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Hydro-Energy Sector in India: A Review

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Abstract:
Hydropower is an important renewable energy resource and clean as well as environment friendly. Energy demand increases due to rapid urbanization and an increase in population growth. So, the time is not very far away when we will not have a sufficient amount of electricity to fulfill our needs. Hydropower plays a vital role in the development of the country because it provides power at a cheaper rate being perpetual and renewable sources of energy. The estimated economically exploitable hydropower potential in India is about 84,000 MW at 60% load factor with a suggested installed capacity of 148,700 MW. The Indus, the Ganga and the Brahmaputra, basins together in the administrative boundary of India could contribute about 80% of the hydropower. The majority of India's hydropower development potential lies in the key basins of Brahmaputra Basin (66 GW), Indus Basin (34 GW), Ganga Basin (21 GW), and the rivers of South India (24 GW). The country has 197 hydropower plants capable of producing more than 25 megawatts (MW), according to the International Hydropower Association (IHA), plus nine pumped storage stations accounting for 4,786MW capacity. More than 90% of India's hydroelectricity is operated by the public sector through companies like NHPC, SJVNL, NTPC-Hydro, NEEPCO. Every year around 140 billion kilowatt electricity is produced in India through hydroelectric power plant. There are more than 5000 dams in India. The largest hydroelectric power project in India is The Koyna Hydroelectric Project with the capacity of 1960 megawatt.

Keywords: Hydropower, Renewable energy, hydroelectricity, pump storage unit, hydel policy.

Introduction:

Hydropower is the cheapest, and cleanest and, hence, regarded the best source of energy. Hydropower refers to the conversion of energy from flowing water into electricity. Historically, one of the first uses of hydro power was for mechanical milling, such as grinding grains. Today, modern hydro plants produce electricity using turbines and generators[1,2]. Hydropower technologies generate power by using a dam or diversion structure to alter the natural flow of a river or other body of water. British-American engineer James Francis developed the first modern water turbine. In 1882, the world's first hydroelectric power plant began operating along the Fox River in the United States[3,4]. The oldest Hydropower power plant in India is in Darjeeling District in West Bengal. Its installed capacity is 130KW and was commissioned in the year 1897[5]. The hydropower potential of India is around 1,45,000 MW and at 60% load factor, it can meet the demand of around 85,000 MW. Around 26% of Hydropower potential has been exploited in India. Chamera-II HE Project (300 MW) in Distt. Chamba, HP. has been completed in a record period is Four & Half years. Three gauges project in China on Yang-Yang river is the largest hydropower station in the world having installed capacity ofaround 18,200 MW. The world's

Largest operating Hydro Electric Power Station is ITAIPU with installed capacity of 12,600 MW. It is located at the Border of Brazil-Paraguay.

Hydropower can be categorized into following sizes: Micro (Up to 100 KW), Mini (101KW to 2MW), Small (2 MW to 25MW), Mega: Hydro projects with installed capacity >= 500 MW, Thermal Projects with installed capacity >=1500 MW[6]. Small hydro projects can be broadly classified in the following two types:

Small Hydro Projects on Hill Streams: Small streams with steep bed slopes are available in the hills, giving rise to medium as well as high head projects utilising small discharges. These schemes are normally run of the river type with a small diversion structure to divert the flows through the head regulator located in the intake portion of the diversion structure. The water conductor system would usually comprise of a diversion and head regulator, a power channel, a desilting basin, forebay, penstock, power house and a tail race leading from the power house to the stream.

Small Hydro Projects on Canal Falls/Dam Toe: Irrigation canals carrying relatively high but assured discharges have several falls along their route. Small hydel projects utilising low heads can be constructed at such falls. Small hydel projects can also be located just down stream of a dam, barrage or similar structure to utilise the difference in the water level in the reservoir and in the canal downstream. A bypass channel to bypass the flows adjacent to the fall structure is constructed and the power house is constructed in the bypass channel. The bypass channel is suitably connected to the main channel[7,8].

India is 5th globally for installed hydroelectric power capacity. As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 46,000 MW, or 12.3% of its total utility power generation capacity. Additional smaller hydroelectric power units with a total capacity of 4,683 MW (1.3% of its total utility power generation capacity) have been installed. India's hydroelectric power potential is estimated at 148,700 MW at 60% load factor. In the fiscal year 2019–20, the total hydroelectric power generated in India was 156 TWh (excluding small hydro) with an average capacity factor of 38.71%. The hydroelectric power plants at Darjeeling and Shivanasamudra were established in 1898 and 1902, respectively. They were among the first in Asia and India has been a dominant player in global hydroelectric power development. India also imports surplus hydroelectric power from Bhutan[9].

Small hydropower, defined to be generated at facilities with nameplate capacities up to 25 MW, comes under the ambit of the Ministry of New and Renewable energy (MNRE); whilst large hydro, defined as above 25 MW, comes under the ambit of Ministry of Power. Koyna Hydroelectric Project is the largest completed hydroelectric power plant in India. It has a power capacity of 1960 MW.

India's economically exploitable and viable hydroelectric potential is estimated to be 148,701 MW. An additional 6,780 MW from smaller hydro schemes (with capacities of less than 25 MW) is estimated as exploitable. 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have also been identified. In central India, the hydroelectric power potential from the Godavari, Mahanadi, Nagavali, Vamsadhara and Narmada river basins has not been developed on a major scale due to potential opposition from the tribal population[10].

Basin-wise Potential of Hydropower

Brahmaputra has highest potential in terms of generating Hydroelectricity followed by Indus, Ganga. East following rivers have largest potential as compared to west following rivers and central Indian basins.

The public sector accounts for 92.5% of India's hydroelectric power production. The National

Hydroelectric Power Corporation (NHPC), Northeast Electric Power Company (NEEPCO), Satluj Jal Vidyut Nigam (SJVNL), THDC, and NTPC-Hydro are some of the public sector companies producing hydroelectric power in India. The private sector is also expected to grow with the development of hydroelectric energy in the Himalayan mountain ranges and in the northeast of India. Indian companies have also constructed hydropower projects in Bhutan, Nepal, Afghanistan, and other countries[11].

Bhakra Beas Management Board (BBMB), a state-owned enterprise in north India, has an installed capacity of 2.9 GW. The generation cost after four decades of operation is about 27 paise (0.34¢ US) per kWh. BBMB is a major source of peaking power and black start capability to the northern grid in India and its large reservoirs provide wide operational flexibility. BBMB reservoirs also supply water for the irrigation of 12.5 million acres (51,000 km^2; 19,500 sq mi) of agricultural land in partner states, enabling the green revolution in the northern India[12].

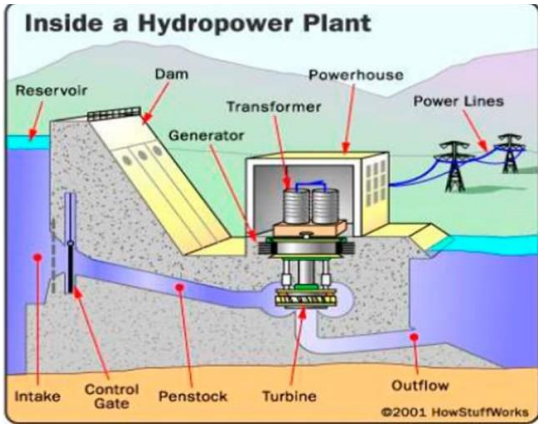

Figure. 1 Generation of Hydroelectric Power

The International Hydropower Association estimates that the total hydropower potential in India is 660,000 GWh/year, of which 540,000 GWh/year (79%) is still undeveloped. India ranks as the fourth country in the world by undeveloped hydropower potential, after Russia, China and Canada, and fifth by total potential, surpassed also by Brazil.

Pumped Storage Units

India has transformed from an electricity deficit state to an Electricity Surplus State. Peak Load Shortages can be met making use of pumped storage schemes which store surplus power to meet peak load demands. The pumped storage schemes also contribute secondary, seasonal power at no additional cost when rivers are flooded with excess water. India has already established nearly 4,800 MW pumped storage capacity with the installation of hydropower plants.

Pumped storage units can also be used as pumping stations to supply river water for upland irrigation, industrial needs, and drinking water. In a tropical country like India, abundant water for agriculture is needed due to a very high annual evaporation rate. The amount of water necessary to meet this demand can be harnessed from India's rivers via pumped storage units. Food security in India is improved with water security which in turn is possible from the energy security to supply the power needed for the pumped storage schemes[13,14].

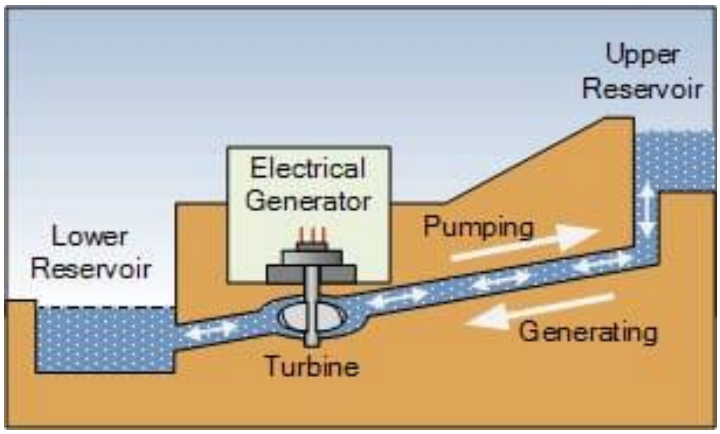

Figure 2 Pumped Storage Hydropower Plant

Hydro Scenario

India is blessed with immense amount of hydro-electric potential and ranks 5th in terms of exploitable hydro-potential on global scenario. As per assessment made by CEA, India is endowed with economically exploitable hydro-power potential to the tune of 1,48,700 MW of installed capacity. The basin wise assessed potential is as under:

Basin/Rivers	**Probable Installed Capacity (MW)**
Indus Basin	33,832
Ganga Basin	20,711
Central Indian River system	4,152
Western Flowing Rivers of southern India	9,430
Eastern Flowing Rivers of southern India	14,511
Brahmaputra Basin	66,065
Total	**1,48,701**

Table 1. Basin wise hydropower generation potential

In addition, 56 number of pumped storage projects have also been identified with probable installed capacity of 94,000 MW. In addition to this, hydro-potential from small, mini & micro schemes has been estimated as 6,782 MW from 1,512 sites. Thus, in totality India is endowed with hydro-potential of about 2,50,000 MW. However, exploitation of hydro-potential has not been up to the desired level due to various constraints confronting the sector[15].

In 1998, Government of India announced "Policy on Hydro PowerDevelopment" under which impetus is given to development of hydropower in the country. This was a welcome step towards effectiveutilization of our water resources in the direction of hydropower development. During October 2001, Central Electricity Authority (CEA) came out with a ranking study which prioritized and ranked the future executable projects. As per the study, 399 hydro schemes with an aggregate installed capacity of 1,06,910 MW were ranked in A,B & C categories depending upon their inter-se attractiveness. During May 2003, Govt. of India launched 50,000 MW hydro initiative in which preparation of Pre Feasibility Reports of 162 Projects totaling to 50,000 MW was taken up by CEA through various agencies. The PFRs for all these projects have already been prepared and projects with low tariff (first year tariff less than Rs.2.50/kWh) have been identified for preparation of DPR[16].

National Policy for Hydro Power Development

Need For a Hydel Policy

Hydro power is a renewable economic, non polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc. and help in improving reliability of power system. Hydro stations are the best choice for meeting the peak demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas.

Our country is endowed with enormous economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor (1,48,700 MW installed capacity). In addition, 6781.81 MW in terms of installed capacity from small, mini and micro hydel schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. However, only 15% of the hydroelectric potential has been harnessed so far and 7% is under various stages of development. Thus, 78% of the potential remains without any plan for exploitation.

Despite hydroelectric projects being recognised as the most economic and preferred source of electricity, share of hydro power has been declining steadily since 1963. The share of hydro power has been continuously declining during the last three decades. The hydro share has declined from 44 per cent in 1970 to 25 per cent in 1998. The ideal hydro thermal mix should be in the ratio of 40:60. Because of an imbalance in the hydel thermal mix especially in the Eastern and Western regions, many thermal power stations are required to back down during off peak hours. The capacity of the thermal plants cannot be fully utilised resulting in a loss of about 4 to 5 per cent in the plant load factor. Even if the share of hydro power is to be maintained at the existing level of 25 per cent, the capacity addition during the 9th and 10th Plan would work out to 23,000 MW. If the share were to be enhanced to 30 per cent, it would require a further addition of 10,000MW of hydro capacity[17].

The constraints which have affected hydro development are technical (difficult investigation, inadequacies in tunnelling methods), financial (deficiencies in providing long term financing), tariff related issues and managerial weaknesses (poor contract management). The hydro projects are also affected by geological surprises (especially in the Himalayan region where underground tunnelling is required), inaccessibility of the area, problems due to delay in land acquisition, and resettlement of project affected families, law & order problem in militant infested areas[18].

Objectives

The programmed capacity addition from hydel projects during the 9th Plan is 9815 MW, of which Central Sector and State Sector will contribute 3455 MW and 5810 MW respectively and the balance 550 MW will be contributed by the Private Sector. Sanctioned and ongoing schemes under implementation will enable a capacity addition of 6537 MW during the 10th Plan, of which 990 MW, 4498 MW and 1050 MW will be the contribution of Central, State and Private Sectors respectively. In addition, 12 projects (5615 MW) have been identified for advance action in the 9th Plan for benefits in the 10th Plan[19].

The Government of India has set the following objectives for accelerating the pace of hydro power development:-

1. **Ensuring targeted capacity addition during 9th Plan:** The 9th Plan programme envisages capacity addition of 9815 MW from hydel projects in the total capacity addition of 40245 MW. The

Central Sector hydel projects would contribute 3455 MW, State Sector would add 5810 MW and Private Sector 550 MW. Keeping in view that the achievement in 8th Plan had been dismal, the Government is determined to ensure that no slippage is allowed to occur and the targeted capacity addition in the 9th Plan is achieved in full.

2. **Exploitation of vast hydroelectric potential at a faster pace:** The Government would initiate advance action for taking up new hydro projects since the ongoing projects will contribute a very small percentage of the desired capacity addition envisioned for 10th Plan and beyond. Towards this end, Government would take up for execution all the CEA cleared projects, and take steps to update and obtain clearances for pending DPRs. Measures for vigorously starting survey and investigations for new green field sites would also be implemented shortly. In addition, Government is keen to restart and activate the hydro projects which are either languishing for want of funds or are remaining dormant due to unresolved inter-State issues[20].
3. **Promoting small and mini hydel projects:** Small and mini hydel potential can provide a solution for the energy problems in remote and hilly areas where extension of grid system is comparatively uneconomical and also along the canal systems having sufficient drops. The small hydro potential could be developed economically by simple design of turbines, generators and the civil works. Small and mini hydel capacity aggregating to about 340 MW is in operation, and Government is determined to provide thrust for developing the assessed small hydel potential at a faster pace henceforth.
4. **Strengthening the role of PSUs/SEBs for taking up new hydel projects:** In view of the poor response of the private sector so far in hydro development which may persist for some more years, the involvement of public sector in hydel projects would not only have to continue but will also have to be enlarged. There are categories of projects such as multi-purpose, projects involving inter-State issues, projects for peaking power and those involving rehabilitation and resettlement which may be taken up and implemented more easily in public sector. Similarly, mega hydro projects in the North and North Eastern region would also have to be executed by CPSUs in case the State or the private sector is not in position to implement these projects.
5. **Increasing private investment:** Even though public sector organisations would play a greater role in the development of new schemes, this alone would not be adequate to develop the vast remaining hydro potential since it will require huge investments which are difficult to be supported from the budget/ plan assistance in view of competing demands from the various sectors. A greater private investment through IPPs and joint ventures would be encouraged in the coming years and required atmosphere, incentives and reliefs would be provided to stimulate and maintain a trend in this direction.

Advantages of Hydropower:

- Hydropower is fueled by water, so it's a clean fuel source, meaning it won't pollute the air like power plants that burn fossil fuels, such as coal or natural gas.
- Hydroelectric power is a domestic source of energy, allowing each state to produce their own energy without being reliant on international fuel sources.
- The energy generated through hydropower relies on the water cycle, which is driven by the sun, making it a renewable power source, making it a more reliable and affordable source than fossil fuels that are rapidly being depleted.

- Impoundment hydropower creates reservoirs that offer a variety of recreational opportunities, notably fishing, swimming, and boating. Most water power installations are required to provide some public access to the reservoir to allow the public to take advantage of these opportunities.
- Some hydropower facilities can quickly go from zero power to maximum output. Because hydropower plants can generate power to the grid immediately, they provide essential back-up power during major electricity outages or disruptions.
- In addition to a sustainable fuel source, hydropower efforts produce a number of benefits, such as flood control, irrigation, and water supply[21].

Drawbacks of Hydropower:

- To produce hydroelectric power, large areas of forest and agricultural lands are submerged.
- Silting of the reservoirs reduces the life of the hydroelectric power installations.
- Water is required for many other purposes besides power generation. These include domestic requirements, growing agricultural crops and for industry. This gives rise to conflicts.
- The use of rivers for navigation and fisheries becomes difficult once the water is dammed for generation of electricity.
- Resettlement of displaced persons is a problem for which thereis no ready solution.
- In certain regions large dams can induce seismic activity which will result in earthquakes. There is a great possibility of this occurring around the Tehri dam in the Himalayan foothills. Shri Sunderlal Bahuguna, the initiator of the Chipko Movement has fought against the Tehri Dam for several years.

With a total capacity of 47,057 M, India is the seventh- largest producer of Hydroelectric energy in the world. Power development in India commenced at the end of the 19th century with the commissioning of electricity supply in Darjeeling during 1897, followed by the commissioning of a hydropower station at Sivasamundram in Karnataka during 1902. As energy is an essential factor of economic development and helps improve the quality of life, Prime Minister Modi recently inaugurated and laid the foundation stone of the hydropower projects worth Rs 11000 crore in Mandi, Himachal Pradesh[22,23].

Table 2 shows the list of Hydro Power Plants in India upto 2022.

S. No.	Name	State and river	establish-ment year	Highlights
1.	Tehri	State- Uttarakhand River- Bhagirathi	1978	It is the **highest dam in India**. It was built in collaboration with the USSR.
2.	Srisailam	State- Andhra Pradesh River- Krishna	1960	It is the second- largest hydro- power project in India.
3.	Bhakra Nan- gal Dam	State- Himachal Pradesh River- Satluj	1948	It is used by both Punjab and Haryana.
4.	Nagarjuna Sagar Dam	State- Andhra Pradesh and Telangana River- Krishna	1967	It is the **world's largest masonry dam** and is protected by 26 gates.
5.	Idukki	State- Kerala River- Periyar	1976	The state of Kerala is heavily dependent on it.

6.	Sardar Saro- var Dam	State- Gujarat River- Narmada	1987	It is the largest dam of the Narmada Valley Project.
7.	Shivanasam- udra	State- Karnataka River- Kaveri	1902	It is the first hydropower plant in India.
8.	Teesta Dam	State- Sikkim River- Teesta	2003	This dam comprises 3 turbines for hydropower generation.
9.	Koyna	State- Maharashtra River- Koyna	1956	It is the largest hydel power project in India.
10.	Salal	UT-Jammu and Kashmir River- Chenab	1970	It is constructed in two stages– I and II.
11.	Ranjit Sagar Dam	State- Punjab River- Ravi	1981	It is also referred to as Thein Dam.
12.	Machkund dam	State- Odisha River- Makchund	1955	—
13.	Hirakud	State- Odisha River- Mahanadi	1957	It is one of the first major multi purpose river valley projects started after India's independence.
14.	Rangit dam	State- Sikkim River- Ranjit	2000	It is the highest dam in Sikkim.
15.	Bansagar	State- Madhya Pradesh River- Sone	2006	—
16.	Indra Sagar dam	State- MP River- Narmada river	2005	It is the **largest reservoir in India.**
17.	Mukkombu Dam	State- TN River- Kaveri	1838	It is the smallest dam in India.
18.	Nathpa Jhakri	State- Himachal Pradesh River- Satluj	1993	It comprises 6 turbines for hydro power generation.
19.	Omkareshwar	State- Odisha River- Indravati	1996	—
20.	Karcham Wangtoo	State- Himachal Pradesh River- Satluj	2005	—

The Prime Minister of India Shri Narendra Modi laid the foundation stone of 2,880 MW Dibang Multipurpose Hydropower Project of NHPC Limited in Lower Dibang Valley district of Arunachal Pradesh, at a Viksit Bharat Viksit North East Program in Itanagar, Arunachal Pradesh today, March 9, 2024.

Conclusions:

Hydro power is a renewable economic, non polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc. and help in improving reliability of power system. Hydro stations are the best choice for meeting the peak

demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas. Globally, 4,250 TWh (terawatt hour) of clean electricity was generated from hydropower, one and a half times the entire electricity consumption of the EU (European Union) and more than all renewable generation combined. Global installed hydropower capacity reached 1,220 GW in 2022, up 22.2 GW from 2021. China grew its lead in installed hydropower capacity, bringing the total to 368 GW in 2022, more than in Brazil, Canada, the United States and the Russian Federation combined. China accounts for 29% of the world's installed hydroelectric capacity, followed by Brazil, the United States, and Canada. Our country is endowed with enormous economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor (1,48,700 MW installed capacity). In addition, 6781.81 MW in terms of installed capacity from small, mini and micro hydel schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. The country has 197 hydropower plants capable of producing more than 25 megawatts (MW), according to the International Hydropower Association (IHA), plus nine pumped storage stations accounting for 4,786MW capacity. More than 90% of India's hydroelectricity is operated by the public sector through companies like NHPC, SJVNL, NTPC-Hydro, NEEPCO. India is 5th globally for installed hydroelectric power capacity. As of 31 March 2020, India's installed utility-scale hydroelectric capacity was 46,000 MW, or 12.3% of its total utility power generation capacity. Additional smaller hydroelectric power units with a total capacity of 4,683 MW (1.3% of its total utility power generation capacity) have been installed. India's hydroelectric power potential is estimated at 148,700 MW at 60% load factor. In the fiscal year 2019–20, the total hydroelectric power generated in India was 156 TWh (excluding small hydro) with an average capacity factor of 38.71%. However, exploitation of hydro-potential has not been up to the desired level due to various constraints confronting the sector.

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