The Use of Hydropower in the Indian Subcontinent

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Abstract

The distribution of limited indigenous energy resources in the Indian subcontinent especially in Bangladesh, India, Pakistan, Nepal and Bhutan makes harder to meet each country's economic and social development needs. The secured energy access at a stable and market price is vital for industrialization and socio-economic uplift. The subcontinent has been notably falling behind in its member country's economic development. Moreover, the lack of employments and job creation for the fast-growing young population pose a risk for social and political instability, and higher poverty level. The subcontinent is also the home of over 200 million extreme poor people. This paper highlights the need for utilization of indigenous hydro resources for power generation that can be used beyond the national boundary in the subcontinent to enhance the collective energy security for economic prosperity and social development

Keywords: Energy, power, hydropower, cross border power trading.

1. Introduction

Globally over 800 million people (including 250 million in the Indian subcontinent) have no access to electricity due to the disparity of energy world (lack of energy access, poverty, inadequate planning, oil market fluctuations and geo political tensions, carbon emission and climate target burden for poorer nations, lack of access to clean energy technology, etc.), The global installed electric power generation capacity in 2019 constitutes by coal 2,112 GW, gas 1,830 GW, hydro 1,308 GW, Wind 624 GW, Solar PV 607 GW, oil 432 GW, nuclear 418 GW and other renewables 176 GW [1-3]. The installed hydropower generation capacity is around 17% of all energy installed capacity. There were over 4,200-terawatt hours (TWh) hydropower generated in 2018. At least 50% hydropower of the total is generated in 66 countries and 90% in 24 countries [4].

The technical potential for hydropower is much higher than the current global production (over 17% of global electric power production). The unused potential hydropower capacity is around 71% in Europe, 75% in North America, 79% in South America, 95% in Africa, 95%, and 85% in Asia [5-6]. Environmental concerns, financial constraints, and lack of power infrastructures including transmission system are the main reasons for slow uptake of hydropower potential. However, it is expected that around 25% of the remaining technically viable hydropower potential will be utilized in Asia by 2050 to meet the rising power demand and rapid industrialization needs. Switzerland and Mexico utilize nearly 88% and 80% hydropower potential respectively [5-6]. The top ten hydropower producing countries led by China is shown in Table 1. The world's largest and 2nd largest hydropower plants are Three Gorges in China on Yangtze River (22,500 MW = 32 turbines x 700

MW each with a hydraulic design head 181m + 2 turbines x 50 MW) and ITAIPU on the Paraná River located in the border between Brazil and Paraguay in South America with installed capacity of 14,000 MW (20 turbines x 700 MW each with a hydraulic design head 118 m). ITAIPU generated power is equally shared by Brazil (50Hz frequency) and Paraguay (60 Hz frequency).

The hydropower generation is highly capital-intensive. However, it is considered renewable source of energy as no consumables are involved (water is used but not consumed in hydropower generation and the water is released for other uses). Additionally, there is little recurring cost resulting in no excessive long-term expenditure. It is cheaper compared to power generated from non-renewable fossil energy resources (e.g., coal, gas and liquid fuel). It incurs lower financial losses due to frequency fluctuations and independent of global fossil fuel price fluctuation and supply security.

Table 1. World's top hydropower producing countries in 2018, adapted from [1,4]

	Country	Installed Capacity GW	Power Produced TWh	Load Factor %	Country's total %
1	China	352	1,233	37	20
2	Brazil	100	418	56	70
3	Canada	76	381	59	60
4	USA	105	292	42	7
5	Russia	55	180	42	17
6	Norway	32	140	49	98
7	India	44	130	43	10
8	Japan	50	89	37	9
9	Venezuela	15	72	67	68
10	France	25	63	46	12
-	Global	1,308	4,200	-	-
-	10 Countries	65%	71%	-	-

One of the major technical criteria of a hydropower plant is the water (hydraulic) head. As shown in equation 1, for the constant volume flow rate (Q), the extracted hydropower of the turbine (P) largely depends the water head (H). Hydropower plant's turbines can convert nearly 90% of available potential energy into power ($\eta \leq 0.9$) which is significantly higher than any other form of power generation, including the best fossil fuel power plants which are around 50% efficient [8-10].

$$P = \eta \, \rho \, g \, Q \, H \qquad (1)$$

Where, η turbine efficiency (varies from 0 to 1), ρ water density, and g is gravitational acceleration.

The general classification of hydropower plants based on power generation capacity and types of turbine based on hydraulic head (H) are shown in Tables 2 and 3.

Table 2. Hydropower plant classifications, adapted from [11-12]

	Classification Name	Power Output (MW)
1	Micro Hydropower Plant	up to 0.1
2	Mini Hydropower Plant	0.1 - 2
3	Small Hydropower Plant	2 - 25
4	Medium Large Hydropower Plant	26 - 500
5	Large Hydropower Plant	500 – 1,500
6	Mega Hydropower Plant	over 1,500

Table 3. Hydropower plant turbine types, adapted from [12]

	Turbine Type	Features
1	Pelton Turbine	It is impulse turbine which is normally used for more than 250 m of water head.
2	Francis Turbine	It is a reaction turbine which is used for head varying between 2.5m to 450m
3	Kaplan Turbine	It is propeller type with adjustable blades which are used for heads varying between 1.5 m to 70 m.
4	Propeller Turbine	It is used for head between 1.5 to 30 m
5	Tubular Turbine	It is used for low and medium height power plants, normally for head less than 15 m.

2. Hydropower in the Indian subcontinent

The nations of the Indian subcontinent (India, Nepal, Bhutan, Bangladesh and Pakistan) are mainly swept by 3 major river systems (Ganges, Brahmaputra and Sindh) originated from the Himalayan mountain range. These rivers are the lifeline of over 800 million people who directly and indirectly depend on these rivers. Nepal, India and Bangladesh are washed by Ganges River system while China (south central part), Bhutan, India and Bangladesh are by Brahmaputra River system. India and Pakistan together share the Sindh river system. Although for over thousands of years, the water from these three river systems are being used for human consumption, agriculture, transport and food, the water is progressively being used for hydropower generation. India and Pakistan's combined installed hydropower generation makes them the 6th largest hydropower producers in the world. India alone is the world's 7th largest hydropower producer (Table 4). As of 31 October 2019, India's installed hydropower capacity stands at 45,399 MW (12.6% of its total installed capacity of 363,370 followed by Pakistan (10,140 MW, 27% of its 37,556 MW), Bhutan (over 1,614 MW), Nepal (~1,000 MW) and Bangladesh 230 MW). The subcontinent's hydropower potential is shown in Table 4. The region's major hydropower plants' pictorial views are shown in Fig. 1.

Table 4. Current status of India, Pakistan, Nepal, Bhutan and Bangladesh in hydropower, adapted from [6-7]

Country	Economically Feasible, MW	Installed Capacity MW	Present Use %
Nepal	80,000	1,000	1
Bhutan	24,000	1,614	7
Pakistan	60,000	10,140	10
India	148,700	45,399	31
Bangladesh	840	230	27

It is evident from Table 4 that Nepal, Bhutan and Pakistan are currently underutilizing their hydropower generation potential. India utilizes its hydropower potential more than any other countries in the subcontinent. The subcontinent's first and second hydro power plants were built at Darjeeling in 1898 and Shivanasamudram in 1902 respectively. They were among the first in Asia [13]. In addition to India's 148,700 MW economically and technically feasible potential, there are further opportunities to generate 6,780 MW through smaller hydropower plants (especially with less than 25 MW capacity). India's hydropower potentials are located mostly in its north, northeast, central and south-western regions as shown in Fig. 2 and Table 5. The state-owned companies (Hydroelectric Power Corporation, Northeast Electric Power Company, Satluj Jal Bidyut Nigam, Tehri Hydropower Development Complex-THDC, National Thermal Power Corporation- Hydro) account for over 93% of India's hydropower generation [12].

a) Pakistan's largest Tarbela hydropower plant in Khyber Pakhtunkhwa-KPK [2,888 MW]

b) India's largest Taheri hydropower plant in Uttarkhand on Bhagirathi River [2,400 MW]

c) Bhutan's largest Tala hydropower plant on Wangcchu River, Southern Bhutan [1,020 MW]

d) Nepal's largest 'Kaligandaki A' hydropower plant on Gandaki River [144 MW]

e) Bangladesh's only Karnafuli hydropower plant on Karnafuli River in Rangamati [230 MW]

Fig 1. Largest hydropower plants in India, Pakistan, Nepal, Bhutan and Bangladesh, adapted from [15-19].

Fig. 2. Major hydropower plant locations in India, adapted from [14].

Table 5. Installed hydropower capacity in Northern India, adapted from [12]

Northern Region State	MW	Eastern Region State	MW	North-eastern Region State	MW
Jammu & Kashmir	2,322	West Bengal	1,396	Assam	457
Punjab	3,809	DVC (WB)	186	Arunachal Pradesh	116
Haryana	1,967	Sikkim	823	Meghalaya	394
Chandigarh	101	Bihar	110	Tripura	69
Uttar Pradesh	3,369	Jharkhand	191	Manipur	95
Uttarkhand	1,816	Odisha	2,151	Nagaland	57
				Mizoram	98
Central Unallocated	751		85		140
Sub Total	17,045		4,857		1,426

Pakistan has 2nd highest hydropower potential in the subcontinent after India. It's hydro resources and hydropower plants are located at the northern region (Punjab, Azad Kashmir and Khyber Pakhtunkhwa-KPK). The country's hydropower generation is owned and managed by the state-owned company 'Water and Power Development Authority' (WAPDA). The locations of some major hydropower plants are shown in Table 6. As mentioned earlier, all hydropower plants were constructed at the mountainous regions of Punjab, Azad Kashmir and KPK on various tributaries of Sindh River system.

At present, the 3rd largest hydropower producer in the subcontinent is Bhutan. The economic backbone of tiny Himalayan state of Bhutan is its hydropower export to India during monsoonal time. It produces over 1,600 MW but it needs around 350 MW for domestic use. Table 7 shows the major Bhutanese hydropower plants with generation capacity and their locations.

Table 6. Major hydropower plants in Pakistan, adapted from [19]

	Major Hydropower Plant	MW	Province
1	Tarbela	4,888	KPK
2	Ghazi-Barotha	1,450	Punjab
3	Mangla	1,150	Azad Kashmir
4	Neelum–Jhelum	969	Azad Kashmir
5	Warsak	243	KPK
6	Chashma	184	Punjab
7	Patrind	147	Azad Kashmir
8	Duber Khwar	130	KPK
9	Allai Khwar	121	KPK
10	Golen Gol	108	KPK
11	Jinnah	96	Punjab
12	New Bong Escape	84	Azad Kashmir
13	Malakand-III	81	KPK
14	Khan Khwar	72	KPK
15	Other 65 smaller hydropower plants	410	
	Grand Total	10, 133	

Table 7. Bhutan's major hydropower plants, adapted from [7]

	Major Hydropower Plant	MW	Major River System
1	Tala	1,020	Wangcchu
2	Chhukha	336	Confluence of Ticchu & Wongcchu rivers
3	Dagacchu	126	Dagacchu
4	Basocchu	64	Basocchu
5	Kuricchu	60	Kuricchu
7	Other 23 smaller hydropower plants	8	-
	Grand Total	1,614	

Despite having large hydropower potential, Nepal is currently producing around 1,000 MW from its hydro resources. According to Nepal Electricity Authority (NEA), its grid connected demand is estimated to be around 1,500 MW [6, 20]. The gap between generation and demand becomes much higher during lean season (winter time) resulting up to 18 hours daily load shedding (power cut). The import of around 300 MW from India becomes a little relief. Current operational major hydropower plants with their generation capacity are shown in Table 8.

Table 8. Nepal's major hydropower plants, adapted from [6,20]

	Major Hydropower Plant	MW	Major River System
1	Kaligandaki A	144	Gandaki
2	Middle Marsyangdi	70	Marsyangdi
3	Marsyangdi	69	Marsyangdi
4	Upper Marsyangdi A	50	Marsyangdi
5	Kulekhani I	60	Tributary of Gandak
6	Khimti I	60	Khimti Khola
7	Other 30 smaller hydropower plants	550	-
	Grand Total	1,003	

3. Discussion and conclusions

In Indian subcontinent, installed hydropower generation capacity varies significantly. However, all countries except Bangladesh have plans to generate more power from their hydro resources. Nepal's installed capacity will be around 3,000 MW by 2020 from its current 1,000 MW when all major under-construction power plants are operational. As per the forecast, Nepal will be power surplus nation after 2020. The Nepal's power demand is expected to be around 5,400 MW by 2030. However, its generation capacity will be over 26,000 MW in 2030 if all 28 proposed hydropower plants are built. At least 75% of 26,000 MW will be surplus. Similarly, Bhutan will have surplus power of over 9,000 MW if its under-construction and planned hydropower plants become operational by 2020. Bhutan has plan to generate 10, 000 MW power by 2020. As mentioned previously, Bhutan is the only power surplus nation in the entire Indian subcontinent. It has currently per capita installed power generation capacity of 2,621 W (2.6 kW) compared to India's 267 W, Sri Lanka's 207 W, Pakistan's 160 W, Bangladesh's 114 W and Nepal's 42 W. However, the installed generation capacity in Nepal, India and Bhutan will make a large quantum of power surplus starting from 2025.

The peak power demand and generation capacity vary significantly due to the seasonal variability in the subcontinent. For example, the power demand in Bangladesh becomes nearly double during summer season when Bhutan and Nepal have the potential to generate more power than they need. The surplus power can be exported to Bangladesh to meet its peak demand. Similarly, in winter, the power demand in Bangladesh is low and creates surplus power while Nepal and Bhutan's generation capacity reduces significantly during this time creating power shortages. Bangladesh can export its surplus power to Nepal and Bhutan to meet their power needs.

The cost of per kWh hydropower is expected to be higher due to mean cost escalation. On the other hand, the per kWh power generation cost based imported LNG and coal in Bangladesh will be much higher than India and hydropower in Nepal and Bhutan. Therefore, based on economic parameter, Bangladesh can economically benefit by purchasing power from India (cheapest) and Nepal and Bhutan (cheaper) in the medium term. Therefore, the future economic return of hydro resources invest in Nepal and Bhutan will depend upon the power purchase by Bangladesh and India. However, India's installed generation capacity is 364,170 MW as of 31 October 2019 making it the world's 3rd largest power producing country. By all indications, India will be power surplus nation by 2020 when all villages are expected to be brought under the national grid. Until and unless, a consorted effort is undertaken, the effective utilization of unevenly distributed domestic energy and hydro resources will not be materialized for the greater benefit of cross-border people (especially India, Bangladesh, Nepal and Bhutan) in the Indian subcontinent. The collective benefit can be further maximized if Pakistan can be brought under the same collaborative network.

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