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Research Article

Multi Stage Power Generation in An Open Canal System by Accelerated Flow

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Abstract. The present work considers the possibility of using river currents to generate electric power in order to supplement existing power units. A physical system consisting of a flowing river/canal with rectangular cross section, an open channel nozzle, and an impact turbine is modelled mathematically. The model is simulated using MATLAB for varying slopes and two nozzle-turbine sequences. It is found that the usage of nozzles demonstrably increases the velocity, and therefore, the kinetic energy of the flow. A total power ranging from 0.34 to 10.79 MW for the lowest and highest value of slope, respectively, is predicted by the model. Possible applications are discussed.

Keywords. Open canal; Numerical model; Nozzles; Cross flow turbine; Power generation

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1. Introduction

In any developing country, power availability to remote regions and rural areas is a fundamental requirement for progress to occur. In India, there are villages that have not been electrified due to accessibility problems and difficulty in transmission of power. A closer look at the electrification data shows that a sizeable number of households in villages across most states are still in the dark, without access to electricity. The best solution in that case would be for the power generation to be located in the vicinity of the supply area. A power plant which can supply the needs of the area without being crippled by fuel transport difficulties and load variations has to be devised. One possible renewable energy source that provides a continuous supply of fuel throughout the year is hydro power. In canals that serve as a path for river water, a micro hydro turbine power plant can effectively serve the purpose.

Khan *et al.* [4] reported flow acceleration through convergent nozzles for run-of-river turbines in open flow channels and presented analytical and computational work to convert kinetic energy of water flow to electric power. They estimated a potential of 234 MW electric power with flow acceleration using convergent nozzles and water wheel arrangements at 120 locations along the entire length of the canal. A normal micro hydro turbine has prerequisites of medium to high head of water flow and relatively higher flow rates. Acharya *et al.* [1] carried out numerical analysis to study the characteristics and the fluid flow in a cross-flow hydro turbine and to optimize its performance by geometrically modifying the several parameters. They selected two phase, steady state with turbulence model in the commercial CFD code ANSYS CFX 13.0 for the numerical simulation. It was geometrically modified to enhance the performance and turbine efficiency improved by 13%. Giosio *et al.* [3] developed a micro-hydro test facility and turbine unit utilising a commercially available pump impeller together with a customised housing for incorporation of inlet flow control. They also carried out design and performance testing of a hydraulic turbine unit suitable for use in rural micro-hydro, and energy recovery installations. The designed micro-hydro turbine unit provides a low cost alternative generating solution for application in remote area power supply and industrial energy recovery systems. Chichkhede *et al.* [2] investigated the effect of design parameters on the flow velocities of a cross flow turbine and varied water inlet angle, blade angle at inlet and outlet to increase overall efficiency and power output of the turbine. The design parameters were varied for different nozzle openings and simulated using CFD. The results showed that of efficiency depends on blade angle at different nozzle openings. The optimum blade angle value was observed to increase with increasing inlet angle for the given geometry. Montoya-Ramírez *et al.* [5] performed an assessment on the potential use of hydrokinetic turbines in the discharge channels of large hydroelectric power plants in Colombia. As a case study, two large hydropower plants were selected, one operated by a Francis turbine and the other operated by a Pelton turbine. The analysis assessed the hydraulic characteristics of the channels and the corresponding discharge flows. The authors reported that when modifications are made to the cross sectional geometry of existing channels, hydraulic modelling shows great potential in increasing the viability of hydrokinetic devices.

The present work is based on theoretical studies carried out by Khan *et al*. [4] on flow acceleration through convergent nozzles in open canals. For low head and slower flow rates, a method of generating power by using low head turbines in stages is proposed. The flow is accelerated through nozzles to the required inlet velocity value, and then passed through the turbines to tap power. After the flow has recovered the pressure loss, the same setup is repeated to obtain a second stage of power generation. Work done in this area includes water wheels to convert the kinetic energy to rotary motion. The development of hydro turbine designs have allowed for more efficient and compact turbines to be used in low head operations.

By implementing this, a continuous source of power which is renewable will be present. This can be a primary source of power generation if there is a continuous supply of water or as a secondary power plant where the water flow is seasonal. This not only reduces the carbon footprint of the power plant on the environment, it can be implemented in any location where there is a provision for a canal flow of water. As the world faces a power crisis and there is a need for more renewable energy, we believe this can fill the void and complement the existing power plants and eventually replace them. This is not an outlandish hypothesis, as Denmark has already implemented a 100% renewable energy model with wind energy, which is available in abundance to them.

In the present work, the concept and various possibilities of generating electric power from open canal system are discussed in the "Introduction" section. In "Theoretical Analysis" section, numerical simulations have been carried out to model a flowing river/canal with an open channel nozzle and an impact turbine to generate electric power. The numerical model has been developed using MATLAB, from basic flow equations. In "Results and Discussion" section, the model has been tested for varying slopes and two nozzle-turbine sequences and system performance has been discussed. Possible applications are discussed in the "Conclusions" section.

2. Theoretical Analysis

In the present work, an imaginary canal (Figure 1) is considered – rectangular in cross section, with a channel width of 50 m and a uniform depth of 10 m throughout its length. The liquid in the canal is water. The objective of this analysis is to devise a scheme to calculate the greatest amount of power – granted certain assumptions about the nature of the devices and implements used – that can be produced by constricting the flow of such a canal using an open channel 'nozzle' of certain dimensions and placing a cross flow turbine upstream of the nozzle.

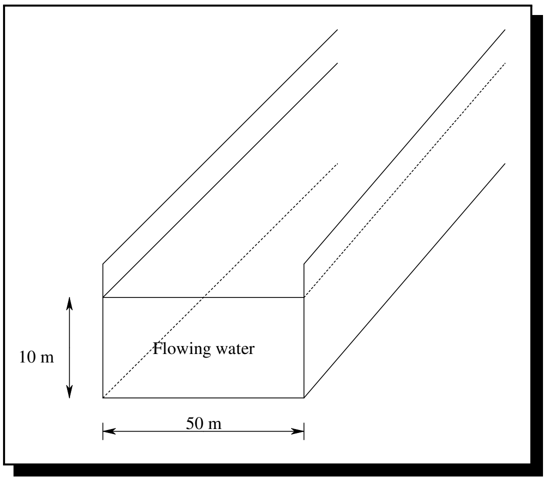

Figure 1. Schematic diagram of an open canal

First, the average velocity of the water in the canal is found out using Manning's formula.

$$V_1 = \frac{R_h^{\frac{2}{3}}\sqrt{S}}{n},$$

where V_1 is the average flow velocity before the constriction, R_h is the hydraulic radius of the channel, S is the slope of the channel, n is the Gaukler-Manning Coefficient.

The hydraulic ratio of the channel is provided by the ratio of the area of the channel to its wetted perimeter. In the case of a rectangular channel:

$$R_h = \frac{A}{P_w} = \frac{DW}{2D+W},$$

where D is the depth of the channel and W its width.

In this idealized model, the hydraulic radius of the channel remains constant throughout its length, and so does n, for a particular type of flow environment. In this study, the average flow velocity and all subsequent velocities are calculated for a range of plausible slopes – from 0.0001 to 0.001. The Reynolds Number of the flow is subsequently calculated for a kinematic viscosity of ϑ.

$$Re = \frac{V_1 R_h}{\vartheta}$$

The Reynolds Number, thus calculated, is used to calculate the Darcy-Weisbach friction factor for the flow, using the relation:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon}{12R_h} + \frac{2.51}{Re\sqrt{f}}\right),$$

where ε, the canal roughness, is assumed. The friction factor is used to calculate the pressure drop due to friction, for a particular channel length L.

$$\Delta P = \frac{fLV_1^2}{8R_h}.$$

Next, an open channel nozzle of predetermined area A_2 is considered and the continuity equation is solved for the velocity of flow upstream of the nozzle, V_2.

$$V_2 = \frac{AV_1}{A_2}$$

and the power available at this stage of the flow is:

$$p_2 = \frac{\rho A_2 V_2^3}{2},$$

where ρ stands for the density of water. An impact turbine is placed at the end of the nozzle – and the flow is considered wide enough for the role of the tangential component of velocity to be neglected. For an assumed turbine efficiency η, the velocity of water flowing out of it is:

$$V_3 = \sqrt{(1-\eta)V_2^2}.$$

These calculations can be repeated for as many turbine-nozzle pairs as desired.

3. Results and Discussion

A simple numerical model of the system is created using MATLAB. In this model, the cross sectional area of the channel is found to be 500 m^2, based on the dimensions stated in the previous section. The length of the channel is assumed to be 1000 m initially. Slopes ranging from 0.1 metres per kilometre of channel to 1 metre per kilometre are used in the numerical model in order to capture better range of slopes that may be found in rivers.

The following values remain constant in the model. Most of them are assumed based on a sampling of data from various rivers. Some of them are obtained from tables of standard values. $n = 0.05$, $\vartheta = 0.801 \times 10^{-6}$, $\rho = 1000\ \frac{\text{kg}}{\text{m}^3}$, $\varepsilon = 0.001$, $A_2 = 317.52\ \text{m}^2$, $P_{in} = 1.2e5$ Pa, $P_{atm} = 1.013e5$ Pa, $\eta = 80\%$.

An analysis of the flow before the constriction shows, predictably, that the flow rate increases with increasing slope (Figure 2). However, the pressure drop due to friction also increases with the slope.

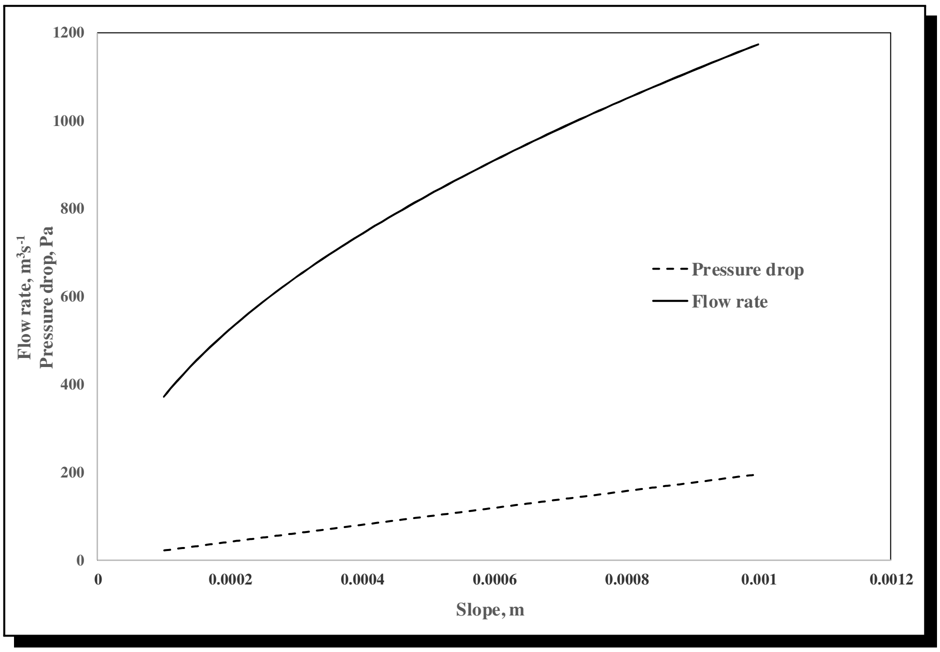

Figure 2. Variation of Flow rate and Pressure drop with Slope

The initial power associated with the flow behaves in a similar manner (Figure 3). For a sample initial velocity of 0.742 m/s at slope of 0.0001, the initial power is 0.25 MW. Since, in an open channel flow, the velocity is proportional to channel slope; as the slope increases, velocity also increases – albeit nonlinearly. In the present case, when the slope increases to 0.001, the flow velocity increases to 2.35 m/s and the power becomes 8 MW.

The constriction placed along the length of the channel increases the flow velocity to 1.17 m/s for the lowest value of slope and 3.69 m/s for the highest value of slope (Figure 4). Water flowing into the turbine has these velocities. Once a part of the kinetic energy of the flow is spent in the turbine, the flow velocities reduce to 0.52 m/s and 1.65 m/s, respectively.

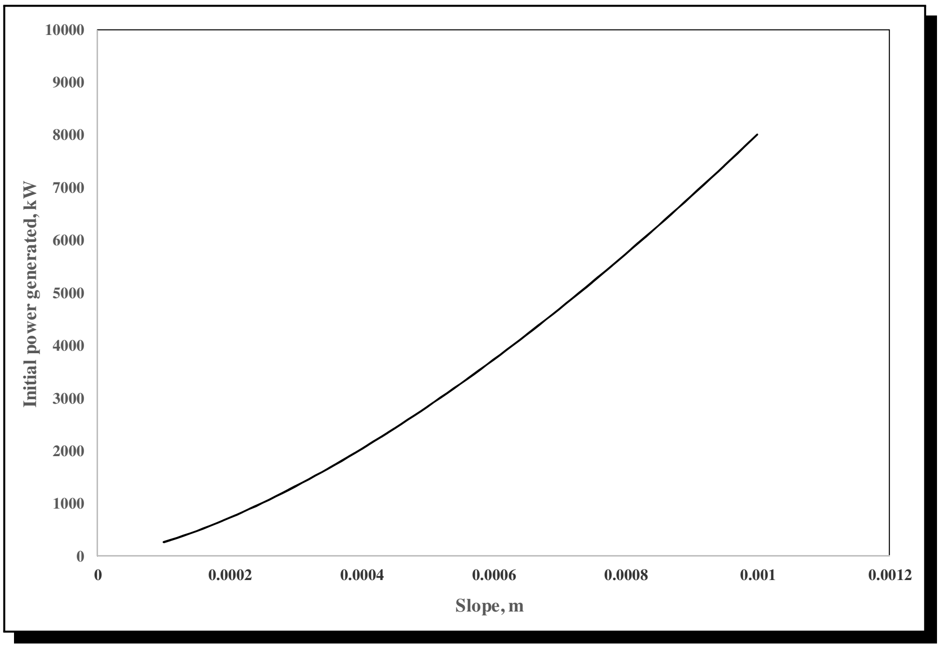

Figure 3. Variation of Power with slope

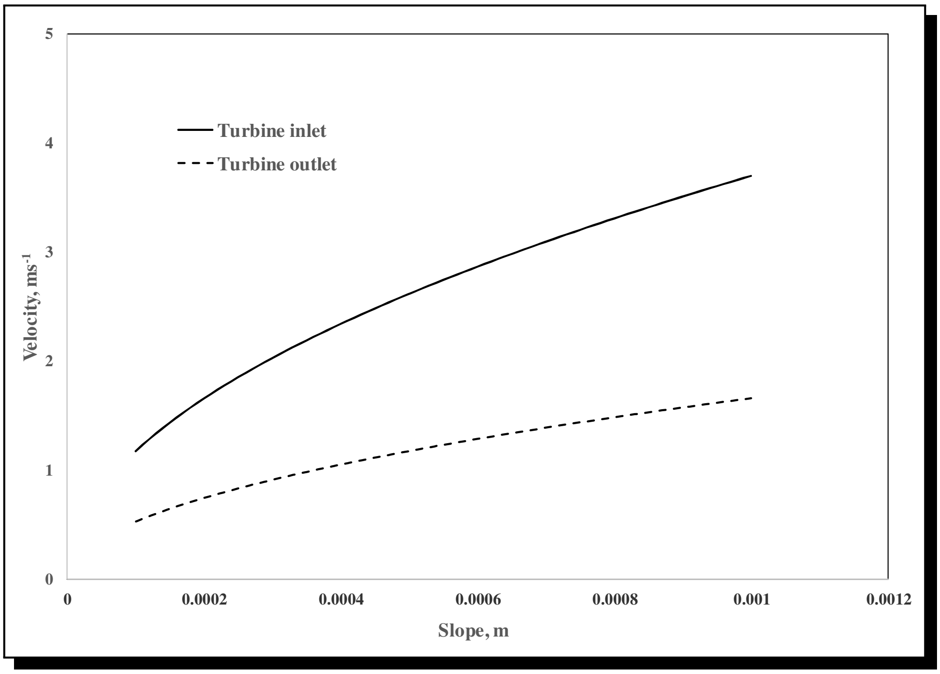

Figure 4. Variation of Velocities with slope

This translates into a power of 0.25 MW for the lowest slope and 8 MW for the highest slope. A second nozzle-turbine arrangement can be placed 1.91 kilometres after the first turbine for the slope of 0.001 m, where 1.91 km is the distance taken for the flow to regain some amount of pressure energy. The power obtained in the second stage is lower, as expected, than the power obtained in the first stage, but still increases with slope, as depicted in Figure 5.

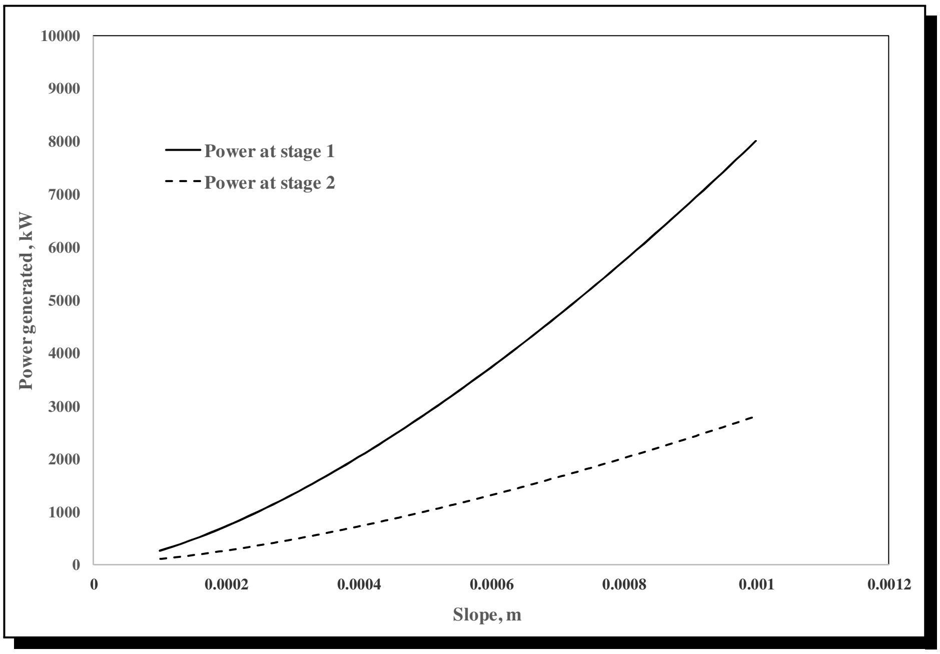

Figure 5. Stage variation of power with slope

The total power obtained by this arrangement is calculated by adding the power obtained in stage 1 and stage 2, and comes to 10.79 MW for the highest slope and 0.34 MW for the lowest slope.

4. Conclusions

The following conclusions are obtained after performing numerical analysis and obtaining values for an ideal assumed case of river canal flow:

- Low head and low flow rates of water flow in rivers serve as untapped sources of a potentially renewable energy source which is widely present.
- Flow acceleration is implemented by using a constriction in flow, which acts as a nozzle to increase the impulse energy available to the turbine.
- The impulse turbine generated power and the loss in pressure is recovered by allowing a certain minimum distance of unhindered flow.
- The power generation of the primary turbine can be supplemented by a secondary stage of the nozzle-turbine setup once the pressure is recovered.
- The above setup can be used either as a standalone or as a peak load plant for a hydroelectric power generation rig. It can also be implemented in the stages between a hydroelectric power plant.
- Power generated increases with an increase in slope value. Maximum power generation capacity is 10.79 MW from two stages of the nozzle-turbine setup.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

References

- **[1]** N. Acharya, C.-G. Kim, B. Thapa and Y.-H. Lee, Numerical analysis and performance enhancement of a cross-flow hydro turbine, *Renewable Energy.* **80** (2015), 819 – 826.
- **[2]** S. Chichkhede, V. Verma, V.K. Gaba and S. Bhowmick, A simulation based study of flow velocities across cross flow turbine at different nozzle openings, *Procedia Technology* **25** (2016), 974 – 981.
- **[3]** D.R. Giosio, A.D. Henderson, J.M. Walker, P.A. Brandner, J.E. Sargison and P. Gautam, Design and performance evaluation of a pump-as-turbine micro-hydro test facility with incorporated inlet flow control, *Renewable Energy.* **78** (2015), 1 – 6.
- **[4]** A.A. Khan, A.M. Khan, M. Zahid and R. Rizwan, Flow acceleration by converging nozzles for power generation in existing canal system, *Renewable Energy.* **60** (2013), 548 – 552.
- **[5]** R.D. Montoya-Ramírez, F.I. Cuervo and C.A.M. Rico, Technical and financial valuation of hydrokinetic power in the discharge channels of large hydropower plants in Colombia: A case study, *Renewable Energy* **99** (2016), 136 – 147.