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International Conference on
HYDROPOWER AND DAMS DEVELOPMENT FOR WATER AND ENERGY SECURITY – UNDER CHANGING CLIMATE

New Delhi
Central Board of Irrigation & Power

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Indian National Committee on Large Dams

International Conference on

Hydropower and Dams Development for Water and Energy Security – Under Changing Climate

April 07 – 09, 2022 at Rishikesh

Need of Paradigm Shift for Pump Storage Development

April 08, 2022

175 YEARS OF IIT ROORKEE

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Overview of India's Electricity Market

- India, third largest producer and consumer of electricity globally, with annual electricity production between 1200-1300 TWh.
- Indian power grid one of the largest synchronous power grids
- India witnessed a peak electricity demand surpassing 200 GW in 2021.
- As per CEA, the storage requirement of 41 GW by 2030 has been forecasted and thus energy storage is getting much awaited attention in the country.
- At COP-26 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.

Energy Transition

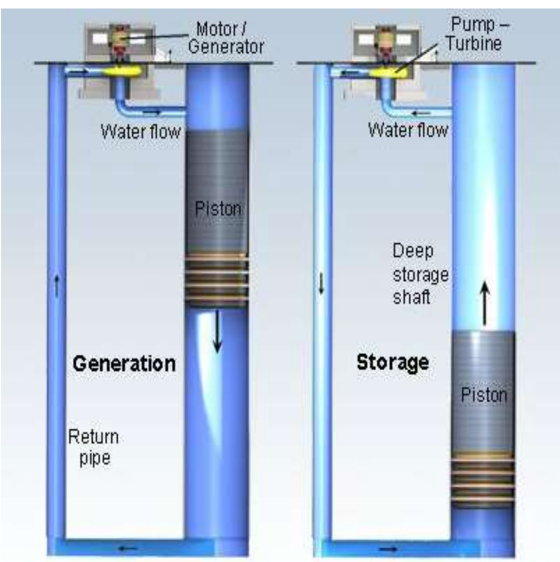
- There is a paradigm change in Power System operation now with the large scale variable renewable energy (RE)
- In the past, fully controllable power generation was following non-controllable load demand. now with renewable energy sources, power generation is no longer fully controllable.
- The variability 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.
- Pumped Storage hydro (PSH) projects are System Operator's Tool and utility scale option to enable smooth transition of energy from conventional sources to renewable sources.

Pumped Storage Hydro (PSH)

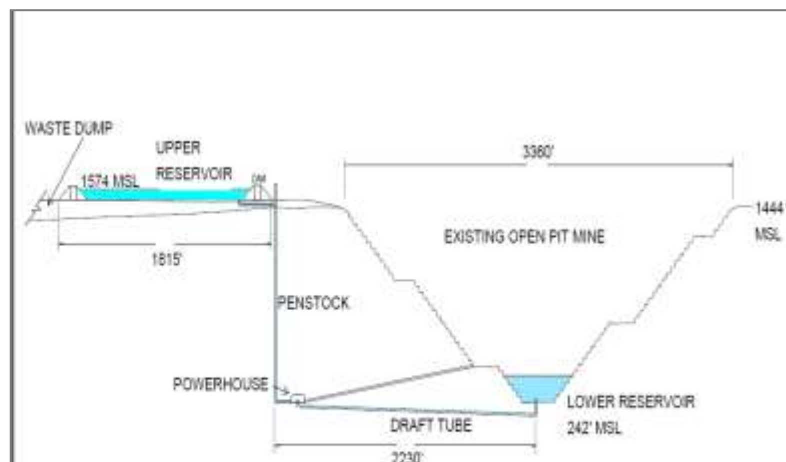
- PSH has advance technology in recent years with the capability for very fast response to grid and an increased flexibility for development of closed loop of river systems.
- closed loop pumped storage system:.
    - A self-contained "off-stream" water system,
    - No need for new dams on main stem rivers,
    - Uses existing infrastructure and
    - 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.
- PSH technology development is on continuous improvement in terms of availability, reliability and cycle efficiency Unit size, head range and reaction time.

Taum Sauk, 450 MW PSP, Missouri, USA

Okinawa Seawater Based PSP, Japan (30 MW)



Gravity based PSH



PSH In Discarded Mine Sites

Comparing PSH with Other Energy Storage Technologies

- PSH is one of the most mature technologies and has high round trip efficiency.
- PSH also has a greater number of storage cycles and a longer total lifetime compared to chemical batteries.
- PSH achieves economies of scale for high capacity, long-duration energy storage
- International Forum for pumped storage hydropower has brought out several reports on PSH covering policy framework, cost, technology and sustainability. Cost and performance characteristics were analysed for the state of technology development in 2020 and projected characteristics in 2030.

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

Potential for PSP

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
	115	125,230

PSP under planning

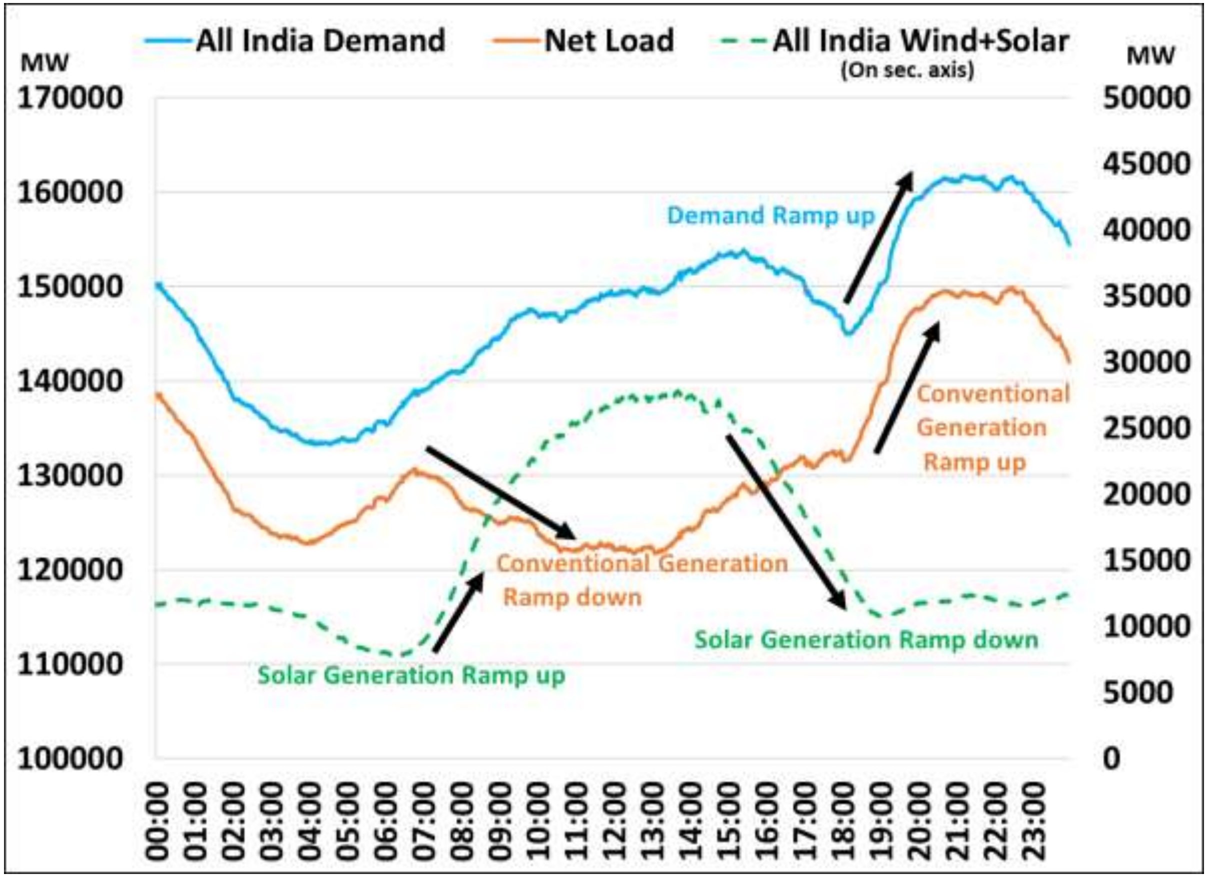
Sl. No.	Name of project	Sate	Installed capacity (MW)	Agency	Present Status
1.	Upper Indravati	Odisha	600	OHPC	DPR to be prepared by June 2022
2.	Balimela	Odisha	500	OHPC	DPR to be prepared by Dec 2022
3.	Upper Kolab	Odisha	320	OHPC	DPR to be prepared by Dec 2022
4.	Sharavathy	Karnataka	2,000	KPCL	DPR to be prepared by June 2022
5.	Saundatti	Karnataka	1,260	Greenko	DPR to be prepared by June 2022
6.	MP 30 Gandhi Sagar	Madhya Pradesh	1,440	Greenko	DPR to be prepared by June 2022
7.	Kodayar	Tamil Nadu	500	TANGEDCO	DPR to be prepared by Dec 2022
8.	Sillahalla St–1	Tamil Nadu	1,000	TANGEDCO	DPR to be prepared by Aug 2022
9.	Upper Sileru	Andhra Pradesh	1,350	APGENCO	DPR is likely to be submitted shortly, 9 clearance have been obtained.
10.	Kurukutti	Andhra Pradesh	1,200	NREDCAP	DPR to be prepared by March 2023
11.	Karrivalasa	Andhra Pradesh	1,000	NREDCAP	DPR to be prepared by March 2023
12.	Gandikota	Andhra Pradesh	1,000	NREDCAP	DPR to be prepared by March 2023
13.	Owk	Andhra Pradesh	800	NREDCAP	DPR to be prepared by March 2023
14.	Somasila	Andhra Pradesh	900	NREDCAP	DPR to be prepared by March 2023
15.	Chitravathi	Andhra Pradesh	500	NREDCAP	DPR to be prepared by March 2023
16.	Yerravaram	Andhra Pradesh	1,200	NREDCAP	DPR to be prepared by March 2023
17.	Warasgaon	Maharashtra	1,200	GoMWRD	DPR to be prepared by Dec 2022
		Total	16,770		

India-Opportunities and recommendations

- The CEA study of optimal generation mix for the year 2030 suggested that battery storage of **27 GW for 4 hours and PSH of 10 GW** is required to sustain the added RE into the grid.
- Govt of India mandates an Hydro power obligation target of **2.82% by 2029-30**.
- The benefits of PSH can be shared across **state and national boundaries**. The policy frameworks that share the costs and benefits can increase the overall consumer and citizen benefits.

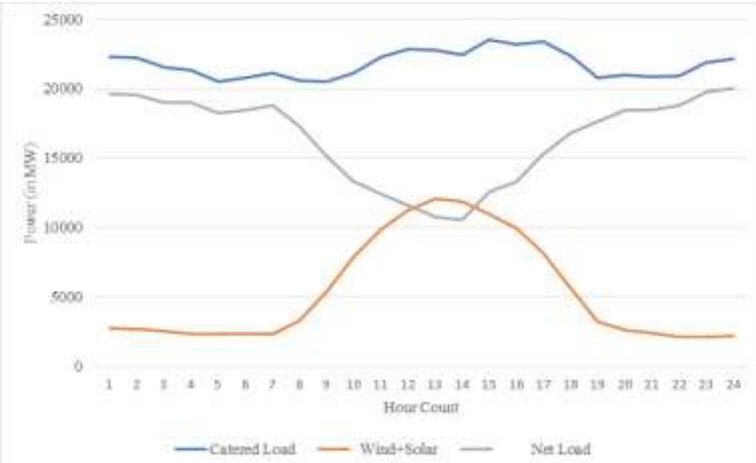
Typical Net Load Pattern

Y - Axis for
All India Demand



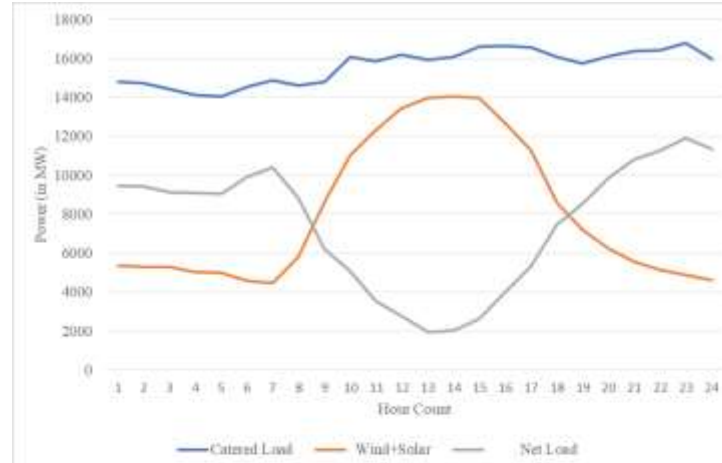
Y - Axis for
All India Wind and Solar

Source: POSOCO

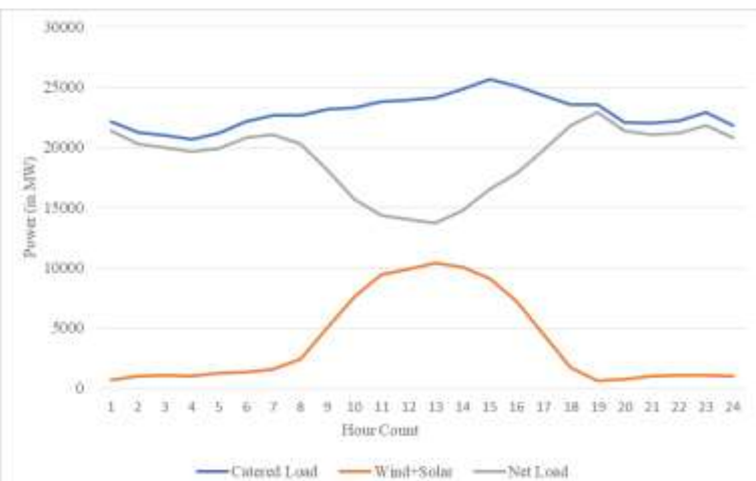


Net load Profile for 14-04-2024

Forecasted demand for 2024 in Gujarat

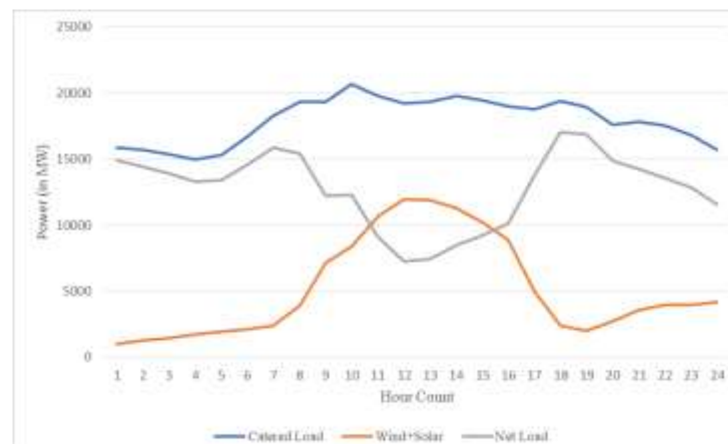


Net load Profile for 08-10-2024



Net load Profile for 05-07-2024

Installed capacity in 2021 Gujarat	
Technology	Capacity MW
Thermal Coal	16,037
Thermal Gas	4,683
Hydro	864
Wind	8,969
Solar	6,158
Total	36,711



Net load Profile for 13-12-2024

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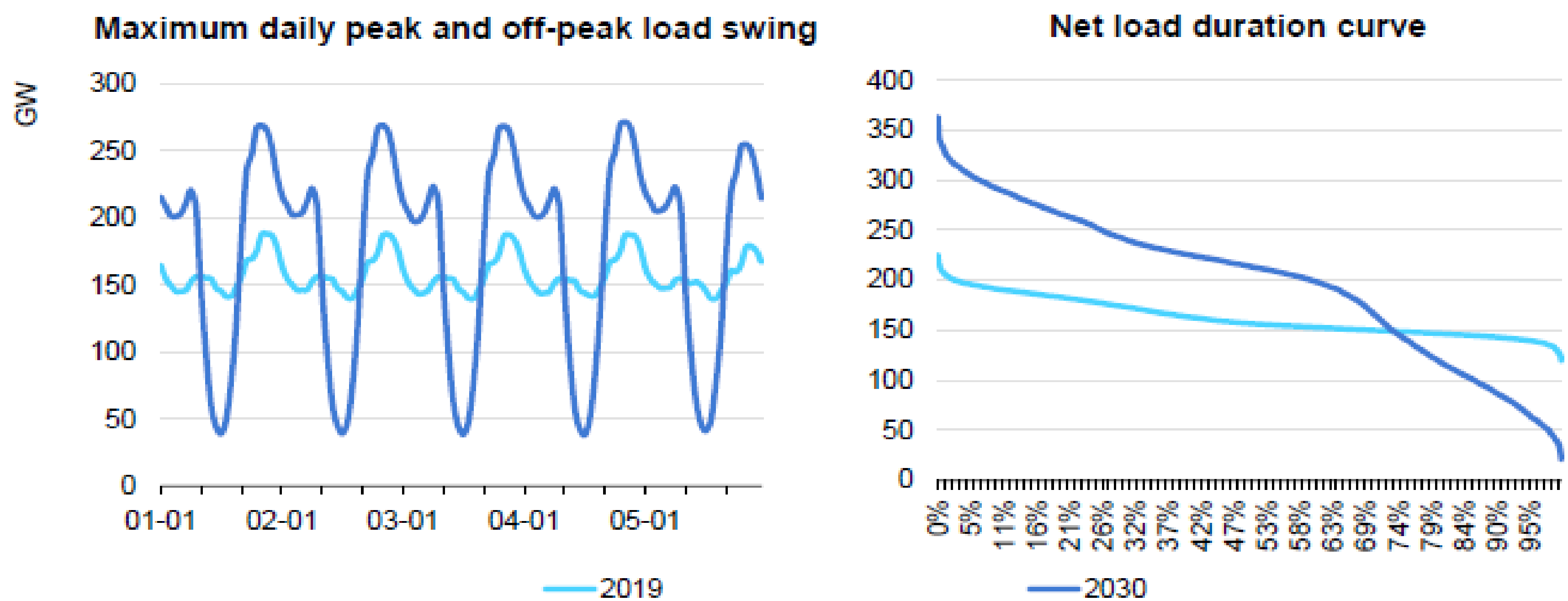
India load swings and load duration curves, 1-5 January 2019 and 2030 (according to the WEO STEPS scenario)



Notes: WEO STEPS = *World Energy Outlook* Stated Policies Scenario. The net load duration curve represents the net demand profile of the entire year from highest value to lowest, with the x axis representing the number of periods in the year in which net demand exceeds that value.

Source: IEA forthcoming, India Regional Model.

Source: IEA (2021), Hydropower Special Market Report, Analysis and forecast to 2030

Andhra Pradesh IRESP: Layout

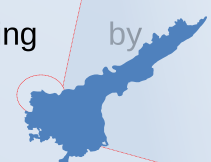
Project details and illustrative site layout (Andhra Pradesh)

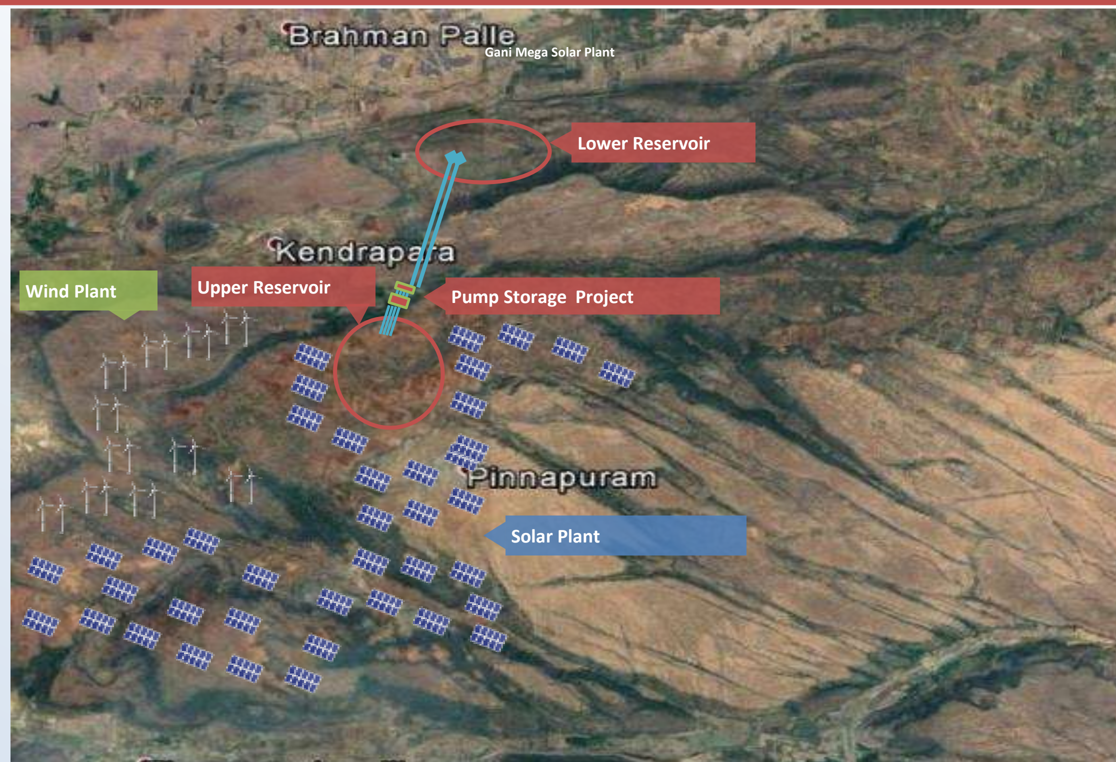
Location

1200 MW PSP in near Kurnool, Andhra Pradesh

Details for Round the clock (RTC) project

- Solar + Wind: 3500MW
- Storage: 1200 MW
- Key Features:
  - Caters to RTC, Fixed and Peak Power requirements
  - Commissioning by 2022





Source: Greenco

Goldisthal pumped-storage power plant, Germany (1053 MW)

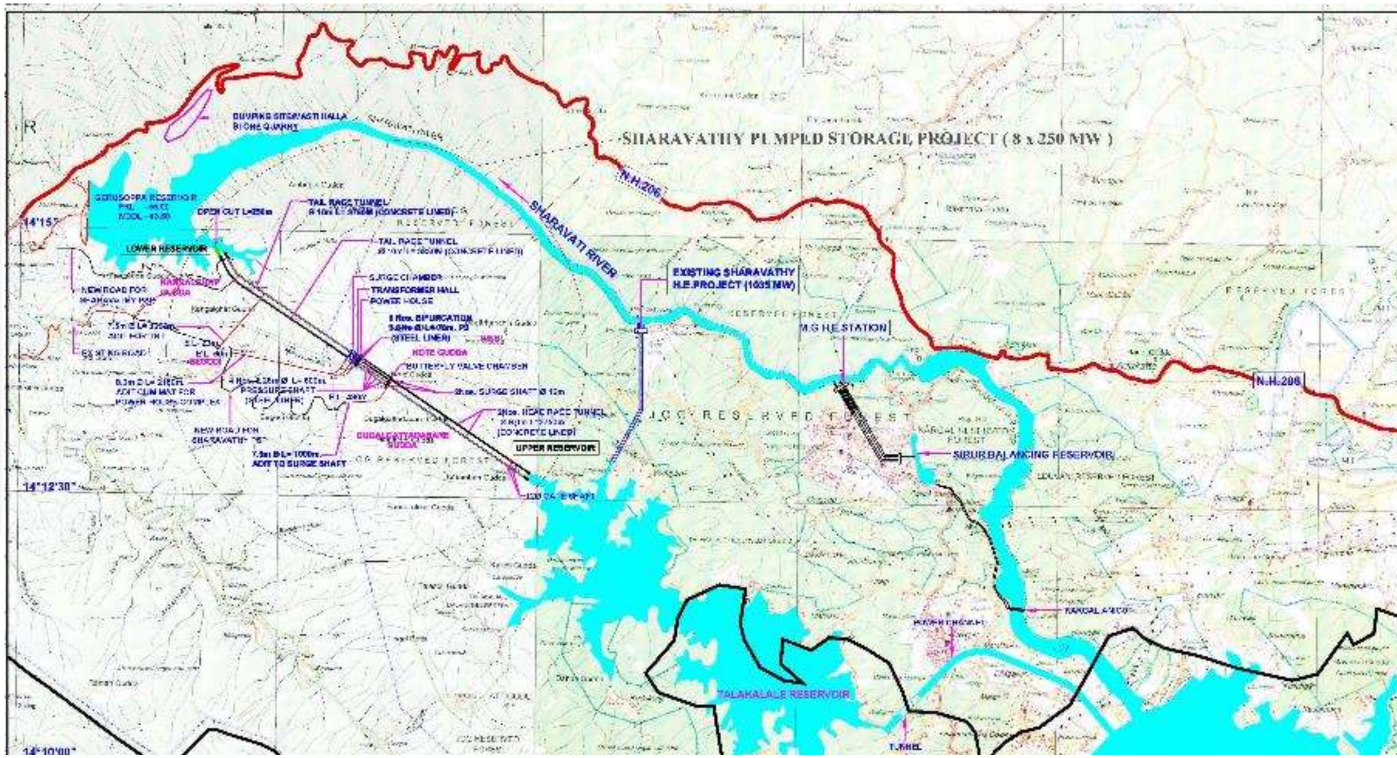
Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

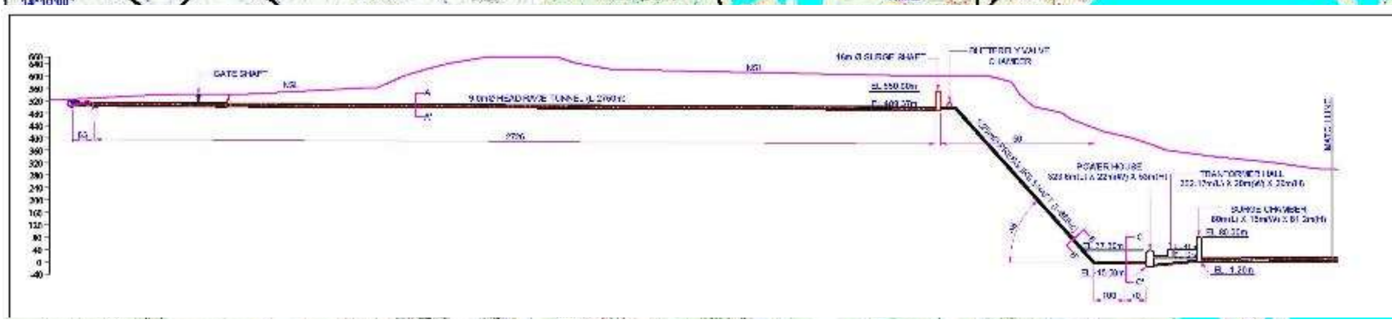
Erzhausen – Pumped Storage, Germany

Outside the Leine River system

The **Porąbka-Żar** pumped-storage power plant, Poland
The upper reservoir - 250 m x 650 m.
The total volume of the reservoir is 2.3 million m3.

Sharavathi Pumped Storage Scheme





Challenges, Barriers and Emerging Opportunities for Pumped Storage Development

- 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.

- Presently Hydro and 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

- PSH is considered as a river valley project, resulting a very long time for obtaining environment and forest clearances from the MoEF&CC.

- Separate guidelines for off-river PSH for early concurrence from MOEF&CC are not available, resulting in a longer time for obtaining financial closure.

- Hydro and PSH being the state govts subject, require support of policy Ministry of Power, MoEF&CC, Regulators and state governments

- Need to adopt IHA sustainability guidelines and carry out an ex-post analysis of a few operational storage projects to dispel some of the apprehensions related to storage projects.

- 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.

- Hearting to note that Policy for PSP has been prepared by the Government of India and announcement expected soon.

- There is a requirement to develop market mechanisms and innovative economic models
- The additional flexibility provided by PSH should therefore be recognised and both MW and MWh for a true comparison and thus name plating of all the storage technologies be done accordingly.
- PSH potential would increase in future with the addition of off-river schemes and thus, identification of the off-river and non-traditional sites be taken up immediately for reducing gestation period.

Shift in Thinking - for PSP Development

- Redesign approval and clearances process from CEA, CWC and MoEF & CC for faster approval for On Stream PSPs.
- Off-River PSPs may be exempted from the process of clearances except those related to safety.
- For enhanced flexibility with Hydraulic Short Circuit, a combination of large and small size (half the big machine) may be explored.
- For promoting use of Variable speed machines, a mix of Variable and Fixed Speed Machines may be adopted

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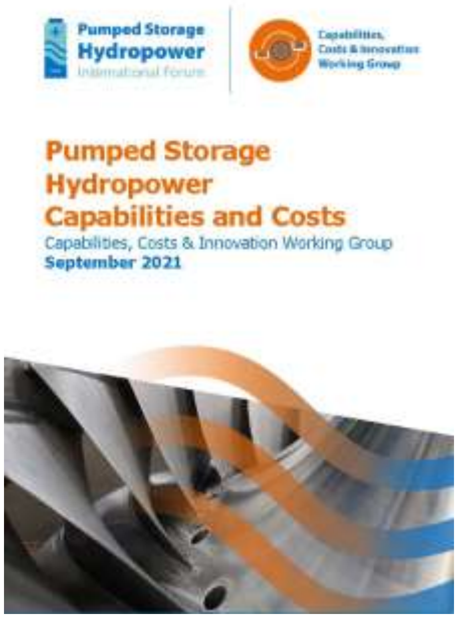

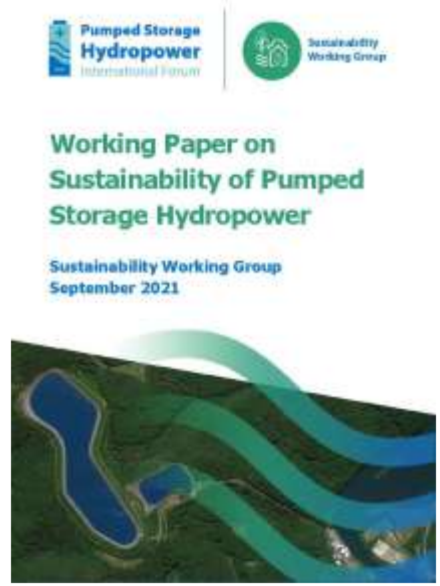

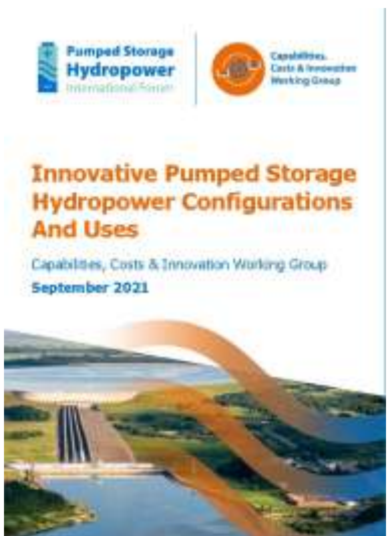

Further PSH Potential

- Off-river Pumped Hydro Energy Storage
- Geomechanical Pumped Storage
- Location Agnostic Pumped Storage (LAPS)
- Seawater Pumped Storage System
- Underground Pumped Hydroelectric Storage (UPHS)

Retrofitting and Upgrading

- Retrofitting existing hydropower reservoirs
- PSH on open pit mine and underground mine
- Double-fed Induction Machines in Hydraulic Short
- Hydraulic Short Circuit at High Head PSH
- Obermeyer Pump Turbine

Hybrid Systems

- Hybrid Pumped Storage
- Hydropower-Battery Storage
- Hybrid Renewable Modular Closed-Loop Scalable PSH System
- Integrated Pumped Hydro Reverse Osmosis Clean Energy System
- Solar PV hybrids
- Thermal Pumped-Storage Hydropower

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4/8/22, 10:18 AM PSH Valuation Tool

Pumped Storage Hydro Valuation Tool

Pumped Storage Hydropower Valuation Tool

A step-by-step tool to assess the value of services provided by pumped storage hydropower plants.

Launch Tool

About the Tool

As an energy storage technology, pumped storage hydropower (PSH) supports various aspects of power system operations. However, determining the value of PSH plants and their many services and contributions to the power system has been a challenge.

This decision tree-based tool provides step-by-step valuation guidance for PSH developers, plant owners or operators, and other stakeholders to assess the value of existing or potential new PSH plants and their services.

This tool was funded by the U.S. Department of Energy's Water Power Technologies Office under the HydroWIRES initiative.

Features

This tool is designed to advance the state of the art in assessing the value of a broad range of services provided by PSH plants, including the following:

- Value of bulk power capacity
- Value of energy arbitrage
- Value of production cost reductions
- Value of ancillary services
- Power system stability benefits
- Transmission benefits

Features of this tool include a back-end benefit-cost analysis tool, a price-taker valuation tool for small-scale PSH, and a multi-criteria decision analysis tool.

Guidebook

The methods outlined in this tool are documented in a PSH valuation guidebook (PDF).

The methods in the guidebook were used to complete techno-economic studies of two proposed PSH plants in Goldendale, WA and Banner Mountain, WY.

Sponsors and Partners

ENERGY Energy Efficiency & Renewable Energy, Argonne, HydroWIRES, INL, NREL, Oak Ridge National Laboratory, PNNL

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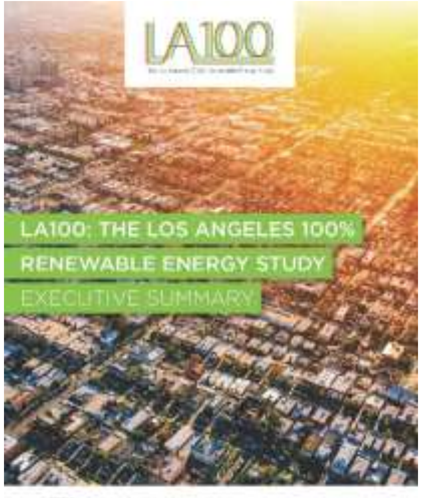
HydroWIRES

Pumped Storage Hydropower Valuation Guidebook

A Cost-Benefit and Decision Analysis Valuation Framework

March 2021



Energy Storage Grand Challenge: Energy Storage Market Report

U.S. Department of Energy

ENERGY STORAGE GRAND CHALLENGE
ENERGY

R&D HYDRAULIC TURBINE LABORATORY

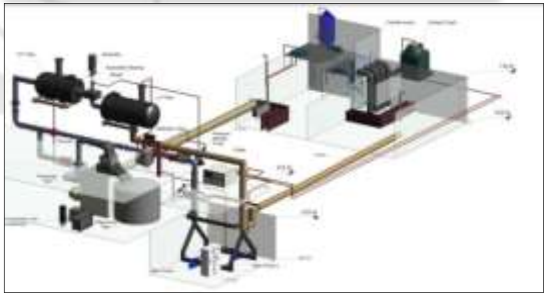
R&D hydro turbine Laboratory of International level at HRED- IIT Roorkee

- research & development
- turbine-model testing,
- human resource development (HRD)
- generation of design data
- design validation through CFD analysis
- Third party evaluation

First independent facility in the region

- Head 15-60 m and discharge 1000 lps
- Building 15x24 m height +13.5 to – 6.5 m
- Water storage 600 cubic m

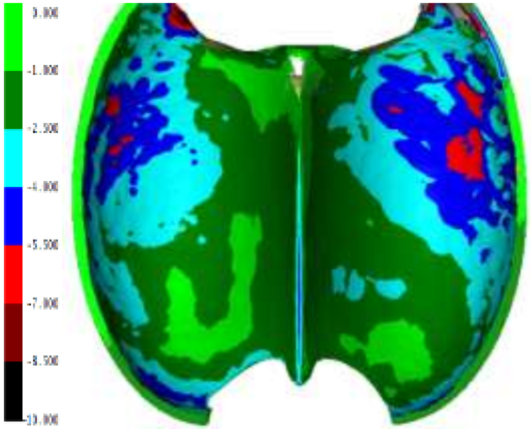
- Laboratory inaugurated in April 2018
- Turbine Manufacturers and project developers may take benefit of the lab



Sediment Monitoring and Impact Analysis Laboratory

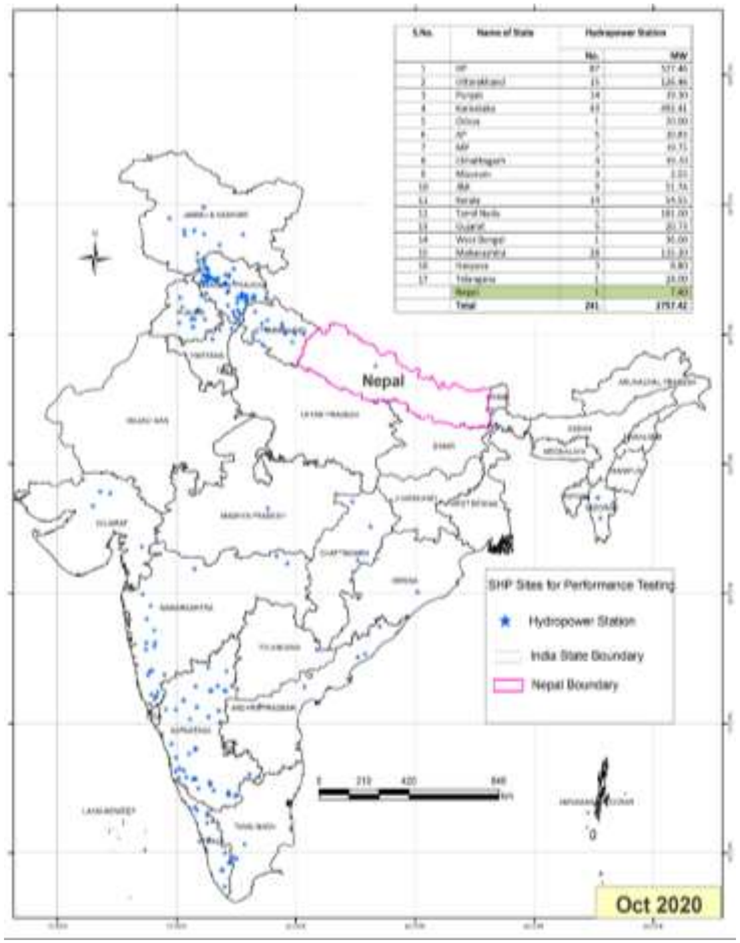
- Laboratory for sediment monitoring and impact analysis studies in hydropower plant is under establishment.
- depository of silt data and online monitoring of silt flow for all hydropower stations experience gained by different power utilities and manufacturers

- Online Turbidity Sensor and Suspended Solids
- Laser Diffraction sediment sensor,
- Acoustic based sediment measurement
- Digitizer for quantifying shape and size
- High speed camera system



PERFORMANCE EVALUATION OF HYDRO PLANTS SINCE 2004 ONWARDS

- Field measurement of flow in penstocks, channel, rivers
- Efficiency measurement for hydro turbine
- Performance testing of control and protection equipment
- Performance evaluation/ efficiency test of over 240 hydropower stations of different capacities in different terrain and states using different methods of discharge measurement and head measurement.



https://hre.iitr.ac.in/departments/HRE/pages/Labs+Instrumentation_Lab.html

Real-Time Digital Simulator (RTDS) for Small Hydropower Plant

Department of Hydro and Renewable Energy, IIT Roorkee

Commissioned in 2007

Thank You