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PUMPED STORAGE DEVELOPMENT – CURRENT TRENDS AND FUTURE CHALLENGES

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ABSTRACT

India has ambitious international commitments to increase share of renewables in its installed capacity generation to 50% and achieve 500 GW of non-fossil fuel-based energy capacity by the year 2030. India has taken lead in the world's renewable energy revolution to achieve these climate targets. With Ambitious goals, concerted strategies, and a collaborative approach these emission reduction targets can be met. Wind and Solar, have become one of the lowest cost sources of renewable energy, however, their inherent variable, uncertain and intermittent nature presents a huge challenge for integrating large Renewables, while maintaining the grid stability.

The increasing Renewables capacities coupled with ever changing dynamic demand curves lead to sub-optimal utilization of the existing base-load assets. Flexible Energy Generation Assets that have a capability to supply both Base Load & Peaking Power efficiently and economically are the need of the future and the necessary solution to address the dynamically evolving energy needs of India. Energy storage represents a huge economic opportunity for India. In the present scenario, the increasing energy demand of the country can only be met sustainably by developing the much required Pumped Storage Projects (PSPs) - Flexible Energy Generation Assets.

Pumped Storage Project are known as 'the Water Battery', which is an ideal complement to modern clean energy systems, as it can accommodate for the intermittency and seasonality of variable renewables such as wind and solar power. PSPs present a viable solution to integration issue of large RE capacities being planned to be added to National grid. While battery storage solutions are still evolving, integrating Wind & Solar with time tested and proven Pumped Storage solutions presents an optimal, economically viable & scalable solution to supply Power with both base load and peak load capabilities. Pumped Storage solutions provide the necessary scale (large volume of energy storage) and have a long life cycle resulting in low cost of delivered energy over the life of the projects.

Pumped storage projects account for over 95 per cent of installed global energy storage capacity, well ahead of lithium-ion and other battery types. The International Hydropower Association (IHA) estimates that pumped hydro projects worldwide store up to 9,000 gigawatt hours (GWh) of electricity.

It is envisaged that in future the focus will change on the type of hydropower, a shift will occur from run-of-river to pumped storage combined with 'other alternative renewable energy resources' to ensure energy security. The future of Pumped Storage in India is bright despite several hurdles in development. The paper discusses Pumped storage development – Current trends and future challenges.

1. INTRODUCTION

For sustaining the human civilization, renewable sources of energy need to be quickly developed to replace the finite and rapidly shrinking reserves of fossil carbon. Renewables, even if intermittent, can be rendered reliable and dispatchable, by developing Energy Storage facilities. One critical source of system flexibility is energy storage. The obvious solution is to develop pumped storage- an indigenously available technology that is well developed, reliable, comparatively inexpensive, and seriously limited by a shortage of suitable reservoir sites. The primary source of stored energy on electricity grids today - at well over 90% of grid scale installations worldwide -is pumped storage hydropower (PSP).

The principle behind the operation of pumped storage power plants is simple. There are two reservoirs viz., lower and upper reservoir. The water in the upper reservoir is used for generating power during peak demand hours. The water now lies in the lower reservoir. During the off-peak hours, this water in the lower reservoir is pumped back to the upper reservoir and the cycle continues.

Without adequate storage, there is a very real risk that electricity grids of the future will not be able to provide reliable power without recourse to high carbon sources of back-up such as gas turbines. For short durations, technologies such as batteries can play their part and for longer duration storages, PSP is best suited. Some of the Advantages of PSP:

- Increase capture of renewable over-generation-supporting large volumes of wind and solar on electricity grids by compensating for their variability
- Reduces renewable energy curtailment -providing large energy storage capacity to reduce curtailments during oversupply of variable renewables like wind and solar
- reducing the need for operating reserves from thermal power plants(typically high carbon coal and gas)
- Providing black start capability to restore the power system after a blackout.
- Provide grid ancillary services like frequency regulation, grid stability and reserves for reliability
- Storing for later use rather than shutting off during times when not needed
- Avoid paying for curtailed energy especially for thermal plants and solar and wind
- Avoid need to buy more renewables to compensate for curtailment and need to meet RPO targets.

Energy storage technologies are crucial to grid reliability and facilitate:

- Reduces system operating costs
- Less cycling and fuel costs (coal and gas)
- Ramp up and down quickly to accommodate over-generation
- Defers the upgrading of transmission lines
- Reduced Transmission Congestion
- Renewables generation from one state is stored in other state
- Flexibility to be able to Adapt to Market dynamics
- Flexibility to change operating profile as per the market changes
- Flexibility to change from day-ahead to hour ahead or real-time ramp up and down to accommodate needs of intra-hour balancing.

Energy storage technologies like fuel cells, batteries, flywheels, caverns filled with compressed air and thermal storage systems etc. are in nascent stages of development and projections in respect of costs, technical characteristics are not yet firmed up. PSPs are the only commercialized long duration energy storage technologies deployed at large scale and have a higher round-trip efficiency compared to other long duration storage such as compressed air energy storage and hydrogen.

Pumped hydro is a **rugged, long-lived, and mature technology** which has consistently proven itself for more than a century. Pumped storage hydropower capabilities can be characterized as:

- **Open loop** - where there is an on-going hydrologic connection to a natural body of water-or
- **Closed loop** - it is a self-contained “off-stream” water system with no need for new dams on main stem rivers, uses existing infrastructure and sidesteps the constraint of site availability thus minimizing environmental impacts. The large scale off-river PSP requires much smaller land area whereas, the small scale PSP can also be easily developed in different geographical areas.

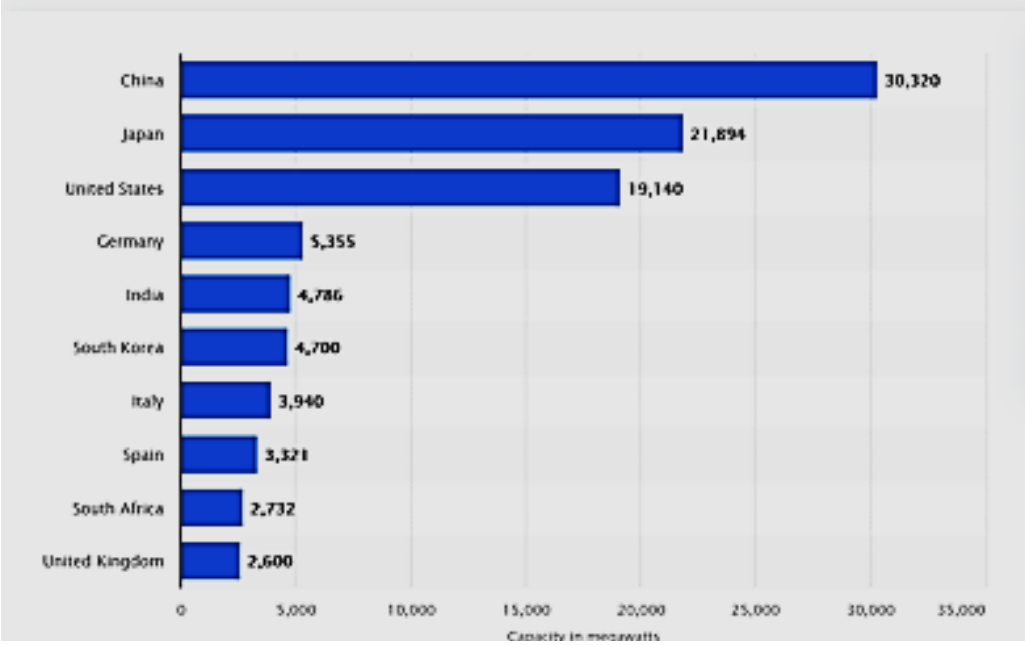
Low-cost surplus off-peak electric power is typically used to run the pumps. This project is operated when inexpensive electricity is available either from intermittent sources (such as solar, wind) and other renewable's, or excess electricity from continuous base-load sources (such as coal or nuclear) to be saved for periods of higher demand. Although the losses of the pumping process make the plant net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest and also helps in stabilizing, grid balancing.

2. CURRENT SCENARIO: GLOBAL & INDIA

By the end of 2020, there was 160 GW of pumped storage hydropower installed globally, comprising 95 per cent of all total installed energy storage. The top six PSP fleets are European Union, China, Japan, United States, India, and South Korea.

China has been responsible for most of the recent growth in pumped hydropower storage in recent years and also announced plans to double national capacity to 120 GW by 2030, a fourfold increase from 32 GW today in less than ten years. Data shows that, if all projects in the pipeline were completed, pumped storage capacity would almost double in future.

In-operation Projects



Capacity of PSP World-wide (2020) in MW

Pumped storage hydropower totalled 1.5 GW of the new additions in capacity, up on the 304 MW added in 2019. Most of this was in China (1.2 GW), with Israel also commissioning the 300 MW Mount Gilboa project under an innovative financing model. In 2020, global hydropower installed capacity reached 1,330 GW. Hydropower accounts for around 17% of global electricity generation today. The IEA estimates that pumped storage will account for 30% of hydropower capacity growth from 2021-30.

It is an energy resource that is set to grow globally, even in regions like Europe where hydropower capacity is more developed.

Indian Scenario

During the re-assessment studies completed by Central Electricity Authority in 1987, likely pumped storage capacity of 96529.6 MW was identified in the country. However, out of them, 19 schemes aggregating 30830 MW have not been found feasible and further, 36 additional schemes of 25695 MW capacity were identified. Accordingly, currently realizable PSS potential is 90294.6 MW from 80 schemes. Presently, 08 PSS (4745.6 MW) are under operation, 3 PSS (1580 MW) are under active construction, and construction is slated to begin shortly for 1 PSS (1000 MW), 1 PSS (1200 MW) has been concurred by CEA, 17 PSS (16770 MW) are under S&I/ DPR formulation stage. The summary of PSP development in the country is as under:

(As on 28.02.2022)

Description	**Pumped Storage**	
	Nos.	**I.C. (MW)**
Identified Hydro Capacity as per Re-assessment Studies of 1987	63	96529.6
I. In operation	8	4745.6
II. Under construction	3	1580
III. Allotted for development		
(i) Cleared by CEA and yet to be taken up for construction	1	1000
(ii) Under Examination/ scrutiny in CEA	1	1200
(iii) Under S&I	17	16770
Sub-total (i-iii)	**19**	**18970**
Total (I+II+III)	**30**	**25295.6**

Pumped storage potential in different states vary from as low as 570 MW in Bihar to almost 35,000 MW in Maharashtra. Further, some of the states like Andhra Pradesh are putting all out efforts for development of pumped storage potential while in other states the development of PSPs remains sluggish. The summary of PSP development across States in the country is as under:

Sr. No.	**State**	**Total Potential Identified**		**In- operation**		**Under-const.**		**Concurred/ UE**		**S&I (incl. held-up)**		**Balance Identified**	
		No.	**MW**	**No.**	**MW**	**No.**	**MW**	**No.**	**MW**	**No.**	**MW**	**No.**	**MW**
1.	Maharashtra	32	34965	2	400	1	80	0	0	2	1860	27	32625
2.	Gujarat	2	1440	2	1440	0	0	0	0	0	0	0	0
3.	M.P.	1	1440	0	0	0	0	0	0	1	1440	0	0
4.	Telangana	2	1605.6	2	1605.6	0	0	0	0	0	0	0	0
5.	Andhra Pr.	10	10600	0	0	0	0	1	1200	8	7750	1	1650
6.	Tamil Nadu	6	5300	1	400	1	500	0	0	2	1500	2	2900
7.	Karnataka	3	3960	0	0	0	0	0	0	2	3260	1	700
8.	Kerala	2	900	0	0	0	0	0	0	0	0	2	900
9.	Odisha	4	3920	0	0	0	0	0	0	3	1420	1	2500
10.	West Bengal	6	5010	1	900	0	0	1	1000	1	900	3	2210
11.	Jharkhand	1	2800	0	0	0	0	0	0	0	0	1	2800

12.	Bihar	2	570	0	0	0	0	0	0	0	0	2	570
13.	NER	10	16900	0	0	0	0	0	0	0	0	10	16900
14.	Chhattisgarh	0	0	0	0	0	0	0	0	0	0	0	0
15.	H.P.	2	3430	0	0	0	0	0	0	0	0	2	3430
16.	J&K	1	1650	0	0	0	0	0	0	0	0	1	1650
17.	Uttarakhand	2	2935	0	0	1	1000	0	0	0	0	1	1935
Grand Total		**86**	**97425.60**										

3. CURRENT TRENDS

The concept of off-river PSP is getting popular in recent years due to huge benefits arising out of its less capital cost/ operations. Therefore, with increased penetration of RES in the grid, PSPs can play a vital role in integration of RE sources in the national grid. There is also growing research on possibilities for retrofitting Discarded mines, open pit or underground mines, underground caverns, non-powered dams and conventional hydro plants for development of PSPs.

Off-river, closed-loop, pumped hydro schemes overcome many of these challenges. The upper reservoir for these schemes is located on hills or plateaus rather than in a river valley which substantially provides an extra head. The reservoirs are also typically small, of the order of tens to hundreds of hectares. This reduces the environmental impact and the need to manage large flood events, which substantially reduces construction cost. These projects, being located away from the main rivers may not involve any inter-state aspects too. Further, there would not be any need of huge dam and spillway/ structures and desilting chambers for the reservoirs to be located away from the main rivers. As such, these projects can be accomplished faster at a much lower cost as compared to conventional PSPs. The off-stream pumped storage projects (OS-PSPs) may supply power for future needs of our country without affecting the existing water/ irrigation system or river basin. They are expected to contribute a significant role in achieving RE capacity addition target.

India has 5264 large dams (National Register for Large Dams, CWC 2018) and provide an excellent opportunity for developing PHES between two large dams in cascade or using one dam and second reservoir on the hill top with very low impact on biodiversity and R&R issues.

- Tehri PSP shall be the first PSP in India to have variable speed vertical Francis type reversible Turbine and is scheduled to be operational in 2022, even though, there are a large number of such plants in Germany, France, Austria, Japan and USA etc. Detailed Studies for identification of sites for off-river closed loop system in India are, however, yet to be undertaken.

4. CHALLENGES

The existing pumped storage projects as well as the proposed new developments faces challenges in terms of (a) regulatory and market hurdles (b) not proper valued (recognized) for the roles they play in providing grid reliability and security services and (c) are neither compensated adequately, nor uniformly, in the present energy market.

There is a requirement to develop market mechanisms and broadly accepted economic models that evaluate energy storage technologies based on their abilities to provide key supporting services to the overall electric grid, particularly when taking into consideration project lifecycle costs, performance and energy storage system degradation.

Some of the other challenges in development of PSP, similar to any other conventional Hydro project, are;

- Delays in Environmental and Forest Clearances
- Land acquisition issues and R&R issues resulting in Local agitation/ Law & Order problems
- Lack of adequate infrastructure/ roads and bridges
- Contractual issues and Funding Constraints
- Geological uncertainties/ surprises
- Power evacuation issues

5. FUTURE SCOPE FOR DEVELOPMENT

Policymakers should assess the long-term storage needs of their future power system, so that the PSPs, which may take longer to build, are not lost. Comparisons between energy storage and flexibility options must follow a consistent, technology

neutral approach that considers all impacts and benefits. Providers of essential electricity grid, storage, and flexibility services should be remunerated for all services that they provide.

Investors in long lasting assets like PSP, must have long-term visibility of revenues, with risk that is shared fairly to deliver the lowest overall cost to society in the long term. Existing hydropower assets and prospective sites should be assessed and mapped for their potential to provide the most efficient long duration storage. Green programmes should include and support PSP, and green finance mechanisms should incentivize PSP.

For undertaking development of PSP in India the existing data on PSPs needs to be reviewed with identification of possible sites using remote sensing data for off river, discarded mines etc. Relaxation in various clearances including the environment and forest clearance may be given especially to Off-the-River close loop type PSPs, Off-the-river open loop type PSPs, On-the-River PSPs on existing reservoirs. It may be appreciated that Off-the-River PSPs being located away from the river course do not involve any longitudinal connectivity issues or E-flows requirements. As described earlier, there is virtually no impact of such projects on river eco-system and these are likely to involve minimal Land Acquisition and R&R issues. As no reservoir is located in any river, the project shall not require flood mitigation arrangements, Silt management arrangements and Diversion arrangement during construction and hence project costs shall be optimized. As such, these projects can be treated differently from conventional hydro projects in order to have faster clearances and consequently quicker implementation of such projects. Similarly in case of On-the-River PSPs proposed on existing reservoirs, there would be minimal impact on the environment as both the reservoirs would be existing and only the Water Conductor System and Power House (mostly underground) associated with PSP would need to be constructed. In light of this, need for public hearings and requirement of 3-season data for such projects can be reviewed.

Further, the construction cost & time of off -river PSP schemes are more predictable as there are less uncertainties such as flash floods etc. and location may be selected near to Renewable Energy Centres & Transmission lines. It is generally easier to select an alternative nearby site if problems arise relating to geology, hydrology, road access, power line easements, land ownership, indigenous rights, environmental impacts or social opposition.

6. WAY FORWARD

Government has already taken various measures to promote hydropower including Pumped Storage projects as under:

- Policy Measures notified by Ministry of Power in March 2019 including Tariff Rationalization Measures & Budgetary support for Enabling Infrastructure i.e., Roads/Bridges, which would be beneficial in reducing the cost of development of Pumped Storage projects.
- Inter-state transmission charges have been waived off if atleast 70% pumping requirement is met from RE sources, by Ministry of Power in June 2021.
- Bundling of RE Power with PSP has also been notified by Ministry of Power in November 2021.
- Pumped Storage developers can avail financial assistance under Viability Gap Funding Scheme of Ministry of Finance according to applicable guidelines.

Further, the policy support, which may be required for incentivizing investments in PSPs may include the following:

(i) Treating the PSPs as “System Tool” rather than a typical hydroelectric project and putting them at the disposal of the Grid Operators for their operation more as a Grid Balancing Project

(ii) PSPs to be categorized as “must and first run Projects” during variable and intermittent generation

(iii) Evaluation of PSPs in terms of Transformation cost of Energy (from off peak to peak) needs to be done

(iv) Making available low interest bearing long term loans for PSPs would boost their development

(v) Involvement of CPSUs in a big way for development of PSPs

A Committee was constituted in March 2021 under the Chairmanship of CMD SECI, with the members from MoP, MNRE, and CEA & POSOCO to suggest ways and means for encouraging/ incentivizing/ making pump storage projects commercially viable, keeping in the view the need of large scale RE integration with the grid and achieving a smoother energy transition. Some of its Key Recommendations are discussed below:

- Inter-state transmission charges may be waived off if atleast 70% pumping requirement is met from RE sources. (since notified by MoP in June 2021)
- Bundling of RE Power with PSP (since notified by MoP in November 2021)

- GST may be reduced to around 5% on machine items used in PSP.
- Debt equity ratio of 80:20 instead of 70:30 is proposed for funding of PSPs
- CERC may facilitate Hydro PSPs through regulatory framework, for example, in providing connectivity, giving priority in LTA/MTOA (Long Term Access / Medium Term Open Access, etc.
- Peaking tariff be appropriately modified by CERC to make the PSP more viable.
- The cost of production of electricity from Solar, Wind & Thermal power in the country has come down to record low i.e. Solar PV from Rs.12.16/ kWh in Dec. 2010, to about Rs. 2/kWh Dec. 2020, Wind power from around Rs. 5-6/kWh in Feed-in-Tariff regime to about Rs. 2.41/kWh in Dec. 2020 and for Thermal power, tariff as low as Rs. 3.26/kWh. On the other hand, average initial tariff of new hydro projects, is generally more than Rs. 5/kWh, which is substantially higher than the average power purchase cost (about Rs. 4 per unit) of the DISCOMS. Therefore, Rationalization of Tariff (Peak and Off-Peak) is required especially for PSPs.

It is proposed that a rolling 5 to 7 years Resource Adequacy Plan including reserve and storage requirements for grid balancing and grid security should be prepared. Based on the above, POSOCO shall regularly identify requirement of Primary, secondary and tertiary reserve for peaking and ancillary service requirements. Accordingly, the reserve capacity/ storage capacity procurement be through the competitive route with power purchase agreement for a period of at least 15 years. This competitive procurement of reserve capacity could be in three time frames i.e the reserve capacity that is required to be added in time frames of (i) 0-3 years (short term for existing unused capacity), (ii) 4-7 years (for new capacity like Hydro PSP, BESS also) and (iii) for more than 7 years (for long term assets like Hydro PSP). Procurement can be through mix mode i.e. around 80% to 90% of the plant capacity is committed through power purchase agreements and remaining 10% to 20% of the Capacity can participate in the energy market and/or ancillary services/ ancillary services market etc.

Renewable Energy Certificate (REC) may be issued for each Mega Watt Hour (MWh) of generation from Hydro PSP. REC may be issued to the procurer of electricity and procurer can sell these RECs in the REC market and mitigate his risk.

7. CONCLUSION

Though many forms of energy storage systems have been installed globally, Pumped Storage Plants (PSP) are playing an increasingly important role in providing peaking power and maintaining system stability in the power system of many countries. Pumped storage technology is the long term technically proven, cost effective, highly efficient and flexible way of energy storage on a large scale to store intermittent and variable energy generated by solar and wind. PSPs improve overall economy of power system operation and reduce operational problems of thermal stations during low load period. The other advantages of pumped storage technology are availability of spinning reserve at almost no cost to the system and regulating frequency to meet sudden load changes in the network. Also, PSPs provide environmental friendly large storage capacity compared to other storage options. It also has the ability to provide ancillary benefits such as flexible capacity, voltage support and Black start facility etc. PSP technology can be effectively utilized to address many issues in power sector e.g. allowing thermal power plants to operate at peak efficiency, energy-balancing, providing operational flexibility and stability to the power system etc. as well as much needed support to the intermittent generation by solar and wind energy.

PSP projects are highly site-specific in their performance, costs, and impacts. Therefore, it is important to focus on the processes that lead to sustainable systems, not just on PSP performance and cost indicators.

Therefore, PSP should be considered as a key enabler of the clean energy transition, alongside other energy storage technologies. The development of PSP projects should rely on a multi-level approach, including an assessment of the storage, flexibility, and ancillary services that a given power system needs; an assessment of the options available to meet those needs; and, once selected, the PSP project should be managed to avoid, minimise and mitigate social and environmental impacts. PSP projects, as with many hydropower projects, can generate one-time or permanent local benefits, which should be considered in their sustainability assessment.