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Design, Analysis and Fabrication of Hydroelectric Turbine for Open Canal's of the River

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Abstract

Hydroelectricity power source as one of the reliable and renewable energy. In India around 12% of electricity production contributed by hydropower. Due to rapid increase in urbanization, global warming and oil crisis increases. For this need advanced renewable energy extraction technique to meet the global demand. Nowadays at transportation sector electrical vehicles enter to market more and more. To meet the power demand open canals water turbine provides a major contribution locally. Open canals water turbine not require high civil structural work, it can be installed with small modification of existing infrastructure. This turbine installed in open canals and safer from any flood or storm damage condition. Thus, research aims at designing a hydrokinetic turbine applicable to zero head and low velocity flow water bodies such as canals. Open canals water turbine CFD simulation has been performed to predict the flow pattern of water. Additionally power was generated from the optimized design model in lab conditions (Ogee weir channel) wherein the flow velocity was less ranging from 0.02-0.05m/s and the turbine rotated within a range of 14-16 rpm. With further consideration in design and implementation gear box higher power can be achieved when implemented on a large canal's or channels.

Keywords: *Water turbine, Water resources, CFD analysis, Energy crisis, Nonrenewable resources.*

1.0 Introduction

Fossil fuels are one of the important energy sources to meet the global demand. But due to greenhouse effect and global warming avoiding the fossil fuel resources, day by day its cost also increases. Government has to rethink towards emission norms (Renewable & Agency, 2017). Climate change and growing energy demand are major motive force for the evolution of innovative energy conversion systems. Many small green energy harvesting units replaced the large scale fossil fuel power plant (Yuce & Muratoglu, 2015).

Renewable technologies provides cost effective source of electricity power generation in rural area, less population and low power demand places. It providing reliable and clean energy, it creates more job and saving money (Woodruff, 2007). Energy is one of the key important factors to predict economic status of the countries. Solar power is one of the major renewable energy sources for fast developing industries

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in India. Due to the draw backs of solar power extraction India cannot became energy surplus. Therefore, hydropower generation sector is most suitable and a promising sector (Nicolli & Vona, 2019). Small-scale renewable technology is a very good option for supplying electric power to isolated rural areas (Mamat et al., 2020). Renewable energy is ecofriendly, cost effective, sustainable and secured. The contribution of renewable electricity power generation year by year increases 18% in 2008 by the end 2022 reaches the 26.5%. It evolves as green energy to meet the global demand (REN Members, 2021).

The global installed hydropower capacity in 2020 was 1308 GW, and it is expected to grow by approximately 60% by 2050 to limit the rise of the global temperature primarily caused by fossil fuels and to satisfy the energy demand. Hydropower growth would help to create six lakhs specialized jobs and would require an estimated investment of 1.7 trillion USD (Adams et al., 2018).

The hydropower sector is affected by new challenges:

i. Pumped hydropower plants are essential to provide and consume energy on demand.
ii. Larger storage reservoirs are required to mitigate floods and droughts.
iii. Rural electrification is also stimulating small-scale hydropower plants by powering existing hydraulic structures and small barriers, which are already serving other purposes.
iv. Hydropower needs to be eco-friendly of wild life and aqua animals (Moran et al., 2018).

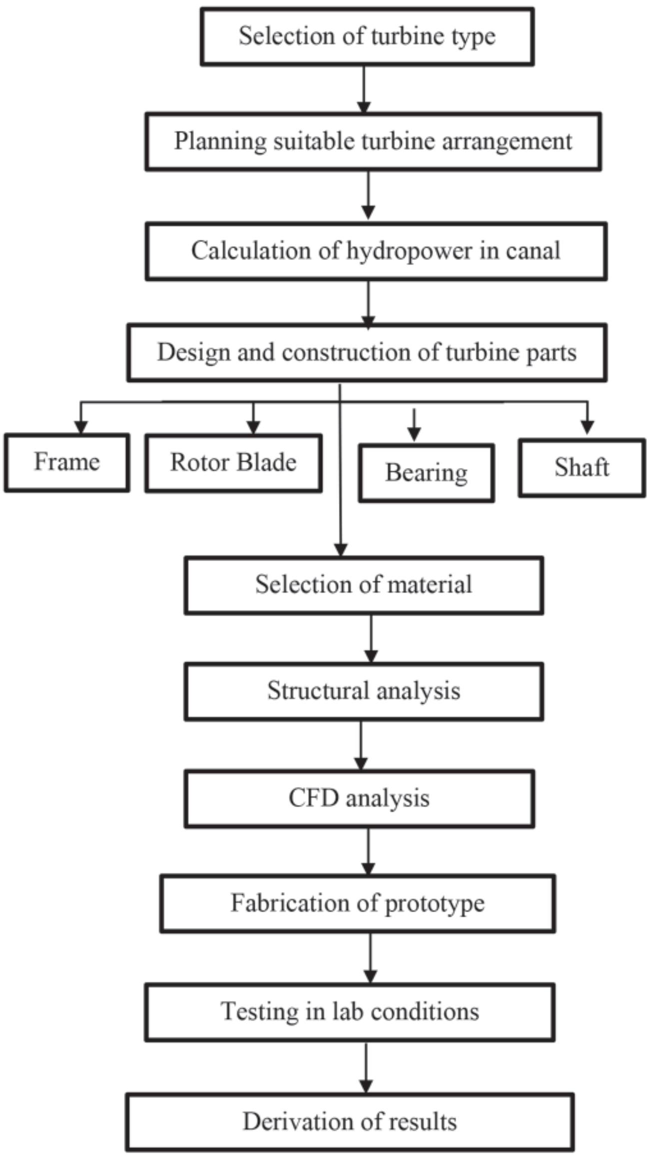

Figure 1: Flow chart of methodology

2.0 Methodology

The research aims at developing an optimal design and model of a vertical axis open canals water turbine, for extracting energy from free-flowing water in man-made canals or channels, with zero head, which is not utilized. The initial phase included literature survey to understand the current scenario of energy harvestment in India and across the world.

An open canals water turbine system is an electromechanical device that extract mechanical work from the kinetic energy of water flow then it converts to electrical energy through a generator and power electronics converter, even though the electricity power output capacity is small, power can generate 24×7 hours. Capacity can be increased by a series of array or modular installation. Turbine system is based on free-flowing water without the construction of a dam or reservoir. The system is easy to transport and shift due to the small size of the turbine plant.

3.0 Turbine Design and Construction

Turbine extracts energy when flowing water pushes the turbine blades. In open canals the water flow velocity is maximum at the top surface. The hydropower in the open channel is given by

$$P_{Hydropower} = (1/2)\times\rho\times A\times V^3$$

The net water power after consideration of losses and inefficiencies.

$$P = (1/2)\times\rho\times C_P\times A\times V^3\times\eta$$

Where

A = Swept area of the turbine.

C_p = Power coefficient of the turbine.

η = Efficiency of the gearbox and electrical inverter.

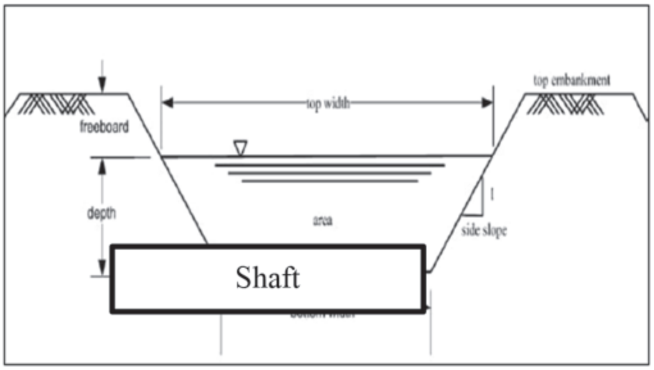

Figure 2: Canal parameters

The energy extraction is maintained in the flow process through the reduction of kinetic energy and subsequent velocity of the water. In smaller turbine electric generator is directly coupled. But for larger turbine, gear box transmission system is coupled with electric generator to improve the efficiency and reliability of the product.

The design of blades is achieved using concepts used in wind turbine blade. The design of turbine is combination of Darrieus, savonius and Gorlov turbine. Two tri-blade rotors are used. The upper and lower spoke is connected by the blades and twisted to an angle of 20° to form an helical darrieus turbine. And savonius turbine is mounted in between the darrieus turbine. The material used for turbine are austenite steel alloy and martensite steel alloy.

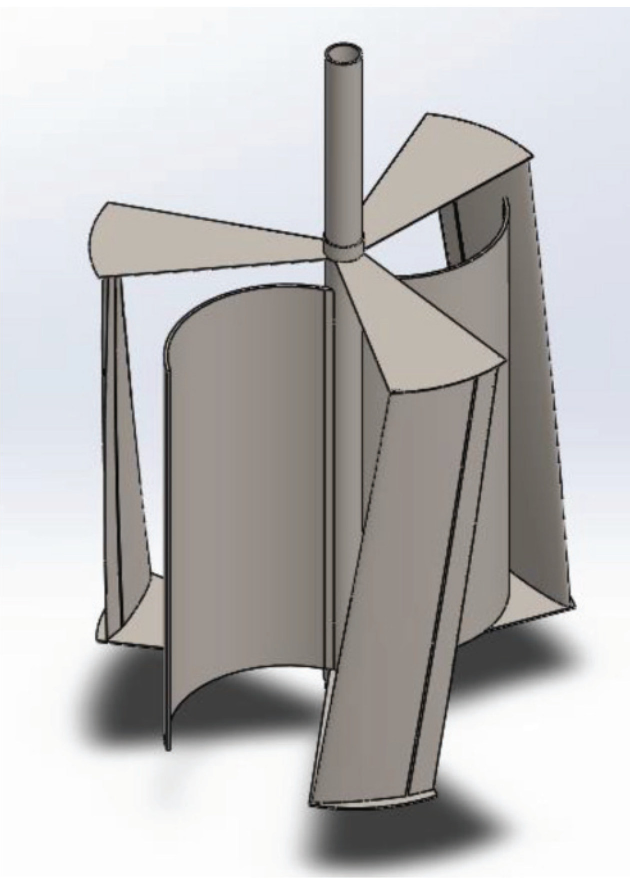

Figure 3: 3D CAD model of open channel water turbine

3.1 Turbine Mounting Structure

The structure comprises civil structural member for holding the turbine and its components rigidly. The structure holds a vertical axis open canals water turbine between the top and bottom structural beams. The frame also has a convolute shape at the middle to concentrate the flow of water into the turbine.

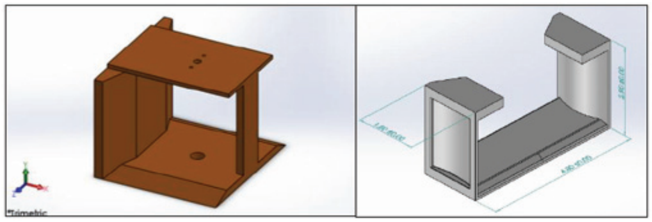

Figure 4: 3D CAD model of turbine mounting structure

The bearing support is mounted on the concrete structure with the help of fasteners. The outer diameter of bearing is press fitted in a bearing support and the inner diameter of the bearing mounts the rotor shaft or turbine shaft. In this set up used two bearing support is used. A hollow shaft with its outer diameter same as that of the inner diameter of the bearing is chosen. Care is to be taken that the shaft is not bent to avoid wobbling and additionally it should be of light weight.

4. Calculations

4.1 Determination of Velocity of Fluid in Testing Channel

Channel Dimensions

Width of Canal = 0.46mts
Height of flowing fluid = 0.30mts
Area of Cross-Section of Channel
(A) = 0.46×0.30 = 0.1380 m^2

Collecting Tank Dimensions

Width of Tank = 0.48mts
Length of Tank = 1.17mts
Rise in Water Level = 0.15mts
Volume of water in tank = 0.48×1.17×0.15 = 0.084240 m^3

Time taken to rise water level to 15cms = 25 sec
Discharge rate of water
$(Q_d) = 0.084240/34 = 0.00247764 m^3/sec$

Velocity of water

$V_w \times A = Q_d$
$V_w = 0.002477.64/0.1380$
$V_w = 0.0305217$ m/sec ... (1)

As we are diverting flow on to the blades, we assumed that flow rate changes to 0.04m/sec.

$V_w = 0.4$ m/sec ... (2)

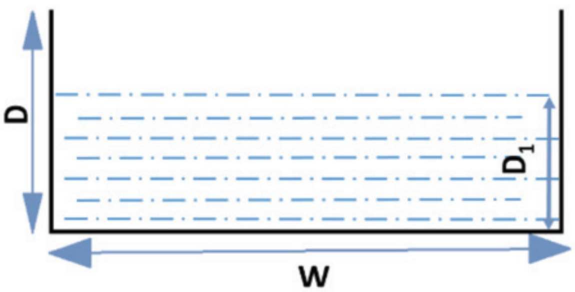

Figure 5: Channel parameters

4.2 Amount of hydropower present in canal

Water density $(\rho) = 1000 kg/m^3$
Cross-section area of Channel
$(A) = 0.46 \times 0.30 = 0.1380 m^2$
Velocity of water (V) = 0.04m/sec
Hydropower $(P_H) = 0.5 \times \rho \times A \times V^3$
$P_H = 0.5 \times 1000 \times 0.1380 \times 0.043$
$P_H = 20$ watts. ... (3)

4.3 Turbine power

Efficiency of the turbine is assumed to be 0.95
Density of water $(\rho) = 1000 kg/m^3$
Velocity of water $(V) = 0.04$m/sec
Power Co-efficient $(C_p) = 0.21$
$P_T = 0.5 \times \rho \times A \times V^3 \times C_p \times \eta$
$P_T = 0.5 \times 1000 \times (0.3 \times 0.14) \times 0.043 \times 0.21 \times 0.95$
$P_T = 10.85$ watts. ... (4)

4.4 Angular velocity of turbine

Tip Speed Ratio (TSR) = 2.4
Radius of Turbine $(r) = 0.14$mts
Velocity of the flow = 0.04 m/sec
$TSR = \omega . r / v$
$2.4 = \omega \times 0.142$
$\omega = 17.14$ rpm ... (5)

4.5 Normal force

Height of the blade (h) = 0.24 mts
Radius of Blade = 0.14 mts
Chordal Length (width of Blade) $(c) = 0.15$mts
Angular Velocity of the turbine $(\omega) = 17.14$rpm
Stream Velocity $(V_\infty) = 2$ mts/sec
Blade Velocity $(V_b) = r \times \omega \times 2\pi \times 60$
$V_b = 0.14 \times 17.14 \times 2\pi 60$
$V_b = 0.1909$ m/sec
Relative Velocity $(V_r) = V_\infty + V_b$
$V_r = 2 + 0.1909$
$V_r = 2.1909$ m/sec
Azimuth Angle $(\Theta) = 15^o$
Axial Velocity $(V_i) = 2$ mts/sec
Chordal Velocity $(V_c) = r \times \omega + V_i \cos\Theta = 0.14 \times 17.14 + 2\cos15$
$V_c = 2.122$ mts/sec
Normal Velocity $(V_n) = V_i \sin\Theta$
$V_n = 2 \times \sin15$
$V_n = 0.51$ m/sec
Angle of Attack $(\alpha) = \tan^{-1}(V_n / V_c)$
$\alpha = 13.7^o$
Co-efficient of lift $(C_L) = 0.3$
Co-efficient of drag $(C_D) = 0.25$
Tangential Force Co-efficient $(C_T) = C_L \sin\alpha - C_D \cos\alpha$
$C_T = 0.3 \sin(13.7) - 0.25 \cos(13.7)$
$C_T = 0.314$
Normal Force Co-Efficient $(C_N) = C_L \cos\alpha + C_D \sin\alpha$
$C_N = 0.3 \cos(13.7) + 0.25 \sin(13.7)$
$C_N = 0.35$
Normal Force $F_N = 0.5 \times \rho \times V_r^2 \times C_N \times h \times c$
$F_N = 12 \times 1000 \times 2.19092 \times 0.35 \times 0.24 \times 0.15$
$F_N = 30.16N$ ... (6)

4.6 Tangential force

Tangential Force $F_T = 0.5 \times \rho \times V_r^2 \times C_T \times h \times c$
$F_T = 0.5 \times 1000 \times 2.19092 \times 0.314 \times 0.24 \times 0.15$
$F_T = 18.08656N$ ... (7)

4.7 Lift force

Area of Cross-section (A) = $0.45 \times 0.3 = 0.135 m^2$
Dynamic Pressure $P_D = 0.5 \times \rho \times V^2$
$P_D = 12 \times 1000 \times 22$
$P_D = 2000Pa$
Lift Force $F_L = C_L \times P_D \times A$
$F_L = 0.3 \times 2000 \times 0.135$
$F_L = 81N$ ... (8)

4.8 Drag force

Area of Cross-section (A) = $0.45 \times 0.3 = 0.135 m^2$
Dynamic Pressure $P_D = 0.5 \times \rho \times V^2$

$P_D = 0.5 \times 1000 \times 2^2$
$P_D = 2000$ Pa
Drag Force $F_D = C_D \times P_D \times A$
$F_D = 0.25 \times 2000 \times 0.135$
$F_D = 67.5$N ... (9)

4.9 Turbine torque

Turbine Torque (T) = $F_T \times r$
T = 18.08656 × 0.28
T = 5.064 Nm ... (10)

Table 1: Theoretical Results

Parameter	Value Obtained
Flow Velocity (V_W)	2 m/sec
Hydro Power of fluid (P_H)	550 watts
Turbine Power (P_T)	21.168 watts
Angular Velocity of Turbine (ω)	17.14 rpm
Tangential Force Co-Efficient (C_T)	0.314
Normal Force Co-Efficient (C_N)	0.35
Normal Force (F_N)	20.16 N
Tangential Force (F_T)	18.08656 N
Lift Force (F_L)	81 N
Drag Force (F_D)	67.5 N
Turbine Torque (T)	5.064 Nm

4.2.1 Stress and Strain Analysis of Hydrokinetic Turbine

The turbine was made up of solid rigid steel structure materials. The properties of materials are shown in Table. Considered turbine was operating under normal climatic condition temperature of south India. For simplification of analysis considered deformation and displacement of turbine structure was zero at fluid flow. But rotating degree of freedom was considered.

Table 2: Turbine Specification

	Properties	Prototype
1	Material	Alloy steel
2	Strength	620.04 Nmm^{-2}
3	Weight	0.7 kg
4	Height	290 cm
5	Diameter	280 cm
6	Density	7850Kgm^{-3}
7	Poisson's ratio	0.3

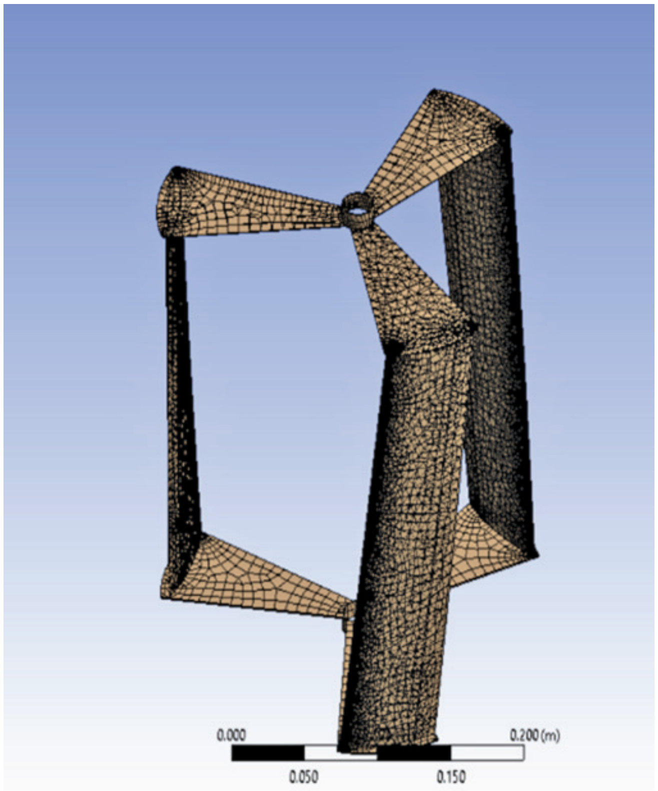

Figure 6: Turbine blade meshing

Using build-in mesh tool in solidworks, auto mesh was built. Accuracy of meshing was refined out locally on larger curvature of turbine blade to avoid numerical instabilities of stress concentration effect. Totally 4,79,080 nodes of mesh presented on turbine blade.

Figures 7 and 8 illustrated turbine maximum stress and displacement variation at operating condition. The maximum displacement is 0.01mm that can be considered negligible reasonably. The maximum stress is 1.207 MPa. It is a 20 times less than the steel fatigue limit. So it has shown turbine design and material selection was strong enough and safe.

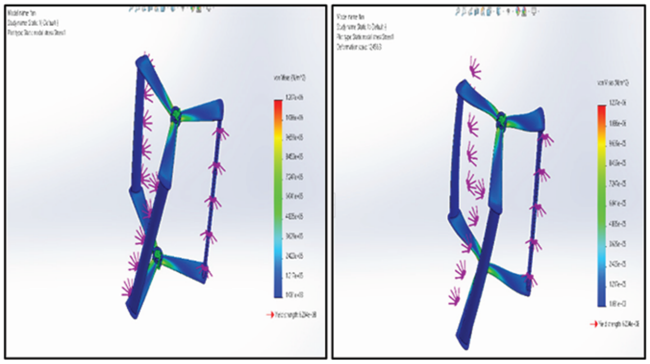

Figure 7: Stress analysis of turbine

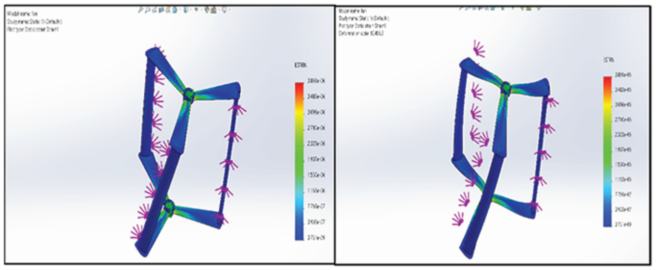

Figure 8: Strain analysis of turbine

4.3 Computational Fluid Dynamic Simulation

The CFD simulation analysis of open canal vertical axis water turbine has been conducted. CFD simulation recognizes the flow field with respect to time and spaces. The major parameters for CFD analysis are 3 blades, hydrofoil NACA 0025 profile, swept area 0.629 m^2, TSR 2.4, length of chord 0.32m, water flow speed at turbine entry 1.5 m/s for turbine power output of 9W.

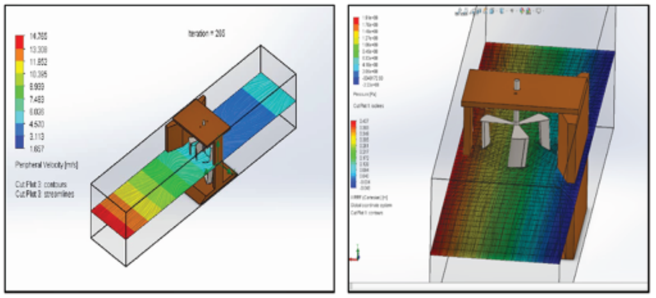

Figure 9: Stream flow analysis

5.0 Result and Discussion

The prototype turbine model is tested at Ogee weir channel which has rectangular cross section. The flow of water in Ogee weir was maintained uniform and steady state with maximum obtained water velocity from the channel is 0.03-0.05 m/s obtained by experimentally. From the calibration of Ogee weir, its co-efficient of discharge is 0.62 and its discharge obtained theoretically ranging from 2500-6000 cm^3/sec for that above velocity range.

The turbine model is fabricated as per the dimensions of Ogee weir channel and model is placed in middle of the channel where the water flow is uniform. For increasing the kinetic energy of water, the deflectors are used which converge the flow and diverts the flow towards the turbine. At the experiment set up condition, as water flow velocity of 0.03 m/sec strikes the turbine blades and the turbine starts rotating with 14 to 16 rpm, turbine generate the electricity by coupled generator to the rotating shaft.

Figure 10: Placement of turbine in channel

6.0 Conclusion

From this research study it was found that the designed blade which is a combination of H-Darius and Gorlov turbine is a suitable turbine to be operated under zero head and less flow velocity conditions. The fabricated experimental model was tested at a flow velocity of 0.031 m/s and turbine shaft had successfully rotated up to 14-16 rpm. Hence, under real time condition wherein the flow rate of the water in canals expected from 3 to 4 m/s, installation of the designed turbine is possible to work optimally. Hence, if further consideration is taken in the turbine design for implanting in canals, the turbine could produce power ranging from 20-25 MW. Finally it is concluded that the designed model turbine is a best turbine for energy extraction from canals with zero head and less flow velocity.

7.0 Acknowledgements

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