Clean Energy Using Hydroelectric Generation from Rivers

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Abstract In today's world, many countries, especially developing countries, are facing energy crisis, an increase in industrialization for development programs being the apparent reason. Fossil fuels being the most prominent source for the energy production are having an adverse effect on our environment. Also, with the rate, we are exploiting the energy resources; fossils fuels may be a principal source of energy that may see its end in the near future. If we continue to meet this demand using conventional methods like thermal power plants, environmental pollution is the most prominent aspect that we will have to continue to compromise. While pollution and climate change are the biggest challenges in the modern era, switching our attention to renewable energy sources to meet our energy demands can be the best feasible solution. Out of different renewable energy sources available, hydropower is the most readily available and clean sources of renewable energy worldwide. It can be considered as the leading source of renewable energy across the world. In this chapter, an attempt has been made to study the different ways to harness hydropower such as using static head, kinetic head, or any other disruptive technology. Environmental aspect of hydropower has also been studied. A review of different technologies such as hydrokinetic, vortex flow turbine, and water wheels have been carried out along with conventional hydropower. Thus, our effort has emphasized hydropower's overall scenario as the most reliable renewable energy source with more emphasis on small hydropower. This book chapter aims to discuss the hydropower production scenario and its all-around aspects and efforts, which are made to develop it as the most significant factor for the sustainable future.

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1 Introduction

Energy is considered as one of the essential aspects of wealth, social infrastructure development, and improved quality of life for both developed and developing countries. When we use energy resources, many factors are considered, such as geographical distribution, availability, and pricing. One of the most important is the environmental aspect. Thus, renewable energy can be regarded as the most feasible solution for the coming future (Capik et al., 2012). Potential resources of renewable energy are solar, wind, hydropower, biomass, and geothermal. These are the primary sources of energy and, most importantly, are clean and inexhaustible. Out of the available resources of renewable energy, hydropower seems to be the most promising. Hydropower holds tremendous potential as the most potential source for clean energy. With the currently installed potential of around 1308 GW globally, hydropower had seen significant development in recent years. In the Indian context, the installed hydropower stands at about 50 GW (International Hydropower Association (Status Report), 2020). In general, hydropower can be classified in terms of size (generating capacity) and the type of scheme (canal based, run of river, pumped storage, dam toe based). However, there is no fixed definition, and the following can be the typical classification bands, as in Table 1 (International Renewable Energy Agency, 2012).

However, different countries have different definition of hydropower as shown in Table 2 (International Renewable Energy Agency, 2012).

Table 1 Classification of hydropower according to capacity (International Renewable Energy Agency, 2012)

Type	Capacity (MW)
Large hydropower	100 MW or more
Medium hydropower	20 MW to 100 MW
Small hydropower	1 MW to 20 MW
Mini hydropower	100 KW to 1 MW
Micro hydropower	5 KW to 100 KW
Pico hydropower	Up to 5 KW

Table 2 Classification of small hydropower (International Renewable Energy Agency, 2012)

Country	Small hydropower definition(MW)
Brazil	Less than or equal to 30 MW
Canada	Less than 50 MW
China	Less than or equal to 50 MW
European nation	Less than or equal to 20 MW
India	Less than or equal to 25 MW
Norway	Less than or equal to 10 MW
Sweden	Less than or equal to 1.5 MW
United States	5–100 MW

Though hydropower has got many advantages, building large dams has seen to cause environmental issues affecting the river flow; thus switching to small hydropower as compared to large hydropower is a more sought-out option for many countries including India.

Small hydropower plays a very crucial role in strategies related to rural electrification and mini-grid (Kougias et al., 2019). Small hydropower provides high conversion efficiency and is equipped with operational and economic superiority. It also provides spectacular flexibility. Identification of the potential sites and installing hydropower projects can save earth from the emissions of the fossils fuels. Quantitative knowledge of the topographical setting and stream network is the key to identify potential sites for hydropower projects. Hydropower potential locations for installation of small hydropower are shown in Fig. 1. Besides conventional hydropower, different technologies such as vortex hydroturbine, hydrokinetic technology, etc. can also be utilized to generate hydropower. More developments in this field can help in exploring greater potential of hydropower sector. Thus, there is a lot need to be developed in the field of hydropower if we want it as the long-serving energy resource for the future and can help in accomplishing the goal of sustainable development.

This book chapter provides a comprehensive study in the field of hydropower development both globally and in India. The technological aspect is also analyzed and briefly discussed the recent developments on small hydropower.

1.1 Global Scenario

Hydropower is one of the largest renewable electricity production sources and plays a vital role in moving towards clean energy and a sustainable future. Hydropower as the source of electricity was first seen in the nineteenth century. The first hydroelectric power plant was built in 1882 across the Fox River in the United States. Germany was the first country to produce a three-phase hydroelectric system in 1891. By 1900 many small hydropower projects were in operation as the technology developed across the globe. The twentieth century also witnessed rapid innovations in the field of hydropower. Towards the end of the twentieth century, China and Brazil became world leaders in the hydropower sector. Low-cost hydropower began to be the most viable source for meeting growing energy demands. Towards the end of the twentieth century, the world also started considering hydropower's environmental and social impact and reassessed hydropower's value. A report published by World Commission on Dams added a challenge to the existing practices and tried to shift focus for sustainable development. Thus the focus shifted towards how to best plan and execute the hydropower projects (Brief History of Hydropower, 2018). With more development in the field and the focus on sustainable development, a 500 GW increase in hydropower installed worldwide capacity from 2000 to 2017, around a 65% increase compared to the late twentieth century.

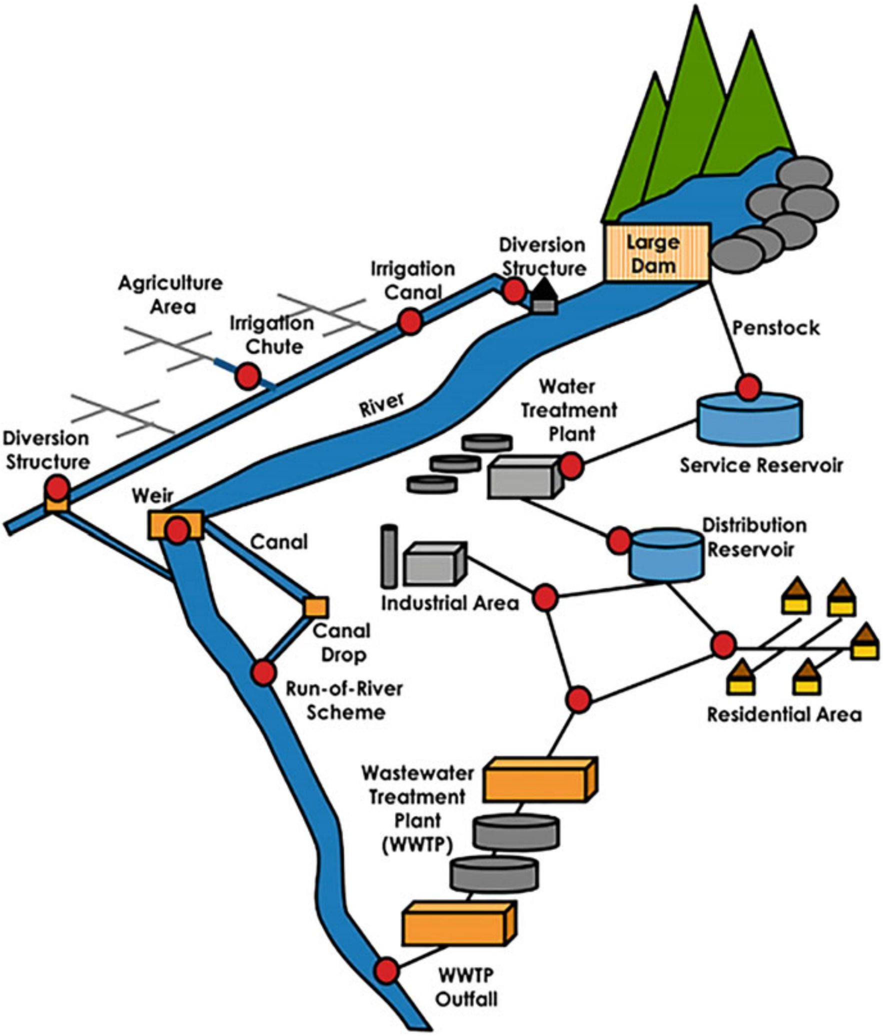

Fig. 1 Potential locations for installation of small hydropower (Sari et al., 2018)

Currently, the global hydropower installed potential is around 1308 GW. Electricity generation from hydropower is approximately 4306 TWh, a record of the most generous renewable energy contribution in history. China is the leading country with an installed potential of around 356.4 GW, followed by Brazil 109.06 GW, the United States with 102.75 GW, Canada 81.39 GW, and India 50.07 GW. The installed potential of the top 10 countries of the world is shown in Table 3 (International Hydropower Association (Status Report), 2020).

The world's most giant hydroelectric power plant has set up in China, named Three Gorges with a potential of 22.5 GW; Itaipu, which is in Brazil and Paraguay

Table 3 Top 10 countries in hydropower installed capacity (International Hydropower Association (Status Report), 2020)

Country	Installed capacity (GW)	Capacity added in 2019 (MW)
China	356.40	4170
Brazil	109.06	4919.18
United States	102.75	7.6
Canada	81.39	–
India	50.07	154.1
Japan	49.91	–
Russia	49.86	462.5
Norway	32.67	134
Turkey	28.50	219
Italy	22.59	95

Table 4 Top 10 hydropower projects in the world (The 10 biggest hydroelectric power plants in the world, 2020)

Project	Potential (GW)	Hydraulic head (m)	Major problems
Three Gorges, China	22.5	80.6	Caused ecological changes including increased risk of landslides, also flooded cultural sites
Itaipu, Brazil and Paraguay	14	118	Over 10,000 families were displaced, caused ecological changes
Xiluodu, China	13.8	–	Relocated 7300 people and can displace 50,000 people in the long run
Guri, Venezuela	10.2	128	Due to overdependence on this dam, it caused blockouts in 2010 and 2016
Belo Monte, Brazil	9.39	89.3	Caused loss of vegetation and natural spaces, changed quality of water and migration routes of fishes, temporary disruption of water supply, and loss of biodiversity
Tucurui, Brazil	8.37	–	Relocation of 14,000 people and caused migration which resulted in increase in cases of AIDS and malaria
Grand Coulee, USA	6.8	116	The environmental effects of the dam negatively impacted the life of native inhabitants
Xianhjiaba, China	6.4	–	Led to biodiversity loss, food insecurities, loss of landscape, and other ecological imbalance
Sayona, Russia	6.4	194	Met certain accidents due to powerful spring floods and suffered a catastrophic accident
Longtan, China	6.3	179	Being another mega dam, it caused ecological imbalance

with 14 GW; and Guri in Venezuela with the prospect of 10.2 GW. Three out of the ten most significant hydroelectric projects are in China which is also evident from the fact that it is the leading project in the potential of hydropower. The top

10 hydropower projects are shown in Table 4 (The 10 biggest hydroelectric power plants in the world, 2020).

With more future developments, hydropower can continue to be the most important source of renewable energy worldwide and help the world fight the challenge of a sustainable future.

1.2 Indian Scenario

India is continuously emerging in the field of hydropower being the fifth largest producer of hydropower all over the world. With growing demand and carbon emission being a major concern, hydropower development is becoming more favorable. Hydropower projects are divided into two categories, one is large hydro and the other is small hydro. The capacity of around 25 MW is considered as small hydropower in India. Large hydropower development in India faces issue of resistance by environmentalists, local communities, and also NGOs due to the issue of deforestation and resettlement issues. As a result, India's government does not consider large hydropower as a source of renewable energy, while most of the small hydro potential is through the run of a river that uses the natural flow of the river to drive the turbine. Thus any dam built is relatively small, which doesn't face the issue of deforestation and resettlement. Therefore, the India's ministry of power looks into sizeable hydropower projects; the responsibility of small hydropower is given to the ministry of new and renewable energy (Central Electricity Authority, 2021).

The first hydropower station in India was developed in Darjeeling with a capacity of 130 MW. Hydropower development in India commenced over a decade ago. The share of hydropower in India in the total installed capacity has decreased over the years. It was around 50% in 1960–1961, but now it is roughly about 14–15%, including small and large hydropower.

India's hydropower installed capacity is about 50.07GW, being the fifth globally in the hydroelectric power capacity (International Hydropower Association (Status Report*)*, 2020). India's hydropower potential is estimated at 148,700 MW at a 60% plant load factor. In contrast, 56 sites for the pumped storage scheme have also been identified with a possibility of around 94,000 MW. The small hydropower program scheme is currently running, intending to encourage the state government entities and independent private producers to set up new small hydro projects for realizing 21,000 MW potential can be realized in a phased and planned manner. In addition to ongoing projects, the immediate objective shall be to encourage them to start work on new projects with a potential of around 1000 MW, with a target to meet a cumulative capacity of 6000 MW by 2022.

According to the reassessment study, the Brahmaputra river basin is the largest capacity of 66,065 MW, out of which only 3974 MW have been developed. In terms of developed capacity, the Indus river basin is at the top with a developed capacity of

14,294.3 MW out of the identified potential of 33,832 MW (Ministry of Power (Government of India), 2019).

2 Estimation of Hydropower Potential

Hydropower can be harnessed basically in two ways as shown in Fig. 2. One is the conventional method which uses the static head and other is using kinetic head. The estimation of hydropower potential is based on the type of head which are discussed in the subsequent sections.

2.1 Conventional Hydropower (Using Static Head)

The governing equation for the calculation of power using static head will be given by Eq. 1:

$$\text{Power } (P) = \rho \times Q \times g \times H \tag{1}$$

The power output is directly proportional to the discharge rate and available head. This method is based upon building dams across rivers and producing electricity with the help of static head or potential energy. The discharge rate can be calculated using different direct and indirect methods. Velocity area method, dilution method, ultrasonic method, etc. are direct methods, while slope area method and stage discharge method are indirect methods. Head is the vertical change in elevation between the reservoir water level and the tailrace water level. Therefore, power from water increases with head and discharge but is limited by pipe friction.

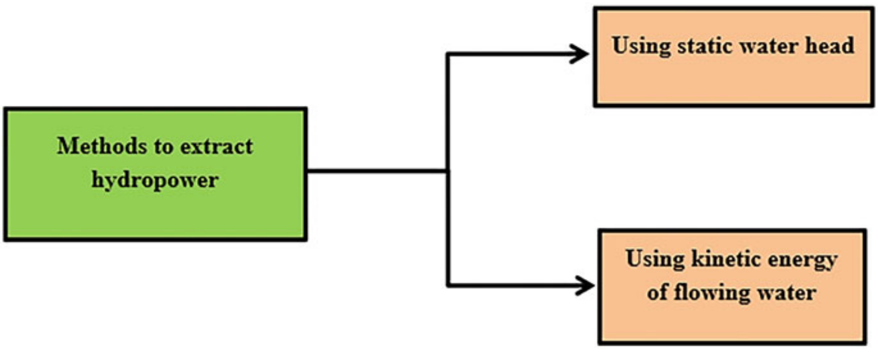

Fig. 2 Methods to extract hydropower

2.2 Using Kinetic Head (Hydrokinetic)

Flowing water stream within itself holds a large amount of kinetic energy which can be tapped using hydrokinetic energy technologies. In the modern era, apart from conventional methods, novel and innovative methods are being developed to harness the hydropower; thus hydrokinetic has emerged as the potential solution to exploit the vast hydropower potential available in flowing rivers/canals (Saini et al., 2020).

The governing equation for the available hydro kinetic energy will be given by Eq. 2:

$$P_{\text{th}} = \frac{1}{2} \times \rho \times A \times V^3 \times C_{\text{P}} \tag{2}$$

where ρ is the density of the fluid which is passing through the turbine (kg/m^3), A is the rotor swept area (m^2), and V is the free water flow velocity (m/s). The measure of dynamic fluid efficiency of the turbine is done through power coefficient C_P, and it depends on the manufacturer (Bernad et al., 2008). On the basis of configuration, hydrokinetic turbines can be basically classified into two types, i.e., axial flow turbines and cross-flow turbines. All the categories of hydrokinetic turbines consist of blades which are mounted on a support structure, which is further connected to a gearbox and generator system. Axial flow turbine consists of a rotor axis which rotates parallel to the incoming water flow. Cross flow turbines are broadly classified into two categories, i.e., vertical axis turbine and in-plane axis turbine. Vertical axis turbines are those in which the rotor axis is on the vertical plan of the water surface, while in the case of in-plane axis turbine, the rotor axis is on the horizontal plane of the water surface.

3 Different Schemes for Conventional Hydropower

There can be various ways in which conventional hydropower can be extracted, with different schemes shown in Fig. 3, which will be discussed further.

3.1 Run of River

This method can be used in areas where elevation drops of the water and water discharge are found to be consistent. The schematic layout is as shown in Fig. 3(a). Thus hydroelectric plants can be constructed directly into the river. Run-of-river scheme is not concerned with large water reservoirs and regulations because stream-lines gets diverted continuously and processed through turbines, which thus returns

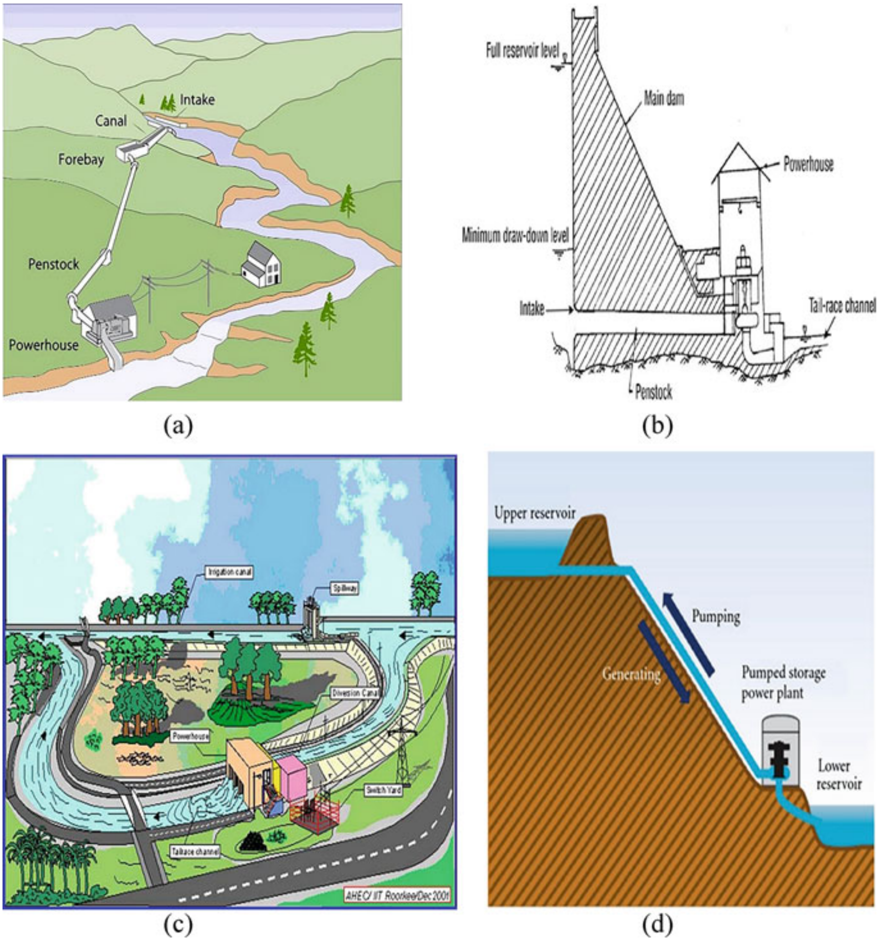

Fig. 3 Different schemes for extracting conventional hydropower: (**a**) run of river, (**b**) dam toe based, (**c**) canal based, (**d**) pumped storage (Varun et al., 2010; Kaunda et al., 2012; Dave et al., 2015; Mejbel Ali et al., 2018)

to rivers (Richards et al., 2017). Run-of-river plant can either be with pondage or without pondage. It can supply base load during good flow conditions and peak load during low flow conditions. Since there are seasonal changes in the river flow, the output may get affected unless interconnected with the grid. Recently a study was done regarding the public's perception of run-of-river projects across Europe. Four perspectives emerged on the importance of run-of-river from the analysis done where it maintains regional control, fights climate change, promotes citizen well-being, and protects natural ecosystem (Venus et al., 2020).

3.2 Dam Toe Based

This is the most common type of hydropower plant equipped with a storage reservoir provided by building a dam across the river. This method is generally implemented in mountainous regions. The schematic diagram is shown in Fig. 3 (b). A dam is constructed across the river in order to store the water. The flow of water from the storage is controlled through which the power is generated. Here the main dam includes the intake system, and the powerhouse is built at the dam's toe. Penstock is installed directly through the dam's body, which conveys water to the turbine (Singal & Saini, 2008). The water storage helps us take care of the water supply fluctuations during flood and draught situations. The flow of water is regulated with a dam's help, and the practical head can also increase. This method's advantage is that it makes the stream flows better utilized for power production and can also serve other water resource development purposes.

3.3 Canal Based

This method utilizes the drops on the existing or proposed irrigation canals. The water flowing through the canal fall is used for energy conversion and thus power is generated. The typical layout is shown in Fig. 3(c). They are planned close to the load center and provide reliable electricity. They provide electricity cost effectively and avoid transmission and distribution losses. In civil works, the system's main components are diversion channel, spillway, and powerhouse building (Singal et al., 2008). The powerhouse can be located at the central canal, or a good bypass can be constructed to locate it.

3.4 Pumped Storage Plant

In this method, hydropower technology is used to store off-peak electricity, which can be used during peak periods. The schematic representation is shown in Fig. 3(d). This plant generally consists of two reservoirs, upper reservoir and the lower reservoir. Pumping of water takes place from low reservoir to high reservoir, and in case of peak in demand, it runs downhill through turbine. In order to pump the water back to the reservoir, a reversible turbine can be used. Otherwise, a separate pump can also be used. On the basis of reservoir volume size, the pumped storage can be classified into pluri-annual pumped storage, seasonal pumped storage, weekly pumped storage, daily pumped storage, and hourly pumped storage. In case of day-night energy arbitrage, daily pumped storage-type plant is generally built. It is one the most prevalent pumped storage applications nowadays. Weekly pumped storage finds its application where the energy from the intermittent sources like solar and wind has to be stored. This technology has emerged over in recent years. In order to store water and energy beyond a yearlong period, pluri-annual pumped storage scheme is used. They are also rare and are estimated to increase further due to increasing energy needs in the coming future. Seasonal pumped storage is also not widely used in the current scenario but is expected to have an enormous potential for the future (Hunt et al., 2020).

Pumped storage plants can have turbines which can be both fixed rotation speed turbine and variable speed turbine. Pumping and generation capacities of fixed-speed turbines are generally expected to be invariable.

4 Large Hydropower

Based on the power generation capacity, hydropower plants can be divided into two categories: one is large hydropower and the other is small hydropower. Different countries have different size criteria to define hydropower projects. Generally, hydropower projects with a capacity of more than 50 MW can be considered as large hydropower.

Large hydropower projects use large water turbines, and large dams are built to store water. Though large hydropower produces a large amount of electricity, its environmental impacts are always a point of debate. The decision to construct large hydropower is based on the country's assessment of the economic development and energy needs (Hennig et al., 2013). Since large hydropower involves constructing big dams, loss of biodiversity, habitats, and aquatic vegetation can be seen in the dam area. It can also lead to accumulation of sediments in the reservoir (Almeida et al., 2005). It also affects the water quality and obstructs migration movements of fishes.

By considering various negative impacts of large hydropower, small hydropower projects are more emphasized by various countries worldwide.

5 Recent Developments in Small Hydropower

Small hydropower, which is considered the clean and renewable energy source, plays a vital role in providing electricity and optimizing energy structure (Zhang et al., 2020). The global installed capacity for small hydropower projects of capacity up to 10 MW is around 78 GW (World Small Hydropower Development Report (UNIDO*)*, 2019).

A study was performed that described the procedure for assessing the fatigue life of penstocks (made up of steel) in hydropower plants based on crack propagation theory. Stress distribution in the material of penstock shells, amplitude, frequency variability, and forecasting of future operation of the hydropower plants were the issues having a significant impact on the fatigue strength. Authentic objects were used for performing the tests and the procedure adopted for the research work was well developed. The results obtained can largely contribute to applying good engineering practices for hydropower plants equipped with steel penstocks (Adamkowski et al., 2021).

Recently, a study of the Bhilangana-III hydropower project located in India was performed, focusing on the high head Francis turbine's sediment erosion. Silt erosion is one among the major problems associated with the hydroelectric power projects installed in the regions of Himalaya. The methodology was performed on the Francis turbine components of the hydroelectric plant. The operation lasted for about 6993.12 h, and a sediment load of around 29,291 MT was noted to be passed through turbine. Analysis of the severely eroded parts of the turbine was performed, observing the wear patterns. CFD analysis was also performed in order to identify erosion-prone zones (Sharma et al., 2021).Corrosion of the components used in hydroelectric power projects can lead to significant technical problems which in turn results into economic losses. Thus, a study was performed to analyze the failure cause of the draft tube casing from a turbine which was used in a hydroelectric power project. Chemical composition of the parts that underwent failure was analyzed and also the microstructural analysis was performed. Light microscopy technique and scanning electron microscopy technique were performed in order to evaluate the present phases. After performing a detailed analysis, it was concluded that the draft tube failure was due to intercrystalline corrosion of stainless sheets. The unsuitable chemical composition of the sheet material and its microstructure were the causes of failure (Horynová et al., 2017).

Another study was performed to design and implement a cross-flow turbine used in Pico hydropower electric project. The study mainly focused on the implementation and design considerations at various nozzle positions, and performance evaluation was also done. To determine the stress and degree of deformation of blade material under the hydraulic jets impact, ANSYS was used. The shaft analysis was also performed under both static and dynamic loading to analyze whether the shaft undergoes plastic or nonplastic deformation at both ends. Response surface methodology was performed, and various simulations/runs (69) were obtained. The factors being considered were distance of nozzle from the shaft, height of the nozzle, and angle of attack in the experimental design. The water head for testing the turbine was 6.4 m and discharged at 0.0042 m^3/s. It was observed that the shaft was safe both in static and dynamic conditions. For turbine blading, carbon steel was found to be suitable (Achebe et al., 2020). Underground pumped storage hydropower (UPSH) electric projects can be one of the potential methods to balance supply-demand electricity crisis. Recently a research was presented which involved a novel method in order to determine the round-trip efficiency regarding the aspect of pumped storage-type hydroelectric projects. Two Francis turbines of 124.9 and 214.7 MW power output while two Francis pump with 114.8 and 199.7 MW power input were selected. 3D CFD numerical simulations were performed for the evaluation. Typical mass water was 45.000 t and the maximum value of gross pressure was 4.41 MP. The pressure value inside the underground reservoir was found to be having a significant impact on the round-trip efficiency, and thus the results obtained were found to be different from conventional pumped storage plant. It was concluded that the reservoir pressure had the negative impacts on the energy balance and also on the financial results (Menéndez et al., 2020).

Kaplan turbines (low head reaction type) are generally preferred for run-of-river type of hydropower projects. Recently a study regarding computational analysis (both static and dynamic) of Kaplan turbine was done by varying profile of the turbine blades. Also a parametric study was performed on a typically complex geometry of Kaplan turbine with complex geometry by varying turbine blade profile at different angles in a CAD model, while CREO was used to develop blade surface geometry and design. Further results showed that by varying the geometry of the blade profile, there can be improvement in CAD models using computational techniques. The study led to 5.43% enhancement in the turbine performance (Janjua et al., 2020).

Micro hydro can be considered as the potential technology which is befitting for irrigation networks installation. It can help in decreasing energy over pressures and can also significantly reduce net energy consumption rate of the irrigation process. Recently a study was performed in which regression models and also the artificial neutral networks computing were utilized in order to predict and analyze potential of energy recovery for micro hydropower across a large spatial scale in on-demand pressure irrigation networks. In the absence of hydraulic models, these modeling techniques were then used to predict the potential of energy recovery across the 164,000 hectare of provinces of Spain (viz., Cordoba and Seville). It was found that if the micro hydro technique could have been adopted in the 2018 irrigation session, it would have led to energy consumption reduction of around 12.8% (Crespo Chacón et al., 2020). Though it is a well-known fact that the small hydropower sector has vast investment potential, the uncertainty issue related to the project cost leads to lack of enthusiasm among the investors. Recently a paper was published which deals with the solution of a trade-off between the investors and the concerned insurance companies. Applied fuzzy logic approach was adopted for risk index assessment. For this research work, thirty-six SHP projects were analyzed by classifying them into different risk classes. The primary objectives of the study were to analyze and identify the risks associated with the investment in the SHP projects of Uttarakhand (India), also to estimate the risk index of SHP projects which have been identified and suggesting various risk mitigation measures which can help investors directly in cost reduction. It was also revealed that in this region, investment loss to the investors was around 35% of the total loss. Thus the authors proposed a variable insurance product which can be an innovative risk mitigator. Various risk resolution strategies were also proposed such as risk acceptance, risk avoidance, risk reduction, research, and risk transfer. For example, risk transfer means shifting the risk to some other person, a group, or an organization. Fixed timescale insurance can help in reducing socio-economic and environmental risks. Power purchase agreements can reduce risk of price uncertainty. In case of geological clearance, construction of projects should be avoided in geographically unstable areas (Roy & Roy, 2020).

It is evident that small hydropower projects interrupt continuity of rivers, causing migration of fishes and causing downstream flow regime to change during its operation. Thus, a study was performed which enumerates the environmental and ecological impacts related to small hydropower projects. Techniques adopted were environmental monitoring data, surveys of different sites, and also the document evidence following an integrated well-developed approach. For case study, ecological impact of *Catalouk* SHP plant (located at the Ceyhan River Basin in Turkey) was assessed. Scorecard evaluating the ecological impact revealed that there were notable gaps relating to the hydro-peaking practice and downstream fish passage and also for management of sediments. Various measures for mitigation were also proposed such as environmental flows enhancement, river basin construction for the purpose of hydro-peaking, and sustainable management of sediments through hydrosuction technology (Alp et al., 2020).

Recently a novel control system to improve the hydro-governor's action was proposed. It mainly focused on allowing more flexibility over the control action and primary frequency control improvement, which would lead to the improvement in the response frequency of overall system. Evolutionary game theory strategy was the basis of the supplementary control. Supplementary control was combined with simulated annealing algorithm. The design aspects and analysis of the proposed methodology was proposed in this work (Chamorro et al., 2019). Another study was done regarding the problem of short-term hydrothermal scheduling (STHS). Different mathematical programming model approaches were presented. Thus for every specific issue regarding the formulation process of STHS, an extensive comparison and discussion were provided. This was regarded as the beginning point in order to find more effective methods which helps in dealing with the challenges associated with unit-based STHS problem (Kong et al., 2020).

Small hydropower projects have the tremendous potential to meet the renewable energy targets globally. But exploitation of rivers in order to meet the increasing energy needs can lead to various ecological and environmental impacts. Thus there is a requirement for water allocation requirement strategies. In this context, a study was proposed which used analytical tools to meet the design considerations of run-of-river hydropower plants. This hypothetical case study was done in a Scottish river catchment. The methodology included the estimation of the hydropower potential along the river flow networks and analysis of environmental aspects related to small hydropower plants. It was concluded that policy and design interaction shall be allowed which will lead to different effective plans and roadmaps for designing run-of-river hydropower plants which can be economically profitable and also does not cause much harm to the ecosystem. One approach can be to build small-sized installations where hydrological connectivity can be sustained through bypass flows that are larger than the capacity. Another strategy can be the construction of relatively larger power plants that can eventually fulfill the ecological needs through the means of flow discharge lower than turbine cut-off value and flow discharge to be minimum (Basso et al., 2020).

6 Hydrokinetic Energy

Hydrokinetic energy conversion technology is one of the novel technologies in the field of hydropower. In order to exploit its entire potential, a lot of research and optimization work are being carried out (Kumar & Saini, 2016). Some of the recent studies regarding hydrokinetic has been discussed further.

Recently a study was done in which a surrogated model (with an oscillating hydrofoil) in a closed water channel, which was following a motion law comparable to the real angle of incidence of a Darrieus turbine blade along its rotation. Tip speed ratio (TSR) and oscillation frequency were the oscillation parameters. The result showed that the flexible blades provide reduction in the higher thrust and also the normal forces value were found to be reduced. Cyclic normal force variations were also reduced resulting in increased turbine lifetime (Hoerner et al., 2019). A study investigated the effect of a ducted augmented system on a straight blade Darrieus hydrokinetic turbine in order to analyze the performance, fluid loads, and stress induced. Real-time computation of stress and loads was done and compared for both non-ducted turbine and ducted turbine. It was found that the power generated and stress experienced in the case of ducted turbine was twice as compared to non-ducted. Thus this study recommended that with careful design considerations taken into aspect, duct augmented system shall be a preferred choice (Tunio et al., 2020). In a recent study, a blocking plate with optimal considerations was located to the upstream side of the retarding valve in order to enhance the performance of Darrieus hydrokinetic turbine. Experimental investigation was carried out to get the specific location of the turbine. The result showed that the coefficient of power of turbine increased considerably (from 0.125 to 0.36) (Patel et al., 2019). With reference to the hydro farm arrangement, an experimental analysis was performed on Darrieus turbine (straight blade) focusing on the application of tidal current and parametric optimization. The result concluded that the minimum distance of 3D and 7D was found to be essential along the span-wise and stream-wise direction, respectively (Patel et al., 2017).

Estuaries have a high potential of exploiting hydrokinetic energy since it is influenced by both the river and the marine flows. In this context a study was performed using hydrodynamic numerical modeling technique evaluating the production of hydrokinetic energy in the Douro estuary. Basically the modeling aimed at analyzing and reproducing the combined effects of tidal and river flows on the velocity patterns of main current. Also locations of estuarine having maximum energy exploitation were identified. Since there is high variability in river flows due to precipitation patterns, different scenarios of discharge were studied, which includes spring tides, neap tides, and low and high flows of river. It was concluded that the upper side of the estuary was having regions with highest potential. The relevance of identifying parameterized magnitudes those were not dependent on a specific instrument was demonstrated in this work, and also this study illustrated that in order to optimize hydrokinetic energy exploitation, estuarine hydrodynamic pattern should be properly characterized (Iglesias et al., 2021).

Hydrokinetic turbines with different designs operating on the principle the same as that of wind turbines have emerged in order to extract energy (hydrokinetic) from flowing streams. Savonius turbine is preferred for extracting hydrokinetic energy especially in the case of low velocity of the flow since it has good starting characteristics. Run-of-river scheme locations with low water velocities and low head or ultralow head (less than 1 meter) can also prefer Savonius turbine. Poor conversion efficiency was found to be one of the major drawbacks regarding Savonius turbine. In order to enhance its performance, turbine with improved design of blades is needed. In order to generate power, in addition to drag force if lift force can also be utilized, the performance of Savonius turbine can be improved. Recently a study was performed focusing on analyzing the performance of a customized Savonius turbine utilizing both the drag force and the lift force in an open flow water channel. The maximum power coefficient (0.268) was found to be higher than other modified Savonius turbines. Thus the study revealed significance of modifying Savonius turbine in order to have efficient and cleaner production of hydropower (Basumatary et al., 2021).

Recently a study was performed in which a simple barrier was utilized to deviate the flow of fluid from reversing bucket of the Savonius turbine in order to improve the power generation. Numerical modeling through computational fluid dynamics was performed to analyze the optimum barrier length. The continuity equation, Reynolds-averaged Navier-Stokes equation, and SST transition turbulence model were solved numerically. It was found that the result indicated were in accordance with the experimental data. The result showed that maximum power generation increased by 18% by utilizing the barrier with an optimum length (Alizadeh et al., 2020). A recent study was performed on single-stage Savonius hydrokinetic turbine; in this study the effect of blade arc angle and blade shape factor on the performance of the turbine were studied. A commercial unsteady Reynolds-averaged Navier-Stokes (URANS) solver in conjunction with realizable k-ε turbulence model was used for numerical analysis. The results showed that at a blade arc angle of 150° and a blade shape factor value of 0.6, maximum coefficient of power value 0.426 was obtained at tip speed ratio (TSR) value 0.9 (Kumar & Saini, 2017b). Another work was carried out in order to study and analyze the performance character sticks of a Savonius turbine rotor for the hydropower generation on a small scale. Irrigation channels of the rural areas which are having enough blade slopes were observed in order to generate hydrokinetic energy. A scale-down model (fabricated in house) of Savonius rotor was also tested. The aim was to analyze the performance under the well-developed controlled conditions. It was revealed that at a channel inclination of 0.5 and a tip speed ratio of 0.92, the power coefficient improved to 40% and coefficient of torque improved to 10%. At a bed slope of 2.0° the power and torque developed by the turbine were found to be maximum (Honnasiddaiah et al., 2021). In a recent study, performance analysis of Savonius hydrokinetic turbine was done which was having twisted blades. CFD study was carried out and flow distribution around the turbine was also discussed, and the result showed that at TSR value of 0.9 and velocity of water at 2 m/s, the turbine yields maximum coefficient of power as 0.39 at twist angle 12.5° (Kumar & Saini, 2017a). Another study was performed in which the effect of number of stages on the performance of modified Savonius turbine was studied. In this study, pressure and velocity distribution around the rotor were also analyzed. After numerical analysis, the result showed that for double-stage turbine at tip speed ratio (TSR) value of 0.9 and Reynolds number value at 37.53×10^4, the maximum power coefficient value of 0.9 was obtained. The numerical data obtained also helped in establishing a correlation for power coefficient as a function of number of stages, Reynolds number, and tip speed ratio (Kumar et al., 2020).

The performance of blade sections of the turbine is crucial because it directly affects the power coefficient of the rotor. Optimized sections of blades for wind turbines and aviation applications are only used since hydrokinetic is a relatively new technology. However it is better to consider hydrokinetics of water during the design process. Recently a study was aimed at optimizing blade sections for hydrokinetic turbines which are stall regulated. Cavitation, high value of hydro-dynamic force, ideal stalls behavior, and leading-edge contamination were the factors taken into consideration. For the optimization process, differential evolution algorithm was employed. Different performances of optimized sections such as blade, lift, drag, transition, and pressure coefficient were analyzed. It was concluded that for hydrokinetic turbines based on various objectives of design and constraints, the performance of optimized hydrofoils was found to be successful (Muratoglu et al., 2021).

A research was carried out aiming at enhancing and evaluating the operational performance of co-axial horizontal axis hydrokinetic turbines (mounted on a single shaft). The blade material was carbon fiber polymer composites. On increasing the number of rotors of the turbine from 1 to 2, it was noted that the efficiency increased by 75%, but the increase was not much when rotor increased to 3. The wake behavior and its effect were also examined. From the structural aspect, the composite materials were found to have the properties suitable for the water turbine blades (Abutunis et al., 2020). In a recent study, the performance of shrouded horizontal axis hydrokinetic turbines was evaluated corresponding to the yawed conditions. Results showed that for nearly all designs that were investigated, the power output in the case of off-axis flows was found to be decreasing. Till 10° value of yaw angle, it was found that the reduction was of negligible value, but as the angle was increased further, the reduction also saw the increasing trend. It was concluded that the convergent-divergent shroud was found to experience loss of performance with respect to other designs (Shahsavarifard & Bibeau, 2020). Another study was performed with an objective of analyzing the cavitation and hydrodynamic characteristics of the horizontal axis micro-hydrokinetic river turbine (HAMHRT). Analysis of the unsteady behaviors of the turbine was also the focus area taken into consideration. The results showed that the designed rotor was having good efficiency and also the stable output (Wang et al., 2019). In a recent study, a prototype of horizontal axis hydrokinetic turbine was manufactured and certain numerical simulations were performed. The results showed that cut in velocity of the turbine was 0.25 m/s with a maximum coefficient of power at 0.33. Thus this study revealed the feasibility of reducing the resistive torque problem in transmission parts with the application of magnetic couplings (Tian et al., 2018). In a recent study, geometric data of the broken blade of horizontal axis hydrokinetic turbine was obtained using reverse engineering approach. After reengineering, the rapid prototyping technique was adopted for manufacturing a new runner and data validation testing was also performed. Theoretical results with good precision were confirmed by the experimental data. Hydraulic power was found to be increased by 5% (Ciocănea et al., 2017).

7 Other Disruptive Technologies

Apart from the technologies discussed above, other disruptive technologies such as gravitational vortex hydroturbine and water wheels (as shown in Fig. 4) have also emerged in the field of hydropower and have great potential to further develop hydropower as the most accessible source of renewable energy. Few of them are discussed further.

7.1 Gravitational Vortex Hydroturbine

Gravitational water vortex turbine (GWVT) uses gravitational vortices generated upon water draining from the bottom of the tank, and power can be generated at low head and low flow rate. The typical layout is as shown in Fig. 4(a). Natural characteristic of water to form a free surface vortex is utilized in this hydropower system. A swirl flow is created by the vortex which has an ability to rotate a turbine. Water vortex that is formed under gravity is artificial, and through this, forces are generated which forms the basis of this type of hydropower system. Its major

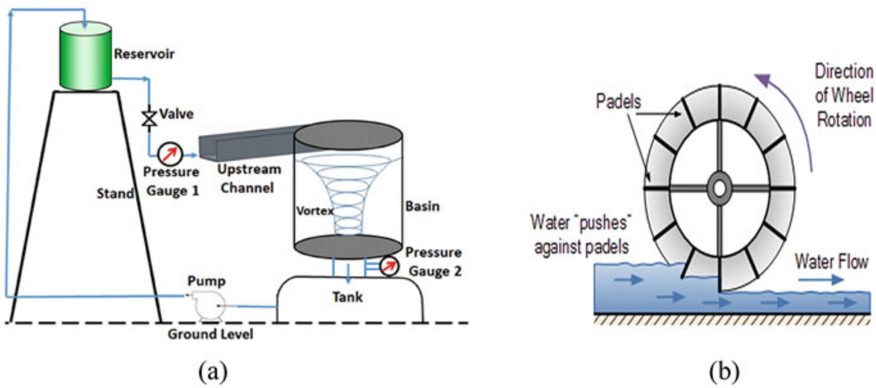

Fig. 4 (**a**) Gravitational vortex hydro turbine (Saleem et al., 2020). (**b**) Water wheel (Quaranta & Revelli, 2018)

components include an upstream channel, a cylindrical basin in which there is an orifice at the bottom, a rotor (with blades), and also a shaft (vertical). Water passes under gravity through a straight upstream channel, and in order to form a vortex, it takes the tangential entry into the cylindrical basin. Vortex is initiated at the free surface due to the effect of Coriolis force. The vortex gets intensified gradually towards the bottom surface of the orifice, and due to this, the water rotation starts getting speed up. The flow energy of the vortex generated can be converted to mechanical power with the help of a rotor. To produce electric power, the turbine rotor shaft is further coupled with the generator. Water passing through the bottom orifice gets return back to main river stream and canal and in this order the cycle is completed.

Recently a study of gravitational water vortex turbine (single staged) aiming at the parametric aspects was performed. This study presented different performance parameters like speed of rotation, torque, and the brake power. Various flow conditions and design aspects were taken into consideration in order to study the mechanical efficiency of the turbine. Systematic error analysis was also performed. The result showed that the parameters which affects the performance of GWVT are height of the vortex and a good shape of the vortex having a developed air core (Saleem et al., 2020).

It is considered as the emerging technology in the field of hydropower because it has less requirement of expertise, head required is low, and space for setup installation is also less. Issue of supplying electricity to the remote and rural areas can be solved with the proper utilization of this technology. Also it is minimally invasive to the ecosystem. GWVT can be operated under small rate of lows and low head, and this makes it, as compared to other conventional technologies, a more worthy hydropower project scheme (Rahman et al., 2017).

7.2 Water Wheels

Water wheels were scientifically investigated in the eighteenth century, but they were not much in use, also not much considered, as a potential technology in the twentieth century. Interest in the field of water wheels in the scientific community has evolved in the recent two decades.

In the field of hydropower, different machines are used to convert energy of water into mechanical energy (Williamson et al., 2014). Hydropower converting machines can be broadly classified as (1) action turbines, for example, stream water wheels, vertical axis water wheels, pelton turbine, turgo turbine, and cross flow turbines; (2) reaction-type hydropower turbines, for example, Francis turbine, Kaplan turbine, etc.; and (3) hydrostatic pressure converters like water wheels and Archimedes screw. Action turbines basically exploit the kinetic energy associated with the flowing water. Reaction turbines also exploit the water pressure. Hydrostatic force of water drives the hydrostatic pressure converters. The typical diagram of water wheel is shown in Fig. 4(b).

In the context of micro hydropower, the most significant and suitable options includes water wheels (gravity and streamed water wheels) and Archimedes screw. Stream water wheels (having maximum power coefficient to be 40%) generally finds its application in flowing water where the head differences are almost negligible. Stream water wheels are broadly categorized into three subcategories: stream wheels in shallow supercritical flow, shallow subcritical flow, and deep flow. Recently a study was published in which an analysis of experimental, numerical, and theoretical data regarding stream water wheels was performed. Guidelines for designing were also discussed focusing on wheel dimensions of wheel, design aspects of supporting structures, and also the blades and speed. Results illustrated that, in shallow water, generation of head difference takes place by the wheels which in turn increases the output power. Hydrostatic water force in addition to kinetic energy of the water flow can also be exploited force in the case of deep flow if hydrodynamic floating is accurate. Thus it can lead to power output improvement of more than 10 KW from 0.5 KW (per meter width), which makes the stream water wheel a potential energy supply technology in zero head sites (Quaranta, 2018).

Gravitational water wheels can be of three types: overshot in which the entry of water takes place from the top, breastshot, and undershot, in which entry of water takes place from the upstream side. A study was performed in order to optimize the performance characteristics of water wheels (gravity type). The results obtained illustrated that the undershot water wheels and overshot water wheels were having maximum efficiency of 85%, while in the case of breastshot water wheel, the range of maximum efficiency was around 75–80%, which was depending on the inflow configuration. Thus water wheels with better designed consideration can be a potential micro hydropower converters which can be both cost effective and efficient (Quaranta & Revelli, 2018).

8 Conclusion

In this book chapter, the focus was mainly on discussing the various aspects of hydropower energy. The worldwide potential of hydropower with Indian context has been studied. This study elaborated about the problems with large hydropower sector, and thus small hydropower can be the potential solution for the future. Different methods to extract hydropower have been discussed taking into consideration both the conventional and unconventional methods. Recent developments in the field of small hydropower sector were also studied. Other disruptive techniques to extract hydropower were also the point of our study.

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