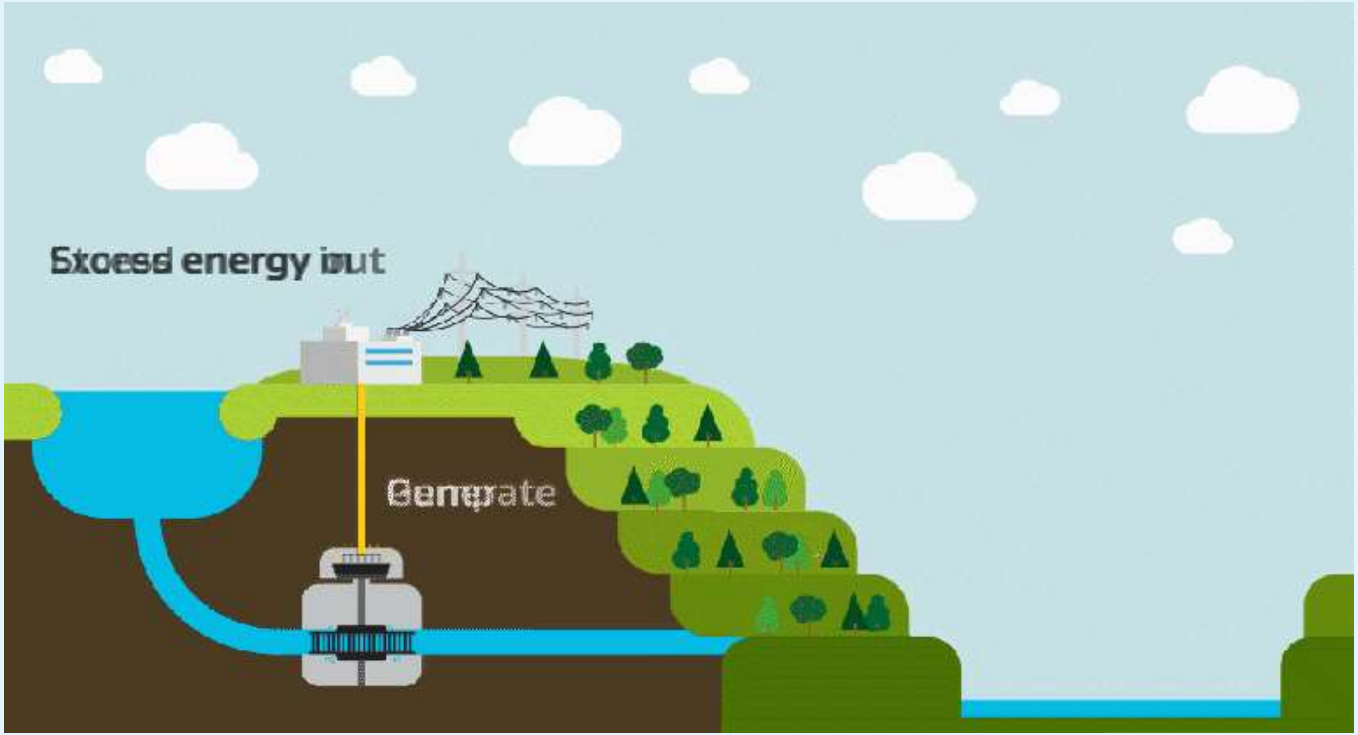
PSP, Current Trends, Future Challenges and Policy for Growth

THDCIL

Agenda

1. PSP- An Overview
2. Current Trends
3. Future Trends in PSP Technologies
4. Challenges Associated with PSPs
5. Policy Interventions for Growth of PSPs

PSP: An Overview
Generation-Pumping



https://www.waikato.ac.nz/news-opinion/media/2020/university-of-waikato-scientist-helps-new-zealand-move-towards-100-renewable-energy

PSP-An Overview

- Pumped Storage Plants can operate as Generators or Load depending upon the requirement.
- During peak demand, PSPs can generate electricity resulting in reduction in upper reservoir water level.
- During low demand, these can pump water from lower to upper reservoir for storage.
- PSPs are the only large scale and proven energy storage solution.
- Global installed capacity of PSPs is 158 GW.

Capacity of Pump Storage Projects Worldwide

Installed Capacity As of 2019

Country/Region	Installed Capacity* (GW)
Global	158
China	30.3
United States	22.9
Italy	7.7
Germany	6.4
Spain	6.1
France	5.8
Austria	5.6
India	4.8
South Korea	4.7
Rest of World	36.1

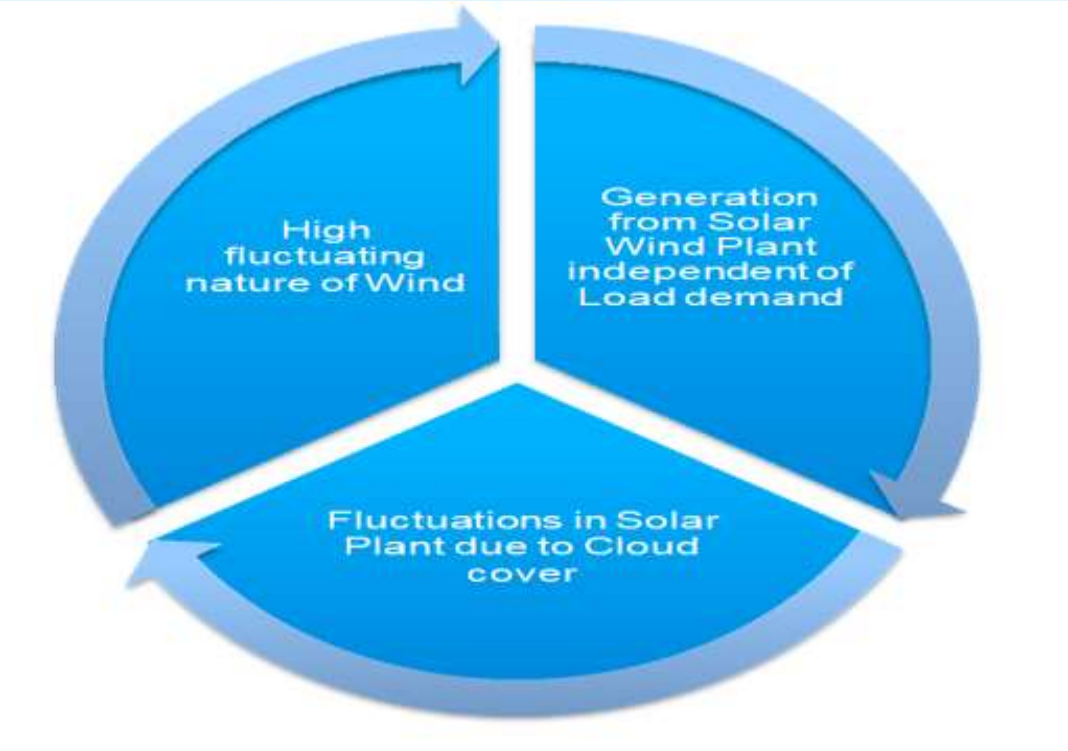
Source: 2020 Hydropower Status Report published by International Hydropower Association

Capacity Planned / Under Construction

Country/Region	Proposed Capacity (GW)
China	53.2
Australia	7.88
Indonesia	4.06
Japan	2.48
Vietnam	1.2
Philippines	0.5

Source: Source: https://ihsmarkit.com/research-analysis/china-leads-asiapacific-region-in-pumped-storage-hydro-project.html

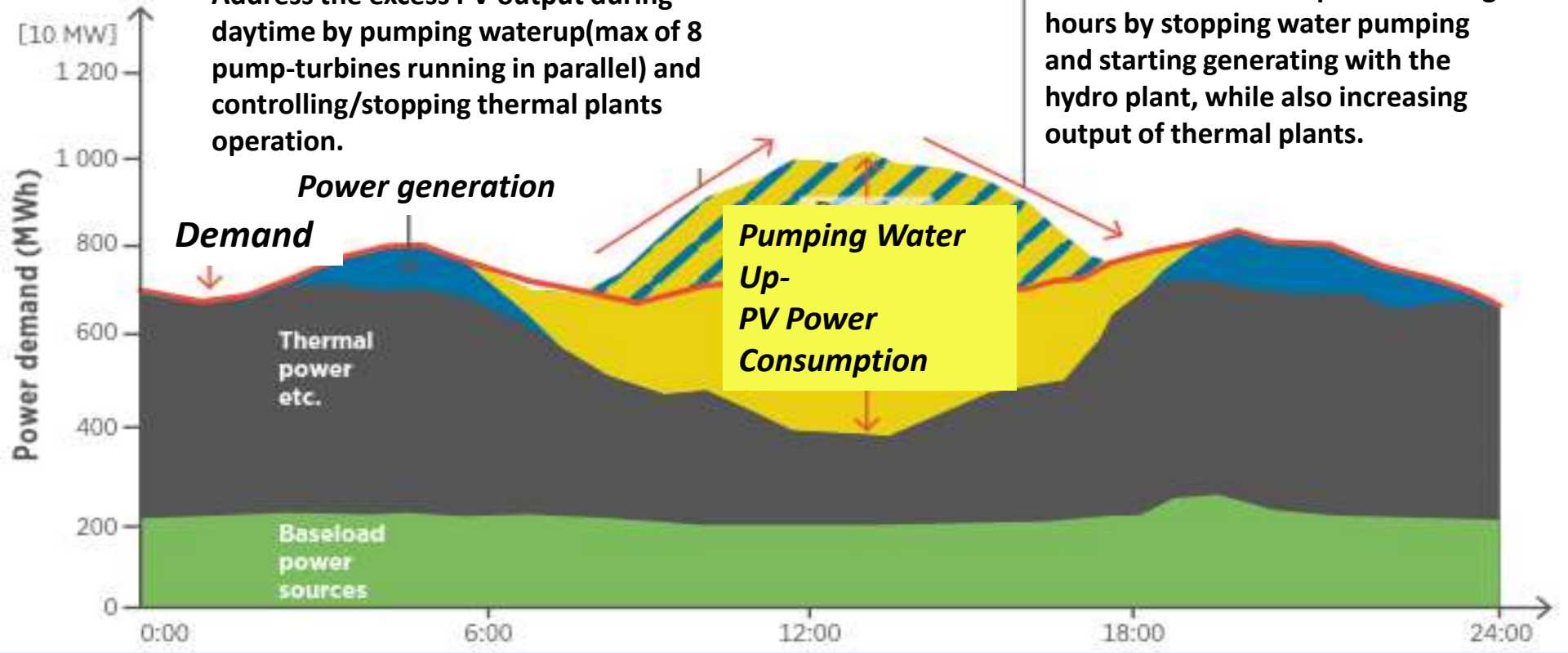
Why Storage


High fluctuating nature of Wind
Generation from Solar Wind Plant independent of Load demand
Fluctuations in Solar Plant due to Cloud cover

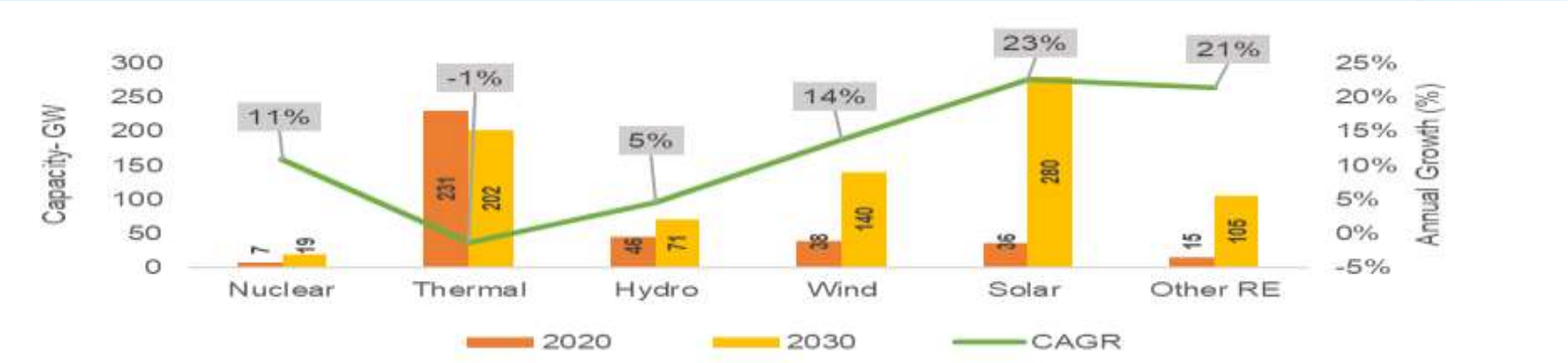
Demand Generation Balance

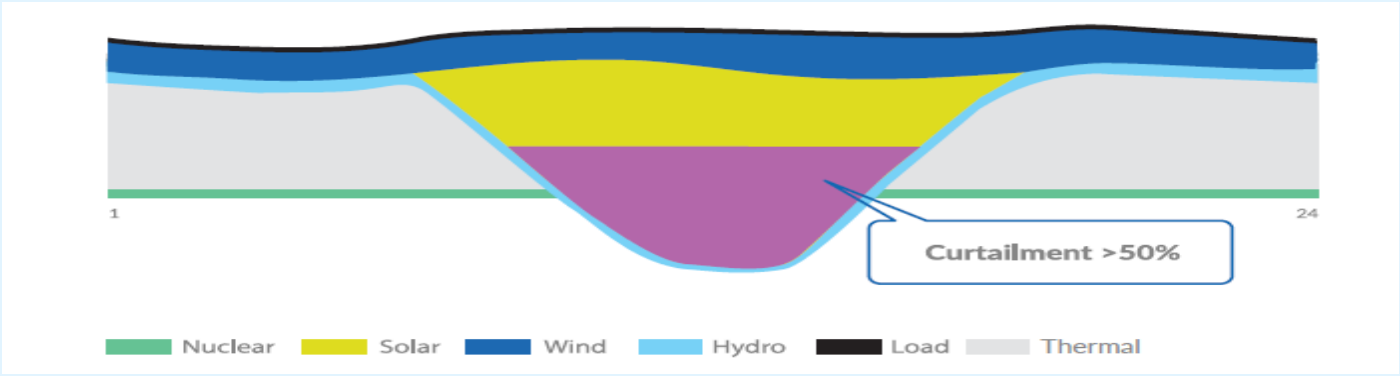
Address the excess PV output during daytime by pumping waterup(max of 8 pump-turbines running in parallel) and controlling/stopping thermal plants operation.

Address lower PV output in evening hours by stopping water pumping and starting generating with the hydro plant, while also increasing output of thermal plants.



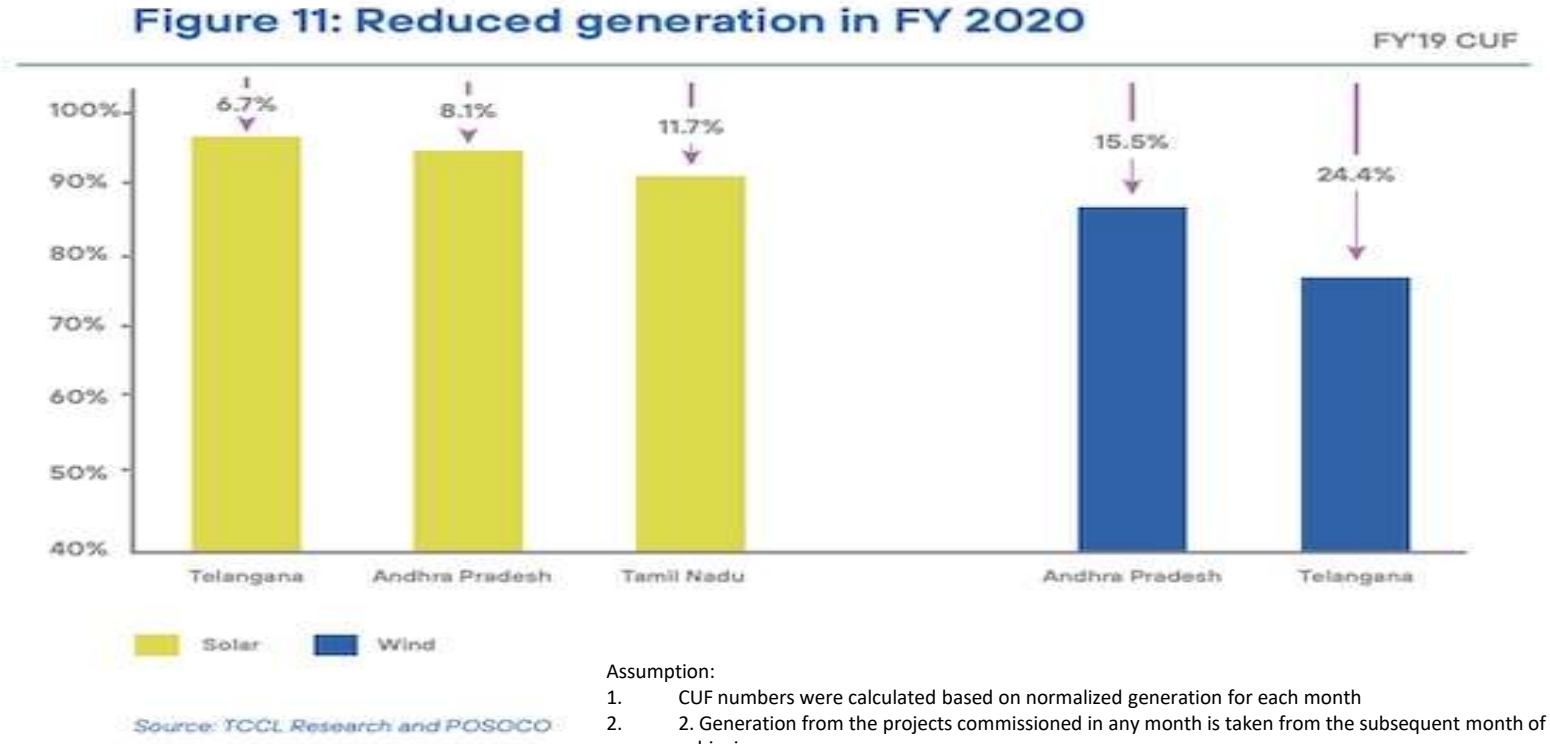
Change in Generation Mix & RE Curtailment (w/o adequate) storage Scenario 2030





Source :
TCCL: Renewable Integration and Curtailment

Why storage- To avoid VRE Curtailment



Assumption:

1. CUF numbers were calculated based on normalized generation for each month
2. 2. Generation from the projects commissioned in any month is taken from the subsequent month of achieving

the commissioning

3. For the analysis, the CUF for FY 2019 was taken as 100% to show the reduced generation for FY 2020

Relevance of PSP in increasing VRE penetration..

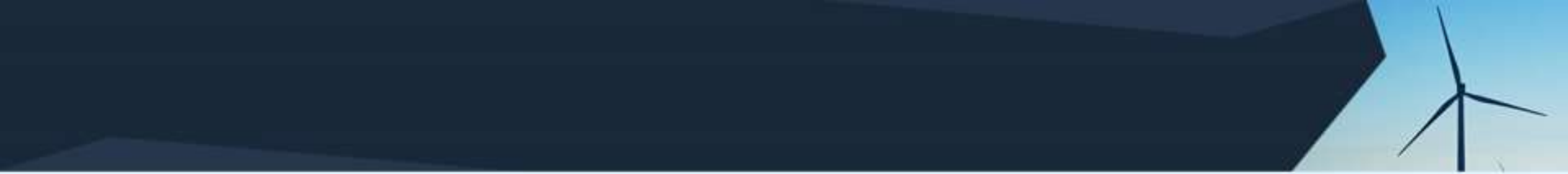
Application	Particulars
Time shifting/ storage	▪ Storage of surplus power during off-peak hours and supply of power during peak demand hours.
Ramping Capability	▪ Quick-start and ramping capability of ~200 MW/ min, taking just a few minutes. ▪ Savings in start-up and shutdown costs of thermal plants and steadier operations.
Peak Shaving	▪ PSPs can meet peak demand in a short period due to their high ramping capability ▪ Can enable supply-demand balancing.
Black Start	▪ Utilization of PSPs for energizing the Grid in case of cascaded tripping ▪ The power supply can be made available to the power system within few seconds of a grid blackout

Relevance of PSP in increasing VRE penetration..

Application	Particulars
Frequency Response	▪ PSPs can follow frequency within the given margins by continuous modulation of active power and meeting moment-to-moment fluctuations in the system's power requirements
Spinning Reserve	▪ PSP can support in maintaining grid stability in case of unexpected load changes or sudden outages or failure of any generator by facilitating stored energy.
Reactive Power and Voltage Control	▪ PSP can provide voltage control services by rendering reactive power balancing services. ▪ PSP can operate in lead or lag modes to meet the Grid's reactive power requirement. PSP can also work in synchronous condenser mode to improve the system power factor.

Year Wise Storage requirement for 2022-23 to 2029-30

Year	Peak Demand (MW)#	Energy Requirement (BU)#	Likely RE I/C (MW)	Total Storage I/C (MW) (A+B)	Total Energy Storage (GWh) Required (C+D)	PSP I/C (MW) (A)	PSP Energy Storage (GWh) (C)	BESS IC (MW)* (B)	BESS Energy (GWh) (D)
2022-23	238899	1703.7	210400	5786	38	5786	38	0	0
2023-24	252288	1795.9	245736	7486	53	7486	53	0	0
2024-25	266844	1895.4	281071	7486	53	7486	53	0	0
2025-26	282418	2001.6	316408	7566	53	7566	53	0	0
2026-27	298774	2113.1	351743	16002	92	10566	70	5437	22
2027-28	311920	2204.8	385144	21223	113	10566	70	10657	43
2028-29	325645	2300.5	418545	30652	150	10566	70	20086	80
2029-30	339973	2400.1	451942	40786	191	10566	70	30221	121



Overview

- With the increased share of intermittent renewable sources in the energy mix of the country, **ENERGY STORAGE SYSTEM"** can be an important tool for Load -Generation balancing and to mitigate curtailment of RE Generation during low demand periods.

- PSH and Battery Energy Storage are the two mature energy storage sources, available predominantly, to cater to the storage requirement.

- As of now, Hydro PSPs are providing nearly 90% storage capacity at global level.

Study on development of PSPs around the world and design of draft development model for India.

- International comparison of how PSPs are operated, regulated and remunerated in various countries such including but not limited to various countries of Europe, China, Australia and USA.
- What could be the alternative compensation mechanism, market structure and design of Indian power market.
- What is the ownership structure of PSPs in various countries considered for comparison and how does the ownership impacts the governance and operation of PSPs

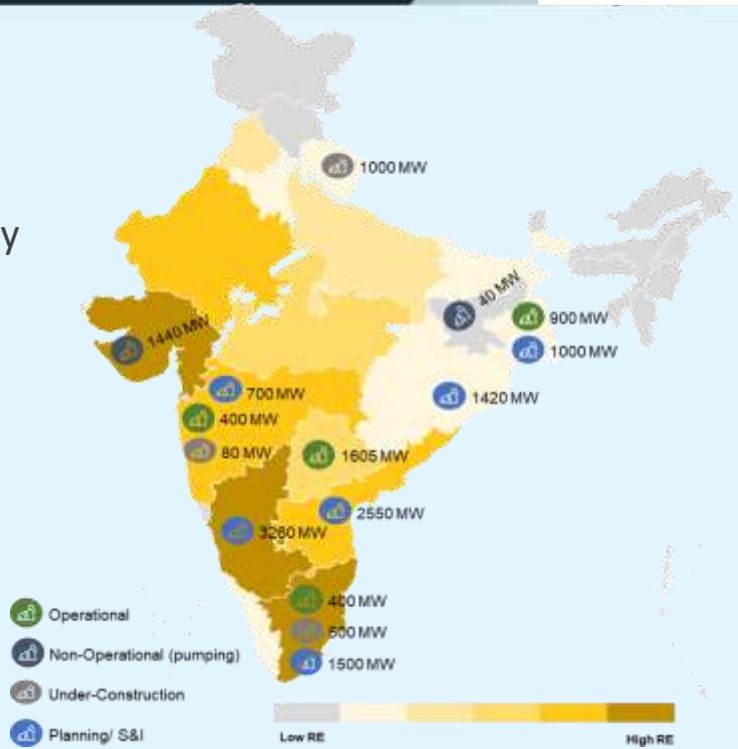
The basic objective of this study was that the outcome and findings would become the basis for formulation of regulatory framework and draft national policy for the

Enabling factors for the Development of PSPs across Geographies

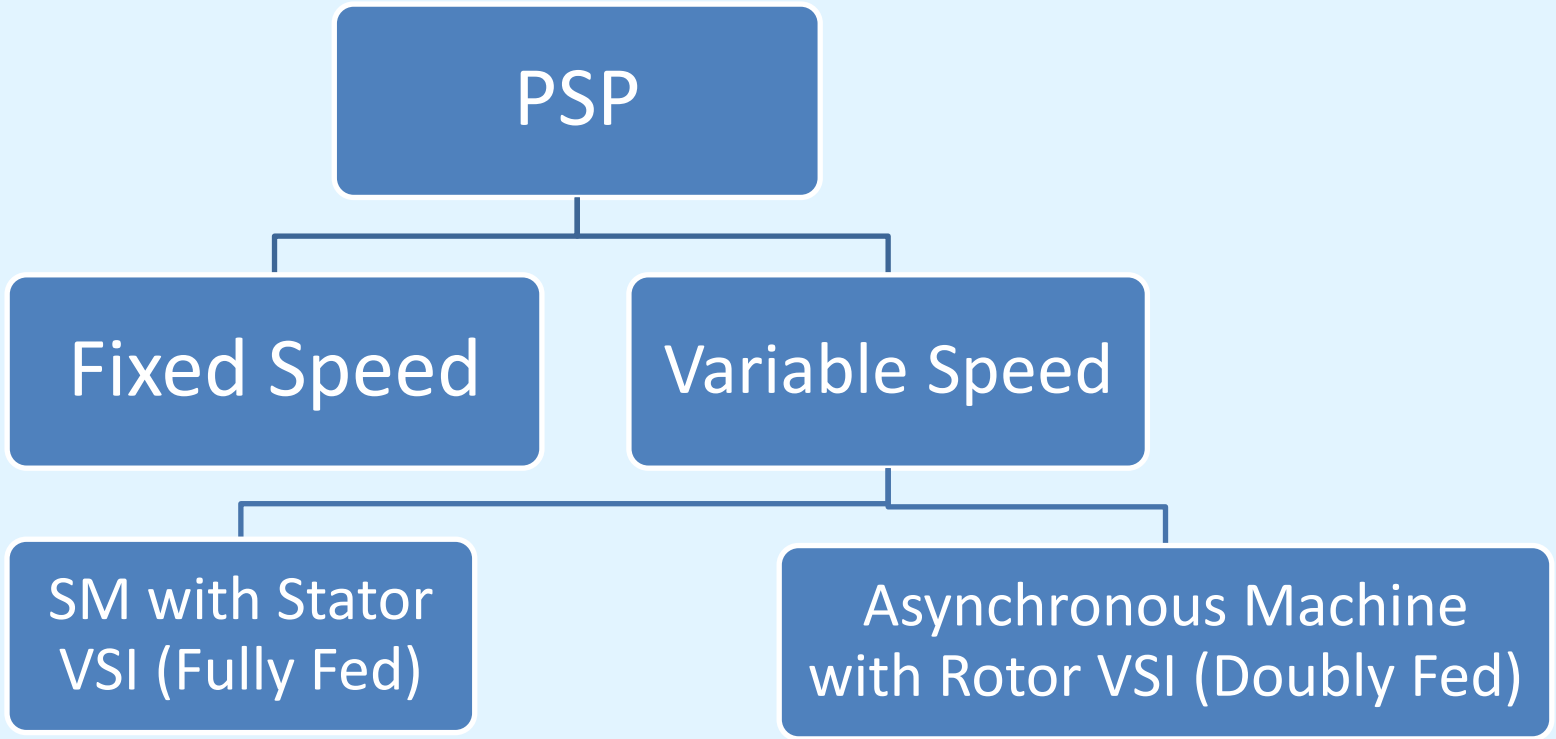
Region / Factors	China	Japan	Australia	Germany	United States of America
Policy push to be carbon neutral and develope storage for the absorption of RE	Yes	Yes	Yes	Yes	Yes
Option with consumers for ToU at low-voltage level	Yes	Yes	Yes	Yes	Yes
Status of the ancillary market – frequency, network, black-start, and others	Evolving	Evolving	Operational	Operational	Operational
Identity of storage	Grid Asset	Generating Asset	Bi-Directional Asset	Generating Asset	Bi-Directional Asset
Energy arbitrage opportunities	Low	Low	High	High	High
Tariffs/ Fixed rates	Fixed Tariff	Fixed Tariff	Market Based	Market Based	Market Based
Grants/subsidies	Yes	Yes	Yes	Not Available	Not Available
The mandate to maintain reliability and reduce RE curtailment	Yes	Yes	Yes	Yes	Yes

Present development status of PSP – In Indian Context..
…last decade has not even witnessed a single commissioning of PSP

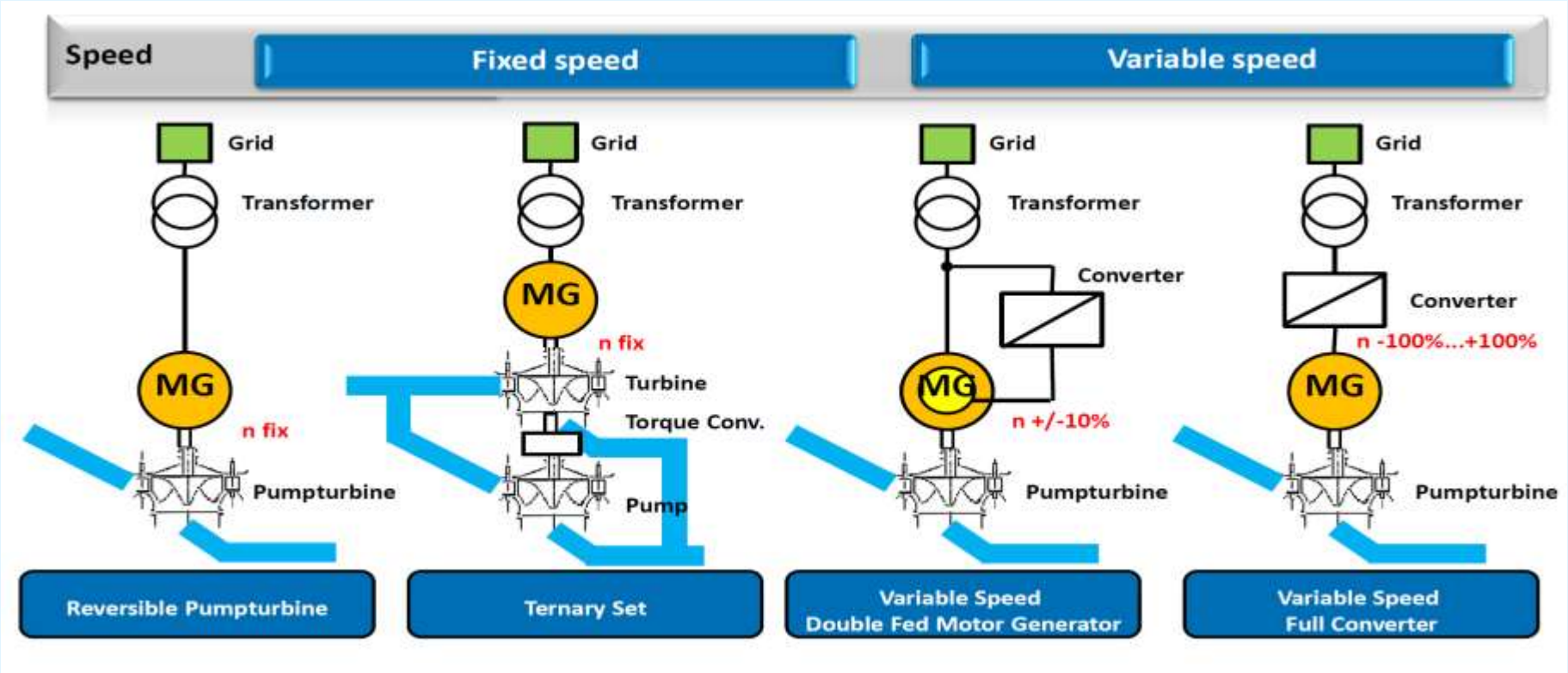
- In 1970 India's first PHS project commenced at **Nagarjuna Sagar in Telangana** with an installed capacity of 705 megawatts (MW).
- As of Mar'21, India has 9 PSP with total installed capacity of 4785 MW.
- 3 PSPs are not operating in pumping mode- Sardar Sarovar 1200MW), (Kadana (240 MW) and Panchet (40 MW).



Pumped Storage Technology- Current Trends



Pumped storage technology



Source : / ANDRITZ HYDRO / SUB GROUP - 3, MOP / 20211011

Pumped storage power plants

TECHNOLOGY CAPABILITY

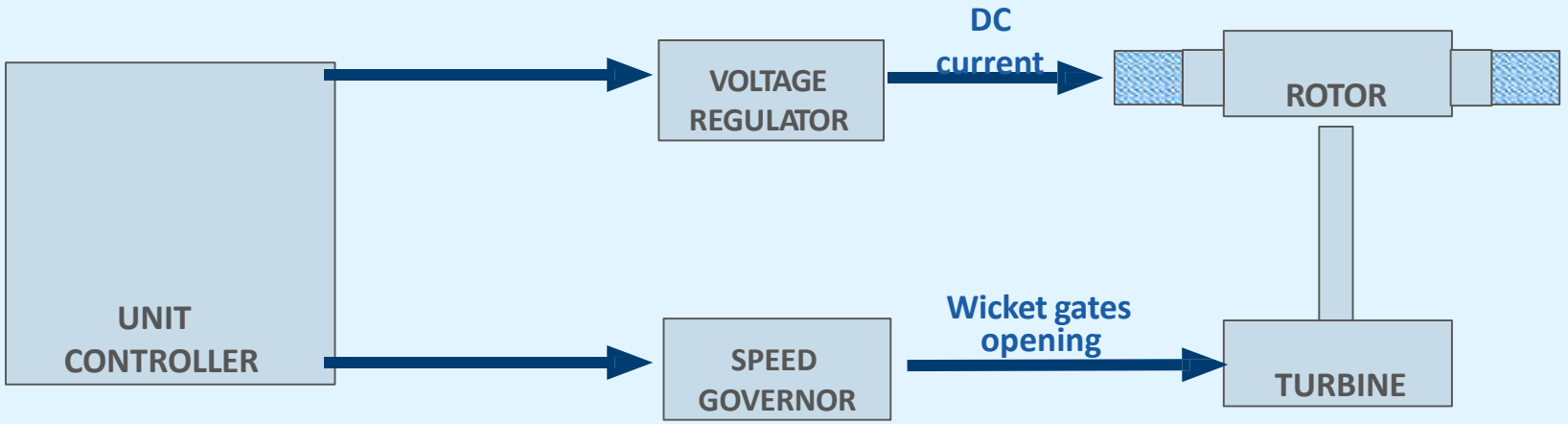
	Fixed speed	Variable speed	
Requirements		**Doubly Fed Motor Generator**	**Full Size Convertor**
Efficiency	Lower Pump Turbine eff. High Motor Generator eff.	Better PT eff. Lower MG eff. due to higher AC exc. losses Overall eff. levels are similar to fixed speed	Lower overall eff. due to convertor losses
Wide range of operation	Limited head variation	Wide head variation	Wide head variation but , technology limited to ~100MW unit size
Variation in pump power	Not possible	Power Consumption can vary between 70%-100%	Maximum flexibility in pump mode
Controllable reactive power	High	High	High
Grid inertia	High	Limited due to wound rotor (limited rotor dia.)	High
Black start	Yes	Yes, special requirements - not fully proven	Yes

Source : / ANDRITZ HYDRO / SUB GROUP - 3, MOP / 20211011

Fixed Speed PSP

- Synchronous machine
  - -Rotor with salient poles
  - - DC excitation through slip rings
- Reversible Francis P/T
- Static frequency converter: For starting machine in pump mode, where the SFC provides a source of adjustable frequency/voltage for starting.
- Stator field speed ns =120 fs / p
  - fs : stator frequency
  - p : poles pairs number
- Rotor field speed n = ns

Fixed speed PSP Units



Turbine control is totally decoupled from rotor control

Variable Speed PSP

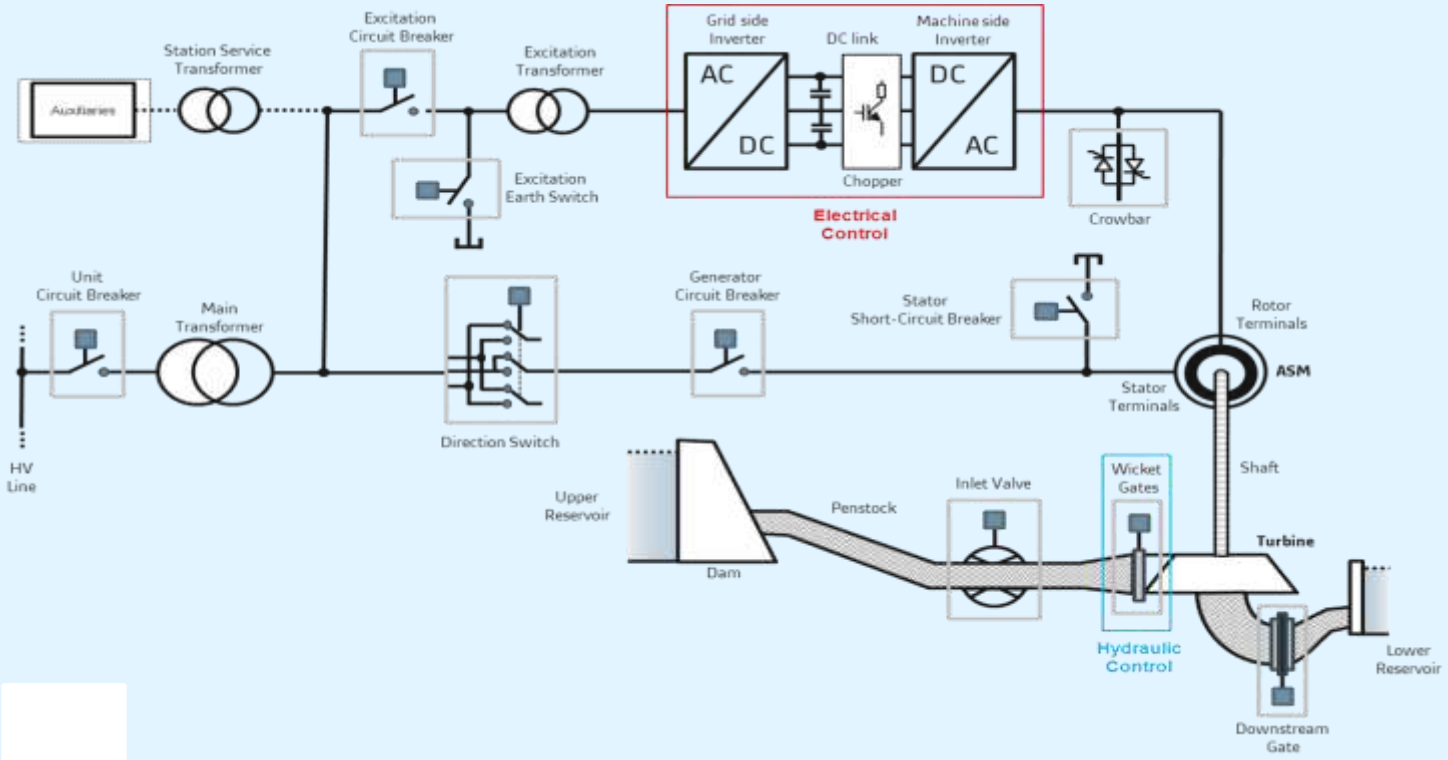
- Speed variation around synchronous speed
- Adjustable pumping power
- Overall Increased Pump Turbine efficiency
- Better utilization of larger head variation
- Faster power adjustment

Variable speed PSP
Doubly Fed Asynchronous Machines

- Doubly fed asynchronous machines
  -Cylindrical rotor with three phase winding

- Voltage Source Inverters (VSI) based AC excitation system on rotor
- Reversible Francis P/T
- Stator field speed ns = fs / p
  fs : stator frequency
  p : poles pairs number
- Rotor field speed nr = fr / p = ns - n

Schematic of Doubly Fed variable speed PSP



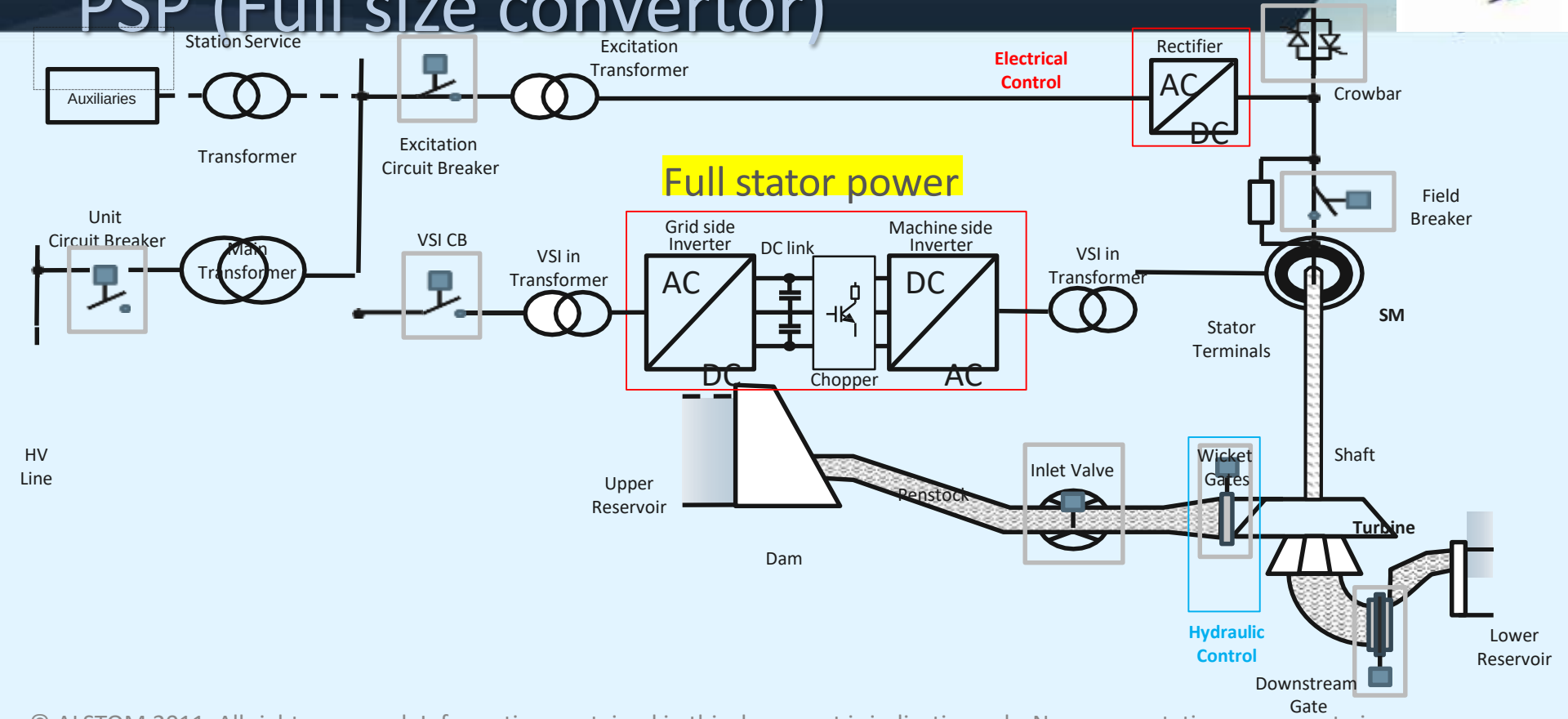
Variable speed Machines with Fully fed synchronous machine(Full Size Converter (FSCS)

- Synchronous machines equipped with full size frequency convertors
- DC excitation system on rotor
- Reversible Francis P/T
- Stator field speed ns = fs / p

  fs : stator frequency

  p : poles pairs number
- Rotor field speed nr = fr / p = ns – n
- Can be used for upto 100 MW units.

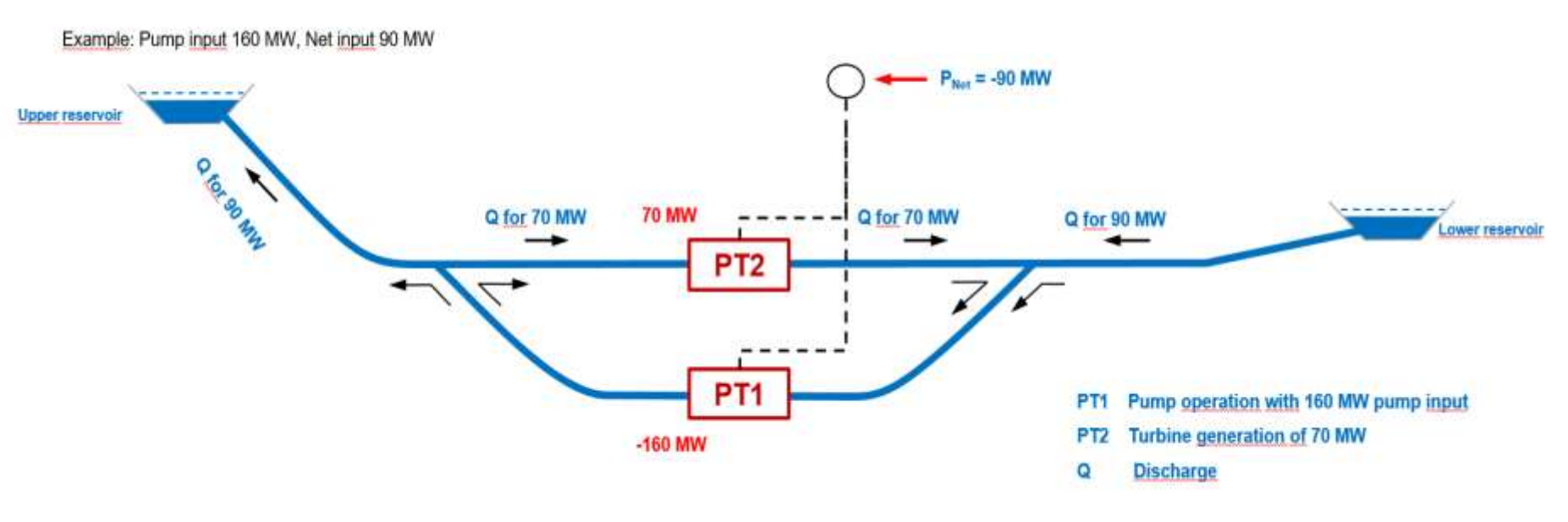
Schematic of Fully-fed Variable Speed PSP (Full size convertor)



Comparison between FSCS and DFIM Technology

Characteristics	FSCS	DFIM
Investment Cost	High	Low
Power Rating	100% of nominal power	Approx. 10% of nominal power
Eefficiency	Low (High Losses)	High
Technology	Synchronous Machine with DC rotor	Asynchronous Machine, Complex AC Rotor
Flexibility of Operation	High	Low
Switching Time	Faster	Slower

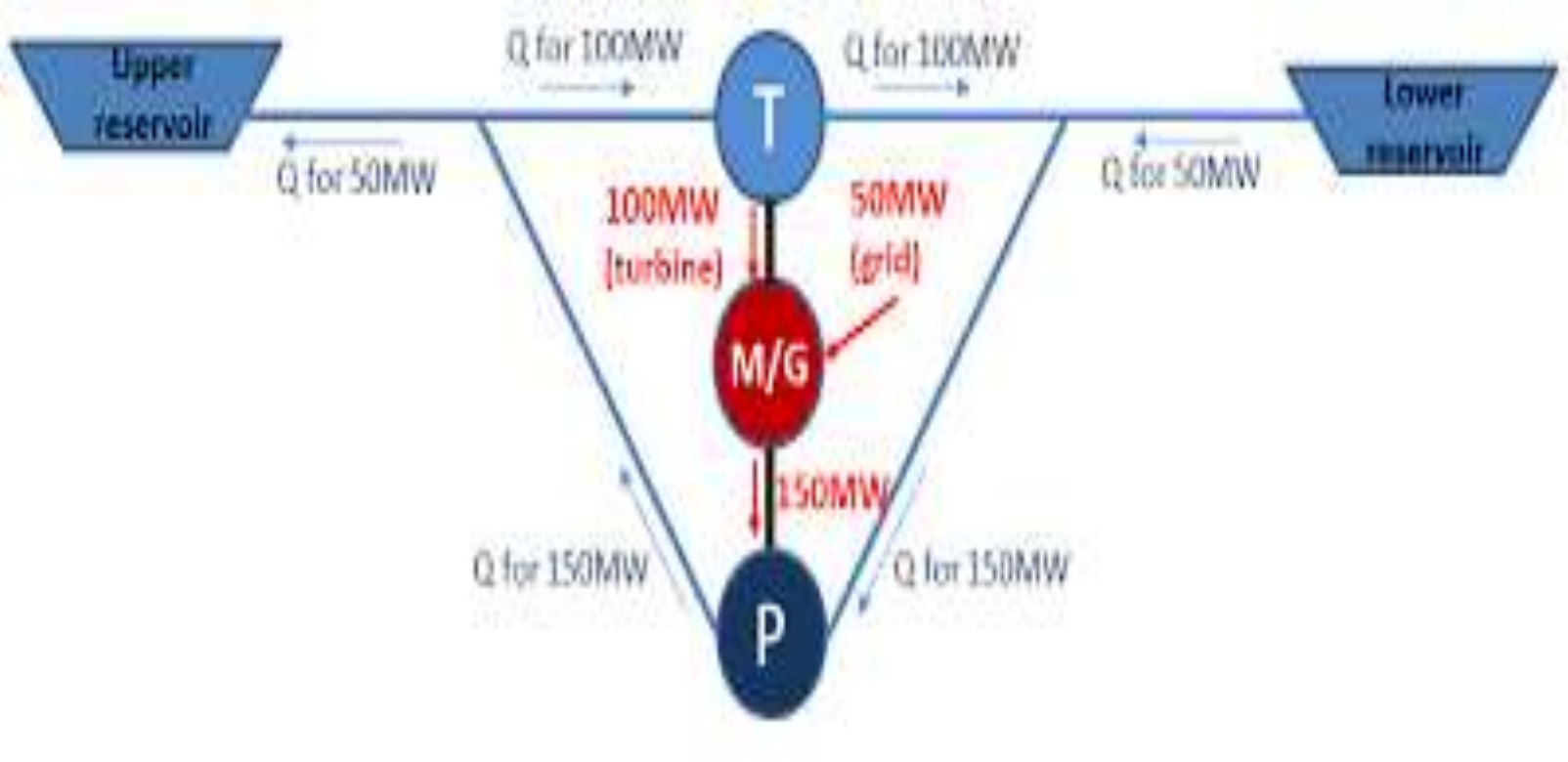
Future technologies- Pumped storage power plants
OPERATIONAL FLEXIBILITY: PUMP MODE AT PLANT LEVEL



Hydraulic short circuit can be used to enhance the operational flexibility.
One unit in the plant operates as pump, while another unit at the same time operates in generation mode.

Source : / ANDRITZ HYDRO / SUB GROUP - 3, MOP / 20211011

Future Technology-Ternary Sets



Source : / ANDRITZ HYDRO / SUB GROUP - 3, MOP / 20211011

Ternary Set PSP/ Hydraulic Short Circuit

- In PSPs usually same equipment is used for generation and pumping synchronous generator used as motor and turbine acts as pump i.e both components are reversible in their functionality.
- But we can have a different configuration as well with separate pump and turbine.
- Ternary PSP consists of a separate turbine and a pump on a single shaft with an electric machine that acts as motor /generator.
- These plants can operate simultaneously both in pump and turbine mode.
- They give added flexibility having same shaft rotating in the same direction thereby eliminating the need to reverse the rotation in transition from pumping to generating or vice versa.

Ternary Set PSP/ Hydraulic Short Circuit

- The flow in penstock is bidirectional. This flow is the resultant of the flow to the turbine and flow from the pump. The flow to the tail race is the same net flow.
- If the plant is operating in pure pump mode, the guide vanes to the turbine are closed.
- In this mode, the pump guide vanes are wide open and there is no regulation capability.
- If regulation is required in pumping mode, both pump and turbine operate i.e employing hydraulic short circuit.
- The transition time from pumping mode to generation mode required for a reversible pump turbine ranges from 1.5 min to 5 min while in ternary sets it takes 0.5 to 1 minute.

Future Adoption-Off Stream PSPs

- **The PSPs are classified as follows:**
- **Off-Stream Closed Loop PSP**
  - Both upper and lower reservoirs which are to be constructed newly are away from natural river course
- ✓ **Off-Stream Open Loop PSP**
  - All newly constructed components (i/c at least one reservoir) are located away from river stream and utilizing one of the existing reservoirs which can be on the river stream.
- **Both These types of Off-Stream PSP Locations are available well spread across the country.**
- Both these types are faster and easier to construct hence recommended for adoption.
- They have minimal to no impact to existing river systems.

Off Stream PSPs

- With these types of projects Modular PSP is also a reality which saves on cost and time.
- Comprehensive database of “Off-Stream” PSPs needs to be developed for promoting its usage.
- Only initial filling of the reservoirs required for closed loop off stream PSPs.
- Additional water requirement is minimal. Operational make-up water required to offset evaporation or seepage losses.
- Closed-loop PSPs do not need to be located near an existing river system or body of water, with the right topographical features, they can be located where needed to support the grid.

4

- Challenges Associated With PSPs

Picture 2

Challenges Associated with PSPs

- **Fragmented Regulatory Environments for Pumped Storage Operation:** Policy spectrum and compensation mechanism differs from country to country.
- Long clearance and approval processes, more reliance on conventional technologies.

- **Market Rules and Ancillary Services Compensation-** In most of the economies PSPs are not remunerated for ancillary services appropriately.
- U.S, Germany, Australia and lately China and Japan have developed ancillary services market.
- **Classification of Asset Class of PSP**- PSPs can serve as generation or load and can also act as grid asset.
- Market rules in most of the economies prohibit transmission asset to participate in energy & ancillary service markets which hinders the realization of entire potential of PSPs.

Challenges Associated with PSPs

- **Price Volatility in Electricity Market:** PSPs get benefitted with differential peak and off peak pricing.

- **Frequent policy changes affect the long-term return:** In several economies PSPs are still reliant on government grant and low-cost funding.

- **Environmental Issues for PSP:** PSPs require construction of large dams & reservoirs thus impact the natural water system. Social activism, R&R etc in case of large dams and reservoirs adversely affects large projects.

Challenges Associated with PSPs

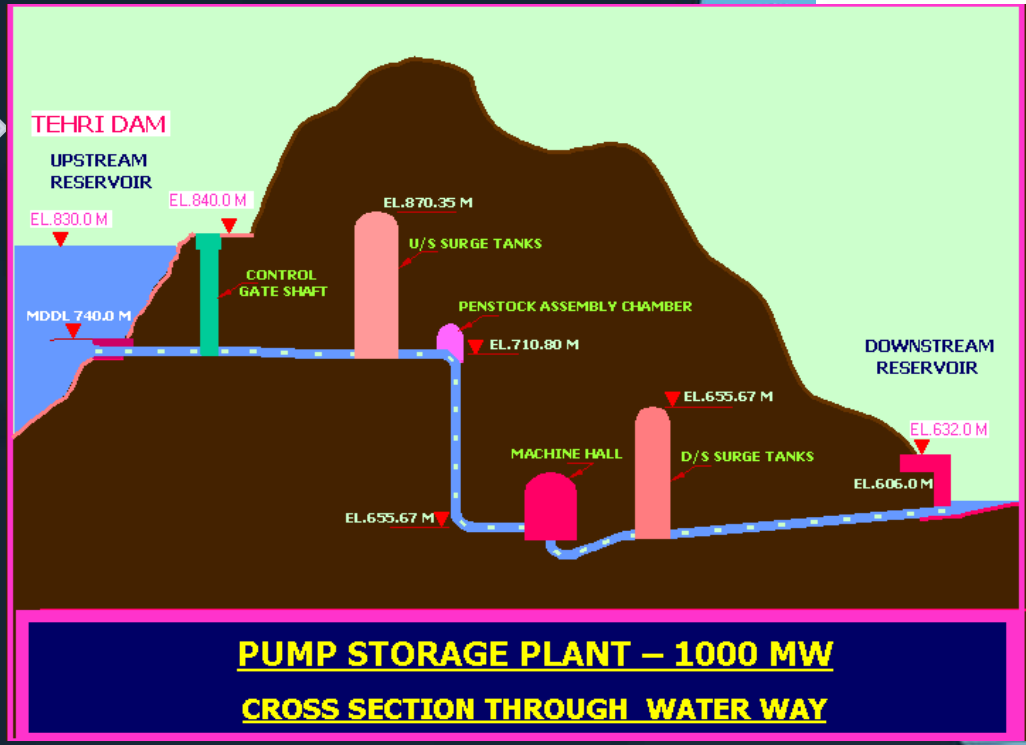
- **Long planning lead-times, high construction cost, and double grid fees:** There are concerns in economies over lead-times during the planning & approval phase , and higher cost of construction for pumped hydro-electric storage. There is a fragmented outlook on the policy front for grid fees (ISTS charges for pumping as well as generation) and taxation.

Challenges Associated with PSPs Indian Context

- **Operation of PSP**: PSPs are mostly utilized to meet peak demand and used locally. Scheduling and utilization at regional or national level is not possible in present framework in India as most of the operational PSPs belong to states.
- **Recognition of PSP**: PSPs are considered as generating assets and no recognition and compensation for grid services are available at present.
- **Ancillary services**: Ancillary services provided by PSPs are limited only to voltage and frequency management.
- **Other Policies and regulation**: The tariff regulation provides for recovery of AFC linked to the achievement of normative capacity factor and incentives in the form of energy charges.
- **Differential Generation Tariff**: Lack of differential tariff for PSP for peaking generation.

5

- Policy Interventions Required for Growth of PSP



Policy Interventions Required for Growth of PSP

- Defining legal identity of PSP as generation/ transmission/distribution/ grid asset.
- Developing Ancillary Services Market. Resources eligible to provide essential ancillary reserves may enter into short to long term agreements with system operator to provide required ancillary services.
- System Operator should specify upfront the capacity and energy requirements along with other balancing service requirements.
- Regulatory framework for tariff for ancillary services provided by storage.

Policy Interventions Required for Growth of PSP

- Single window clearance mechanism for storage projects.
- Explicit policy provision that RE generators must provide firm power with a penalty if the prescribed conditions are not met.
- Establishing an alternative, simplified clearance process for low-impact pumped storage hydropower, such as off-channel or closed-loop projects.

Way Ahead- Indian Context

- To establish commercial viability of PSP, the Indian Govt has brought in a set of policy, regulatory, financial interventions.
- Measures such as waiver of ISTS charges for PSPs/BESS has already been granted. Waiver of ISTS charges to be granted for 25 years to all ESS projects commissioned before 30th June 2030 as per the proposed measures.
- Energy Storage Policy is under formulation and ancillary services regulations are also underway.
- Policy on Energy storage includes promotion of technology agnostic energy storage system which focuses on various

Way Ahead- Indian Context
Major Highlights of Energy Storage Policy

- Energy Storage System to be designated as a power system element utilized as Generator, Transmission or grid element as defined u/s 2(50) of the Electricity Act.
- Setting up of ESS shall be de-licensed activity requiring only registration with appropriate regulatory commission.
- DISCOMs/Bulk Consumers/Open Access Consumers mandated to procure at least 10% of requirement through ESS.
- For upcoming RE projects, provision of co-located storage of minimum 10 % of RE capacity at the bidding stage itself.

Way Ahead- Indian Context
Major Highlights of Energy Storage Policy

- Procurement of power from ESS to qualify for RPO compliance.
- An ESS to be granted two RECs, one for drawl and other for injection if charged from Renewable Energy.
- ESSs shall be granted connectivity to ISTS under the General Network Access (GNA) Rules.

Way Ahead- Indian Context
Major Highlights of Energy Storage Policy

- Setting up or procuring energy storage through competitive bidding process shall be governed under Section 62 or 63 of the Electricity Act respectively.
- ESS to be included as an element of transmission in the transmission planning exercise.
- Notification of peak and off-peak tariffs for generation by Appropriate Commission to provide appropriate pricing signal.

References

- Picture1: https://theconversation.com/five-gifs-that-explain-how-pumped-hydro-actually-works-112610
- Picture 2: https://www.eqmagpro.com/india-takes-a-step-forward-towards-decarbonisation-and-promotion-of-re-hydro-psp-and-bess-2/
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