Anusandhan- Rabindranath Tagore University Journal Vol. XI/Issue XXI September 2021 ISSN: 2278-4187

An Overview of Hydroelectric Power Development

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Abstract- *In this paper, the challenges imposed by climate change and the role of hydropower in mitigating the impacts of climate change are discussed. The outline of development made in hydropower in India and the world are also explained. There are hydropower projects that have completed more than 100 years and are still in operation. The main objective of hydro schemes has generally been a water management and to preserve and supply water for drinking, irrigation, industries, and hydroelectric power development. The working of hydropower plant along with the approach to control the voltage and frequency are included.*

***Keywords*:** History of hydropower development, working of hydropower plant, global and Indian scenario of hydro power development.

I. CLIMATE CHANGE AND HYDRO POWER

Climate change is one of the biggest global challenges of the 21st Century. The rapidly increasing severe disasters are the evidence of impacts of climate change. Lives on earth are already affected because of rising temperatures, sea levels, changing wildlife, floods, droughts, storms etc. Any further delay in taking the corrective measures threatens to cause enormous damage to the mother earth, the only known planet that supports lives.

Water is a major source of renewable energy and is the indispensable natural resource for the existence of living beings on earth. Hence, there is no other way to conserve water. In order to fulfil the ever-increasing demand for water, meticulous management of water has become all the more significant. Hydroelectric power is a renewable and an eco-friendly source of power generation and plays important role in the fight against climate change.

It is further to mention that in recent years, the ambient temperature has been increasing alarmingly. The weather experts are of the opinion that it is causing high absorption of moisture, which is causing sudden high floods, storms etc. This underlines the necessity of exploring the possibility of planning new dams to minimize/avoid such floods.

II. HISTORY OF HYDROPOWER DEVELOPMENT

Solar heat causes the water cycle. The water at a height possesses the potential energy and water flows downwards due to the earth's gravitational force. Thus, potential energy gets converted into the kinetic energy. There is a long history of over 2000 years of the usage of hydropower for mechanical applications, mainly grinding the grains and pumping of water for irrigation. In the late 19th century, the generation of hydroelectric power started. Since then, a lot of research and innovations have taken place in the development of modern turbines.

Hydropower is an eco-friendly source of clean energy and does not require any burning of fuels and hence there is no emission of gases. Operation and maintenance costs of hydropower generation are much lower than other types of power plants. The cost of generation also reduces with time. In fact, dam-based storage type projects are multi-purpose and offer several benefits such as flood control, water supply, irrigation, navigation, etc. which contribute in economic prosperity of a nation. However, there are some environmental and social concerns also associated mainly with large hydro projects, such as deforestation, rehabilitation, aquatic lives, sedimentation behind the dam etc [1-2].

III. CLASSIFICATION OF HYDROELECTRIC POWER PROJECTS

The classification of hydropower projects is shown in Figure 1.

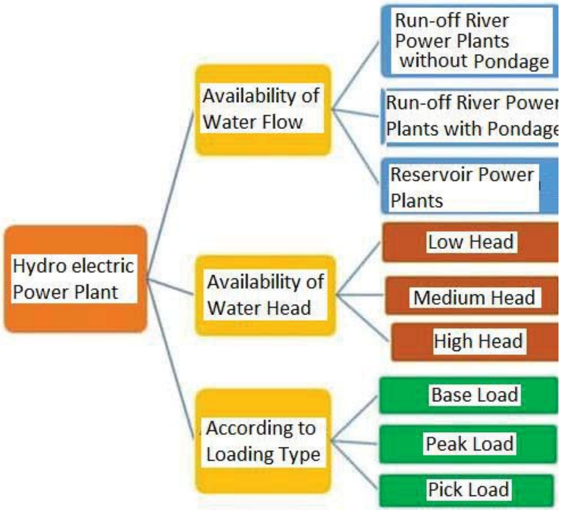

Fig. 1 Classification of hydroelectric power projects [3]

(a) Run-of-river projects

In a run-of-river project, there is no dam to store flowing water. However, in some cases a barrage is built to fulfil the water requirement due to load variation. Run-of-river plants may be located at the downstream of a canal fall or open flume. A stream's flow may also be diverted around a dam or fall.

A chronological development of hydropower is given in Table 1.

Table 1: Chronological development of hydropower [4]

Between 202 BC and 9 AD	Trip hammers powered by water wheel were used to grind the grains, break ore, and paper-making during Han Dynasty in China
1771	Richard Arkwright set up Cromford Mill in England's Derwent valley to spin cotton. It was one of the world's first factory systems used for economic growth
1827	French engineer Benoit Fourneyron developed the first version of reaction turbine, which was capable of producing around 6 HP
1849	British–American engineer James Francis developed the first modern hydro turbine, named after him. It is the most widely used turbine globally
1878	The first commercial Pelton Wheel was installed at Mayflower Mine, Nevada City, USA
1878	The world's first hydroelectric project was installed at Northumberland, England. It powered a single lamp in the Crag side country house
1882	Appleton hydro power plant, Wisconsin, USA was the first to supply power to private and commercial consumers
1891	The first three-phase hydroelectric power system was commissioned in Germany
1895	Australia launched the first publicly owned hydroelectric power plant in the Southern Hemisphere
1895	The Edward Dean Adams Power Plant, the world's largest hydroelectric with each generator output of 3.7 MW (5000 HP) development of the time, was built at Niagara Falls. The power system was built by WestinghouseElectric and Manufacturing Co. The power was transmitted 25 miles at 25 Hz using single wire
1897	2 × 65 kW hydroelectric project, the first in India, was set up in Sidropong valley, Darjeeling
1902	2 MW large hydro generating unit was set-up in Shivasamudram, Karnataka, India
1912	480 kW station, the first in China, was set-up in Shilongba, Yunnan province
1913	Austrian professor Viktor Kaplan developed a turbine. It was named 'Kaplan' turbine. It is basically a propeller-type turbine with adjustable blades
1930	The first pumped-storage, reversible unit was commissioned in USA. Water was pumped from the Housatonic River to 230 feet high upper reservoir
1936	1,345 MW Hoover Dam on Colorado River, USA, was the largest hydroelectric power plant of the time in the world
1942	The 1,974 MW, Grand Coulee Dam (now 6,480 MW) was the world's largest capacity hydropower project of the time located in Washington, USA
1984	12,600 MW, Itaipu Dam on Parana River dividing Brazil and Paraguay (since been enlarged and upgraded to 14,000 MW) The power plant in Brazil has 10× 700 MW, 60 Hz generating units The power plant in Paraguay has 10× 700 MW, 50 Hz generating units
1998	1883 m, highest head and most powerful 3x423 MW, 5 jet, Pelton turbines in operation at Bieudron Hydroelectric Power Station, Switzerland
2008	Three Gorges Dam, China is the highest capacity hydropower project equipped with 32 ×700 MW + 2 × 50 MW generating units
2013	At 770 MW, it is the highest capacity Francis turbine commissioned for the Xiluoda Dam Hydropower Project, China
2016	At 230 MW, it is the highest capacity Kaplan turbine with 8.6 m diameter runner for Tocoma Dam Power Plant, Venezuela
2019	India crossed 50,000 MW installed hydroelectric power capacity in 2019 and reached 51,162 MW by July 2021 (large and small hydro combined)

The power plant operates as per the available flows, otherwise power generation is lost. The discharge varies on day-to-day basis as per natural flow of water from the catchment area; the characteristics of which depend on the hydrological features. Figure 2 shows 2,620 MW Chief Joseph, USA, the largest capacity run-of-river hydropower project of the world.

Fig. 2 Chief Joseph, the world's largest run-of-the-river hydroelectric power project [5].

The possibility of installing mini-micro units in large size pipes (above 2 m) for supplying water in mega cities needs to be explored. It will recover some energy consumed in pumping water for long distance supply.

(b) Storage type

The dam is built across the river to store the flowing water of a river. In a hydropower project, water is released from the reservoir as follows:

i. Normal operation: Water is released through the penstock to rotate turbine runner which is coupled to the generator for power generation.
ii. Excess water: In case of excessive water inflows or flood, the release of huge quantity of water becomes inevitable for safety of dam by opening the gates of a dam. The gates may be partially or fully opened. The opening of the number of gates depends on the quantum of water to be released.

(c) Pumped-storage projects

It is well known that power demand reduces substantially during late night and starts increasing from morning. The power demand is also less during holidays. In a pumped-storage project, a lower reservoir is also built on downstream of dam. The surplus power in the grid is utilized in pumping the water from a lower reservoir to an upper reservoir and reuse the same for power generation. However, in order to meet load demand during the day and evening peaks, the power plant is operated in a generation mode and supply power to the grid.

The pumped-storage project is normally equipped with reversible units, that operate as turbine-generator in one direction of rotation and as pump-motor in the reverse direction. These two modes of operation are given here:

i. Generation mode: It operates as a conventional turbine generator.
ii. Pumping mode: in this mode of operation, the turbine acts as a pump and the generator as a motor in the reverse direction of rotation. The motor draws power from the utility grid to drive the pump. The water is pumped to the upper reservoir using the same water conductor system.

In the reversible units, Francis turbines are best suited for operation in both the modes as turbine as well as pump. The advent of variable speed technology paved the way for operation at higher efficiencies. The reversible units operate in synchronism with the grid frequency in the generation mode. The pump is designed to operate at its peak efficiency at rated grid frequency (50 Hz in India) in the pumping mode. An illustrative of pumped-storage project with underground power house is shown in Figure 3.

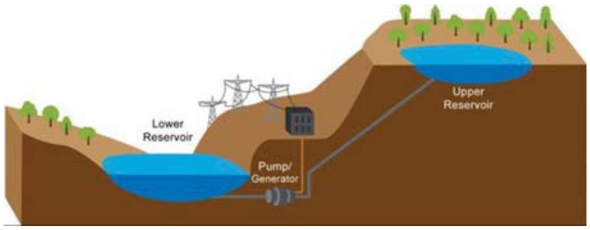

Fig. 3 An illustrative underground pumped-storage station [6]

Looking to the recent planning of large capacity solar power plants, the possibility to use this solar power for pumped storage plants needs to be explored. In other words, it will be a sort of storage of solar energy which can be used during peak hours.

IV. WORKING OF POWER PLANT

Figure 4 shows a typical layout of a hydroelectric power project and its basic components.

(a) Dam and Reservoir: The dam is built across a river to store water at a height. The dam forms a reservoir behind it. The head and quantity of stored water in reservoir determine the potential energy of stored water.

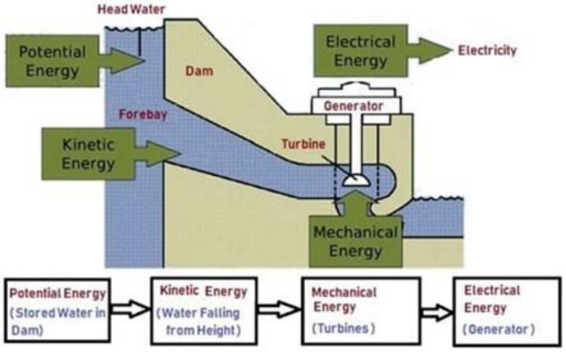

Fig. 4 Typical layout of a hydroelectric power project [4]

(b) Flow Control Gate/Valve: Water from the higher elevation flows through the penstock to rotate the turbine runner. The flow of water is controlled (only full open/close and emergency shut down) by the gate provided at the upper end of the penstock, called penstock gate or by a main inlet valve installed inside power house before the turbine. The quantity of water flowing through the penstock depends on the opening of penstock gate/main inlet valve.

(c) Penstock: A penstock is generally made of steel for high heads. However, concrete or fiber-reinforced composites penstocks are also used for low head projects. Potential energy of water is converted into kinetic energy as due to gravity, water flows down through the penstock.

(d) Water Turbine: Water from the penstock rotates the turbine runner which is coupled to the generator shaft through turbine shaft. Kinetic energy of the water drives the turbine and the generator mechanically coupled to it through shaft. There are two main types of water turbines; (i) Impulse turbine and (ii) Reaction turbine. Impulse turbines are used for large heads whereas reaction turbines are used for medium and low heads.

Gross head of a reaction turbine = Reservoir water level – tail water level

Gross head of an impulse turbine = Reservoir water level – center line of the runner

(e) Surge Tank: It is provided in case of a very long penstock. When there is sudden reduction in load on the turbine, say due to load throw-off, the gate/valve of the turbine close to stop/ reduce the water flow. This causes water pressure to increase abnormally (called water hammer) which is prevented by a surge tank, in which the water level rises to reduce the pressure. However, when the gates are suddenly opened to meet increased load, the surge tank supplies the available excess water.

(f) Generator: A generator converts the mechanical energy into the electrical energy. Flexibility is a great advantage with the synchronous generators which can be taken to full load in two minutes. Further, a synchronous generator has capability to operate at lagging, leading or unity power factor by adjusting its excitation. This is the reason that synchronous generators are used in hydro, thermal as well as nuclear power plants.

The generator shaft is coupled to the turbine shaft. When the turbine runner is rotated, it drives the generator and electricity is generated. The generated electrical power is supplied to the step-up transformer for the high voltage power transmission.

(g) Operation in synchronism: The generator has to operate in synchronism with the utility grid i.e., generated voltage and its frequency should match with those of the utility grid. The frequency matching is achieved through governor whereas the voltage matching is done by excitation system.

(h) Governor: The rotational speed of turbine is directly proportional to the frequency of grid-connected synchronous generator used in the hydro/thermal/nuclear power plants. The frequency of utility grid is compared with the turbine speed and as per the difference, the water flow is regulated to increase/reduce the water flow through the turbine.

(i) Excitation system: The utility grid voltage is sensed and compared with the generator voltage. The generated voltage is adjusted to match with the grid voltage by regulating the field current through the excitation system.

V. GLOBAL SCENARIO OF HYDROPOWER

On September 30, 1882, the world's first commercial hydroelectric power plant came into operation on Fox river in Appleton, Wisconsin. The Appleton paper manufacturer H.J. Rogers was inspired by Thomas Edison's plan for installing an electric power-generating station in New York. He later named the power plant as Appleton Edison Light Company. The power plant generated enough electricity to light Rogers' home, the power plant itself, and a nearby building.

There are over 150 countries which generate hydroelectric power, although around 50% of it is generated by just 4 countries: China, Brazil, Canada, and the United States. Environment friendly and low-cost hydropower plays key role in boosting the economy of these countries. The global installed hydropower capacity and leading countries are given in Table 2.

Table 2: Leading countries in installed hydropower capacity as on December 2020 [5].

S. No.	Country	Capacity, GW
1	China	370.2
2	Brazil	109.1
3	USA	102.0
4	Canada	82.0
5	India	50.5
6	Japan	49.9
7	Russia	49.9
8	Norway	33.0
9	Turkey	31.0
10	France	25.5

The global hydropower generation and break-up of installed power capacity as of December 2020 are shown in Figure 5.

Fig. 5 Leading countries in installed hydropower capacity [7]

Globally, the large-capacity conventional hydroelectric power projects are listed in Table 3.

Table 3: World-wide large-capacity conventional hydroelectric projects [4].

Station	River	No. × capacity (MW)	Total capacity (MW)	First unit commissioning
Three Gorges, China	Yangtze	32 × 700 + 2 × 50	22,500	2008
Itaipu, Brazil/Paraguay	Parana	20 × 700	14,000	1984
Xiluodu Dam, China	Jinsha	18 × 770	13,860	2013
Guri, Venezuela	Caroni	10 × 730 + 4 × 180 + 3 × 400 + 3 × 225 + 1 × 340	10,235	1978
Tucuruí, Brazil	Tocantins	12 × 350 + 11 × 375 + 2 × 22.5	8,370	1984
Grand Coulee, USA	Columbia	27 × 252	6,809	1942
Xiangjiaba, China	Jinsha	8 × 812 + 8 × 800	6,448	2012
Longtan, China	Hongshui	9 × 714	6,426	2009
Sayano-Shushenskaya, Russia	Yenisei	10 × 640	6,400	1978-85
Krasnoyarsk, Russia	Yenisey	12 × 500	6,000	1972

Table 4: Large capacity pumped-storage projects [4]

Station	Country	No. × Capacity (MW)	Capacity (MW)	Commissioning
Bath County	United States	6 × 480/500.5	3,003	1985
Huizhou	China	8 × 300/312	2,448	1994-2000
Guangdong	China	8 × 300	2,400	1994-2000
Okutataragi	Japan	4 × 483	1,932	1974
Ludington	United States	6 × 362	1,872	1973

Table 5: Large capacity run-of-river projects [4]

Station	Country	Capacity (MW)
Chief Joseph	United States	2,620
John Day	United States	2,160
Beauharnois	Canada	1,903
The Dalles	United States	1,779.8
Inga dams	Democratic Republic of Congo	1,775

VI. INDIAN HYDROPOWER SCENARIO

The first power project in India was a 2 × 65 kW hydropower plant commissioned on 10 November 1897 in Sidrapong valley, Darjeeling by Darjeeling Electric Supply Co. Later, it was merged with the West Bengal State Electricity Board in 1978. The project is still maintained as heritage site.

As of 31 July 2021, India's total installed hydropower capacity (large and small) was 51162 MW against the estimated potential of 148,700 MW at 60% load factor. In addition, for pumped-storage schemes, 56 sites have been identified with the total installed power potential of 94,000 MW.

The hydropower projects are developed by government sector, state utilities, joint sector and private sector. The examples of government sector are Karnataka Power Corporation Limited (KPCL), state irrigation departments etc. There are some joint sector projects also like NHDC Limited which is a joint venture between NHPC Limited in central sector and Madhya Pradesh State Government. NHDC has executed 1000 MW Indira Sagar and 520 MW Omkareshwar hydropower Projects on river Narmada in Madhya Pradesh.

The public sector has a major share in India's hydroelectric-installed power capacity. The public sector companies involved in developing hydroelectric power are mainly:

i. Bhakra Beas Management Board (BBMB)
ii. National Hydroelectric Power Corporation (NHPC)
iii. Northeast Electric Power Company (NEEPCO)
iv. Satluj Jal Vidyut Nigam Limited (SJVNL)
v. Tehri Hydro Development Corporation (THDC India Ltd.)
vi. NTPC-Hydro
vii. Narmada Hydropower Development Corporation (NHDC Ltd.)

The private sector is also contributing in the development of hydroelectric power mainly in the Himalayan ranges, the northeast and to some extent in other parts of the country. Indian companies have also executed hydropower projects in Bhutan, Nepal, Afghanistan, among others. Some of the players in the private sector are Jaiprakash Associates Limited, Tata Power, Greenco, Lanco, LNJ Group, GVK Group etc. The large-capacity hydroelectric power projects in India are listed in Table 6.

Table 6: Conventional large Capacity hydroelectric power projects [4]

Project	**State**	**River**	**Capacity (MW)**	**Remarks**
Naphta Jhakri	Himachal Pradesh	Satluj	6 × 250 = 1500	SJVN Ltd.
Bhakra Nangal	Himachal Pradesh	Satluj	5 × 157 = 785	Right bank/BBMB
			5 × 108 = 540	Left bank/BBMB
Koyna St.-IV	Maharashtra	Koyna	4 × 250 = 1000	MAHAGENCO
Karcham- Wangtoo	Himachal Pradesh	Satluj	4 × 250 = 1000	Run of the river JSW Group
Indira Sagar	Madhya Pradesh	Narmada	8 × 125 = 1000	NHDC
Dehar	Himachal Pradesh	Satluj	6 × 165 = 990	BBMB
Kalinadi (Nagjhari)	Karnataka	Kali	6 × 150 = 900	KPCL
Srisailam (Right)	Andhra Pradesh	Krishna	6 × 150 = 900	APGENCO
Koldam	Himachal Pradesh	Satluj	4 × 200 = 800	NTPC
Parbati-II	Himachal Pradesh	Parbati	4 × 200 = 800	NHPC
Idduki Dam	Kerala	Periyar	6 × 130 = 780	KSEB
Nagarjun Sagar	Telangana	Krishna	7 × 100 = 700	APGENCO

(a) Pumped storage projects

In the pumped storage projects, mostly the Francis turbines are used which act as pumps in the reverse direction. However, Deriaz pump turbines are used in Kadana pumped-storage plant. The pumped-storage projects in India are given in Table 7.

Table 7: Pumped-storage projects in India [4]

Project	**State**	**River**	**Capacity (MW)**
Sardar Sarovar	Gujarat	Narmada	6 x 200 = 1,200
Tehri	Uttarakhand	Bhagirathi	4 x 250 = 1,000
Purulia	Bengal	Kistobazar Nallah	4 x 225 = 900
Srisailam Left Bank	Andhra Pradesh	Krishna	6 x 150 = 900
Nagarjunsagar Tail Pond	Andhra Pradesh	Krishna	7 x 100 = 600
Kadamparai	Tamil Nadu	Aliyar	4 x 100 = 400
Kadana	Gujarat	Mahi	4 x 60 = 240
Bhira	Maharashtra	Kundalika	1 x 150 =150
Ghatgar	Maharashtra	Pravara	1 x 125 = 125
Panchet (DCV)	Jharkhand	Damodar	1 x 40 = 40
Paithan (Jayakwadi Dam)	Maharashtra	Godavari	1 x 12 = 12
Ujjaini	Maharashtra	Bhima	1 x 12 = 12

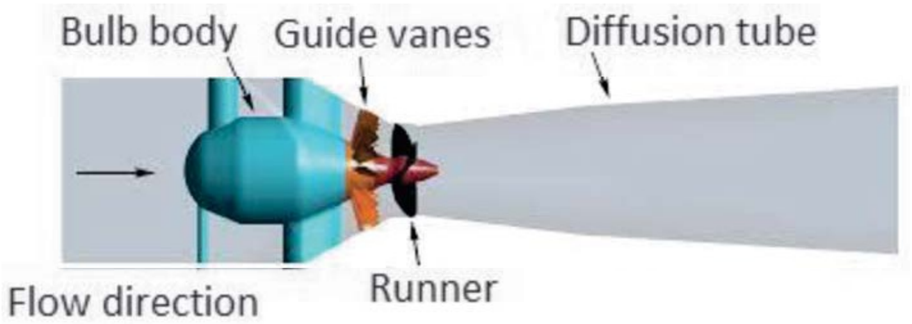

Fig. 6 Bulb turbines in the water passage [6]

(b) Bulb turbine projects

There is a special class of turbines suitable for low head and high discharge. In this arrangement, the turbine and generator are installed inside the bulb shaped waterproof steel housing. The bulb itself is installed in the water passage and flowing water rotates the turbine runner. Figure 6 shows the bulb turbine placed in the water passage.

The hydropower projects in India equipped with bulb turbines are given in Table 8.

Table 8: Bulb turbine projects in India [4]

Project	*State*	*No. × capacity (MW)*	*Capacity (MW)*	*Commissioning*
Sone Link Canal	Bihar	6 × 1.732	10.4	1992
Teesta Canal Fall-I	Bengal	3 × 7.5	22.5	1999
Narayanpur LBC	Karnataka	2 × 5.8	12	
Lower Jurala	Telangana	6 × 40	240	2013–16
Lower Mettur Barrage-III	Tamil Nadu	2 × 15	30	1988
Eastern Gandak	Bihar	3 × 5	15	1997
Western Yamuna Canal –Phase-I	Haryana	2 × 8	16	1989
Western Yamuna Canal –Phase-II	Haryana	2 × 7.2	12	2004

VII. CONCLUSION

In this paper, the challenges imposed by climate change and the role of hydropower in mitigating the effects of climate change have been discussed. An overview of hydropower development in India and the world is presented along with the list of different types of hydropower projects. With the fast-growing population, to make provision of water to all is challenging and in this regard hydro projects with dam-storage play crucial role in managing the water resource for its utilization for drinking, irrigation (India built Afghan-India Friendship Dam, formerly Salma Dam to store water for irrigation and drinking purposes), industries, and may be power generation, if needed and found techno-economically viable. Lastly whether the climate calamity can be converted into boon by making use of storm, high floods to some extent; needs to be explored/examined.

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