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Potential of PSPs in India and Cost Economics

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Pursuant to the commitment for a Net Zero Carbon emission by 2070, India is undertaking aggressive power generation transition from fossil fuel based to the Renewable Energy Sources. India has established several targets for renewable energy (RE) capacity in the coming years as announced in September 2015, at the United Nations Climate Action Summit (COP 21), most notably the target of deploying 175 gigawatts (GW) of renewable energy generation capacity by 2022. Later on in COP 26 it was raised to 500 Gigawatts (GW) by 2030 when 50% of the energy shall be derived from RE sources.

Out of 500GW of RE sources, 420GW will be from VRE (Variable Renewable Energy) only comprising wind and solar energy sources. The Indian power grid is going to be fully loaded with generation from VRE by 2030. By the virtue of their intermittency in nature of generation, the Indian grid is anticipated to be subjected to instability due to sudden addition and withdrawal of generation from VRE. Hence there may be huge surplus from VRE during non-peaking hours that need to be curtailed or store them in the some energy form to be derived during the peaking requirement. Addition of renewable energy into the grid would be the mainstay for energy for the next 50 years.

India has been on full drive to add more and more Renewable sources specially the solar and wind sources of generation. These are highly intermittent sources of energy, and the generation of power from these cannot be accurately predicted. Moreover, power from these VRE sources cannot be dispatched based on real-time demand.

World scenario

Pumped storage project comprises about 96% of global storage power capacity and 99% of global storage energy volume.

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Table 1

	Country	Installed Capacity
1	China	36390
2	United States	21912
3	Japan	21894
4	Germany	5212
5	India	4786
6	South Korea	4700
7	Italy	3940
8	Spain	3331
9	South Africa	2732
10	Taiwan	2602
11	United Kingdom	2600

The world scenario of PSPs up to 2021 is shown in Table 1:

Indian Scenario

All India installed capacity from various power sources as on 31.01.2023 (1) is as shown in Table 2:

Out of 500GW of RE sources, 420GW will be from VRE by the year 2030. Since pumped storage projects are having more advantages over the other form of energy storage, Government of India is focussing on development of pumped storage projects.

When we look at the generation over the last 5 years, there has been a decreasing trend of generation from. Thermal and increasing trend for RE generation. In between them hydropower has been flatly maintained at around 11% over many years. A graph showing the trend of addition of RE sources is given in Fig.1.

RE sources from wind and solar are called VRE (variable renewable sources) as their generation matching with the demand in the grid cannot be controlled. There is a paradigm change in our power system operations with addition of more and more VRE in the grid. In the past, fully-controllable power generation followed non-controllable load demand. Now with the variable renewable energy (VRE) sources, generation is no longer fully controllable. Variability in RE sources due to weather fluctuations means uncertainty in generation output. This requires the adoption of grid-scale energy storage technologies to complement the sources.

Table 2

Fossil Fuel	Installed capacity in MW	Total capacity
Coal	204435.50	
Lignite	6620	
Gas	24824.10	
Diesel	589.20	
Total fossil fuel		236468.91
Non fossil Fuel		
Hydro	46850.17	
Wind, solar and other RE	121549.52	
Wind	41983.18	
Solar	63893.83	
BM power/cogen	10209.81	
Waste to energy	523.05	
Small hydro	4939.65	
RE sources		168399.69
Nuclear		6780
Total non-fossil fuel		175179.69
Total installed capacity		411648.60

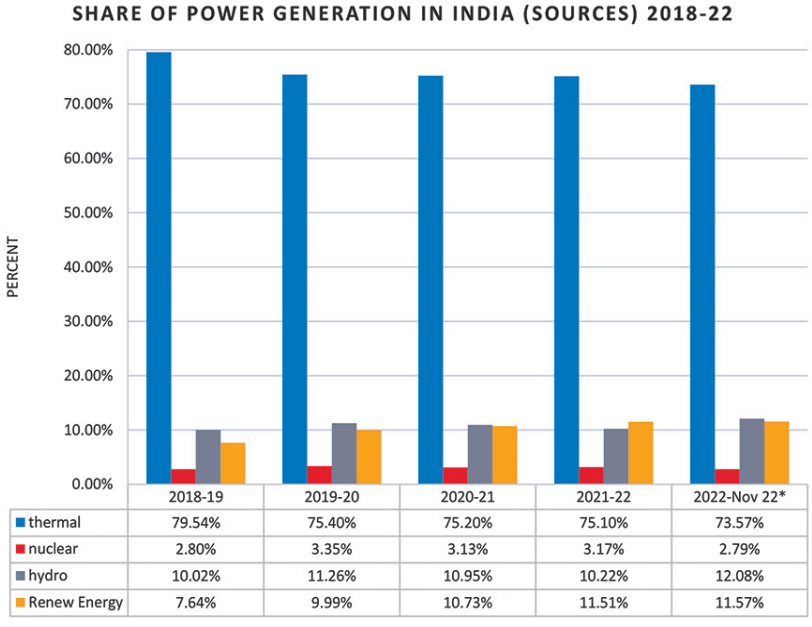

Figure 1

Recently Government of India has taken big initiative by roping in the CPSEs for development of pumped storage projects in the country. PSP is getting the much awaited attention in the country. As per a study done by a the CEA, pumped storage requirement by the year 2030 is forecast as 18.8GW.

Pumped storage plants are highly useful options for the integration of RE power with the power system. PSPs are storage systems based on hydropower operations between two or more reservoirs (upper and lower) with an elevation difference. At the time of demand, downward water flow under the gravity generates electricity with hydraulic turbine and water is pumped back to the upper reservoir using power from grid or RE sources. The system has an overall efficiency of 75-80%.

In India, there is a PSP potential of about 120GW and identified at about 120 sites. Our country has 5745 large dams, which provide an excellent opportunity for developing pumped storage projects by placing the plant in between two large dams at different elevation, or by using one dam and create a second reservoir on a hill-top in a manner that will have a very low impact on biodiversity and involve few resettlemt and rehabilitation (R&R) challenges. Hence many more PSP sites are likely to be identified.

Total installed capacity of PSPs in India is 4745.60 MW[2]. However presently 2612MW is operating in pumping mode from various due to issues like construction of lower reservoir, machine vibration issue etc. (Table 3)

India has huge potential of pumped storage projects, which can be developed in coming years. This would require proper engineering planning, site investigation, economic business model, favourable government policies.

Economics of PSPs

Pumped sorage hydro is a mature technology that includes pumping water from a lower reservoir to a higher one where it is stored in the form of potential energy until needed to be retrieved. The water, when released from the upper reservoir work against gravity through a turbine and generates electricity.

Table 3

	Name of the Projects	State and Owner	Capacity in MW
1	Kadamparai PSP	Tamilnadu,TANGEDCO	400
2	Purulia PSP	West Bengal, WBSEDCL	900
3	Srisailem Left Bank PSP	Andhra Pradesh, AP GENCO	900
4	Ghatghar PSP	Maharashtra, MAHAGENCO	250
5	Bhira PSP	Maharashtra, TATA	150
6	Paithan PSP(Jayakwadi Dam)	Maharashtra. MAHAGENCO	12
	Total		2612

Pumped storage projects are classified into 3 configurations:

1. ON stream pumped storage schemes where both reservoirs are located on any perennial river/stream.
2. OFF stream pumped storage scheme-open loop where one of the reservoir is located on any perennial river/stream.
3. OFF stream pumped storage scheme closed loop where none of the reservoirs is located in on any river/stream.

Pumped storage projects generally being accepted in the energy sector to be a viable option of energy storage. Technology of pump-turbine coupled with generator-motor offer different features and capabilities, including fixed speed, variable speed and can support the ancillary services like ramping up and down, voltage increase and decrease required for the grid. A pump-turbine can change its mode from pump to generator within 10-15 minutes and vice versa.

A pumped storage project now-a-days is designed for operation for a period of 6 hours of generation and pumping for 7-7½ hours. Accordingly, upper and lower reservoir capacities are created.

During the pumping mode, water is pumped by the same pump-turbine (in reverse direction) from the lower reservoir to the upper reservoir working against the resistances of hydraulic losses in the water conductor system. Depending upon the pump capacity of the pump-turbine and the discharge it has to deliver to the upper reservoir, the required time of pumping and pumping power consumption would vary. This gives rise to the basic difference of PSPs from conventional hydro projects, where the input power for operating a PSP in pumping mode is more than what is delivering during generating mode. The percentage ratio of output power to input power is termed as the cycle efficiency of the plant. Normally the cycle efficiency of any techno-economically viable PSP varies from 75% to 80%. Cycle efficiency is one important factor that distinguishes a PSP from the conventional hydro project.

The pumped storage projects offer multifunctional roles to the grid/market:

1. RE smoothing: During the large scale integration of the VRE into the grid, PSPs help to smooth out the excess generation by storing in form potential energy in the upper reservoir.
2. Seasonal storage: VRE generation from solar and wind vary seasonally. PSPs has the ability to meet the seasonal mismatches arising out of VRE generation.
3. Peak load shaving: PSPs are effective in peak load management of the grid by storing the surplus energy during off-peak hours and supplying it when the demand is high.
4. Energy arbitrage: PSPs prove to be economical in daily energy arbitrage business as it buys energy during off-peak hours when the price is less and sell it during the peak hours when the price is high.
5. Load following: PSPs with the fast ramping up and down capability, maintains the stability in the grid by taking care of the sudden changes in load.
6. Ancillary services: PSPs provide voltage support to the grid by generating/absorbing reactive power, maintains the grid frequency within the desired range, acts as a spinning reserve during generation failure or power shortage, and energises part of the grid or generation station during unplanned events or blackouts.

Two aspects which assume importance before taking up any PSPs besides the pertaining technical issues are as follows:

- Economical cost of the project
- Gestation period of the project

There is a myth among the general people and treat the PSPs are same as the conventional hydro projects. PSP locations are so selected that unlike hydro projects, most of the PSPs are least affected by any geo-hazards like avalanches, GLOF, LLOF, Avalanches, flash flood etc which enhances the safety of the project. Myths are to be broken that PSP encounter obstacles similar to those conventional hydro projects. Uninterrupted flow of the stream/river in the downstream of the dam, destruction of aquatic life, degradation of forest cover, displacement of population etc. are the least that are encountered in most of the PSPs.

Need of the time is to transform the mindset of the planners, intellect and other stakeholders to understand that PSP is not merely a generator of hydro energy which needs to recover its cost by selling power at a determined tariff to the beneficiaries/

consumers, but it is to be treated as a bankable consumer of energy which store surplus energy during the period of excess generation avoiding the cost of RE curtailment and honestly supply back at the time of demand. When water is being pumped from the lower reservoir to the upper reservoir, the PSP draws power from the grid or captive RE sources and acts as a consumer, whereas at the time of releasing water and generating energy, it acts as a energy generator. Hence, there is a need for developing a differential pricing mechanism for PSPs during its pumping and generating mode.

Tariff of the PSPs are computed as per the CREC Regulation 2019-24. As per the regulations, the tariff for a PSP includes fixed cost and variable cost components. The fixed cost component, or capacity charge, is to recover the capital cost incurred on the plant on an annual basis such as plant and machinery, manpower, and administration cost. The variable cost component, or the energy charge, is used to recover the cost incurred during the operation of the plant. It is calculated at a flat rate of 20 paise per kWh of the total energy scheduled (in excess of the design energy) plus 75% of the energy consumed in pumping from the lower reservoir to the upper reservoir.

Tariff of the PSPs are higher than the conventional hydro, as it comprises the conversion cost and pumping energy cost. Conversion cost is amounted to the storage cost of the PSPs and depend on all direct charges which include one or two water reservoirs with dams, intake structures, water conductor system and a power station with electro-mechanical components etc. Indirect charges are computed in percentage of the direct charges. Project cost comprises direct charges, indirect charges, contingency and GST @18%.

The capacity charges of a generating station (PSP) are derived on the basis of Annual Fixed Cost (AFC) which consist of the following components:

(a) Return on equity;
(b) Interest on loan capital;
(c) Depreciation;
(d) Interest on working capital;
(e) Operation and maintenance expenses:

Parameters considered for computation of the tariff of PSP are similar to the conventional hydro project as per the regulation shown in Table 4:

- Rate of interest for the debt is taken @ 11-12% depending upon the company's financial soundness and balance sheet. NTPC consider the ROI @ 8 to 10% which (changes from time to time) reduces the IDC (Interest during construction) to an appreciable amount.
- Loan repayment period may be varied from 12 to 18 years which impact the storage cost of PSPs.
- ROE is normally considered to be at 16.5%. However this can be further reduced to make the cost and tariff attractive.

Conversion cost of PSPs is comparatively attractive in comparison with equivalent size of the conventional hydro project. Few factors which influence the overall project cost and economics of the PSP are as follows:

Table 4

1	Debt: Equity ratio	70:30(%)
2	Rate of O&M charges	3.50%
3	Annual increment in O&M charges	4.77%
4	Spares (15% of O&M charges)	15.00%
5	Rate of interest on working capital	10.50%
6	Return on equity	16.5%
7	Rate of depreciation	5.28%
8	Discounting rate (calculated)	9.20%
9	Auxiliary consumption (underground PH)	1.20%
10	Plant useful life (except civil structures which is considered to be 75 years)	40 years

1. Short length of HRT (head race tunnel) and water conductor system and closeness of the structures; Closeness of different components of the project is desired. Compactness of the project will result in shorter length of the water conductor system, mainly the HRT, pressure shaft and tailrace tunnel. Shorter length of the water conductor system will reduce cost and time.
2. Low L/H ratio: Ratio of the L/H (length of water conductor/ gross head) system may be as minimum as possible. Normally, it ranges in between 10-12. However, this is not the only criteria for economic evaluation of the PSP. Some of the projects may have higher L/H ratio, but do not affect the economy of the project e.g in case PSP is constructed in between the existing reservoirs where there is least possibility of reducing the WCS beyond certain limit. In such case, even with higher L/H ratio, total cost of the project is economical as construction of new reservoirs is avoided.
3. Variation of head and adoption of variable and non-variable speed machines: Variation of the head in the PSP gives rise to the criteria of the selection of the variable speed machines. Normally, as per the manufacturers' practice, if the ratio of maximum head to minimum head is within 1.3, fixed speed machines are selected and for higher ratio, variable speed machines are adopted. Adoption of the variable and non-variable speed machines impact the cost of the electro-mechanical equipment. There is an increase of cost of EM equipment by 30-50%, Powerhouse size increase by 25-30%, PH civil cost by 20% for adopting the variable speed machines. As per the new concept, a mix of variable and non-variable speed machines are considered for operational flexibility of the plants. However, addition of the variable speed machines increase the cost of the project.
4. Good topography and geology: Good topography and geology is essential for the projects. In case project is located in south Indian region where geology is very competent, less surprises are expected during the construction period in comparison with projects located in

Himalayan region. A good geology aid in the construction schedule of the projects and promise for timely completion.

5. Moderate gestation period of the project: The time of completion of the pumped storage projects is much less than the conventional hydro projects. It is well kwon that one of the private developer who is doing the much talked about PSP in Andhra Pradesh has set a completion time of 36 months. It is uncertain to say that such a time period will be possible in all types PSP. But one thing is sure that, the time of completion of the PSPs could be much less provided detailed planning is done during the pre DPR and DPR stage. Preconstruction activities will have to be given priority during DPR stage. If the PSPs are developed with new dam/dams, reservoir impounding time will have to be considered.
6. Adopting higher machines speed: The specific and the synchronous speed of the machines are based on the power, discharges and the head. With a calculated head of the plant, if the speed of the machines are selected to be higher (within the limits of standards), machines sizes are reduced leading to economy in civil works like sizes of power house building, reduction on the weight of the EOT cranes in addition to EM cost. Hence it would ultimately result in economy of the plant.
7. Size of the units: It is understood from the manufacturers that cost of the bigger units of machine in PSPs are economical than the small size machine for the same capacity plant. Hence a balance is to be maintained while selecting the unit sizes.
8. PSPs with existing reservoirs: Considering the large number of existing reservoirs, PSP can be planned in between these reservoirs where adequate head is available. One reservoir at the higher elevation will act as the upper reservoir and at lower elevation will act as the lower reservoir. The length of the water conductor system may be longer than the usual PSPs and hence the higher L/H ratio, but the project cost is economical as additional cost for construction of dam and reservoirs is avoided.
9. Multiple cycle of operation: It intend to increase the energy generation from the plant. More energy is generated, less is the storage cost of the plant. An example of one of the PSPs with 6 hours of generation and 7 hours of pumping for 1 cycle and 1.5 cycle operation is indicated in Table 5:
10. Forest diversion area and R&R issues: PSPs with smaller forest land diversion offer the advantage in terms of lowers NPV and cost of land for afforestation. Further minimum or zero R&R means less resistance to the project execution and lower compensation and lower gestation period. This lowers the project cost and economizes the project.
11. Transmission line: Dedicated transmission lines at appropriate voltage level are to be constructed for connectivity to the grid for supply of power to the beneficiaries. Cost of the transmission system up to the pooling points is required to be included in the project cost. However there has been a demand from the PSP developers to include the cost of the dedicated transmission lines in PSP policies for reimbursement as an infrastructure development expenditure.

Table 5

Parameters	1 Cycle operation	1.5 Cycle operation
Daily hours of generation	6Hrs	9Hrs
Daily hours of pumping	7Hrs	10.5Hrs
Annual power		
a. Annual generation	2496.40 MU	3697 MU
b. Annual pumping	3184.44 MU	4776.66 MU
c. Cycle efficiency	78.40%	78.40%
f. Total cost (including IDC & FC)	4411.67	4411.67
Cost per MW (in Cr.)	3.67	3.67
Storage cost (in Rs/KWh)	3.39	2.26
Conversion cost KWh including RoI @ 11 % and pumping cost of Rs. 2.50 per unit		
a. Levelized	6.62	5.49
b. First Year	7.07	5.79

Conclusion

Developing PSPs is overdue in Indian power grid. Percentage of VRE plant capacity in the grid is already creating imbalance in grid. Hence PSPs should be looked into as a reliable grid regulation asset. A number of PSPs may be developed in the country in decentralized manner. Participation of grid regulators and discoms for operation of PSPs will deliver a better outcome for maintaining the stability of the grid.

Apart from the competent technical selection of the pumped storage projects, the project cost is needed to be moderated to make them economically viable. In order to implement pumped storage projects with economic viability, Government policy support is required. Incentives in terms of reduction of GST, waiver of ISTS charges, budgetary support for enabling infrastructure would reduce the project cost and make these projects more attractive economically.

Further to the above, services from the PSPs may be monetised to the advantage of the projects. The services from the PSPs like spinning reserves, reactive support, black start, peaking supply, tertiary and ramping support, faster start-up and shut down which would help grid stability may be monetised. PSPs would also reap economical benefit when the tariff for peaking and non-peaking hours of generation is notified.

References

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