Performance Analysis of Gravitational Vortex Hydro-Turbine

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Abstract - *Gravitational vortex hydro-turbine works on the principle of a vortex It converts centrifugal head of vortex into shaft power. GVHT can generate electricity from renewable sources of energy. In a Gravitational vortex power plant, water enters a circular basin in tangential direction & energy is extracted from the free vortex using a turbine.*

The main advantages of GHVT are that it can generate electricity from the very low hydraulic head, it is environment-friendly & it is economically & socially viable. It is a new and not well-developed technology to generate electricity from low-pressure water energy sources. There is limited literature available on the design, fabrication, and physical geometry of the vortex turbine and generator. Past researches focus mainly on the optimization of turbine design, inlets, outlets, and basin geometry. However, there is still insufficient literature available for the technology to proceed beyond the prototyping stage. The turbine's theoretical energy conversion efficiency is computed to be up to 85%. The maximum efficiency obtained by the researchers is 30%, while the commercial companies claim the efficiency of the turbine around 50%.

The project is based on factors such as availability of the source, desired requirement, or generation of power, a flow rate of the source and safety of the marine life in the source used. To adjust the flow rate of the inlet water from the source, a governor is mounted at the entrance of the circular basin, to ensure a desired flow rate of water, and thus, obtaining the desired capacity of power to be generated. The safety of the marine life, that may enter from the source, is ensured to slip right through the mechanisms, safely without any harm.

The project aims to determine the gap in currently available technology & research progress made in recent years. The methodology includes performance analysis of GVHT, finding out the optimum shape of the basin & channel. The methods include both simulations on ANSYS fluent & manufacturing of a considerable amount of energy for the prototype based on the result obtained from the simulations for experimental analysis & testing. It also aims to study the feasibility of GVHT in a country like India.

***Key Words*: vortex, hydraulic head, viable, efficiency, optimization, conversion, ANSYS, feasibility**

1. INTRODUCTION

Since Thomas Edison lighted the first bulb in human history in 1879, electricity has played a pivotal role in the development & illumination of human resources. According to the Ministry of Power (India) & Central Electricity Authority (India), between 31st March 2017 - 31st March 2018, Electricity production in India increased by around 6% from 1,066,268GWh to 1,130,244GWh.

Coal and fossil fuels are the prominent energy source in India. About 80% of electricity produced from coal and fossil fuels. Renewable energy sources generated about 16% of the electricity produced in India.

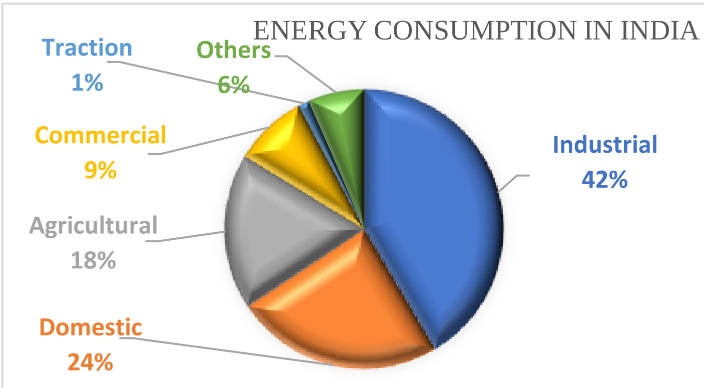

Figure 1 – Energy Consumption in India

Hydropower is one of the most economical sources of energy. Hydropower is also the most efficient source of electricity with an average efficiency of around 86% - 95%, In comparison thermal power plants have an average efficiency of 33%. Solar energy has an average conversion efficiency of 15%.

A Gravitational vortex hydro-turbine works on the principle of a free vortex. It converts rotational energy / centrifugal head into electrical energy. In GVHT water enters a circular basin tangentially & energy is extracted from free vortex using a turbine.

The GVHT can operate under low heads of 0.7m to 3m. It can generate nearly 12Kw to 15Kw of energy which is enough to power about 60 rural homes. As it is comprised of less moving parts, It's maintenance is easy. Due to lower specific speeds, the marine life in the channel is unaffected making the turbine environmentally friendly

The cost of a small GVHT plant is approximately half that of the thermal power plant of the same capacity. Hence making it economically feasible. The GVHT is compact in design. It doesn't cause mass displacement of human resources hence it is socially viable.

2. LITERATURE REVIEW

Christine Power et. al. - [1] Used a laboratory model of a cylindrical tank of 0.85m height & 0.6m in diameter. The outlet diameter was 0.11m. A discharge of 8.6litres / second & constant head of 7.8m was assumed. Two blades of length 0.2m & 0.08m were considered for the test. The two turbine models having 12 & 8 blades were used.
The paper describes the experimental analysis of operating characteristics GVHT. The following parameters were recorded - 1.) Flow rate. 2.) Number of blades. 3.) Size of the blade. 4.) Vortex height. 5.) Applied resistance force / Turbine braking force.

The following parameters were calculated – 1.) Power input. 2.) Power output. 3.) Efficiency.

The analysis had the following results & inference – Turbine efficiency increases with blade number & size. Optimum performance of the turbine was observed when the turbine was placed at 35% of the tank height from the base.

H. M. Shabaraa et. al , A. H. Elbatran et. al - [2] ANSYS CFX was used to simulate the free vortex pool. The analysis was carried out for two conditions.

1. Outer diameter constant 100cm & water height 60cm, 80cm & 100cm.
2. Water height constant 100cm & outlet diameter 75cm, 100cm & 125cm.

The simulations had the following result & inferences. Outlet speed is inversely proportional to outlet diameter. Higher velocities can be obtained using higher water height.

A.H. Elbatran et. al – [3] The research paper reviews of low-head micro-power hydropower plants. It compares operational cost, discharge & turbine capacities of various turbines. It also evaluates the cost of low head power plants.

Subash Dhakal et. al – [4] Used a laboratory model of a cylindrical tank of 0.85m height & 0.6m in diameter. The outlet diameter was 0.11m. A discharge of 8.6litres / second was taken.
Vortex strength of the conical basin & cylindrical basin was evaluated experimentally. The conical basin yielded an efficiency of 26.93% which was significantly higher than the efficiency of the cylindrical basin.
The efficiency of the turbine with a smaller number of blades was found to be higher. The larger blades also resulted in a decrease in efficiency, this is attributed to frictional losses at basin and turbine.

Yasuyuki Nishi et. al – [5] For the experimental analysis the following dimension of runner, basin & turbine were taken. Outer diameter = 0.14m, Inner diameter = 0.09m, Inlet width = 0.091m, Outlet width = 0.091m, Inlet angle = 71.9°, Outlet angle = 19.0°, Tip clearance = 0.5mm and Number of blades = 20. The experiment was conducted under a constant discharge of 0.00285 m^3/s.
The experiment & numerical analysis gave the relation for optimum speed and discharge. It also described the optimum discharge & speed v/s torque characteristics.

S. Wanchat et. al - [6] Simulations were carried out for two conditions 1.) Orifice diameter constant at 40cm & water height was taken 20cm, 30cm, 40cm, 50cm & 60cm respectively for five calculations. 2.) Water height was kept constant at 40cm & Orifice height was taken 20cm, 30cm, 40cm & 50cm respectively for four calculations.
The simulations gave a distribution of tangential velocity distribution along with depth & radial direction. The result the simulations give the optimum tangential velocity & discharge of a GVHT with a cylindrical basin.

P Sritram et. al – [7] For the experimental analysis, the two models of the turbine with blades of height 32cm & 45cm were taken. The materials considered for the turbine in this experiment were Steel & Aluminium Flow rates of 0.68 m^3/min, 1.33 m^3/min, 1.61 m^3/min, 2.31 m^3/min, 2.96 m^3/min and 3.63 m^3/min & Electrical load of 20W, 40W, 60W, 80W & 100W was set up. The experimental was calculated to find 1.) Efficiency 2.) Torque 3.) Power.
The experiment yielded following the results – The efficiency of the Steel turbine was 33.56% & the efficiency of the Aluminium turbine was 34.79%. The maximum discharge observed was 3.63m^3/min. The torque & generation efficiency was found to be higher in Aluminium than that of Steel by an average of 8.4% & 8.14% respectively.

Ankit Gautam et. al - [8] The simulations used CATIA & ANSYS fluent for analysis. The experimental setup was as follows. The basin diameter was 400mm, the channel height was 200mm. The notch angle & cone angle was 10° & 28° respectively.

The speed versus efficiency plot was evaluated experimentally and with simulations for GVHT models with runner booster & without runner booster. The runner booster was found to have efficiency 6% higher than of GVHT without a runner booster.

Shashidar PeddiReddy et. al - [9] The function of the governor is to maintain the mean speed of the engine within specified limits whenever there is a variation of the load. The objective of our investigation is to modify the Watt Governor (pendulum type) to increase the minimum speed limit.

Generally, we have seen that watt governor is best suitable for 60-80 r.p.m minimum speeds only, in our study we extend the lower arm and fly ball position of the watt governor to the downside from the intersection of link and arm, and then we derive the equation for governor speed. We fabricated the model of the governor and observed the effect of the extension of lower link and fly ball weight on the minimum speed of the governor. This analysis carried out by extension of lower links of the governor and position of fly balls.

3. METHODOLOGY

ANSYS FLUENT is able to handle both steady-state and transient analyses and has several different options for modeling turbulence. Conservation of both mass and momentum is solved in all fluid flow cases, and incompressible flow or heat transfer cases. Consider a control volume which encloses a specified mass of fluid in a steady-state flow field. Also consider a control surface around this volume, through which a certain mass of fluid enters and exits over a specific interval of time. If the flow is dE/dt state these quantities are equal therefore, there is no change in the mass of the volume. This is the principle of continuity.

This equation states that the time rate at which mass increases within the control volume is equal to the net influx of mass across the control surface Conservation of momentum can be written as

$$\nabla \cdot \vec{V} = 0$$

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho \left(\vec{V} \cdot \nabla \right) \vec{V} = -\nabla p + \mu \nabla^2 \vec{V} + \rho \vec{g}$$

Figure 1 - Navier-Stokes equation.

Where g and f are the gravitational and body force vectors, the stress tensor t.

Fluid behavior can be characterized in terms of the fluid properties velocity vector u (with components u, v & w) in (x, y and z directions), pressure p, density r, viscosity m, heat conductivity k, and temperature t. Changes in these fluid properties may occur over space and time. Using CFD these changes are calculated for small elements of fluid, following the conservation law of physics listed above. These changes are due to fluid flowing across the boundaries of fluid element and can also be due to due to fluid flowing across the boundaries of the fluid element and also be due to sources within the element that produces changes in fluid properties.

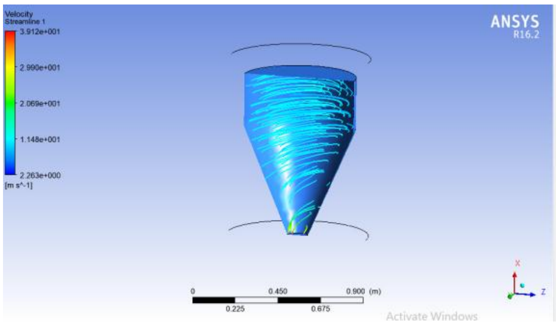

Figure 2 – Streamline flow from CFD analysis of conical basin

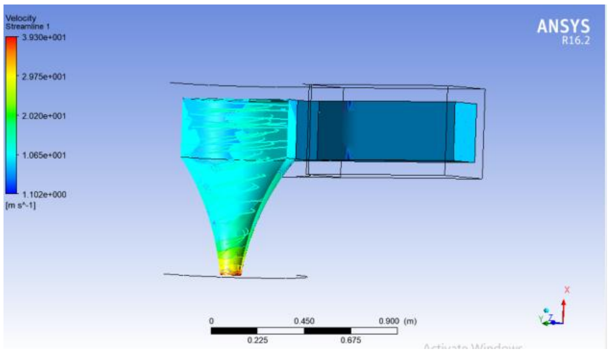

Figure 3 – Streamline flow from CFD analysis of inwardly curved basin

4. DESIGN AND CALCULATIONS

4.1 DESIGN

CHANNEL:

For constructing channel draw a semicircular ring of the diameter ‘d’ with thickness ‘t’. Extrude the sketch and cover the basin. While developing the converging part draw the channel then a rectangle from the centerline of the channel up to its edge on the top surface having width ‘t’. Now revolve the above drawing and remove the excess material. Extrude up to surface.

Figure 4 – Channel

TURBINE:

For the generation of the hollow cylinder to fix the shaft, create a cylinder of thickness 't' and length 'l' and extrude it. Select the surface of the cylinder by adding an extra plane. Select the side view of the respective plane and draw the profile of the turbine blade. Extrude with the desired thickness 't' and mirror the entire blade as per the number of blades required. The profile of the blade is inclined since the turbine becomes much more efficient by using this design.

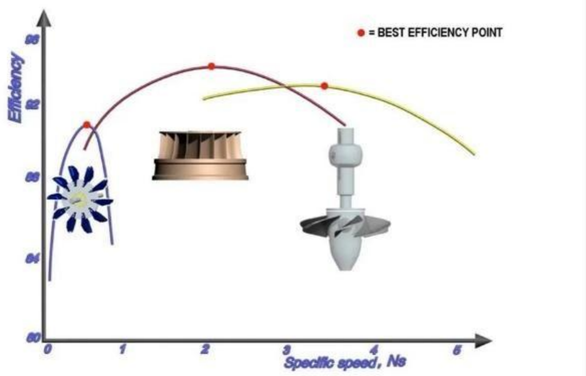

Figure 5 – Efficiency of Francis v/s Pelton Turbine

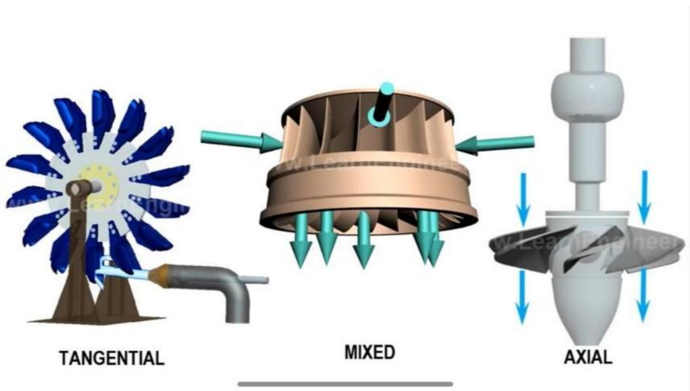

Figure 6 – Working of Francis Turbine

BASIN:

For designing of basin draw two horizontal lines at a height h and the upper line 'L1' of distance do/2 while lower line 'L2' at 'di/2' from the origin. From the 'L1' draw a vertical downwards till a distance of 'H'. Then construct an inward curve of radius from this point to 'L2'and revolve the whole sketch. Now on the vertical edge surface draw a rectangle and arc and extrude both. This will create the passage for the channel to enter.

Figure 7 - Basin

GOVERNOR:

The governor to be designed is a Hartnell governor. For designing this, first sketch a shaft of height 'h' and diameter 'd'. Extrude it. Then, by using the revolve command, draw the upper part by sketching in the front plane. Then select the middle axis. Give proper distance and draw the bell crank levers by sketching three circles and drawing lines joining in the shape of a bell crank lever, going tangentially through them. Rollers are placed at the ends of this bell crank lever. Select the axis again and draw the balls to be mounted on the bell crank lever by appropriate distance from the center axis. Draw another shaft from the base of the bell crank lever. By using the spline command, we can draw a spring by using the same technique that we use to make threads in a screw. Extrude that outwards to make a round about the shaft. Then again, by using the revolve command, design the frame and nut of the governor as per the respective height of the internal shaft holding the spring.

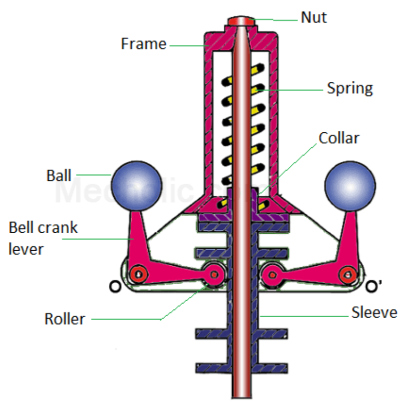

Figure 8 - Hartnell Governor

SUPPORT SYSTEM:

Since the stand is squarish, it is designed by extruding 'L' Beams. The L Beams are designed by extruding a design in the shape of 'L' with thickness 't' and length 'l'. Then, in assembly mode, the entire shape is assembled and the .asm file is saved.

Figure 9 – Support System

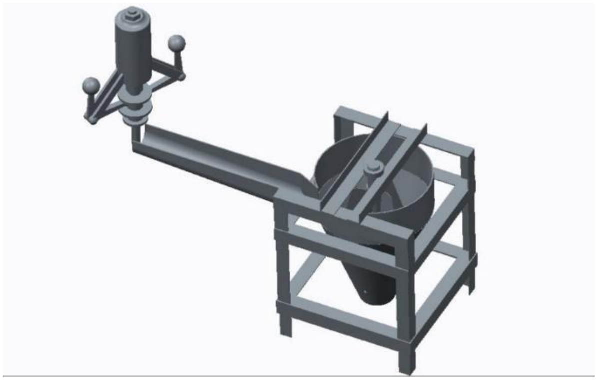

Figure 10 – Assembly

4.2 CALCULATIONS

Since the gravitational force is a predominant force in case of channel flow, therefore flow in the channel is characterized by Froude's Number (Fr) like Reynold's Number (Re) in case of pipes.

Froude's number: -

$$Fr = \frac{V}{\sqrt{gD}}$$

Where
D = Hydraulic diameter (D = 2R)
G = Acceleration due to gravity
V = average velocity of the flow in the channel

Hydraulic Radius (R) It is the ratio of the cross-sectional area of the flow to the wetted perimeter. It is also called a hydraulic mean depth.

$$R = \frac{A}{P}$$

The area is constant, the Hydraulic radius is maximum if the wetted parameter is minimum. This condition is used to determine the dimensions of economical section of different forms of channels. The best form of the channel which compiles with this condition is one which has a semicircular cross-section.

Where,

A = Cross sectional area of the flow = $\frac{\pi D^2}{8}$

P = Wetted perimeter = $\frac{\pi D + 2D}{2}$

$$R = \frac{\frac{\pi D^2}{8}}{\frac{\pi D + 2D}{2}}$$

On further simplification, we get

$$R = \frac{\frac{\pi D}{8}}{\frac{\pi + 2}{2}}$$

Now, D = 2R

$$D = \frac{\frac{2\pi D}{8}}{\frac{\pi + 2}{2}}$$

$$D = \frac{\frac{\pi D}{4}}{\frac{\pi + 2}{2}}$$

$$D = \frac{\pi D}{2\pi + 4}$$

For calculating velocity, we use the formula

$$V = \frac{Q}{A}$$

As available

$$V = \frac{0.0042}{\frac{\pi D^2}{8}}$$

Assuming Froude's Number = 0.8 for subcritical flow, Substituting Average velocity (V), Hydraulic diameter (D) in Froude's Number formula.

$$0.8 = \frac{\frac{0.0042}{\frac{\pi D^2}{8}}}{\sqrt{\frac{9.81 \times \pi D}{2\pi + 4}}}$$

Therefore

$$D = 0.08121m$$

The optimum ratio for Height & diameter

$$\frac{H}{D} = \frac{850}{600}$$

$$\frac{H}{D} = \frac{17}{12}$$

Basin top diameter: 218 mm
Basin bottom diameter: 62 mm
Basin total height: 270 mm
Inward curve height: 180 mm
Inward curve radius: 4R

5. RESULTS & DISCUSSIONS

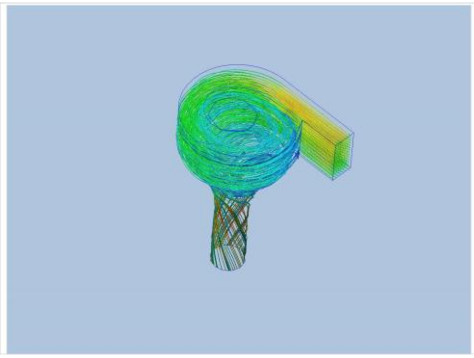

Figure 11 - Velocity Distribution

inlet 1	inlet bulk pressure	0.0 N/m^2
	inlet bulk temperature	0.0C
	inlet Mach number	6.7375e-08
	mass flow in	3.89346 kg/s
	minimum x,y,z of	0.0
	node near minimum	16.0
	Reynolds number	60999.4
	surface id	18.0
	total mass flow in	3.89346 kg/s
	total vol. flow in	0.00390048 m^3/s
	volume flow in	0.00390048 m^3/s

outlet 1	mass flow out	-4.76163 kg/s
	minimum x,y,z of	0.0
	node near minimum	195.0
	outlet bulk pressure	-0.0 N/m^2
	outlet bulk	-0.0 c
	outlet Mach number	1.11047e-07
	Reynolds number	88416.4
	surface id	17.0
	total mass flow out	-4.76163 kg/s
	total vol. flow out	-0.00477022 m^3/s
	volume flow out	-0.00477022 m^3/s

Table 1 - Results

Wall Pressure

pressx	-2.7042 Newtons
pressy	-49.85 Newtons
pressz	-0.021932 Newtons
shearx	-0.31631 Newtons
sheary	-0.1748 Newtons
shearz	0.029596 Newtons

Table 2 - Wall pressure

Field Variable results

VARIABLE	MAX	MIN
cond	0.6W/m-K	0.153 W/m-K
dens	1050.0 kg/m^3	998.2 kg/m^3
econd	32494.7W/m-K	0.0W/m-K
emiss	1.0	0.0
evisc	7.62819 kg/m-s	0.0 kg/m-s
gent	1838.391/s	0.0316228 1/s
press	0.0N/m^2	-3846.53 N/m^2
ptotl	475.983N/m^2	-3717.3 N/m^2
scal1	0.0	0.0
seebeck	0.0V/K	0.0V/K
shgc	0.0	0.0
spech	4182.0 J/kg-K	2050.0 J/kg-K
temp	0.0C	0.0C
transmiss	0.0	0.0
turbd	3.6831 m^2/s^3	0.000538025 m^2/s^3
turbk	0.0605141 m^2/s^2	1.003e-06 m^2/s^2
ufactor	0.0	0.0
visc	0.001003 kg/m-s	0.0kg/m-s
vx vel	0.995206 m/s	-1.49391 m/s
vy vel	0.188528 m/s	-1.95122 m/s

vz vel	1.04719m/s	-0.785937 m/s
wrough	0.0m	0.0m

Table 3 -Field Variable results

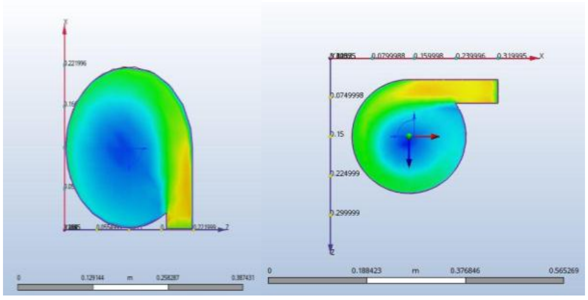

Figure 12 - Comparison of velocity profile of Conical (left) & inward curved (right) basins

6. FUTURE SCOPE & APPLICATIONS

6.1 Future Scope

The main motive behind this project is to get our vision into reality by the application of engineering knowledge gained within years. The project has been developed for a fixed value of discharge, A governing mechanism to control the flow of the water needs to be worked on.

The model needs to be subjected to various test conditions (ie Sewage water, Chemical Plants, etc.) Development of a standard design procedure for designing a Gravitational Vortex hydropower plant needs to be developed to increase its potential

6.2 Applications

Rainwater Harvesting

The water stored at the time of rains can be helpful to generate the electricity from a very low head. The wastewater that may not be used, can give a low yet definite rate of power generation.

High Towers in load shedding regions

Areas in which face load shedding can use the water stored in the compound tanks, which are located at the top of the buildings. The GVHT may be situated by modifying the pipeline, as water is supplied from the tanks. Obviously, this would be the excess amount of water that may be unused due to the regular fulfillment of water that the tanks help to store.

Agricultural Use

The water supplied to fields via motors and pumps can be used to generate electricity using GVHT. Once the GVHT is situated at the water inlet, if given enough, it may produce enough power to run the motor that pulls up the water and even light the lamps in the near vicinity.

Drainage Water

The drainage water from buildings can be used to generate electricity utilizing GVHT. The sewage will bounce off of the turbine, thus protecting the turbine and increasing its life. This may be situated underground, thus occupying no extra space in the compound.

7. CONCLUSION

Thus, the Gravitational Vortex Hydro – Turbine is a device that generates electricity from a low head and can be used in regions with a scarcity of water and Load Shedding areas. It is a highly versatile device, which has high volumetric efficiency. The cheaper cost helps in the mounting of this device in rural areas. As there are less than 3 moving parts, the maintenance is very cheap and the parts are readily available. The idea of this project came from the villages of India which have water sources nearby, yet suffer from lack of electricity. This device may also help in generation of power for agricultural purposes.

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