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Hydro Power and Turbine Systems Reviews

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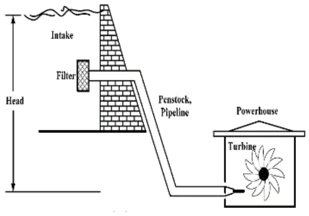
Graphical abstract



Abstract

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, Mini, Micro and Pico Hydropower. Nowadays most of rural areas in developed and developing countries use the hydropower plant for producing electricity, it is cheap and effective. This paper gives a review of hydropower technologies and turbines; it is focusing on the categories and performance of hydro power systems and the most suitable turbines which can be used.

Keywords: Hydropower; dammed reservoir; runs of river; in stream; gravitational vortex; turbines

■1.0 INTRODUCTION

Nowadays, the researchers give their interests for the importance of a sustainable energy, especially it has been noticed that fossil fuel is costly and due to a large negative effect to the environment. Renewable energy presents the most suitable solution to get a great connection between renewable energy and sustainable development [1]. The role of renewable energy has been defined as great significance for the global environmental concerns. Hydro-power is an efficient type example of renewable energy and its potential application to future power generation cannot be underestimated [2]. Therefore, hydropower stations produce no air emissions but in most cases it has a bad effects on the water quality, wildlife habitats and prevent the fish migration [3], but recently, new technology such as gravitational water vortex power system can solve this problem issue [4], [5]. Hydropower is currently the most secure, efficient and reliable source of renewable energy, based on more than a hundred years of professional experience [6]. Global hydroelectricity generation is increasing which representing 20% of world's electric generation in the last statistical data [7]. Hydropower is produced from the extracted energy of water moving from higher to lower locations. It is predictable, economical and commercial technology. The overall efficiency of the station (water to wire operation) is almost 90% efficiency. On the other hand, the startup cost of hydropower schemes is high, but it has low operation and maintenance cost, thus it is more efficient in long terms [8]. The hydro power extracted from the potential energy of water is driving turbines as shown in Figure 1 to produce power. The energy extracted from water depends on the capacity and head between down and up streams. The general equation for any hydro system's power output is:

$$P = \eta \rho g Q H \qquad [1]$$

Where P is the mechanical power produced at the turbine shaft (watts), η is the hydraulic efficiency of the turbine, ρ is the density of water volume (kg/m^3), g is the acceleration due to gravity (m/s^2), Q is the flow rate passing through the turbine (m^3/s) and H is the effective pressure head of water across the turbine (m).

In last years, many publications focused on the importance of utilizing simple design and fabrication turbines to achieve minimum initial cost of the hydropower plants [10]. Hydro power turbines have a rapid growth in the power generation field especially in rural and hilly areas and thus the power feeds different load demand requirements on a grid supply [11]. Hydro power turbines generate very reliable power with very simple designs and fabrications [12], turbines are of two types: impulse and reaction turbines, each suitable for different types of water flow.

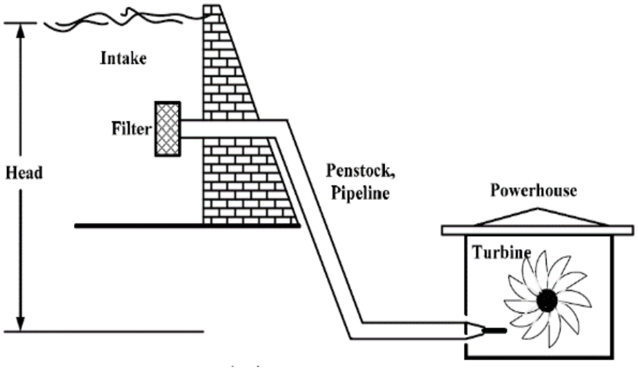
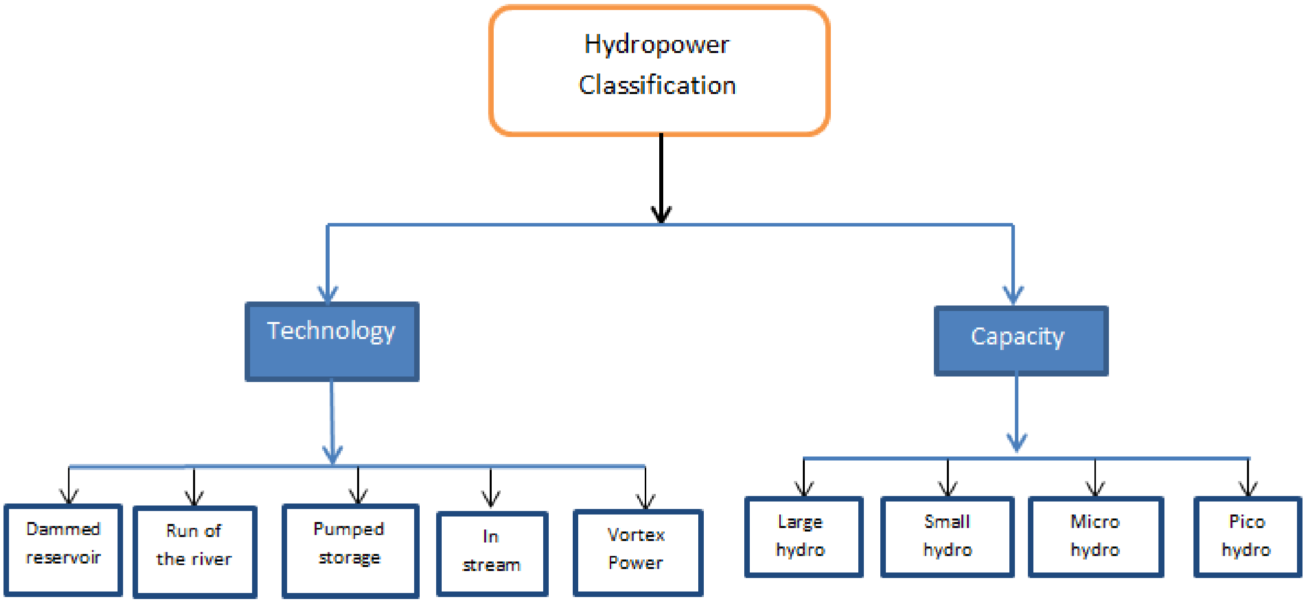


Figure 1 Hydroelectric power generation diagram [9]

■2.0 HYDRO POWER TECHNOLOGY SYSTEMS

The power capacity and facility (technology) are two criteria for the classification of hydropower plant. The first one consists of four technologies dammed reservoir, run of river, pumped storage, in stream technology and new technology which is vortex gravitational energy. Classification according to power scale is large, small, Mini, micro and Pico. See Figure 2.



(a) (b)

Figure 2 Hydropower categories (a) facilities (technologies) (b) power capacity

2.1 Power Capacity and Head Classification

Head is the difference between the upper and down streams of the water levels as shown in Figure 1. The high head, medium head and low head are different defined from country to country, and no generally accepted scales are found [8]. For example, reference [11] classified that low head is <10 m head. Therefore the capacity measured in MW is the criteria to define categories such as micro, ‘small hydro’ and ‘large hydro’. Various countries define various scales of hydro power plants; some examples are descriped in Table 1. Micro hydropower plants generate power less than 100 KW [13, 14] where the plant is more than 100 kW and less than 1 MW is called Mini hydro power plant. Also Pico-hydro is from a few hundred watts up to 5 kW [15].

Table 1 Small-scale hydropower (MW) as defined by various countries [8]

Country	**Small-scale hydro as defined by installed capacity (MW)**
Brazil	≤30
Canda	<50
China	≤50
EU Linking Directive	≤20
India	≤25
Norway	≤10
Sweden	≤1.5
USA	5-100

2.2 Classification by Technology

Hydropower plants are often classified in three main categories according to operation and type of flow as shown in Table 2. Run-of-river (RoR), storage (reservoir) and pumped storage HPPs all vary from the very small to the very large scale, depending on the hydrology and topography of the watershed [16]. In addition, there is a fourth category called in-stream technology, last gravitational vortex technology which is a young technology.

Table 2 Types of hydroelectric projects [16]

Type of Technology	Services Provided	Main Impact Source
Dammed Reservoir	Power and Energy	Changes of habitat and social impacts due to reservoir Modification of river flows
Run Of River	Base load with limited flexibility	Limited flooding River flows unchanged
Pumped Storage	Power only, Net consumer of energy	Impacts related to upper storage pool
In Stream	Energy and power	Reduction of flow downstream of diversion

2.2.1 *Dammed Reservoir Technology*

Damming rivers has extracted energy over 4500 years into the past [17]. The fluctuation of the water flow can be reduced by the reservoir. The generating stations are located at the dam to or further downstream, connected to the reservoir through tunnels or pipelines as shown in Figure 3 [18]. Landscape and the nature of sites are the main factors which decide the type and design of reservoirs and in many countries around world are surrounded river valleys where the reservoir is an artificial lake. In geographies with mountain sites, high-altitude lakes make up another kind of reservoir that often will retain many of the properties of the original lake [8].

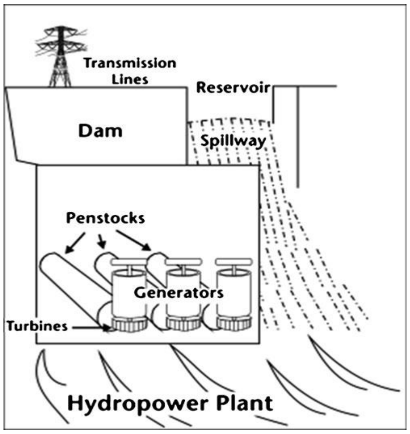


Figure 3 Typical hydropower plant with reservoir [18]

2.2.2 *Run of River (ROR) Technology*

Run-of-river scheme is a type of small hydropower stations that produces electricity based on the available hydrological variations of the site [19]. This type of hydropower generation utilizes the flow of water within the natural range of the river; the components of a small run-of-river hydropower project are shown in Figure 4 [8]. Therefore no or little reservoir was utilized. Small hydropower plants attract the efficient and reliable investments because it takes a minimum time for construction and exploits small area, uses of local labor and material, and cost per kW is low as compared to other power projects [20]

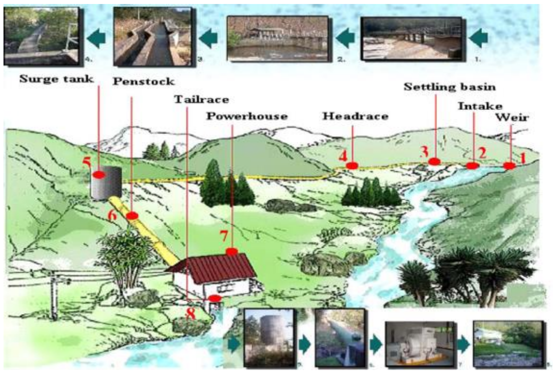


Figure 4 Components of a small run-of-river hydropower project [20]

2.2.3 *Pumped Storage Technology*

Pumped-storage plants pump water into an upper storage basin during off-peak hours by using surplus electricity from base load power plants as shown in Figure 5. They subsequently reverse flow to generate electricity during the daily peak load period. They are considered to be one of the most efficient technologies available for energy storage. The concept of pumping water back to the upper reservoir during off-peak hour's means that these plants are net energy consumers: it takes more power to pump water up to the top reservoir than is produced by the plant when the water rushes down to the lower reservoir [8].

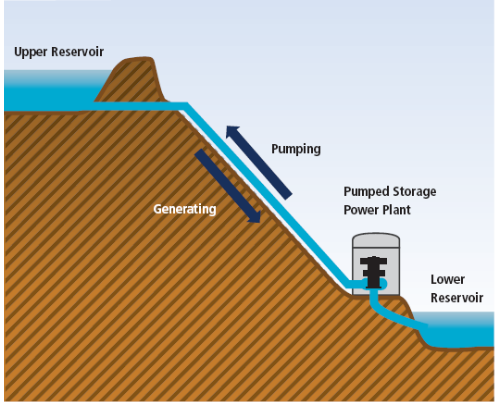


Figure 5 Typical pumped storage project [8]

2.2.4 In-Stream Technology using Existing Facilities

Installing the hydrokinetic turbines in stream of rivers or canal to generate energy can optimize existing facilities like weirs, barrages and falls. These basically function like a run-of-river scheme, as shown in Figure 6. Hydrokinetic devices being developed to capture energy from tides and currents may also be deployed inland in both free-flowing rivers and in engineered waterways [21].

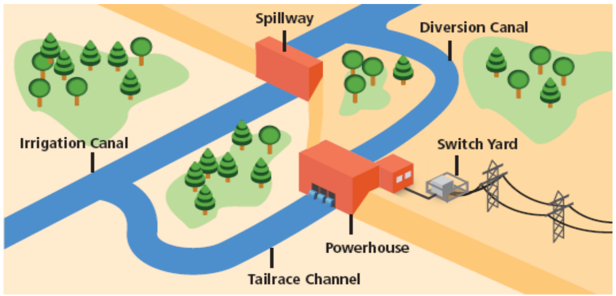


Figure 6 Typical in-stream hydropower plant using existing facilities

2.2.5 Gravitational Vortex Energy

Nowadays, gravitational vortex plant and VIVACE converter are two technologies which harness the vortex energy to generate the electrical power.

- **Gravitational Vortex Plant**

The elementary vortex with a vertical axis of gyration, source of the rotation-symmetric and stable vortex is the Gravitation-so we called it Gravitation Water Vortex (GWV) [22]. The Gravitational Water Vortex Power Plant 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. Vortex pool is a structure which has the ability to form a gravitational vortex stream see Figure 7. Such a high velocity water vortex stream can possibly be used as an alternative energy resource [23].

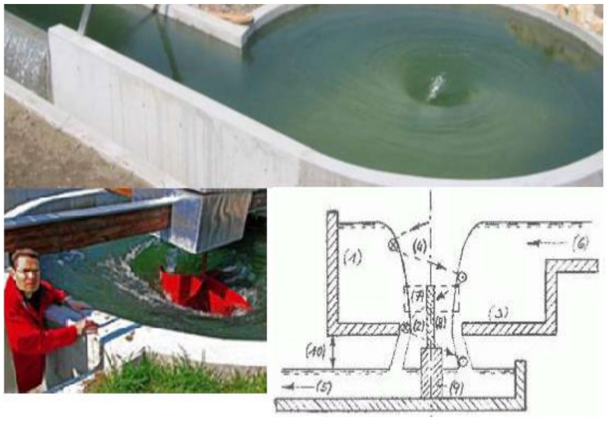
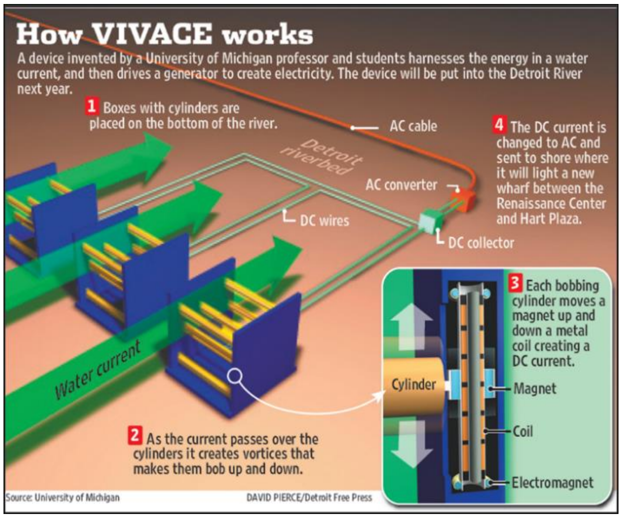


Figure 8 Gravitational vortex plant (designed by Franz Zotlterer)

- **VIVACE Converter Technology**

The VIVACE converter harnesses hydrokinetic energy of river and ocean currents. This converter is unlike water turbines as it does not use propellers. VIVACE uses the physical phenomenon of vortex induced vibration in which water current flows around cylinders inducing transverse motion. The energy contained in the movement of the cylinder is then converted to electricity. The VIVACE converter is a transformational technology. It taps into a vast new source of clean and renewable energy, that of water currents as slow as 2 to 4 knots previously off limits to conventional turbine technology that target rivers with water currents greater than 4 knots. The vast majority of river/ocean currents in the United States are slower than 3 knots, Figure 8 illustrates how VIVACE works [24].


How VIVACE works

A device invented by a University of Michigan professor and students harnesses the energy in a water current, and then drives a generator to create electricity. The device will be put into the Detroit River next year.

1 Boxes with cylinders are placed on the bottom of the river.

2 As the current passes over the cylinders it creates vortices that makes them bob up and down.

3 Each bobbing cylinder moves a magnet up and down a metal coil creating a DC current.

4 The DC current is changed to AC and sent to shore where it will light a new wharf between the Renaissance Center and Hart Plaza.

Source: University of Michigan

DAVID PIERCE/Detroit Free Press

Figure 8 VIVACE components and Technology [24]

3.0 IMPULSE TURBINES

Impulse turbines are most efficient for high head and low flow sites [9] that are used for situations with heads rangly from 6 feet to 600 feet [25]. The impulse turbine uses the velocity of the water to move the runner and the water flows out the bottom of the turbine housing at atmospheric pressure. The flow strikes the turbine as a jet in an open environment to create a kinetic energy which is producing the power [26]. These types of turbines generally are simple design and inexpensive [12]. Turgo, Pelton and cross flow turbines are used for lower head micro sites; they are becoming an accepted alternative practice in many countries [27].

3.1 Turgo Turbines

By 1920 Gilbert Gilkes Ltd invented Turgo turbine as shown in Figure 9 [28]. They are commonly used as high and medium head impulse turbines [11], The Turgo can handle significantly higher water flow rates, allowing for efficient operation in lower head ranges because it can generate significant power by using more water with less head [29-31].

Figure 9 Turgo turbine [28]

The jet of water hits and exits the runner at a sharp angle [29-31]; the water also in a Turgo turbine exits from the bottom of the wheel and does not interfere with the inlet jet [4]. This allows the diameter of the wheel to be smaller for a given jet diameter, increasing the rotational speed [29-31]. Figure 10 shows the interaction between the water jet and Turgo turbine cups [29].

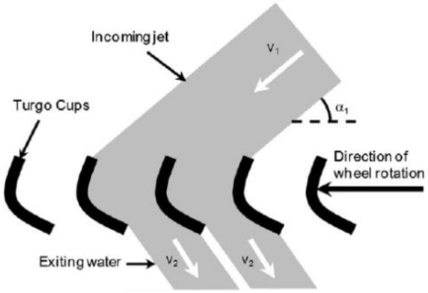


Figure 10 The torque generation mechanism for Turgo turbine [29]

3.2 Pelton Turbines

In a Pelton turbine Figure 11, water jets from nozzles strike the double cupped buckets attached to the wheel, arranged on a circumference of a runner or wheel, causing a force that rotates the wheel [25] at high efficiency rates of 70 to 90 percent [32]. A Pelton wheel has one or multi free jets see Figure 12. Alos, the torque generation mechanism for Pelton turbin is showed in Figure 13. Pelton turbines are suited for high head, low flow applications [25]. Recently Pelton turbines can also be used for small hydropower systems. For small systems, a single water jet is typically used [29-31].

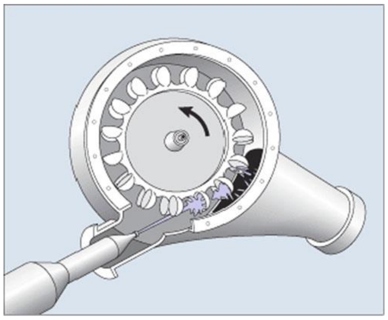


Figure 11 Small hydro Pelton wheel [32]

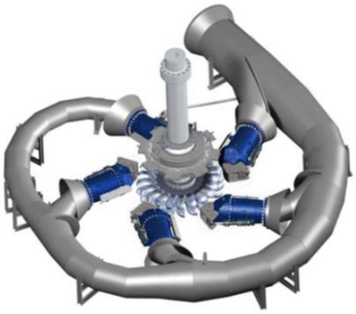


Figure 12 Multi jet Pelton turbine [29]

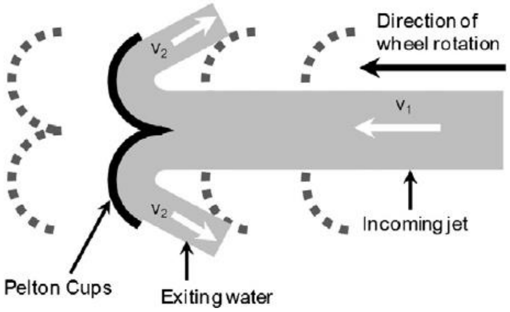


Figure 13 The torque generation mechanism for Pelton turbine [29]

3.3 Cross Flow Turbines

A cross-flow turbine, also it known as an Ossberger turbine which is designed by Ossberger Co, is shaped like a drum and uses an extended, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner [33]. The cross-flow turbine allows the water to flow through the blades twice. During the first pass, water flows from the outside of the blades to the inside; the second pass is from the inside back out. These types of turbines can be used both in horizontal and vertical orientations (Figure 14). These turbines can familiar with higher water flow and lower head than the Pelton turbine [4], [14], [33].

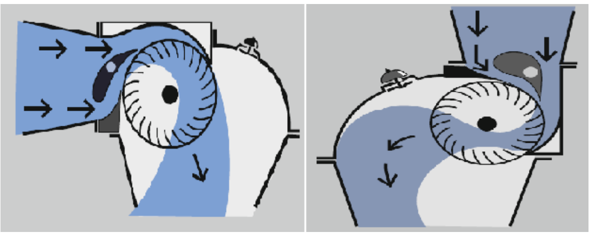


Figure 14 Inflow in horizontal and vertical orientations [33]

4.0 REACTION TURBINES

Reaction Turbines have a better performance in low head and high flow sites. They have not nozzles, the blades project radially from the periphery of the runner are formed and mounted so that the spaces between the blades have, in cross section, the shape of nozzles [4], [9]. A reaction turbine generates power from the combined action of pressure and moving water [4]. In the slow operating speed, the efficiency of reaction turbines is better than the impulse turbines [9]. Also Reaction turbines are generally preferred over impulse turbines when a lower head but higher flow is available [4], [18].

4.1 Axial Flow Turbines "Propeller Turbines"

Most of the reaction turbines are a propeller type turbine; it is practical, which indicated a good efficiency, simplicity, cost-effectiveness [34]. A propeller turbine as shown in (Figure 15) generally has a runner with three to six blades in which water streams hit continuously at a constant rate. The pitch of the blades would be fixed or adjustable [4], [26], [34]. The major components besides the runner are a scroll case, wicket gates, and a draft tube [35].

There are four different types of propeller turbines, Bulb turbine (Figure 8), the turbine and generator are unity cased in front of water flows. Straflo, the generator is attached directly to the circumferential of the turbine. Tube turbine: the penstock bends positioned before or after the runner to make straight line connection to the generator [26], [36]. In 1913, variable pitch propeller turbine was designed by Kaplan, thus it is called the Kaplan turbine. Its runner is hydraulically similar to the propeller turbine runner except that the hub is different which including mechanism to adjust blades and wicket gates angles as shown in Figure 16 [18], [26].

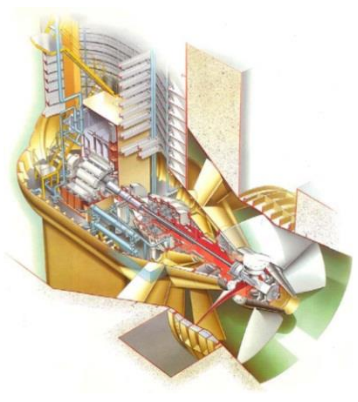


Figure 15 The bulb propeller turbine [26]

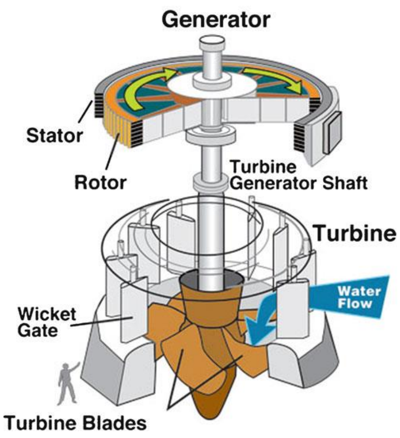


Figure 16 The Kaplan turbine [4]

4.2 Francis Turbines

A Francis turbine is the most common used in hydropower [37]; it has a radial or mixed radial/ axial flow runner which is most commonly mounted in a spiral casing with internal adjustable guide vanes. Water is introduced just above the runner and all around it and then falls through, causing it to spin. Besides the runner, the other major components are a scroll case, wicket gates, and a draft tube. The cross-sectional view of a Francis turbine is shown in Figure 17 [36], [38].

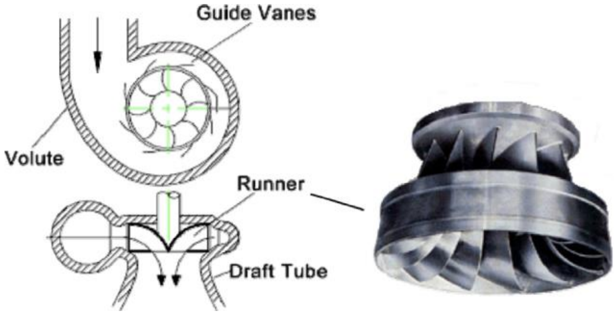


Figure 17 Francis turbine [39]

4.3 Pump as Turbine (PAT)

In pumping mode, the fluid enters at suction side of pump at low pressure and gets energized by the impeller, which is rotated by some external means, and leaves the casing at high pressure. Whereas in case of PAT in Figure 18, the pump rotates in reverse direction, water enters in the pump at very high pressure from the casing and moves through the impeller blades and releases its pressure and kinetic energy to the impeller shaft as mechanical energy and fluid comes out from the eye of pump at low pressure [40], [41]. The efficiency is as high as 85% [28].

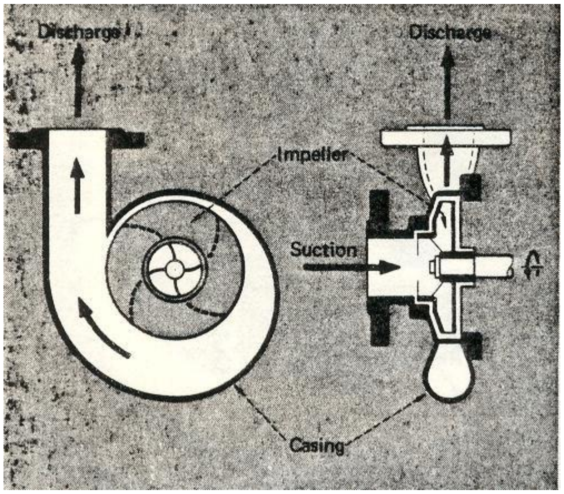


Figure 18 Radial flow pump as hydraulic turbine [41]

4.4 Other Reaction Turbines

4.4.1 Kinetic/ Free-flow Turbine

Kinetic turbines exploit the kinetic energy in water streams to produce electricity power rather than the potential energy from the head [28], [36]. They can operate in rivers, channels, tidal waters, or ocean currents. Kinetic systems use the flowing water natural path way, so they do not require diversion of water through man made channels, river beds, or pipes. However, they can be applied in such conduits [21], [28], [32]. Figure 19 shows a free-flow turbine.

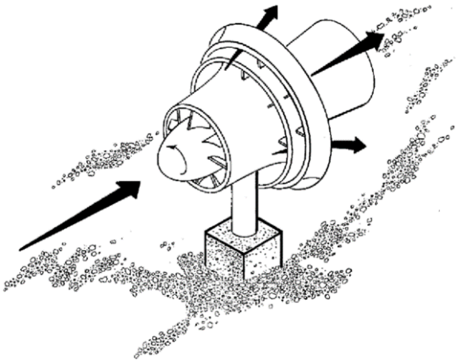


Figure 19 Free-flow turbine [21]

4.4.2 Screw Turbine

With an Archimedes screw as shown in Figure 20, screw is turned by water falling through it. The turning screw rotates the gear box to generate power electricity [4], [21]. Archimedes screw is becoming more suitable for lower head sites; heads can be as low as 1 meter. It is especially suited to sites with large flows [42].

Figure 20 Archimedes Screw turbine (43)

5.0 CONCLUSION

This article focused on hydro power systems and technology and its turbines in renewable energy fields; it indicated that hydro is a corner stone of the electric generation power plant which is achieved great significance for the global commercial, economic and environmental concerns. On the other hand, this paper showed various types of hydropower turbines; it presented a general description of hydropower turbines systems and there various components and performance. From the above study, it can be provided a guideline to reach about the suitable hydropower system and turbine which can be used in the different hydropower projects.

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