The gravitational vortex water turbine puts a spin on small hydro

The interest in small hydropower systems, which can be used to generate local and off-grid electricity in small rivers and streams, has led to the development of a number of new designs all exploiting technologies which are not suitable for large scale hydro generation.

The vortex turbine uses both kinetic (run of river) and static potential energy (head) principles and promises to provide a power generation system that results in minimum interference with the river and aquatic life.

Mini hydropower plants have a good potential for providing electricity to remote communities. The gravitational water vortex power plant (GWVPP) is an economic and clean energy system which allows the conversion of the low-head potential energy into kinetic energy to drive power turbines by using a gravitation vortex pool.

Fig. 1: A typical gravitational water vortex power plant [7].

Small hydro systems can use either run of river (ROR) or drop in elevation, to extract energy and generate electricity. ROR systems have to be placed in the river to exploit the water flow, and static head based systems require either a weir or dam, or a significant natural drop such a waterfalls or rapids. The vortex system uses both river flow and a gravitational vortex to turn a turbine and generate electricity

The gravitational water vortex turbine is an ultra-low head turbine which can operate in a low head range of 0,7 to 2 m, which is often seen as too low for conventional hydro turbines, and has a similar yield to conventional hydroelectric turbines used for the production of electricity. In addition there is positive environmental effect on the river as water passing through the turbine is aerated.

The gravitational vortex is seen as a milestone in hydrodynamic development because in the past it was necessary to use energy to aerate water, but this technique uses a water aeration process to produce electrical energy.

Fig. 2: Transportable GWVPP [5].

The turbine does not work on pressure differential but on the dynamic force of the vortex.

Systems range in size from <500 W to 100 kW [2], and a series of units can be installed in a serial or parallel configuration along the river to increase power production. The limiting factors to the size of the unit are not clear but may be the formation of a vortex and the inlet and outlet size restrictions. The vortex may not form on larger sized basins and with larger sized outlets. The use of multiple controllable smaller units is probably a better option than a single large unit. The lower limit of size is seen to be a minimum head of 0,7 m and flow rate of 1 kl/s, although several units work with lower flow rates [1].

Operation

In the vortex power plant, water is introduced into a circular basin tangentially, creating a free vortex (Fig. 1) and energy is extracted from the free vortex by a turbine.

The system operates as follows:

- River water is channelled at the bank of the river and conveyed to a circulation tank. This circulation tank possesses a circular orifice at its base.
- The combination of localised low pressure at the orifice and the induced circulation at the tangential entry influences strong vortex flow.
- Potential energy is entirely converted to rotational kinetic energy at the vortex core which is then extracted by means of a vertical axis turbine.
- Water is then returned to the river through the tail race.
- The turbine, which is located at the top the vortex, is turned by the rotary motion of water in the vortex.

Since the hydraulic head requirement is as low as 1 m, this type of power plant can be installed at a river or a stream to generate enough electricity to power a few consumers, or farm equipment. Water may be fed to the vortex turbine through an open channel or in some cases through a closed conduit or pipe, which is more suitable for smaller systems [5].

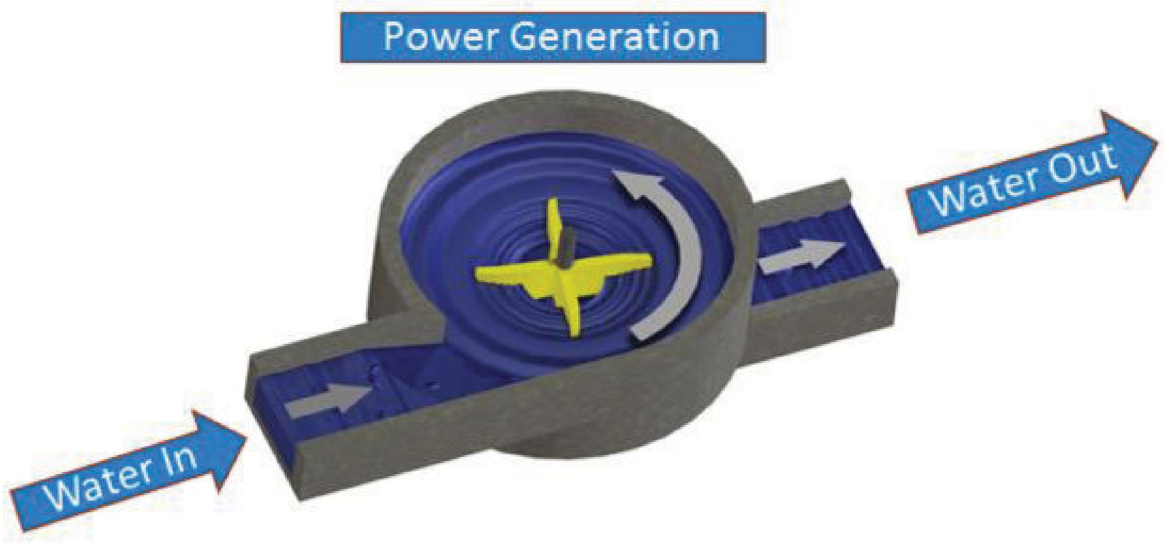

Fig. 3(a): A cylindrical basin design.

Although the vortex structure is very basic and simple, analysis of the operation is not, and involves complex computational fluid dynamics (CFD) modelling. Many of the studies published on the topic make use of computerised modelling and are fairly difficult to understand.

Gravitational water vortex formation

Although vortex characteristics are well understood, the mechanism behind the formation of a gravitational vortex is not. The fully developed air core vortex is often attributed to the Coriolis effect, but this is seen to be too weak at the scale of water vortexes to have any affect. In the case of the GWV the initial rotation is caused by the shape of the basin and is amplified by gravitational force.

A vortex is defined as a region of flow that is rotating around an axis that can either be straight or curved. Vortex formation occurs when the transition from open channel (free surface) flow to pressure flow is not smooth and uniform. When flow does not maintain gradual transitions that attempt to keep a uniform velocity distribution and acceleration, then vortices can occur. The main causes of vortex formation are non-uniform approach flow to the intake, shear layers of high velocity gradients and rotation caused by obstructions in the approach flow. In the GVWG the initial rotation is caused by the shape of the basin.

Vortices are formed at the outlet of hydraulic structures, where a large amount of water is drained into the outlet. This flow into the outlet causes a vortex to initiate at the free surface. This vortex gradually intensifies, causes the water rotation to speed up and in turn causes the pressure in the centre of the vortex to decrease. This pressure gradually decreases to an extent that ultimately it reduces below the atmospheric pressure and sucks the air into the intake and forms an air core. The radius of the air core gradually reduces while moving from the free surface to the outlet [5].

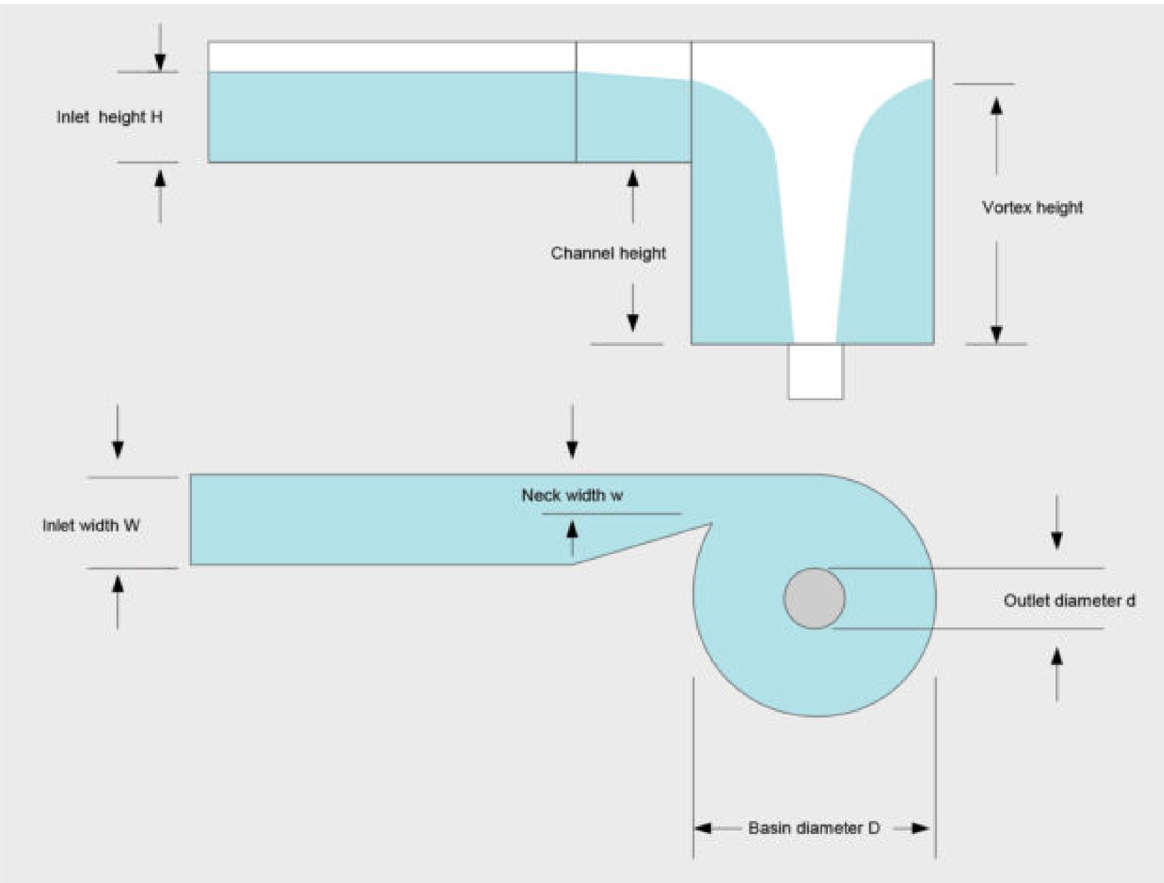

Fig. 3(b): Parameters of the cylindrical basin GWVG.

Basin construction

Basins and feeder channels are generally constructed on-site of concrete or other construction materials, but it is possible to construct small transportable systems with a steel based basin, as the pressure is in the centre of the vortex and not on the exterior. Such transportable systems use a pipeline instead of a channel to feed water into the vortex [5].

Two types of basin are encountered:

- Cylindrical basin
- Conical basin

The cylindrical basin construction is shown in Fig. 3.

The parameters that influence the operation of the cylindrical basin are shown in Fig. 3(b)

Several studies have yielded the following useful characteristics:

- Optimum vortex strength occurs within the range of orifice diameter to tank diameter ratios (d/D) of 14 to 18% for low and high head sites respectively.
- The vortex height varies linearly with discharge. That is as the discharge rate increases, the height of the vortex increases. This has an impact on the turbine placement, as at low discharge rates the turbine will not be fully immersed in the water, and this could limit the operational range of the system.
- Linear correlations for HvQ can be scaled accurately to prototype size
- Maximum hydraulic efficiency should arise when the impellor velocity is half that of the fluid velocity [3].

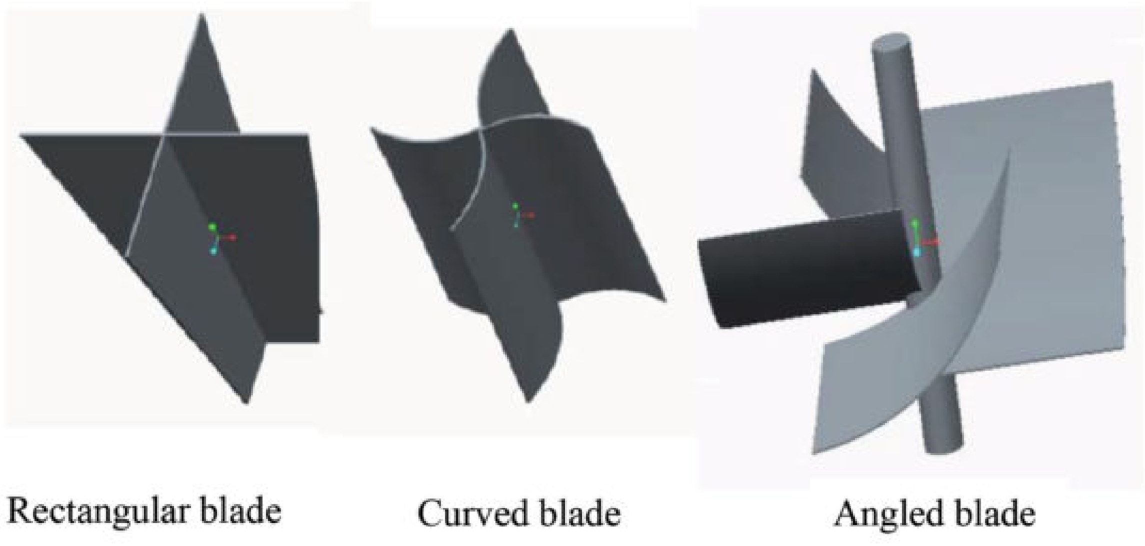

Fig. 4: Blade shapes [6].

Power output and efficiency

The maximum hydraulic power output of the turbine is given by:

P = rgQHv watts (1)

Where:

Hv = Height of vortex (m)

Q = flow rate (m^3/s)

g = gravitational constant

r = water density (kg/m^3)

The maximum power output for several combinations is given in Table 1.

From this table it can be seen that a maximum hydraulic output of 1 kW can be obtained with a flow rate of only 0,1 m^3 and a head of only 0,6 m. The simple design of the turbine makes it easy to downscale to small sizes. The power output is influenced by the height of the vortex and the water flow rate Q.

The speed of the water, and hence the speed of the turbine is affected by two factors:

- The kinetic energy of the water flowing into the turbine
- The potential energy of the hydraulic head

Depending on how the intake channel is placed, the water flow rate can be influenced by the speed of water flowing in the river. If the intake is place at right angles to the flow, the effect will be less than if the intake is placed in the line of flow. Higher flow rates will increase output power above that of a static body of water.

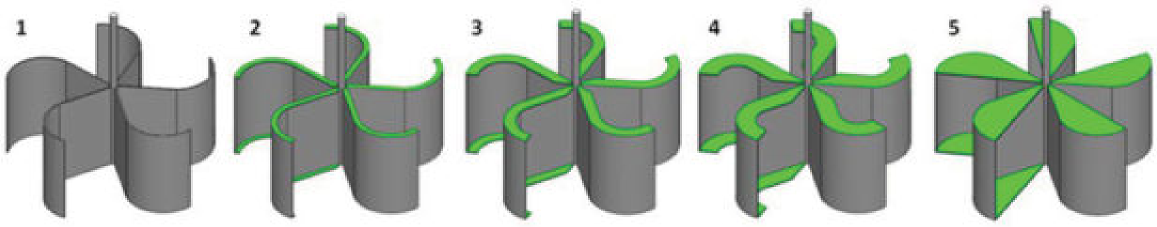

Fig. 5: Baffled blades [7].

The efficiency of the turbine is defined as the mechanical or electrical power output compared to the theoretical hydraulic power available. Studies indicate efficiencies in the region of 30 to 40% while commercial claims go as high as 80%. In the example in Table 1 an efficiency of 50% will give 500 W output for a flow rate of 1 m3/s and a head of 0,6 m.

Blade shape

Much attention has been paid to the design of the turbine blades in cylindrical basin systems, with the aim of increasing the efficiency of energy conversion. Variations in width, height, shape, curvature and the number of blades has been investigated, but the simple design remains the most common in use and easiest to manufacture. The positioning of the blades in the vortex has also been considered. The efficiency has been shown to decrease with increase in number of blades since they cause a greater distortion in the vortex. The efficiency also decreases with increase in radii of the blades since the water velocities at radii far away from the core are lower [1].

Simple blade shapes

The simple blade is rotated by the movement of the water in the horizontal plane. The rectangular blade consists of a rectangular bladed fixed to the shaft. The number of blades varies with the design, but studies have shown that performance improves with a lower number of blades. The curved blade is also rectangular but curved to better capture the force of the water. The angled blade also captures energy from the vertical movement of the water.

Baffled blades

These are curved blades with baffles at the top and bottom to further capture the water. Studies show that the optimum baffle size is 30% of the closure. Larger baffle sizes tend to retain water and increase the inertia of the blade.

Generator placement

Most designs place the generator above the vortex and extend the shaft to the generator. This avoids the need to waterproof the generator. There are some designs where the generator is attached directly to the blades and the shaft does not extend above the top of the blade assembly.

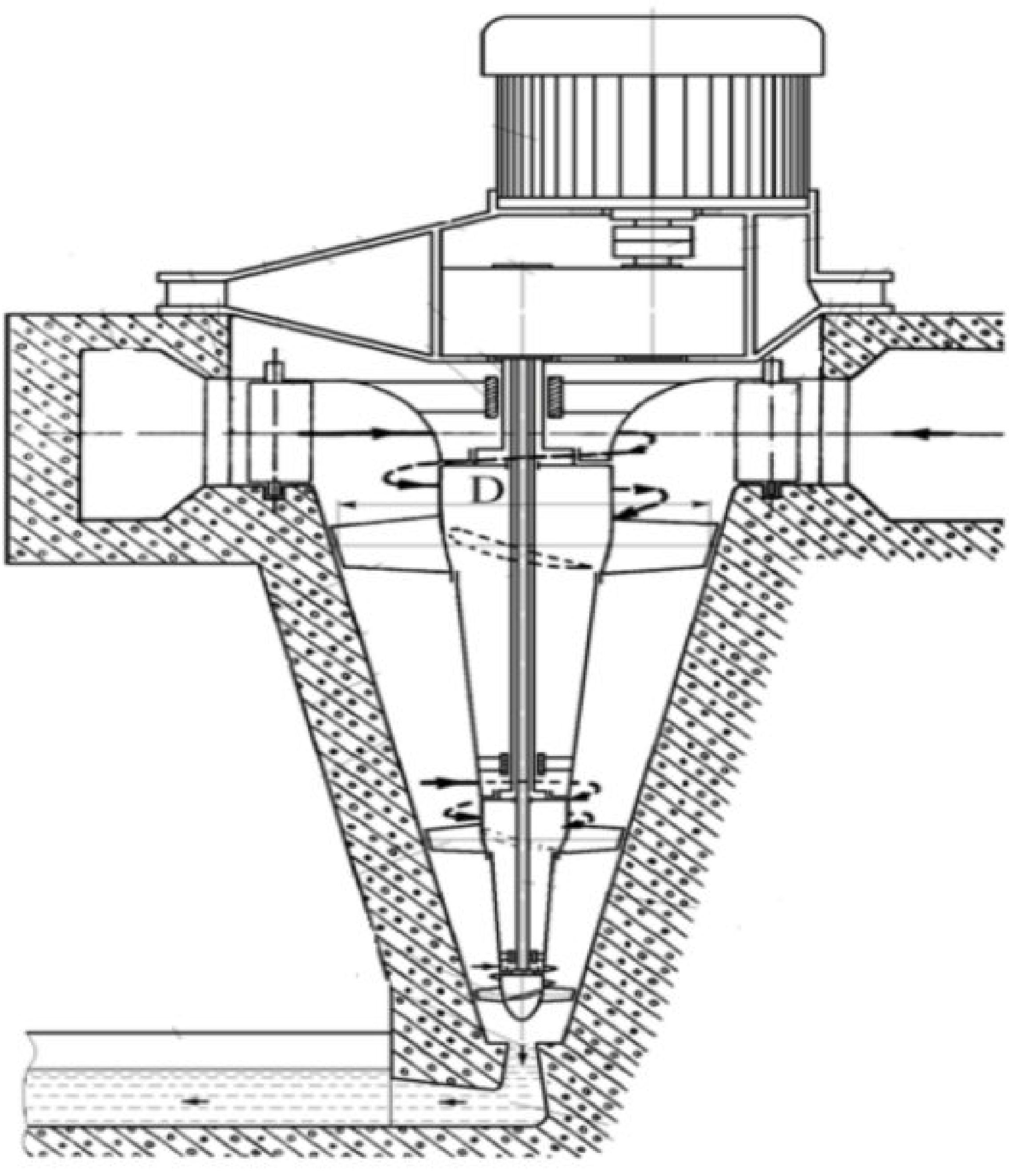

Fig. 6: Conical basin design [4].

Conical basin

The conical basin design (Fig. 6) attempts to exploit the fact that water moves down the vortex in a circular motion, and energy can be extracted at every level. Whereas in the basin design, water passes through the blades once, in the conical design, it passes through a series of blades on the way to the outlet.

The conical basin design is at a theoretical stage at the moment and there are no known working models. The design is intended to follow the natural shape of the vortex and extract energy in several stages instead of the single stage turbine used in the cylindrical vortex design. As the water velocity varies with the depth of vortex in the conical basin, each of the sets of blades will rotate a different speed and requires gears to max the individual shaft speeds to the main drive shaft speed. To extract the maximum energy, each of the rotors spins at a different speed, and is coupled to the drive shaft by gears.

Additional benefits

The turbine is tolerant of muddy and polluted water, as the vortex action carries small solid particle through the turbine.

The design originated from a goal of water aeration with minimal disturbance to the biosphere. Aeration occurs as the vortex sucks air into the water stream.

The turbine is claimed to be fish friendly and should allow the passage of fish in both and up and downstream direction. The turbine operates at a low speed does not cut the natural stream of water and therefore it does not harm the aquatic and marine life.

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