, therefore the kinetic energy available from a 5 knot ocean current (2.5m/s) is equivalent to a wind velocity of 270 km/h. Kinetic energy of a moving fluid can be extracted and converted to useful power using a suitable type of turbine rotor. By the theory of momentum, the total power P in W (watt) available from a stream of water having a density of ρ (kg/m^3) and flowing at a velocity v (m/s) can be given by the relation,

$$P = \frac{1}{2} \rho a v^3 \qquad (1)$$

where,
ρ is the density of water (1040 kg/m^3),
a is the cross-sectional area of the rotor in m^2 and
v is the free-stream velocity of the current.

The table below gives an idea about the significance of the cube law stated above. It can be seen easily that a small increase in available velocity increases the power density significantly. Theoretically, a threefold increase in velocity results in a twenty seven fold increase in the power density or available power. It is for this reason that the converging area feature of a creek is one of the critical reasons for considering it as a possible power source.

TABLE 2.1: POWER DENSITY AND CORRESPONDING VELOCITY

Velocity (m/s)	1	1.5	2	2.5	3
Velocity (Knot)	1.9	2.9	3.9	4.9	5.8
Power Density (kW/m^2)	0.52	1.74	4.12	8.05	13.91

The conclusions from the background study can be summarized as follows,

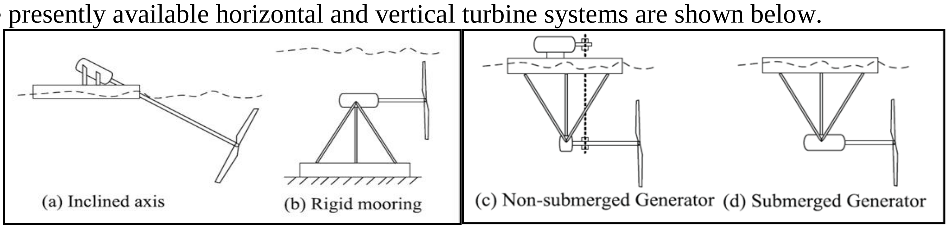
- The potential power available in the flow in a creek is proportional to the cube of current velocity in the creek.
- The velocity available in a creek varies continuously and it is most commonly in the range of 0.5m/s to 3m/s.
- The direction of flow reverses every six hours due to tide cycle (rotation of the earth).
- Current velocity is higher in creeks due to a natural venturi like effect.
- Intra-day peak velocity also varies and it is the least on full moon day and maximum on no moon day.

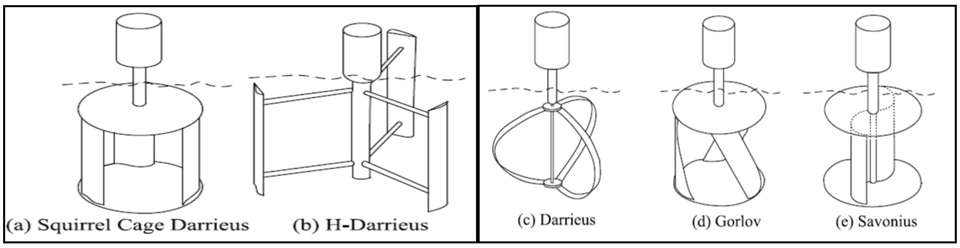
3. STUDY OF TYPES OF TURBINES

After getting an idea about the power available in the current flow in a creek, it is important to study how it can be extracted in the most efficient and most importantly in the most economical manner. Thus, data on the types of turbines available for the application has to be compiled. Among these the turbines operating on very low head are to be preferred. The features of each of the shortlisted turbines for the prototype design are summarized below. There are both turbine and non-turbine systems available for using tidal energy. However the aim was to develop a turbine system and hence only the turbine type systems will be focused on. The following types of turbine systems are in wide scale commercial use currently,

- Axial (horizontal): The rotational axis of the rotor is parallel to the incoming water stream. These types of turbines employ either lift driven or drag driven blades.
- Vertical type: The rotational axis of rotor is vertical to the water surface and also orthogonal to the incoming water stream. These types of turbines employ either lift driven or drag driven blades.
- Cross-flow type: The rotational axis of rotor is parallel to the water surface but orthogonal to the incoming water stream. These types of turbines employ either lift driven or drag driven blades.
- Venturi type: Accelerated water resulting from a choke system (that creates pressure gradient) is used to run an in-built or on-shore turbine.
- Gravitational vortex type: Artificially induced vortex effect is used in driving a vertical turbine.

All the above mentioned turbine systems are of the submerged type, however the concept suggested as a part of the problem statement was that a turbine with flat plate blades be used above the water on a floating platform. But the flow reverses every six hours and also flat plates perform poorly as a turbine blade. The cross flow type of turbine system was eliminated since it is a complex design and not economically feasible. The venturi and gravitational vortex systems were not economically feasible either. Hence the horizontal and vertical turbine systems would be considered as potential candidates for building a low cost standalone power generation system. The presently available horizontal and vertical turbine systems are shown below.





4. DESIGN OF PROTOTYPE

After the feasibility study and market survey it was concluded that a vertical axis turbine system was best suited for the application. It also fulfilled the very aim to design the system to be simple, easy to manufacture, easy to assemble and disassemble and most importantly it should be economical and built with minimum expenditure. The vertical axis turbine system basically has two types of blades configurations,

- Savonius turbines with blades that are arc of a circle.
- Other types having blades of airfoil shape.

The NACA airfoil series is available easily in market and one can even get an airfoil custom made for one's application. However the option is expensive and beyond the economy range for the targeted application. Hence the design shall proceed with the Savonius turbine kind of blades. Arcs of a circle will form the blades of the turbine. The blades shall be placed circumferentially between two solid discs with the shaft passing through the

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center of the discs. The blades will be attached to the discs by L-plates and stiffener shall be added to increase bending strength of the blade. Slots shall be made in the discs so that the stiffeners would fit into them further increasing the rigidity of the blades. The dimensions of the prototype shall be decided giving highest priority to the cost and ease of manufacture and transportation. The prototype shall be modeled in Catia and analyzed for its weight and inertia. The budget allocated to the prototype manufacture was two thousand Indian rupees and the manufacturing was done at the machine shop inside the MIT Collge of Engineering, Pune campus. The detailed specifications of the first prototype are listed in the table given below,

PART	DIMENSION/SPECIFICATIONS
TURBINE	DIAMETER – 457.2MM (1.5 FOOT)
	MATERIAL – WOOD
BLADE	ARC DIAMETER – 152.4MM (6 INCH)
	BLADE HEIGHT – 304.8MM (12 INCH)
	ARC ANGLE - 110°
SHAFT	LENGTH – 1200MM
	DIAMETER - 30MM AT TOP 200MM LENGTH
	30 X 30 MM SQUARE FOR REST OF THE LENGTH
	MATERIAL - WOOD
BEARING	ID – 30MM
	OD – 72MM
L-PLATES	25.4 X 25.4 X 3 MM
	MATERIAL - ALUMINUM
BOLTS, NUTS	NUMBER 8 NUT AND BOLTS USED IN AUTOMOBILES. (M5)
STUD	M6
PAINT	STANDARD BLACK OIL PAINT

The dimensions for blade

DIMENSION	VALUE IN MM
RADIUS OF CURVATURE	101.6
THICKNESS	3
LENGTH	410

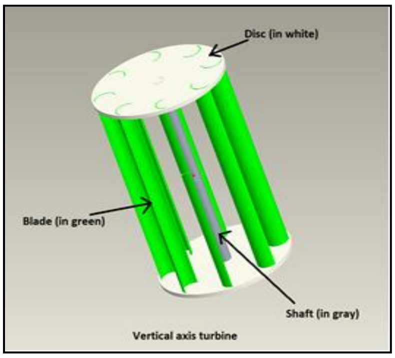
Other dimensions

DIMENSION	VALUE IN MM/SPECIFICATION
BOLT DIAMETER	M5
L-SECTION	38.1 X 38.1
L-PLATE LENGTH	25.4
STUD DIAMETER	6
BEARING	PLUMMER'S BLOCK BEARING 40MM ID

Dimensions of the assembled prototype

DIMENSION	VALUE IN MM
TURBINE DISC DIAMETER	810
TURBINE DIAMETER	580
TURBINE HEIGHT	410

The Catia model is shown below



5. MANUFACTURE OF PROTOTYPE

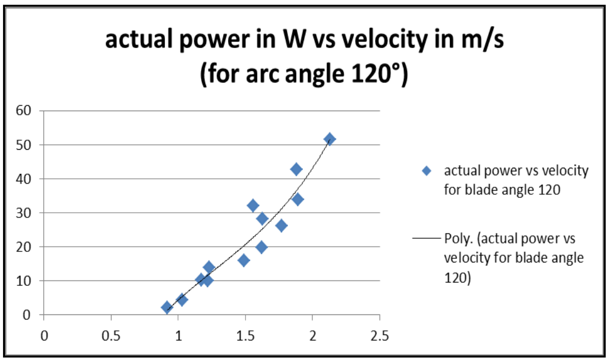
After the dimensions and materials were finalized the manufacturing of prototype was done using standard manufacturing practices. The PVC pipes were cut first into pieces of required length and then into two halves so that two blades of 180° arc angle were obtained. Next it was reduced to 110° using shearing machine so that the side bending load would be reduced. It was decided to use three different blades having different arc angles for the turbine. A special shaft was manufactured which was round at the top and square section for the rest of the length just to make it easier to hold during installation and to avoid slipping within the discs. The finished initial prototype is shown below,

6. TESTING AND RESULTS

The velocity readings for five days were taken at the site during site survey. Based on these readings the maximum available power for these five days was obtained and the prototype was tested during the same five lunar days of the next month. The maximum power available for these five days is tabulated below,

day	max power available for arc angle 120° in W
1	178.3273246
2	271.2135698
3	391.7851322
4	594.3628396
5	792.0000181

The actual mechanical power recorded at the turbine shaft on one of the test days is shown below as a function of the varying velocity,



Clearly, the actual shaft power is a lot lesser than the maximum available power. This is because drag type turbines are supposed to have very poor efficiencies of the order of about 10-20%. However the aim of the project is to make the system as economical as possible. Hence efficiency is secondary if enough power is being generated at a low cost. The actual power obtained is about 10 percent of the maximum available power which confirms to experimental studies on drag type turbines.

CONCLUSIONS

After obtaining the result tables for all the three arc angles and studying them the following important conclusions were made,

- Proof of concept for backwater power generation was established. There is definitely scope to develop an independent power generation system using tidal current energy. However a lot of iterative design

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improvements are required to be done before establishing the finished product on a commercial scale.

- The amount of power obtained, in general, is very less thus the size of turbine should be increased by a significant amount. Otherwise if a large sized turbine is not desirable then multiple small turbines should be used to obtain higher power outputs. A turbine farm concept should be explored and studied for harnessing the energy commercially.
- The power obtained varies continuously. The reason for this is the varying velocity of water and in turn the varying rpm. Hence a gearbox that would give a constant output speed has to be used before coupling to the generator. Alternatively a flywheel could be installed to regulate variations in rpm over a limited range.
- The next step should be finding out the optimum blade arc angle. This could be done experimentally of using fluid analysis software packages, depending upon the availability of the relevant technology and skillsets.
- The blade mounting angles could also be varied to obtain a more uniform torque. In the tested turbine the blades were mounted perpendicularly between the two discs. However they could be mounted at an angle between the two discs for gradual loading of the blades and tested.
- The power that will be generated after coupling the current turbine to a generator can be used for minor applications such as lighting of the jetty using energy efficient LED lights.
- Use of polypropylene for shaft, bolts and other components that are presently used in metal can reduce inertia and hence the starting torque. Also polypropylene is much more durable than any other material in corrosive environment. Hence the use of polypropylene should be explored for better durability and performance
- The average power available comes to about 20W at a cost of 15000 rupees for the prototype. Thus the investment per kW of power is estimated at 7.5 lakh Indian rupees. However with improvement in turbine design and efficiency more power can be extracted and by mass production the cost of turbine will reduce by 50%. Thus the cost per kw power will be comparable to other non-conventional energy sources like solar and wind which are developing rapidly. Also this type of energy has an advantage that it will require very less maintenance which will be the replacement of bearings periodically.
- The most important advantage of the turbine is its extremely simple design and ease of manufacturing which will help in achieving economy.

Finally as a concluding statement it can be said that the results of the turbine were much below the expected results and much more improvements and extensive experimentation is necessary before actually establishing this type of energy on a commercial scale to compete with the present conventional and non-conventional energy harnessing plants economically and technically.

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