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Innovative Design and Performance Analysis of Gravitational Water Vortex Turbines

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Abstract: Due to limited availability and risk of extraction of non-renewable natural resources for energy extraction and production of electricity in future we will be relying on various renewable energy resources. Therefore we intent to aid THE GRAVITATIONAL VORTEX TURBINE SYSTEM in the field of hydro electricity generation. The turbine is capable of generating clean energy from streams without interfering with the environment. It will be capable if converting energy of moving fluid to kinetic energy which can be further utilized to convert it into electrical energy using a low hydraulic head. Electrical power is essential in commercial and social investments like lighting, heating, communications, Computers, industrial equipment, transport etc. Therefore hydropower energy is one of the most suitable and efficient source of renewable energy which depends on more than century of experience for this issue. The power capacity and facility are two criteria required for the classification of hydropower plant. The first one consists of five technologies: dammed reservoir, run of river, pumped storage, in stream technology and new technology gravitational vortex. The other one is classified according to power scale is Large, Small, Micro and Pico Hydropower. This project is focusing on micro hydropower especially gravitational vortex power which increases the sustainability and health of the water as a whole. It presents an overview from both flow and power points of view by discussing the free surface vortex (FSV) and the suitable turbine systems which are used in micro hydropower. The use of subjects like Fluid mechanics, Theory of machines and Engineering Mechanics will provide a backbone of this project. From this Project we will illustrate the micro hydro power generation technique.
Keywords: Gravitational, Vortex, Blade, Basin and Bearing.

I. INTRODUCTION

The need for cleaner sources of energy has become a major global issue owing to the effects of global warming and environmental pollution brought about by conventional fossil fuel usage. To this end and coupled with the ever-increasing energy demand, Efforts have been made to develop alternative sources of energy (renewable). Renewable energy such as hydropower has become one of the most demanded sources of energy for its clean generation. Low head hydropower plant is demanded in area which cannot see grid extension due to difficult geographical terrain and other reasons. Water vortex power plant is one of such low head turbines in which the Mechanical energy of free surface flowing water is converted to kinetic energy by tangentially passing the water to a basin, which forms a water vortex. Water energy being a clean, cheap and environment friendly source of power generation is of great importance for sustainable future; however, designing such energy system to harness energy from water is usually a major Challenge. Energy from water can be harnessed using different approaches, some of which Include: hydrostatic and hydrokinetic methods. Hydrostatic approach is the conventional way of producing electricity by storing water in reservoirs to create a pressure head and extracting the potential energy of water through suitable turbo- machinery. In hydrokinetic approach, the Kinetic energy inside the flowing water is directly converted into electricity by relatively small-scale turbines without impoundment and with almost no head, which is usually placed inside a river and activated by the water current. Gravitational water vortex turbine is an ultra-low head turbine which can operate in a low head range of 0.7–2 m. The concept of micro Hydropower system is a promising technology in renewable energy. Micro hydro power systems are capable of generating electricity up to a capacity of 100 kW. The energy in rural, remote and hilly areas is inadequate, poor and unreliable supply of energy services, micro hydropower able to provide rural area where grid extension is too costly and consumers have low incomes. In general, hydropower plants produce no air emissions but, in most cases, affect the water quality, wildlife habitats and especially prevent the fish migration, gravitational water vortex 2 power system which is classified as micro hydropower can provide a solution for this Environmental problem, it is a horizontal form of the hydroelectric dam. The benefits of using an artificially induced vortex above gravity-accelerated water increases Efficiency, decreases cost, and not only lowers the negative impact on the environment, but actually increases the sustainability and health of the river as a whole.

They have low emission of greenhouse gases (GHG) and do not require large structures for their implementation compared to large hydroelectric.

II. WORKING

Water vortex turbine consists of a circular basin with a central drain. Water enters tangentially inside the basin and forms a stable vortex at the central drain. Symmetrical eddies are formed Inside the circular basin. In gravitational vortex flow turbine free vortex flow (irrotational) Occurs.

$$v = r * \omega \qquad \ldots\ldots 1$$

V= tangential velocity or strength of vortex ω = angular velocity, r = radial distance from Centre Vortex strength is a constant, so shorter streamlines have high values of V. From Bernoulli's equation, we have:

$$P\rho g + \left(\frac{v^2}{2g}\right) + z = constant \ldots..2$$

As velocity (V) increases, pressure (P) decreases. The radial velocity increases due to gravity. The tangential velocity of water increases continuously in the direction of the vortex center. The vortex tube is squeezed by the inward water flow which presses it from all sides. As radius Decreases, rotation increases. At a certain rotational speed, centrifugal force comes into play and pushes water radially away from the drain. This causes a depression to be developed and a funnel shape is formed. Gravity pulls water down the drain; water pressure pushes inward and Centrifugal force pushes outward.

III. DESIGN METHODOLOGY

The design methodology is divided into three steps. The first step is the selection of Dynamo. The second step is the selection of a basin which has a full air-core vortex and higher gain in tangential Velocities, along with a reasonable height of the vortex. The third step is the Designing of blades to achieve maximum output power.

A. Dynamo

Table 1: Dynamo Specifications

Power	20 watts
Length	130 mm
Motor Diameter	36mm
Shaft Length	22mm
Shaft Diameter	10mm

B. Basin Design

Wanchat and Suntivarakorn suggested that a cylindrical tank with a discharge hole at the bottom center was the most suitable configuration to generate a water vortex along with a tangential water entry into the basin. They also suggested that the optimum basin diameter to outlet diameter ratio is 0.14 to 0.18. This led to the designing of the basin. When the mean tangential velocity of water in a vortex basin increases, the water motion becomes tangential instead of axial and the height of the vortex increases, thereby increasing the vortex strength. Therefore, focus was put on the designing of a basin that generates a free surface air core vortex, with maximum possible height and higher velocities at the core of the vortex. For this purpose, a reference basin dimensions were taken into consideration.

To increase the vortex strength, the vortex dependency parameters of the basin geometry are

Varied from the reference values one by one while keeping all others constant and are analyzed for the tangential velocities of the water in the vortex core, vortex height and the quality of air core ranging from 0 (for no air- core) to 1 (for full air-core). Besides varying the geometry parameters, the flow conditions are also varied to analyze the effect of flow velocities on the vortex formation. Since vortices with fully developed air-core have higher potential for power production as compared to those which do not have a fully developed air core, therefore, formation of air core was also focused during the selection of basin.

The parameters that are analyzed for the effect on the vortex and the tangential velocities are:

1) Basin Diameter (0.4m to 0.8m)
2) Outlet/Basin Diameter (0.13 to 0.17)
3) Basin Height to Diameter Ratio (0.5 to 1.5)

4) Inlet Channel Width Ratio (0.1 to 0.5)
5) Inlet Channel Depth Ratio (0.1 to 0.5
6) Inlet Velocity (0.1 to 0.6 m/s)

Table 2: Basin Specifications

Basin Diameter	500
Basin Height	500
Outlet Diameter	150
Inlet Width	150
Inlet Depth	150

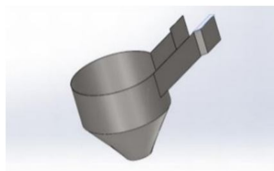

Figure 1: Basin Model

C. Turbine Blade Design

Turbine blade is one of the most vital components for GWVPP. It is positioned at the center, aligned with the central outlet of the basin. The turbine is forced by the water power that come from the water vortex. In the design of vortex turbine blade, some valid assumptions were made for the design of the model turbine. They are listed below:

1) Head and pressure losses are negligible.
2) The velocity with which the water strikes the runner is uniform along the length of the turbine.
3) The flow in the water vortex is inviscid and irrotational.

Let β1 = 15°, β2 = 19°, ID = 10mm, OD = 12mm for initial design. The head (H) was measured to be 0.3m while the flow rate was calculated was Q= 0.00675m3/s. Turbine depth from the upper surface of vortex was measured to be h = 0.3 m. At this depth, the radius of vortex was calculated to be r =12 mm by substituting in the parabolic trend line.

Internal Diameter = 12mm
Outer Diameter=15mm
(β1)- Blade inlet angle= 15◦
(β2)- Blade outlet angle=19◦
Cross section area of the outlet:-
(0.15) x (0.15) = 0.0225m^2
Mass of water striking the blade=> Q= V x A
= 0.00675m3/sec.
Maximum force of water (by velocity triangle):-
= ρ*a*v*r*l (Vw1 + Vw2), when β is acute. (Considering this for calculation)
Vortex Velocity Components:-
Vr (rotational velocity) =0 (fluid is irrotational)
Q= 0.0067m3/sec
K= Vortex strength factor

$$K = \left(\frac{Q}{h}\right)$$

= 0.0067/0.3 = 0.022m^2/sec
K= 0.022m^2/sec.
Vθ = rotational velocity of vortex:-

$$V\theta = \left(\frac{k}{2\pi r}\right)$$

= 0.022/2 x 3.14 x 12 = 0.291m/sec

(r=12mm vortex radius)
$V\theta$ = 0.291m/sec.
NT - Design speed of the turbine
Given by= Given by=

$$Nt = \left(\frac{39\sqrt{H}}{outerdiameter}\right)$$

NT= 1780 RPM
Calculation for Turbine Velocity
Tangential Velocity component (VT):-

$$VT = \sqrt{2gH}$$

= $\sqrt{2}$ X 9.81 X 0.3 = 2.426m/sec
V1= VT + $V\theta$
= 2.426 + 0.0291 = 2.717m.sec
U1- Blade Velocity
$U1 = (\frac{\pi \; x \; od \; x \; Nt}{60})$ = 1.11m/sec
Vf1= Vt X sin β1 = 2.426 x sin15◦ = 0.627m/sec
Vw1= 2.426 X cos β1= 2.426 X cos 15◦ = 2.31m/sec.
INLET VANE ANGLE (α1):-
INLET VANE ANGLE (α1):-
$tan - 1 \; (\frac{Vf1}{Vw1 - U1})$ = 23.7◦

Calculation for inlet:
$U2 = (\frac{\pi \; x \; id \; x \; Nt}{60})$
= ((3.14 x 0.010 x 1780)/(60))
= 0.93m/sec (outlet blade velocity)
V2=Vf1=Vf2= 0.627m/sec
OUTLET VANE ANGLE (α2):- = 30.96◦

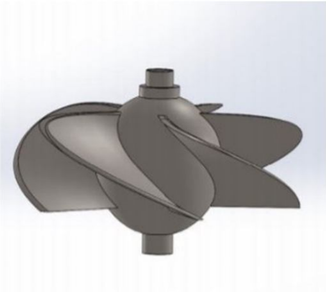

Figure 2: Blade Front View

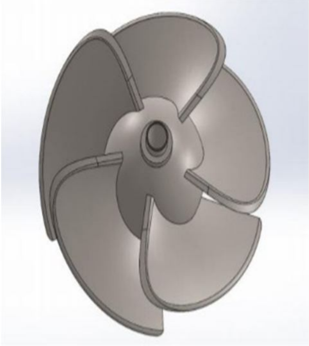

Figure 3: Blade Top view

D. Hydraulic Power

$$P0 = \rho \, x \, g \, x \, H \, x \, Q$$

Where, ρ- Density of fluid
g- Gravitational constant
H- Water Head
Q- Discharge
P0 = 1000 x 9.81 x 0.3 x 0.0067
= 19.7watts == 20 watts

E. Design of Shaft

The material commonly used for shaft is cold drawn low carbon steel with carbon content 0.1 to 0.35 percent. When great strength is required, as in high speed machinery, an alloy steel shaft such As nickel, nickel chromium or chrome vanadium steels are used the diameter of shaft was checked by taking yield stress of mild steel as 250Mpa.
The shaft was found complete safe to operate and the final diameter was found to be ID= 10mm.and OD= 12mm.

F. Bearing

The purpose of the bearing is to reduce rotational friction and support radial and axial loads.
Specifications:- 6001 Open Ball Bearing, bearing is made from Chrome Steel. Inner diameter is 12mm, outer diameter is 28mm and Width is 8mm

1) Item: 6001 Ball Bearing
2) Type: Deep Groove Ball Bearing
3) Closures: Open
4) Size: 12mm x 28mm x 8mm
5) Inner Diameter: 12mm
6) Outer Diameter: 28mm
7) Width: 8mm
8) Quantity: One Bearing
9) Dynamic load rating Cr: 5,100 N
10) Static load rating Cor: 2,390 N
11) Limiting Speed:

Grease Lubrication: 28,000 RPM
Oil Lubrication: 32,000 RPM

IV. RESULT

The basin (optimized to generate a full air core vortex) along with a considerable increase in the kinetic head and a decrease at the bottom. Conical basin with uniform cylindrical inlet of diameter 500mm and outlet (tapered diameter) 150mm was modeled. The cross section was taken to be uniform length and width of 150mm. The flow rate measure using these parameter was approximately 0.00675m3/sec.
For GWVPP, the inlet flow rates are the water that is released into a channel connected to the basin.
The channel is responsible to direct the water flow into the basin tangentially. It can be horizontal or slanted at desired angle. The channel width between two ends could be different or the same.
One of the study that will be mentioned below also shows that the inlet of GWVPP could be in the form of pipe instead of channel (Power C & McNabola et. al, 3rd December 2019) (Kouris Centri Turbine, 4th December 2019). The inlet height has two meaning, first one deals with the height of water while another one indicate the height of channel from the bottom of the basin. The head (m) varies inversely with the power (W), discharge (L/s), hydraulic, volumetric and mechanical efficiency.
A method for designing the runner for the GWVPP has been proposed using basic hydrodynamic equations, and three alternative runner designs were proposed. CFD analysis for three different
Runner blade profiles showed that a curved blade profile is most suitable for the GWVPP, with an Angle between the blade and the hub of 19°, achieving a calculated maximum efficiency.

The blade was designed considering the effect of vortex velocity and tangential velocity, curved blades was vane inlet angle 24◦ and vane outlet angle 32◦ was calculated and modeled. Considering all the parameters, the hydraulic power of the model was calculated (by conventional formula) as approximately 20watts.

V. CONCLUSION

By doing this analysis we determine that the power produced by this turbine is of 19Watts, which helps in use of domestic purpose.

1) The turbine is tolerant of muddy and polluted water, as the vortex action carrier's small solid particles through the turbine. So the maintenance of this kind of turbine is less as compared to other type of turbines.
2) The turbine is claimed to be eco-friendly. The turbine, which operates at a low speed does not cut the natural stream of water so does not harm aquatic and marine life.
3) Power generated from drainage water turns out to be a major source of renewable energy. Metropolitan cities like Delhi etc.
4) Its simple design also allows it to be fabricated in basic workshops, allowing the design to be replicated across the world.
5) The GVWPP can be scaled using hydrodynamic similarity, and therefore offers an opportunity for power generation in the remote villages where it is difficult to provide the national power grid.
6) It is recommended to keep long notch length as it would gradually increase basin inlet velocity and thus will prevent unwanted losses.

VI. FUTURE SCOPE

Hydropower is an important renewable energy resource in worldwide. The gravitational water vortex power plant is an economic and clean energy system allowing for the conservation of low head streams for generation of power.

1) These hydro power plants have good potential for providing electricity to remote communities.
2) We created a technology that can make use of all these small waterfalls or canals in a way that safe for the environment. That's why we have a project that improves the world just that little bit in power generation.
3) This project can be used in any urban or rural areas for power generation with low investment cost.
4) This turbine will generate energy in 24/7 at incredibly low cost of energy, so the cost of power generation will be less with low maintenance.
5) Totally scalable project can be fabricated on a larger scale.

VII. ACKNOWLEDGEMENT

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We take full responsibility for any remaining sins of submissions.

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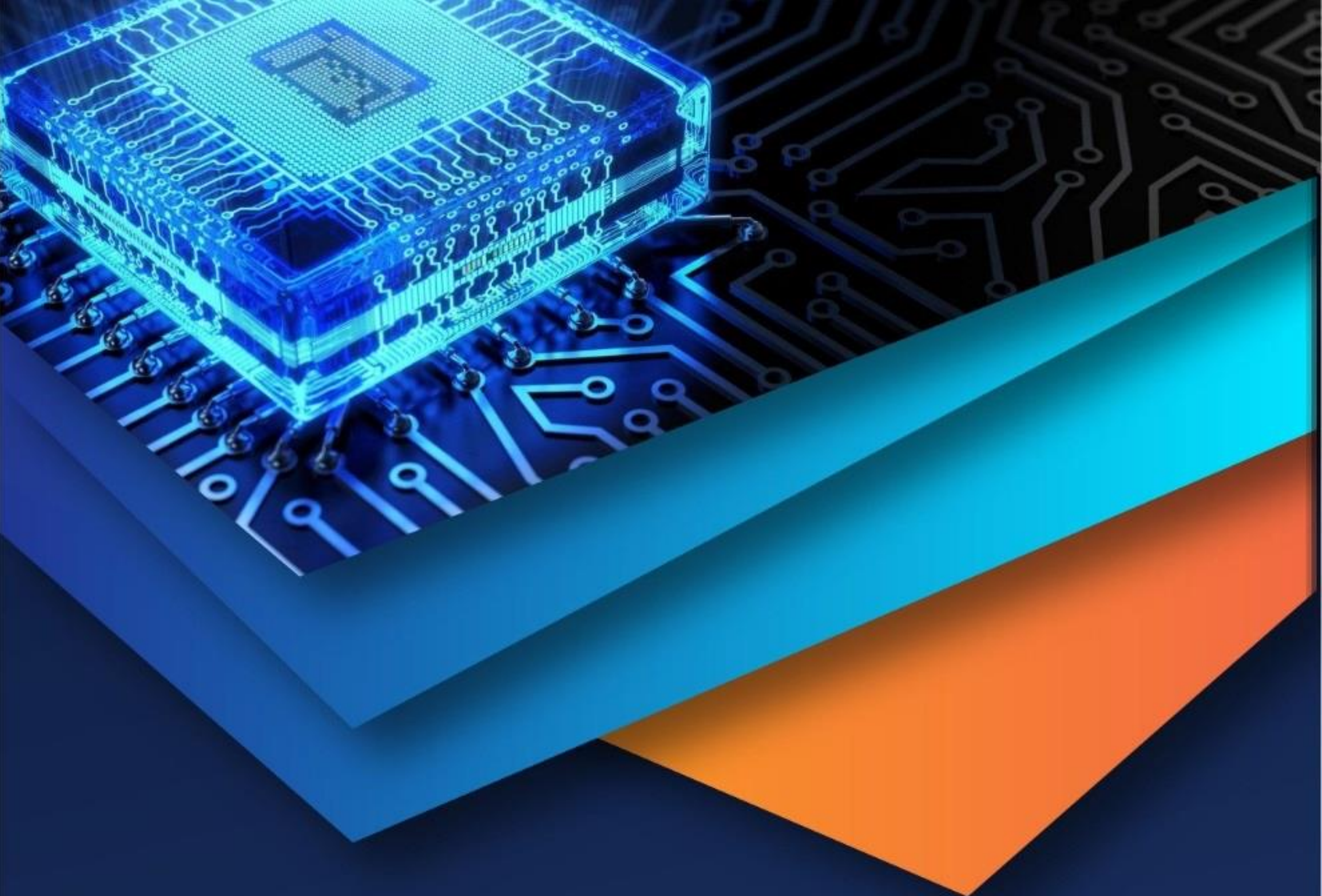

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