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NEED OF PARADIGM SHIFT FOR PUMP STORAGE DEVELOPMENT

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1. OVERVIEW OF INDIA'S ELECTRICITY MARKET

India is the third largest producer and consumer of electricity globally, with annual electricity production between 1200-1300 TWh. The Indian power grid is one of the largest synchronous power grids in the world. During last decade, electricity production in India grew at an annual growth rate of about 5% excluding last two years. The Electricity Act, 2003 delicensed power generation activity, which gave impetus to generation capacity addition and led to rapid coal-based generation capacity expansion during 2007-2017.

As of December 2021, the installed generation capacity of the country stood at 393 GW, comprising 235 GW of thermal, 151 GW of renewable (Wind, Solar, Hydro, and Biomass), and 6.78 GW of nuclear. India witnessed a peak electricity demand surpassing 200 GW in 2021. As per study carried out by Central Electricity Authority (CEA), the storage requirement of 41 GW by 2030 has been forecasted and thus energy storage is getting much awaited attention in the country [9].

With the ambitious decarbonisation target of the Government of India, in Nov'21, at the COP26 Climate Conference in Glasgow Prime minister raised the nationally determined contribution (NDC) target of non-fossil energy capacity to 500 GW by 2030, from 450 GW earlier that India will achieve net zero carbon emissions by 2070.

2. ENERGY TRANSITION

There is a paradigm change in Power System operation now with the large scale variable renewable energy (RE) [5]. In the past, fully controllable power generation was following non-controllable load demand. now with renewable energy sources, power generation is no longer fully controllable. The variability of RE resources due to characteristic weather fluctuations introduces uncertainty in generation output on the scale of seconds, hours, and days and needs adoption of grid scale energy storage technologies to complement these sources. The pumped storage hydropower plants (PSH) can be highly useful for facilitating the integration of high variable RE power into the power system. Pumped Storage hydro projects are System Operator's Tool and utility scale option to enable smooth transition of energy from conventional sources to renewable sources.

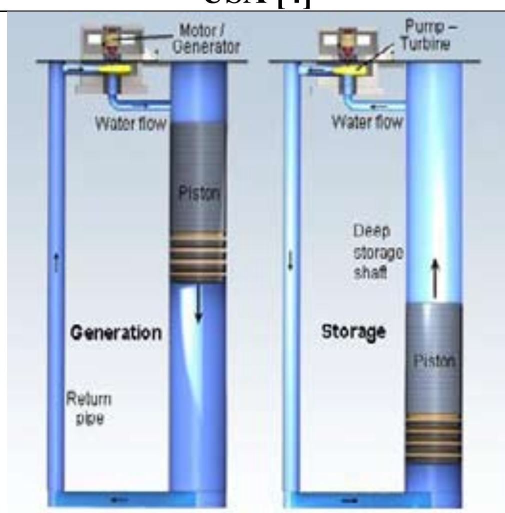
3. PUMPED STORAGE HYDRO

Pumped storage hydro (PSH) plants are electric energy storage systems based on hydropower operation between two or more reservoirs (upper and lower) with elevation difference. Water flow from upper to lower reservoir generates electricity using hydraulic turbine at the time pf demand and pump water from lower to upper reservoir through turbine as pump using excess power from grid or RE sources with an over efficiency of 75 to 80 % in such storage. PHS are also referred to as pumped hydro energy storage (PHES), pumped storage hydropower (PSH) or pumped storage plants (PSP) [13].

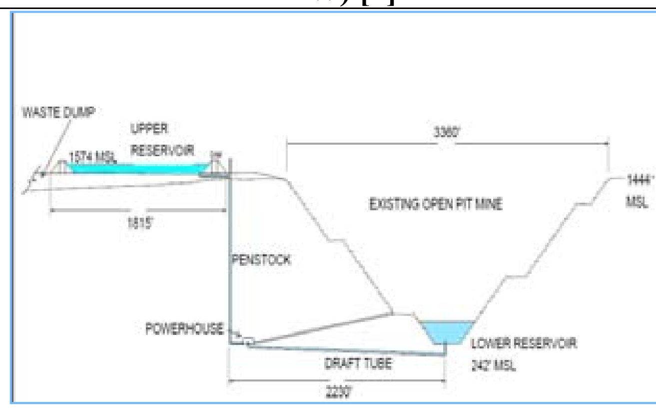
Pumped storage hydropower (PSH) has advance technology in recent years with the capability for very fast response to grid signals, and an increased flexibility for development of the closed loop of river systems. There are several benefits of closed loop pumped storage system viz. (a) is a self-contained "off-stream" water system, (b) there is no need for new dams on main stem rivers, (c) uses existing infrastructure and (d) sidesteps the constraint of site availability thus minimize environmental impacts. Large scale off-river PSH requires much smaller land area. Small scale PSH can also be easily developed in different geographical areas. (Fig 1)

Taum Sauk, 450 MW PSP, Missouri, USA [4]

Okinawa Seawater Based PSP, Japan (30 MW) [1]



Gravity based PSH [6]



PSH In Discarded Mine Sites [14]

Fig. 1 : New Technology for PSH development

PSH technology development is on continuous improvement in terms of availability, reliability and cycle efficiency Unit size may from 5 to 500 MW, head range may be from 10-2000 m and reaction time from 50 to 100 % may be about 15 seconds.

4. COMPARING PSH WITH OTHER ENERGY STORAGE TECHNOLOGIES

Comparing the technical capabilities of PSH with other energy storage technologies, PSH is one of the most mature technologies and has a high round trip efficiency. PSH also has a greater number of storage cycles and a longer total lifetime compared to chemical batteries. In general, PSH achieves economies of scale for high capacity, long-duration energy storage

The U.S. Department of Energy's 2020 Grid Energy Storage Technology Cost and Performance Assessment provided a comprehensive evaluation of commercially available energy storage technologies with respect to system size and duration capabilities. Cost and performance characteristics were analysed for the state of technology development in 2020 and projected characteristics in 2030. (Table 1). International Forum for pumped storage hydropower has brought out several reports on PSH covering policy framework, cost, technology and sustainability [7, 8, 12, 15]. Kumar et al, highlighted the India country response included in the policy framework of international forum for pumped storage hydropower report [10]. A Pumped Storage Hydropower Valuation Guidebook: A Cost-Benefit and Decision Analysis Valuation Framework [7] and Energy Storage Grand Challenge: Energy Storage Market Report [3] have been brought out by US Department of Energy.

Table 1 : Comparison of energy storage technologies for 100 MW and 4-hour duration in 2020 and 2030

Comparison metrics	Type of energy storage	Pumped Storage Hydro	Li-Ion Battery Storage (LFP)	Lead Acid Battery Storage	Vanadium RF Battery Storage	CAES compressed air	Hydrogen bidirect. with fuel cells
		100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 10hr
Technical Capabilities	Technical readiness level (TRL)	9	9	9	7	7	6
	Inertia for grid resilience	Mechanical	Synthetic	Synthetic	Synthetic	Mechanical	no reference
	Reactive power control	Yes	Yes	Yes	Yes	Yes	Yes
	Black start capability	Yes	Yes	Yes	Yes	Yes	Yes
Performance Metrics	Round trip efficiency (%*)	80%	86%	79%	68%	52%	35%
	Response time from standstill to full generation / load (s*)	65...120 / 80...360	1...4	1...4	1...4	600 / 240	< 1
	Number of storage cycles (#*)	13,870	2,000	739	5,201	10,403	10.403
	Calendar lifetime (yrs*)	40	10	12	15	30	30
Costs 2020	avg. power CAPEX (USD/kW*)	2,046	1,541	1,544	2,070	1,168	3.117
	avg. energy CAPEX (USD/kWh*)	511	385	386	517	292	312
	avg. fixed O & M (USD/kW/yr*)	30	3.79	5	5.9	16.2	28.5
	effective CAPEX (USD/kW based on PSH life of 80 years and 6% discount rate**)	2,710	4,570	5,070	8,370	3,340	8,900
Estimated costs 2030	avg. power CAPEX (USD/kW*)	2,046	1,081	1,322	1,656	1,168	1.612
	avg. energy CAPEX (USD/kWh*)	511	270	330	414	292	161
	avg. fixed O & M (USD/kW/yr*)	30	3.1	4.19	4.83	16.2	28.5
	effective CAPEX (USD/kW based on PSH life of 80 years and 6% discount rate**)	2,710	3,210	3,920	4,910	3,340	4,620

Source: Pumped Storage Hydropower Capabilities and Costs Capabilities, Costs & Innovation Working Group September 2021, International Forum on Pumped Storage Hydropower [8]

5. CURRENT STATUS OF PUMPED STORAGE & DEVELOPMENT POTENTIAL

CEA has initially PSH estimated potential in 1987 as 96 GW [2]. In India though a potential of about 125 GW for PSH has been identified at about 115 sites, yet some of these sites could be taken up only after clearing the land, forest and environmental issues that they are facing (Table 2). Only 9 plants with an installed capacity of 4,785 MW have been commissioned, and 3 plants with a capacity of 1,580 MW are under construction. Out of 9 commissioned PSH plants, 3 plants of 1,480 MW capacity are yet to be operated in pumping mode for different reasons. Most of the PSH plants are used for peaking power. Apart from these, about 12 PSH projects with an installed capacity of 10,000 MW are located in different states and are under various stages viz. pre-feasibility study, detailed surveys and investigations, detailed project reports, and obtaining clearances of different stages initiated by different state governments and IPPs.

Comprehensive identification of the sites for off-river closed loop system, use of sea as the lower or upper reservoir and gravity based hydro power plants is yet to be done in India. India has 5,745 large dams and provides an excellent opportunity for developing PSH by placing it in between two large dams in cascade or using one dam and second reservoir on the hill top with very low impact on biodiversity and resettlement and rehabilitation (R&R) issues. Lu et al., from Australian National university has developed global atlas for prospective PSH sites using GIS [11].

Presently most of the PSHs are owned by state governments, center-state joint venture power generating utilities, except one project being developed by an Independent Power Producer (IPP) as a special bid for peaking power supply.

In India, a decentralized and federal governance model for the electricity sector has been adopted where-in both States and Central Government have rights to develop and implement power sector.

Table 2 : Potential for PSH

State	No. of sites	Capacity (MW)
Himachal Pradesh	2	3,300
Uttar Pradesh	1	1,935
Rajasthan	2	3,915
Uttarakhand	2	1,005
Andhra Pradesh	8	8,450
Bihar	5	5,370
Madhya Pradesh	4	6,150
Chhattisgarh	3	5,000
Gujarat	2	1,440
Manipur	2	2,000
Assam	1	2,100
Mizoram	7	7,200
Maharashtra	31	35,925
Odisha	4	3,820
Telangana	3	2,575
Karnataka	7	11,600
Kerala	17	11,505
Tamil Nadu	7	6,900
West Bengal	7	5,040

The Government is in the process of revising electricity policy and incorporating the energy storage including pumped hydro for grid balancing. The Government has recently issued the order for extension of wavier of interstate transmission charges for PSP plants to be commissioned by 30th June 2025, with integration of solar and wind power plants.

Pumped storage schemes have 70% components of civil works with complete Indian produced material and most portion of 20% cost towards electrical mechanical works is manufactured in India and thus makes PSP as part of Atmanirbhar Bharat. Energy storage systems is being encouraged on a wide scale in the country. Ministry of power has clarified Energy Storage System (ESS) shall be an integral part of the power system under the Electricity Act and that setting up of standalone ESS shall be a delicensed activity.

6. CHALLENGES, BARRIERS AND EMERGING OPPORTUNITIES FOR PUMPED STORAGE DEVELOPMENT

At present, PSHs in India are being dealt with the conventional model approach without market intervention and in the face of declining tariffs of solar energy, beneficiaries/users like DISCOM's find it costly and less attractive to use this storage technology. In view of high investment cost and long gestation for a storage project, private participation has been low. Presently PSH predominantly being owned by the public sector (State/Central), also finds it difficult to invest in further development of PSH until the cost recovery of high investment is addressed or a stack of value added services market is well defined for an assured long term revenue streams.

The meeting of societal goals for carbon reduction and having technology neutral policy with levelized incentives is a challenge for PSH development. PSH is considered as a river valley project even if there is no constructions of new dams in the river resulting in a very long time (3–5 years) for obtaining the environment and forest clearances from the Ministry of Environmental and Forest and Climate Change (MoEF&CC). The separate guidelines for off-river PSH for early concurrence from MOEF&CC are not available, resulting in a longer time for obtaining financial closure.

The un-expected depleted wind generation scenario, lower solar generation due to cloudy weather conditions compounded with significant number of coal fired thermal power stations out either under planned shut-down for annual overhauling/ maintenance or were taken off bar under economic shut down (reserve shut down) due to less demand prevailing in the grid in monsoon, the system operators need to harnessing the flexibility (peaking & ramping support) from storage type hydro units, including PSHs.

The hydro and PSH being the state governments' subject, require the support of policy makers including the Ministry of Power, MoEF&CC, electricity regulators and state governments for PSH development. There is a need to adopt IHA sustainability guidelines and to carry out an ex-post analysis of a few operational storage projects as this might help to dispel some of the apprehensions related to storage projects.

MoP, Government of India, in March 2019 announced several policy measures to promote investment & growth in the hydroelectricity sector viz. large hydro projects (above 25 MW) to have the status of renewable energy, the introduction of Hydro purchase obligations (HPO), valuing the flood moderation component of storage type hydro projects, and budgetary support for the cost of enabling infrastructure viz. road, bridges, etc. Ancillary service regulation 2022 for secondary and tertiary reserve ancillary services, bundling of hydro with solar and wind is also notified for promotion of hydro. It is hearting to note that Policy for pumped storage has been prepared by the Government of India and expected to be announced soon.

There is a need for identification, carrying out surveys and investigations, preparing detailed project reports, obtaining the clearances, improving the market, and bring out the regulatory improvements for PSH development in the country. With the current procedure time before starting the construction of PSH plants, it may take 2 to 4 years and thereafter 4 to 5 years to make it operational. Therefore, it is the need of hour that this environmentally benign technology to support renewable energy integration immediately be taken up.

Similar to transmission elements, the PSH projects should also be delinked from the per unit energy cost basis for speedy development. The benefits of PSH can be shared across state and national boundaries. Appropriate policy frameworks that share the costs and benefits can increase the overall consumer and citizen benefits. To build more confidence in PSH, existing PSHs that are currently only operated in hydropower mode (i.e. they do not provide pumping services) should be refurbished and operationalized as soon as possible.

There is a requirement to develop market mechanisms and innovative economic models that evaluate energy storage technologies based on their abilities to provide key support services to the overall electric grid, particularly when taking into consideration project lifecycle costs, performance, and energy storage system degradation. When compared on the flexibility metrics, PSH can be considered as a MW limited resource while the battery is an MWh limited resource. Some recent studies indicate that PSH hydro would be a more viable alternative for a longer duration (~8-10 h) storage requirement and BESS would be more suitable for a shorter duration (4-6 h). For the shorter duration storage requirements, existing PSH units can be deployed with multiple cycle operations. The additional flexibility provided by PSH should therefore be recognised and it is important to note each proposed development's capabilities in respect of both MW and MWh for a true comparison and thus name plating of all the storage technologies be done accordingly.

In addition to capital cost and energy supplied, PSH developers and policy makers, for prioritising projects, should consider the factors: the location of the project under protected area or within 10 km of projected area boundary or otherwise, off-river or on-river, duration of storage, availability of the pre-feasibility report, detailed surveys, and investigations, detailed project report, etc., the market forces towards the cost of the energy supplied as well as the value of flexibility rendered by PSH units.

PSH potential would increase in future with the addition of off-river schemes and thus, identification of the off-river and non-traditional sites should be taken up immediately for reduction in gestation period.

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