RENEWABLE HYDROPOWER TECHNOLOGIES

CHAPTER 2: SMALL HYDROPOWER TECHNOLOGY

2.1. Introduction

Renewable energy sources, with their clean and sustainable production methods, can help to mitigate the environmental impacts that power generation using non-renewable energy resources has in their nature. Alternative energy sources include wind, hydro, biomass, geothermal, and solar all of which are already present in different countries' energy grids.

A technology utilized in the renewable form of little hydropower, according to the United Nations Industrial Development Organization (UNIDO), allows for the advancement of rural communities and the approach to energy for a slice of the community inhabiting in these certain areas, as well as contributing to social incorporation and long-lasting growth. These are some of the factors that contribute to a positive assessment of government policies (Liu et al., 2013). The deployment and maintenance costs of hydroelectric generation are high as well as some short-term limitations exist. In the longer term, it becomes appealing for a sustainable and clean generation as well as the advantage of being utilized extremely near to high consumer centers, lowering the prices of distribution , for instance.

2.2. Plants of Small hydropower

Small hydropower plant definitions have no international acceptance and their categorization is completely dependent on a country's level of hydroelectric expansion. **Table 2.1** below depicts the definitions and classifications used in some of the world's most prominent small hydropower generators.

Table 2.1. SHP classification and definition in some countries (Ferreira et al., 2016).

Country/organization	Small (kW)	Mini (kW)	Micro (kW)
China	≤50,000	≤2000	≤100
USA	<15,000	501–2000	<500
Japan	<10,000	-	-
Sweden	101–15,000	-	-
Philippines	<15,000	51–500	-
India	-	<2000	<100
Brazil	1001–30,000	101–1000	<100
Nigeria	-	501–2000	≤500
New Zealand	<50,000	<10,000	-
France	<50,000	501–2000	<500

Canada	1001–1,500	<1000	-
United Kingdom	-	-	<1000
Norway	1000–10,000	101–1000	<100
Russia	<30,000	-	-
Turkey	<10,000	101–2000	<100
Germany	<12,000	501–2000	<500

There are three different types of hydropower plants (Okot, 2013):

1. Impoundment: This hydroelectric system uses a dam system to store water in a large reservoir for significant generation.
2. Diversion: A canal or penstock must be built to allow a section of the river to flow to the producing group in order to generate energy with diversion. The system of dam cannot be completely reliant on the system of diversion.
3. Run-of-river: This system makes advantage of the river's natural flow, obviating the necessity for impoundment in some situations.

The preference for little technology of hydropower plants is dependent on the utilization of a run-of-river system, which utilizes the kinetic power of flowing water to move turbines and requires few or no dams on the place that keeps the project of hydropower. The run-of-river system mitigates the negative impacts of large hydroelectric dams in the installation area of the plant, such as changes in river composition and temperature and farmland flooding(Kosnik, 2010)

2.2.1. Components and Characteristic

Figure 2.1 A typical illustration of run-of-river small hydro scheme.

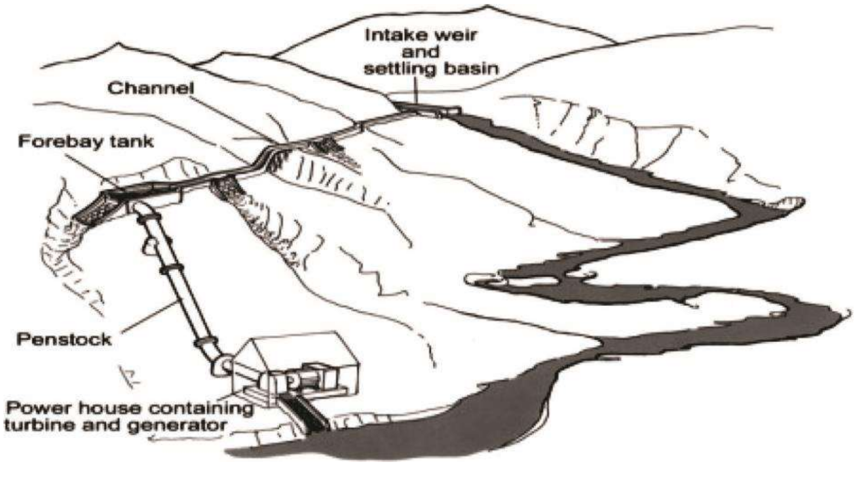

Figure 2.1. layout of typical hydro site.

[Source: https://www.sciencedirect.com/science/article/abs/pii/S1364032115013003]

The weir, a small canal, the penstock, or "leat", and the settling tank (forebay) are the basic components. An intake at the weir diverts water from the main river's passage. The weir is an artificial barrier that controls the flow of water via the intake. Water is passed through a settling tank to remove particulates before entering the turbine. In the settling tank, the water is adequately decelerated to allow particulate matter to settle out. To safeguard the turbines from larger materials like man-made litter, timber, stones, and leaves that may be found in the waterway, a metal bars protective rack(trash rack) is found close to the forebay(Okot, 2013).

To comprehend the parameters that influence the advantages of an SHP, one must first comprehend the role of the key components in a hydroelectric project. The following factors are remarkable for small hydropower plants (Kim et al., 2015).

1. A dam is a plant structure that elevates and maintains the engine room upstream level, artificially producing a local irregularity.
2. Water intake channels, leakage channels, low-pressure adduction tunnels, pipes, external or underground powerhouses, high-pressure ducts, any surge shafts or load chambers, and tunnels are all part of the generation circuit. The designed generation circuit is to introduce water into the process of transforming mechanical energy to electrical.
3. A spillway was constructed to reduce the more important design flow required to sustain the reservoir's demanded water level while avoiding the chance of water entering the dam crest. This is the dam's protection system.

We have a generation circuit such as:

1. Penstock: The structure that connects the intake of water to the under-pressure powerhouse. External or passageway penstocks are available.
2. Water intake: structure for capturing water and transporting it to the adduction tunnel or penstock.
3. Powerhouse: The electrical and mechanical equipment is housed in this structure. The kind of generator and turbine determines the typical powerhouse configuration, as it does with any project of this nature.
4. Equilibrium chimney: aims to avoid pressure changes caused by total or partial changes in load variations, water outflow in initial conditions, or generating unit load shedding.
5.
6. Channel and adduction tunnel: Adducting water toward the forced comportment within arrangements of a shunt is the responsibility of structures.
7. Tunnel or tailrace: The channel by which the water turbinated is drained and reverted to the river is installed at the bottom of the suction duct between the powerhouse and the estuary.
8. Load chamber: The change within the penstock and channel the water intake is made by this structure. It is designed to withstand critical starting conditions as well as a sudden shutdown of the generating unit.

2.2.2. Project steps

The utilization of hydropower potential is governed by institutional, commercial, and environmental rules. Multidisciplinary practices are mixed all across the project execution process, forming the legal structure for the overall project. **Figure 2.2** depicts the interdisciplinary nature of studies by illustrating the activities that are ideal for the study of an SHP and growth.

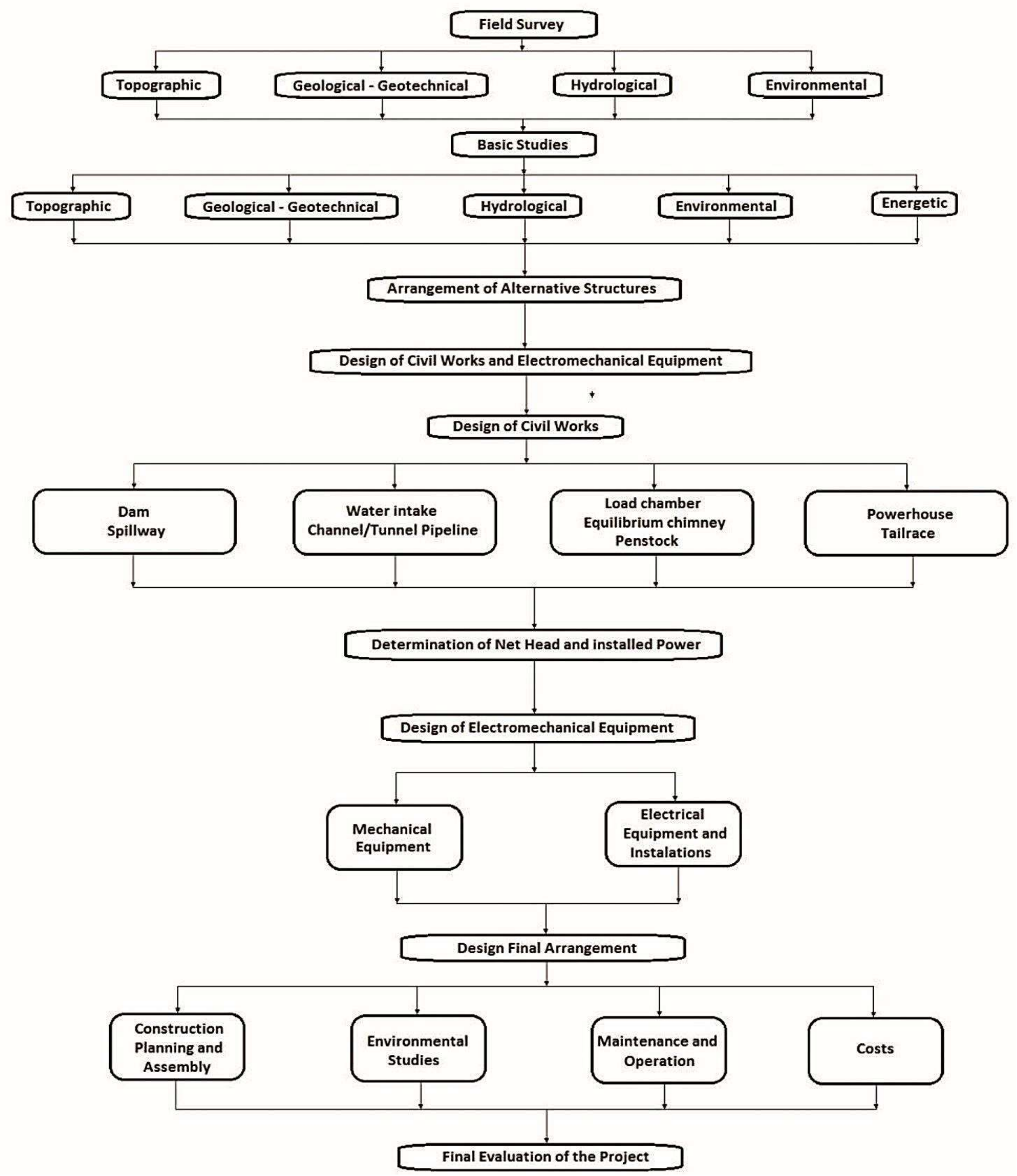

Figure 2.2. SHP projects and studies.

[Source: https://cnpp.iaea.org/countryprofiles/Brazil/Brazil.htm]

A step cycle for implementing a project that focuses to use a hydropower project for electricity production includes phases for estimating, executing, and planning the project. According to reference (Teixeira et al., 2004), these phases are as follows:

1. Viability: The studies are more detailed here, with a focus on technical, economic, energy, and environmental viability, intending to determine the best use of the power auction. The research findings include on-site field investigations, as well as the layout of the reservoir's use and its sphere of influence, as well as the regional infrastructure projects required for its execution. Analyze the water various uses as well as the effects on the environment. We prepared an enterprise-specific environmental impact report (EIR) and environmental impact assessment (EIA) based on these research findings to obtain a preliminary license (PL) from environmental agencies.
2. Hydropower potential estimation: This step entails a preliminary examination of the river basin's characteristics, particularly in terms of geological, topographic, environmental, and hydrological aspects, and to confirm the river basin's ability to generate electricity. Such analysis, which is done in the office and is based only on existing data, enables for a preliminary evaluation of the watershed's capability and price estimate, as well as prioritization of the next step.
3. Hydroelectric inventory: This is defined by the modeling and development of different water resource alternatives of falling division, which are comprised of several projects that are compared to determine which one offers the best balance of deployment costs, environmental impacts, and energy benefits. This evaluation is dependent on secondary data, which is completed with field data and is directed by fundamental research in geology, cartography, hydrology, energy, multiple water uses, geotechnical engineering, and environmental science. The main features of this analysis are cost/benefit, indexes, and environmental indices, which will happen in the exploitations set. It is part of an inventory study that submits alternative uses for the research assessment of integrated environments to help with the process of licensing. Then added these exploitations to the nation's record of inventoried uses, which can be used to create the expansion plans explained above.
4. Basic design: The structure of the feasibility studies is defined in depth in order to more clearly describe the project's technical characteristics, including electromechanical and civil equipment technical specifications, as well as programs of environmental and social. The basic project of environment should be produced to specify the contained recommendations in the EIA in order to get the installation license (IL) for the contracting of works.
1. Executive project: it involves the creation of drawings that detail the electromechanical devices and civil works needed to complete the project and install the devices. In this stage, each necessary step for the construction of reservoirs is taken, comprising the execution of

environmental plans to decrease or neutralize environmental destruction, and an operating permit should be ordered.

2.3. Project Costs

To reduce installation charges and enhance generation of power, it is critical to assess the existing conditions at a hydroelectric plant's installation site. The cost of installation varies depending on the location of the installation, the infrastructure available, and the capacity of the generator. The cost of a plant is influenced by a variety of factors, including the equipment. Even though they are smaller, small plants have higher installation costs (Okot, 2010).

According to Hosseini et al. (2005) and Forouzbakhsh et al. (2007), all construction, maintenance costs, and operation must be divided into two categories: annual costs and investments, while the study phases of an SHP. Civil structures, electrical equipment, mechanical equipment, towers of transmission, and some other costs(indirect) are all included in investment costs. . Annual costs are already essential for component and equipment maintenance, replacement, operation, and prevention (Hosseini et al., 2005; Forouzbakhsh et al., 2007).

2.3.1. Investment costs

As mentioned below (Hosseini et al., 2005; Forouzbakhsh et al., 2007). direct costs encompass electro-mechanical devices expenses, line of power transmission expenses, and civil costs:

1. Civil expenses are calculated for the structural features of a plant's design and construction, such as the penstock, dam, tailrace channel, and forebay, as well as other features that are developed during the feasibility stage.

2. Mostly during the planning phase of an SHP, actuation, turbines, substations, control systems, protective equipment and generators, and other electrical equipment are included in the costs of electromechanical equipment. The prices of an SHP's electromechanical equipment can fluctuate depending on the plant's potential.

The electromechanical equipment cost can also be calculated using a small hydropower plant's power(P), and total head(H), from the (Ogayar & Vidal, 2009):

$$\mathrm{C\,ost} = a\,P^{\,b\text{-}1}\;H^{\,c}\;(\text{€/kW}) \qquad (1)$$

where coefficients(a,b,c) are dependent on the spatial, geographic, or field time in which they are utilized.

1. Transmission line expenses encompass lines from the point of generation to the point where electricity is delivered to the substation. These expenses are determined by the SHP's generation

capacity, roadways, location, infrastructure, and current systems. However, as the length of the transmission line grows, the value rises.

supervision and administration (S&A) cost, inflation, Engineering and Design (E&D) cost, and cost over the construction period are all included in the indirect expenses, according to Hosseini et al. (2005).

2. E&D expenses: E&D expenses are affected by factors such as the project's size and location. These costs, as well as the apparatus and civil works, are examined as a percentage of the total building expenses. These variables differ from one region to the next. According to studies, the cost of plants with little potential can be as low as 5%, while the cost of plants with high potential can be as high as 8%.

3. S&A costs: S&A costs include the cost of management operations, the cost of land acquisition, monitoring, and inspection. This cost is comparable to E & D's, and it is similarly calculated as a percentage of total building costs. Based on the project location, the values can range from 4% to 7%.

4. During all phases of the project, the rate of inflation must be taken into account. The inflation rate for the time and the upcoming few years, as estimated by the inflation rate(average) of the prior years, must be factored into deployment costs.

1.3.2. Annual costs

Annual costs, as well as investment expenses, should be assessed to determine a project's net benefit. Operation and Maintenance (O&M), Depreciation of equipment, and refurbishment expenditures and replacement are all included in annual costs (Hosseini et al., 2005).

1. Equipment depreciation: During the project's economic planning, the wear, service life, and variables that may impact the equipment's functioning must all be considered.

2. O&M costs: the annual costs include the money invested on specialists in an project(SHP), such as taxes, salaries, consumables, and insurance. These costs are adjusted for local inflation each year. It is based on a 5% rate of inflation to correct professional charges. These expenses account for 2% of the cumulative yearly investment.

3.Expenses of renovation and replacement: some of the most important components of electromechanical, such as turbine runners and generator windings, will have to be exchanged and replaced at some point. After 25 years, it is expected that the expenses of equipment repairs and maintenance will be equal to the overall cost of the equipment. As a result, wear costs for equipment each component used in the power generation process of an SHP should be calculated.

1.3.3. Principles

The fundamental premise of hydropower is the transformation of a significant portion of the gross head(H(m)), into Energy(electrical and mechanical). Hydraulic turbines use the water pressure to transform potential into mechanical energy, which is used to power equipment like an electric generator and others. Water's energy is in direct relationship to its flow and pressure. The SHP components are depicted in Figure 2.2.

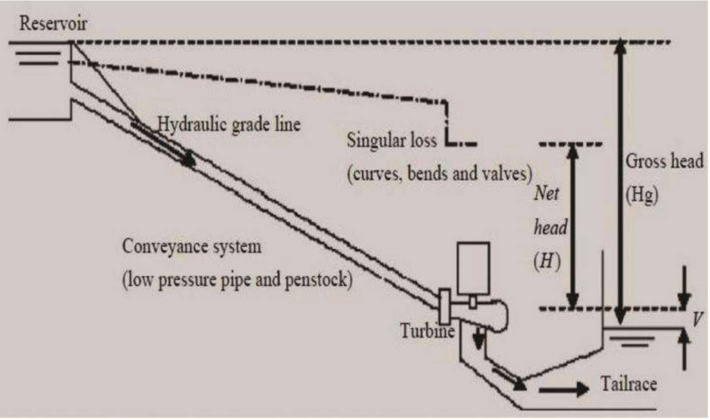

Figure 2.3. small hydropower Components.

[Source: https://ideas.repec.org/a/eee/rensus/v11y2007i9p2152-2165.html]

The hydraulic power(P0 in kW) and the related energy(Eo in kWh) in a time interval (Δt(h)) are generally equal to:

$$P_0 = \rho g Q H \qquad (2)$$

$$E_0 = \rho g Q H \Delta t \qquad (3)$$

where g and ρ stand for gravity acceleration (ms2) and water density (kg m3) , respectively. P0 is smaller than P in terms of final power supplied to the network. Any hydroelectric plant's electricity output is determined by

$$P = \eta P_0 \quad (4)$$

η is the turbo-hydraulic generator's efficiency.

First, the volume and head of local plant installation and river water are measured to determine the type of hydraulic turbine for a project. Moreover, for a comprehensive and objective examination, the cost and efficiency of each available kind of turbine must be considered. For the SHP (Kim et al., 2015), there are two main types of turbines:

1. reaction turbines —Kaplan, propeller, and Francis
2. Impulse turbine— Turgo,Pelton, and cross flow.

1.4. Turbine selection

2.4.1. There are two types of hydro turbines: reaction turbines and impulse turbines. The distinction is in the manner in which energy is generated from inputs (Okot, 2013).

2.4.2. Impulse turbine

The impulse turbine runner is driven by the water kinetic energy and releases to atmospheric pressure. The impulse turbine runner is operated within the air and is propelled by water jets. “The water that flows into the water tail after hitting the buckets has very little energy going to remain,” according to Okot, (2013). As a result, the turbine has a light housing that shields the environment from splashing of water. This turbine works well in systems with a lot of water falling but little flow. In power plants, three different kinds of impulse turbines are commonly used: turgo, Pelton, and cross flow .

2.4.2.1. Pelton

The operating head of the Pelton turbine (Figure 2.3a) is very high. Because of the high operating head, the flow rate is often low, ranging from 0.2 to 0.4 cfs. The turbine demands a high-pressure flow via the inlet, which necessitates a suitable penstock design. To concentrate the fluid flow on a runner, the Pelton uses a nozzle in the spear jet. In even tiny hydro applications, the spear buckets and jet are devised to cause limited damage resulting in a 90% potential efficiency. Up to 6 spear jets (that can be seen in Figure 2.3b) can be found in a Pelton turbine, which efficiently boosts the velocity of flow to the turbine, producing increased efficiency and power generation(Cada et al., 2012).

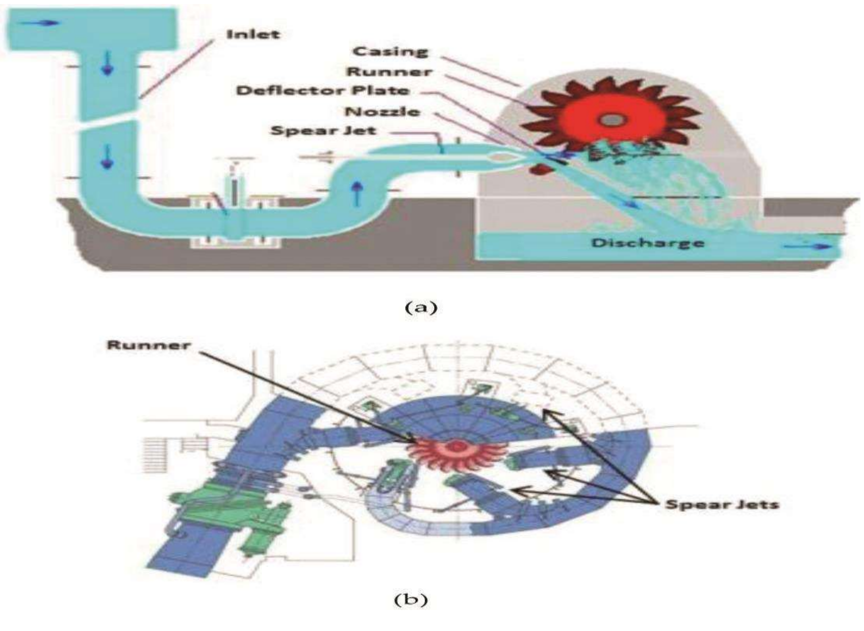

Figure 2.4. (a) Schematic of Pelton turbine. (b) Pelton turbine Cross section.

[Source:https://www.colorado.gov/pacific/sites/default/files/atoms/files/CO%20Small%20Hydro%20 Handbook_0.pdf]

2.4.2.2. Cross flow

The cross-flow turbine gets its name from the way water flows over the runner (Figure 2.4). This is because many cross-flow structures feature two or even more input guiding vanes at the entrance. This impulsive turbine class can handle a wide range of flow rates while maintaining great efficiency. Flow could be directed towards either a runner piece under the full runner or lower inflow when large flows are required, by changing the function of the input guide vanes to perfect match the conditions of flow. The cross-flow is capable of maintaining a steady efficiency, as seen by the efficiency curve (Cada et al., 2012)..

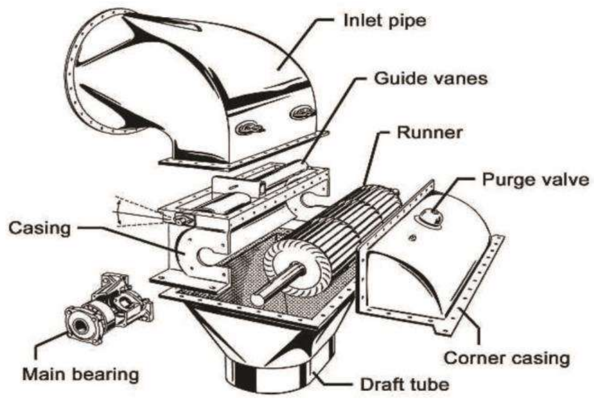

Figure 2.5. schematic of Cross flow.

[Source:https://www.researchgate.net/publication/318702637_Prospects_of_Smal_Hydropower_Technology]

2.4.2.3. Turgo

This turbine and Pelton are identical, but the buckets are shaped differently, as well as the jet hits the runner plane at an angle. The turgo turbine differs from the Pelton turbine in a few ways that make it a better fit for specific purposes. Because of its faster working speed, this turbine offers high overall performance and little maintenance, enabling a direct linkage between the generator and turbine. Due to the rate of flow going into this is not constrained as an inlet jet of discharged, the turgo turbine could have a less diameter than the Pelton, enhancing power generation**(Okot, 2013)**..

2.4.3. Reaction turbine

The mutual activity of water pressure and flow generates energy in reaction turbines. They work while the rotor is immersed in water and is constrained to pressure casing. “The blades of a runner are so shaped that pressure variations along them exert lift forces, similar to that on aircraft wings, that cause the runner rotation," according to Okot, (2013). Reaction turbines, unlike impulse turbines, can be used in areas with a short height drop and a larger water flow. Turbines such as Kinetic, Francis, and propeller **(Okot, 2013)**. are examples.

2.4.3.1. Propeller

According to Okot (2013), a propeller turbine has a three to the six-bladed axial flow channel, based on the water head designed. Upon reaching the turbine hall, the water must be swirled for efficiency. Propeller turbines are best suited to locations with little water flow. Propeller turbines include Straflo, Bulb, and Kaplan

"For introducing inlet swirl, incorporate fixed guide vanes installed upstream of the runner and for the runner a snail shell housing, where the water flows tangentially and is pushed to spiral into the runner," according to Okot, (2013). The runner blades of Kaplan turbines are set." Fixing the blades of the turbine and guiding vanes can promote efficiency greatly in a broad array of flows, but it is costly and thus only feasible in bigger systems. Propeller turbines with unregulated waterfall and flow are widely utilized when there is a possibility for little plants including waterfall and flow are reasonably steady. A typical propeller turbine is depicted in Figure 2.5.

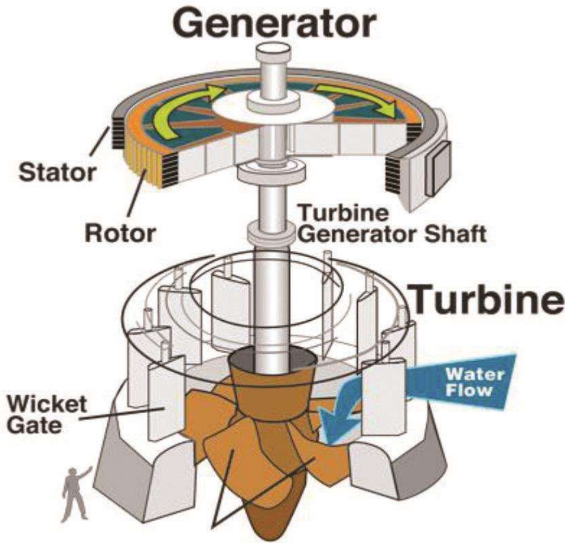

Figure 2.6. Propeller schematic.

[Source: https://econpapers.repec.org/article/eeerensus/v_3a26_3ay_3a2013_3ai_3ac_3ap_3a515-520.htm]

2.4.3.2. Francis turbine

The Francis turbine, one of the most traditional hydraulic turbine designs, has an efficiency curve that can perform in a variety of flow and height circumstances, as well as fixed runner blades and adjustable guide vanes (Johnson et al., 2015).

Okot, (2013) reports that this turbine (Figure 2.6) "usually features a mixed axial/radial or radial flow runner that is most typically installed in a spiral casing with internally adjustable guiding vanes." The runner spins because the water inflow is radially through it and emerges axially. The draught tube and wicket gates, including the runner, are important parts."

When the project level is average, the turbines of Francis can have a 90% efficiency, but they can be ineffective when the measured flow at the site differs significantly from the design flow. This turbine can be mounted on a penstock or an open trough (Okot, 2013)..

2.4.3.3. Kinetic

Kinetic turbines use the water kinetic energy to generate electricity utilizing the natural f water flow. As a result, the systems of kinetic do not rely on artificial channels or deviations; instead, they rely on the river's natural course. They can, however, be used in such conduits (Okot, 2013).. A kinetic turbine is depicted in Figure 2.7.

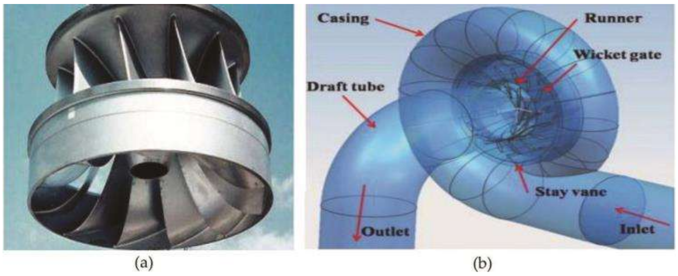

Figure 2.7. (a) Francis runner. (b) Francis schematic.

[Source:https://www.researchgate.net/publication/318702637_Prospects_of_Smal_Hydropower_Technology]

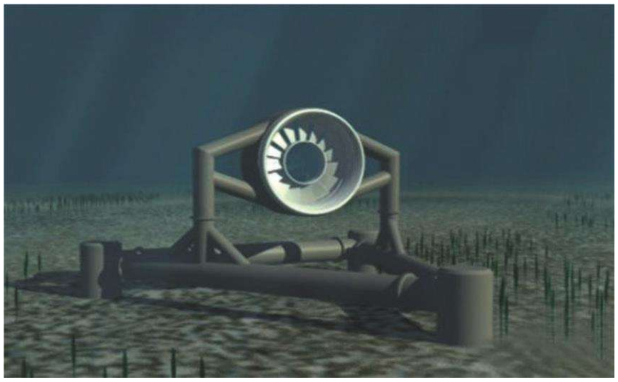

Figure 2.8. Hydrokinetic model.

[Source: https://www.renewableenergyworld.com/baseload/ocean-tidal-stream-power-identifying-how-marine-and-hydrokinetic-devices-affect-aquatic-environments/]

2.4.4. Selection

In small plants of hydroelectric, establishing the turbine type that will be capable of function as well as the data design, can be carried out in the turbine standard size, however, there is an efficiency difference. The chart below (Figure 2.8) depicts seven primary kind of turbines and the suggested flow and range of head for each (Johnson et al., 2015).

Figure 2.8 is a graph that may be used in the introductory studies stage to determine which class of turbine to employ based on the flow of water at the installation location of a plant and project height as well as to assess their hydroelectric potential. If the local is placed at a level of 100ft with a 100 cfs flow, the Francis, Kaplan, and cross-flow turbines are equipped with as possibilities, every with its own set of benefits and drawbacks.

Manufacturers of hydraulic turbines provide an efficiency curve. This graph depicts the link between waterfall and flow, as well as the efficiency with which these two variables are examined. It is possible to examine any type of turbine and its behavior in various project scenarios. A turbine with a flatter efficiency curve may often run at a wide range of flow and head. Slightly narrower and steeper curves indicate a turbine intended for smaller operating ranges. The turbine efficiency graph is shown in Figure 2.9.

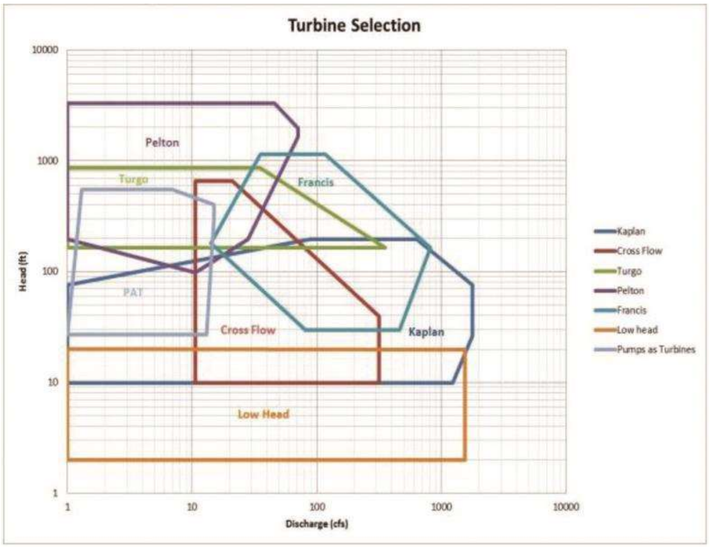

Figure 2.9. Turbine selection chart.

[Source: https://www.intechopen.com/books/renewable-hydropower-technologies/prospects-of-small-hydropower-technology]

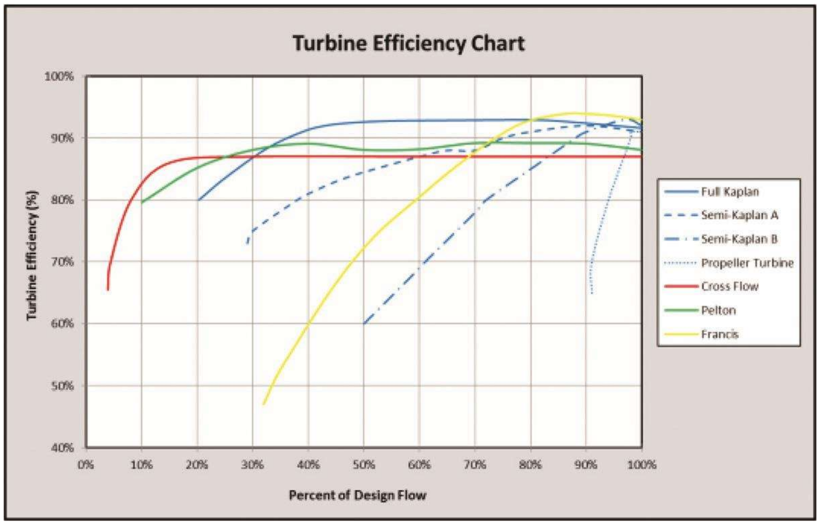

Figure 2.10. Chart for Turbine efficiency

[Source: https://www.intechopen.com/books/renewable-hydropower-technologies/prospects-of-small-hydropower-technology]

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