Viability Study of Implementing Cross Flow Helical Turbine for Micropower Generation in India

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Abstract- Hydro power offers an extensive amount of energy all over the world and exists in more than 100 countries, contributing roughly 15% of the global electricity production. China significantly exceeds the others, representing 24% of global installed capacity. In several other countries, hydro power accounts for over half of the electricity generation. In India alone during 2012, an estimated 27–30GW of new hydro power and 2–3GW of pumped storage capacity were commissioned. Even then, according to the Energy Statistics Report published by government of India in 2016, the increment in installed capacity was just by 9.8%. In most occasions, the advancement in hydro power was assisted by renewable energy support policies and CO2 penalties. Rather than relying on conventional methods of hydro power, alternative methods such as Axial Flow Turbine, Cross Flow Turbine, Oscillating Water Column, and Oscillating Wave Surge Converter are better research options as they are more efficient. A Gorlov helical Turbine (GHT) was modelled using SolidWorks and analysed using CFX platform. The proposed study investigates the viability of implementing Gorlov helical Turbine which is a vertical flow helical turbine (known for its self-starting capability) for power generation from tidal/river sources in India. The article also showcases the underused hydroelectric capacity potential and relevance of micropower generation. A micropower system is proposed to provide a power of the order of 20 Watts. Such system often comprises of 30 to 40 individual units, each producing approximately 0.6 Watts.

Keywords: Gorlov Helical Turbine, Structural Analysis, Flow Analysis.

1. Introduction

Tidal energy is a form of renewable energy that is harnessed from the gravitational interaction between the Sun and the Moon on the Earth's oceans and seas [1]. In contrast to other forms of renewable energy (such as solar and wind), tidal currents are anticipated within a judicious level of cert for several years into the future. The complete potential of energy by tides on Earth is estimated to be around 3 TW, while the combined total potential in possible exploitable areas around 120GW [1]. Kinetic power density is often employed to relate the tidal current velocity to the power of the resource. The kinetic power density, or power per unit area, of the current, is specified by:

$$K = \frac{1}{2}(\rho V^3) \tag{1}$$

Where ρ is the density of fluid medium and V, the flow velocity.

The Gorlov helical turbine (GHT) [2] is a marine centred turbine developed from the Darrieus turbine [27], designed by modifying its blades. Professor Alexander M. Gorlov of North-eastern University is often referred as the brain behind the system. It has been understood from literature that for effective power generation of microsystems [1, 25, 26], river/tidal Current should be in the order of 1.5 to 6.5 m/s.

2. Environmental Menaces of Dams

Before erecting a reservoir infrastructure, dam projects are generally assessed as per the latest developments in engineering standards with respect to floods, seismic vulnerabilities and other causes of failure, such as overtopping of the dam, foundation defects etc. Budgetary constraints are always a broader prospective problem in the implementation phase. The water of a cavernous reservoir naturally stratifies with a large dimension of cold, oxygen deprived water in the hypolimnion. It was discouraging to note that the temperature variation was 16.7^{0}C between the free surface and bottom at the Murray Darling Basin (Australia) [3]. The erection of a dam chokes the flow of residue downstream, leading to downstream erosion of these Sedimentary depositional environments, and increased sediment build-up in the reservoir. The marine life is always affected by the dam and its related units. One key example: fish gets entangled in traditional turbines. In order to rectify the system a dam-less system with helical turbines is proposed in the article.

3. Relevance and Need of the System

The Ministry of New and Renewable energy (MNRE-India), made a calculation of the potential tidal energy in the country [4, 23]. The study exposed an assessed potential of about 8300 MW with 7000 MW in the Gulf of Kambhat, 1200 MW in the Gulf of Kutch in Gujarat, and about 100 MW in the Gangetic delta in Sunderbans (West Bengal) alone [4]. The total assessed tidal potential of the country is 12,455 MW but so far there is no installed capacity. The Gulf of Kutch Project (50 MW) is yet to be commissioned.

India's hydroelectric capacity is estimated to be 148,701 MW with a supplementary 6,780 MW from smaller hydro schemes (with capacities of less than 25 MW), but only 13.5% of it is utilized [5, 21]. The underutilization of the hydro power in India has many reasons. Destruction of forest, loss of wild life, men –money and material all add up to the grievance in building a DAM. Developing 'Dam-less Hydro power generation system' is a studious solution whose back bone relies on submersed turbines.

4. Model

Solid models of the GHT [6] are created using SolidWorks based on different chord length and height combinations. For this, basically, the Extrude and Helical Sweep options are employed which is illustrated in figure 1. The aerofoil cross section [7] is drawn in sketcher module using the plot points of NACA 4412 [8]. The plot points of NACA 4412 are based on x/c and y/c values; where "c" is the chord length. A set of values of x and y coordinates are obtained which is plotted to generate the aerofoil shape. This shape is swept using helical sweep.

As the number of blades is 3, the height of helical sweep is given as 3 times the required height of turbine. For example, for a turbine height of 600 mm, the helical sweep height is given as 1800 mm. This exercise is carried out from 600 mm height to 900 mm height with increment by 50 mm thus obtaining 7 different sets for each chord length.

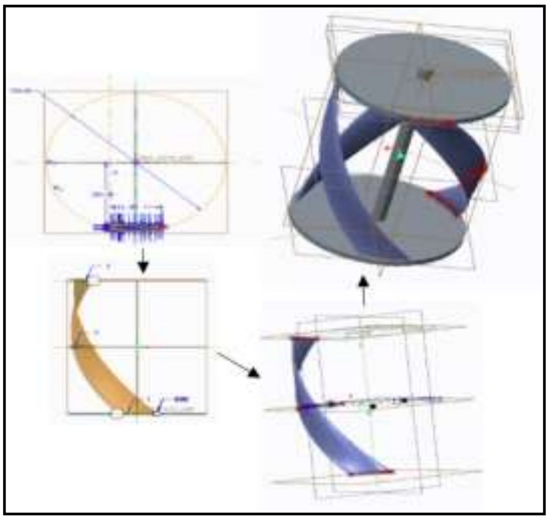

Figure 1: Modelling a GHT

5. Design

The Gorlov turbine design calculation [9, 10] program is made using Microsoft Excel. Formulas which were mentioned in earlier section are used to find the drag force, torque and power of the turbine. The projected area of the turbine is a function of relative solidity of the turbine blades. The turbine used here is a tri-bladed one.

The drag force [11] is found using Gavasheli's formula as below:

$$F = 0.5 \text{ x } C_{d\ avg}\,.\rho.\sigma.A.V^2 \qquad (2)$$

Where, ρ = Density of water = 1000 kg/m^3
Cd avg. = Average Coefficient of drag for NACA 4412
V = velocity of flow, m/s, σ = Solidity ratio
A = frontal area of the turbine = H x D
H = height of the turbine, mm
D = mean diameter of the turbine, mm
The tip speed Ratio (TSR) of Gorlov turbine is estimated between 2 - 2.5, to reduce the effect of cavitation. Based on the TSR, the turbine angular velocity is given as:
$\omega = 2V\lambda / D$
Where, ω = angular velocity of turbine, rad/s
λ = Tip speed ratio (TSR)
Similarly, the mean torque (T in N-m) is given by:
T = 0.5 x F x D
And the Power developed (P in watts) is given by,
P = T x ω
Based on these formulae, the design program is made to find the torque & power. The sample calculation is done for 150 mm chord length and 600 mm height with a TSR of 2.25. The power developed was found to be 0.6021W along with a Torque of 53.5 N-m. The analysis is completed using data from different chord lengths and heights.

6. Structural Analysis

The structural analysis is generally conducted to study the strength of the blades under the dynamic pressure of fluid flow [12]. For this, the GHT model is imported into analysis software's like ANSYS WB 15-static structural module. Material is specified as "Frozen" in order to define contact. The structural analysis is conducted for two alloys, i.e; Carbon steel (CS) and Stainless Steel (SS). The procedure of analysis remains the same for both except the Engineering data. The yield point For Carbon steel (grade A36) is around 200Gpa and for Stainless steel (Grade 301) 1300Mpa. It can be understood from table 1 that all stress in the structure is well below the yield point, hence it is stable. Similarly the maximum deformation as per figure 2 is 0.0472m, which is within the safe limit.

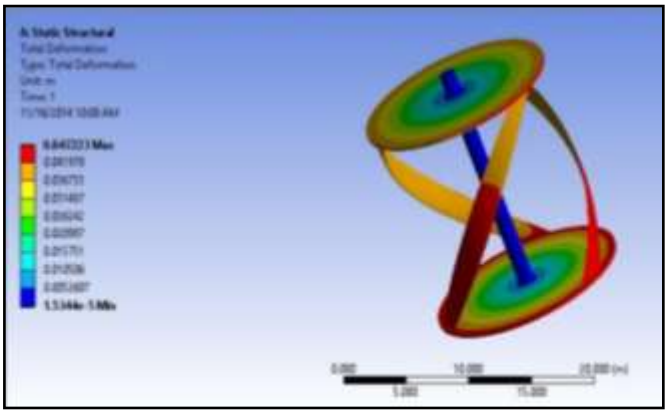

Figure 2: Total deformation

The imported frozen model is meshed in mesh module. The solid model contains extruded part and swept part. Hexa dominant meshing is used for swept volumes. Minimum size of mesh is kept as 5 mm. Analysis is illustrated in table 1, from which one can read out the safety.

Table 1: Structural Analysis Results

Criterion	Value	Condition
Deformation	0.0472 m	Safe
Von Mises Stress	3604.2 pa	Safe
Principal stress	4.98x107 Pa	Safe
Shear stress	2061Mpa	Safe
Elastic strain	0.008	Safe

7. Flow Analysis of GHT

The foremost objective of the flow analysis is to study the behaviour of Gorlov Helical turbine over a range of varying chord lengths and heights. This is carried out by FEA method using CFD analysis [13, 22, 24]. The static resistance against the flow is governed by the geometry (structure) of a turbine such as its size, number, proportion and inclination of blades. The most frequently used geometrical characteristic of the turbine is its relative solidity [11] defined by the ratio,

$$\sigma = \frac{n \times b}{D} \tag{3}$$

where n is the number of blades,
b – chord of each blade transection,
and D – turbine diameter. Generally relative solidity is employed for assessing the drag force developed by the turbine in the water. Nevertheless, for the thrust calculation based on drag force, it is more convenient to use the following formula based on the projection of all blades on a plane perpendicular to the shaft axis. Denoting the solidity of the helical turbine by S (projection of blades on the shaft's plane). The general expression [11]:

$$S = \frac{2nHr}{\pi}\left[d + \sum_{k=1}^{n} \sin\left(\frac{\pi k}{n} - d\right) - \sin\left(\frac{\pi k}{n}\right) \right] \tag{4}$$

Where n, H and r are the number of blades, height and radius of the turbine correspondingly. d is 50% of the blade's chord in radians (with respect to the axis of rotation).

Designating σ = S/2Hr in the above expression, Equation 4 can be restated as

$$\sigma = \frac{n}{\pi}\left[d + \sum_{k=1}^{n} \sin\left(\frac{\pi k}{n} - d\right) - \sin\left(\frac{\pi k}{n}\right) \right] \tag{5}$$

For a helical turbine with three blades,

$$\sigma = \frac{3}{\pi}\left[d - \sqrt{3} + \sin d + \sqrt{3}\cos d \right] \tag{6}$$

Equations above are used to obtain methodical values of the water pressure on the turbine or its thrust. With turbine solidity known, the turbine thrust [11] can be calculated as

$$F = \frac{1}{2} C_d \rho \sigma A V^2 \tag{7}$$

(6)

It is this Force F, which is due to water pressure on the turbine that contributes to peripheral loads on the shaft, bearings and other parts of the subsidiary structure. The Torque [11] developed is calculated using the equation mentioned below:

$$T = F \times \frac{D}{2} \tag{8}$$

Where D is the mean diameter of the GHT.

The meshed model as indicated by figure 3 is brought into the setup module where the boundary condition are applied [9, 12]. A linear velocity of 1.5 to 4.5 m/s at inlet of the enclosure is applied [10]. The outlet is defined as 1 Atm pressure. Enclosure walls are defined with "no shear" (as there is no shear present for these). But for the default body (GHT) placed in the flow path, wall shear shall be applied. Number of iteration is set as 150 which yields convergence of the model [14].

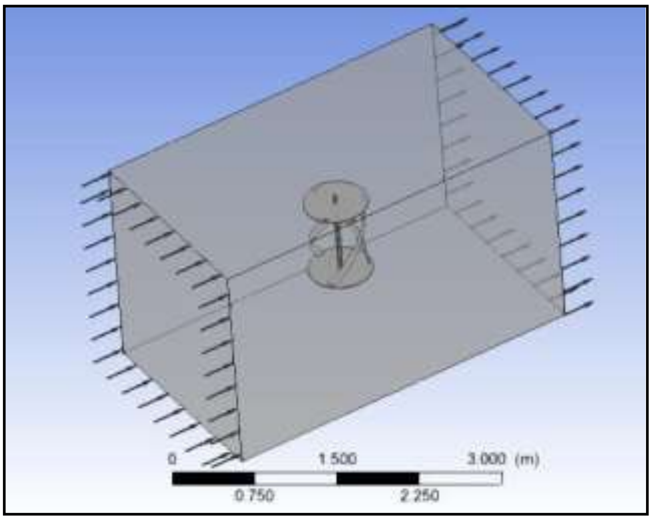

Figure 3: Boundary condition in meshed model

The fluid is defined as water at 250C and standard atmospheric conditions. After 100th iteration, the model is brought into the solution module where the solution is run. On obtaining convergence, the results are plotted. This exercise is carried out for all the sets of heights and 4 sets of chord lengths making an analysis of 28 sets.

8. Experimentation

The vertical cross flow helical turbine was first modelled using suitable SolidWorks and then investigated using CFX platform [13]. Mathematical formulations from basic aero foil theory [15] were used for validation.

The experimentation involves the scaled down model placed perpendicular to the flow direction [16]. The water was agitated by an aquarium pump. All parameters including velocity, pressure etc. were tabulated, from which torque was estimated. Strain gauge placed in the blades could provide additional information on structural stability. Further particulars on experimentation need not to be discussed, as it is beyond the scope of the paper.

The physical principles of the GHT are identical to Darrieus turbine [17]. The appellation "foil" is used to define the profile of the blade cross-section at a given point, with no distinction for the "hydrofoil". The helical blades curve around the axis, which has the effect of consistently distributing the foil sections throughout the rotation, so there is always a foil section at every probable angle of attack. This unique design helps to keep the summation of the lift and drag forces on each blade constant over the entire rotation. Smoother torque curve and less vibration [18] are added advantages of this design. Simulations reveal that peak stresses are found minimized in the structure, and expedites self-starting of the turbine. In testing environments, the GHT has been observed to have up to 35% efficiency [1] in energy capture reported by several researchers. The Gorlov Helical turbine have undergone scale testing at laboratory or sea just like the other vertical-axis turbine systems. Overall, these technologies characterize the present model of tidal/river current energy extraction.

9. Results

The Fluid analysis [19] of GHT on flow path yields interesting pressure (figure 5) and velocity patterns. The results and contours are illustrated in figures 5, 6 and 7. A total of 28 plots were obtained for 4 chord lengths and 7 values of height ranging from 600 mm to 900 mm.

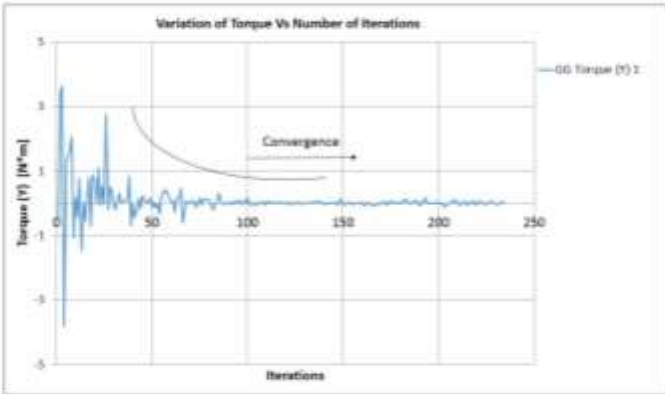

Figure 4: Convergence of iteration

The general pressure pattern as illustrated in figure 5 is such that, the intensity of pressure at the centre of the blades is more than that on the disc periphery. This is owing to the fact that blades oppose with the maximum projected area against the flow [20]. The need of reinforcing the midpoint of blades could be understood from the pressure pattern for a turbine of greater height. The benefit of using helical blades is that it refines the self-starting capability of the turbine when compared with a Darrieus turbine. As the helical blade sweeps along the circumference of rotation of the turbine, a section of the blade profile positioned at the optimum angle of attack even in static conditions, allows for a more uniform starting torque irrespective of turbine azimuthal position.

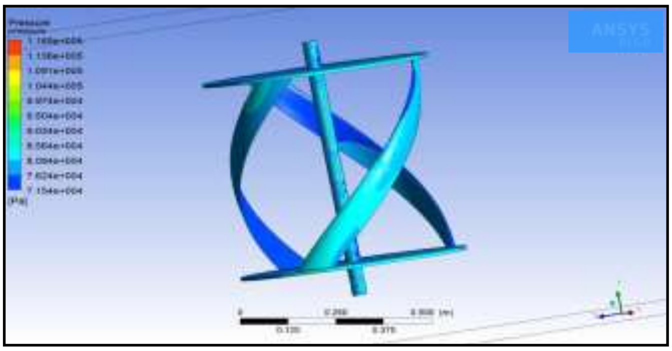

Figure 5: Pressure plot of GHT

It is clear from the velocity pattern (figure 6) that velocity increases over the tip of the blades. Eddies were observed when the flow has past GHT, which could hamper the effectiveness of power generation.

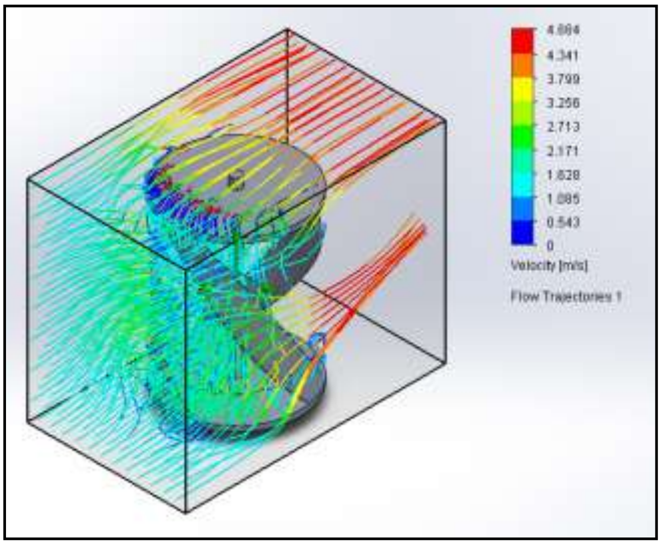

Figure 6: Flow trajectory in Z direction

It is also worth noting that, as the height of the GHT increases, the torque and consequently the power rises which is undoubtedly due to the increase in the area opposing the flow as defined by solidity index. The mathematical expression for solidarity index or relative solidarity seems insignificant in all aspect.

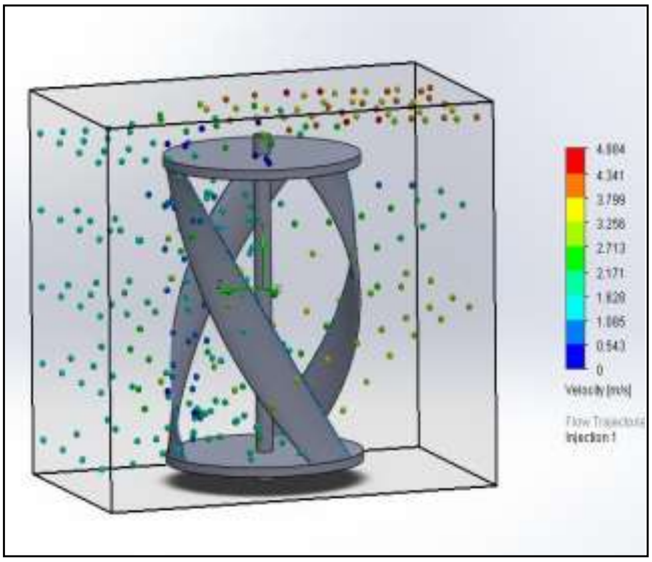

Figure 7: Particle injection

Through effective comparison with a physical model, an effective formulation for solidity index could be developed. For a particular chord length, on varying the heights, there is no stable performance except for 150 mm chord length. Further experimentation involves the fabrication and flow analysis of a 600m high, 150mm chord length GHT, as simulations show optimistic result.

10. Conclusion

A foreseeable, consistent and equitable conducive policy environment is certainly required for India to spawn a host of mini grid stakeholders who will supply energy to millions of people. The Ministry of New and Renewable Energy (MNRE) identified mini grids as a separate section under the Off-grid. A notable instance was in January 2015 when the ministry invited companies to empanel themselves as Rural Energy Service Providers (RESP), and notified a programme under which it intends to provide for central financial assistance to RESPs implementing mini grids in rural areas. In addition to residential building in rural parts, micro hydro plants could even power a certain extent of machinery assisting small businesses.

A suitable scaled GHT for the purpose of power generation was studied using CFX tools and was found sound enough for deployment. An excess of 2500 plus potential sites could be identified for commissioning GHT which utilizes the natural flow of water. Regions in Karnataka, Himachal Pradesh and Arunachal Pradesh have the most untapped potential for GHT. 3D Printing could be employed to print GHT, which would cost less than 100 USD. Various structural analysis along with flow analysis shows that the model seems to be strong enough for prototype development. To sum up, GHT could possibly replace the existing water wheels/ Traditional turbine [28] for micro power generation in India.

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