National Workshop on Pumped Storage Hydropower Projects

8th & 9th February 2018
Energy Management Centre
Thiruvananthapuram

Compendium of Presentations

Day 1

INDEX

Vorarlberger Illwerke AG

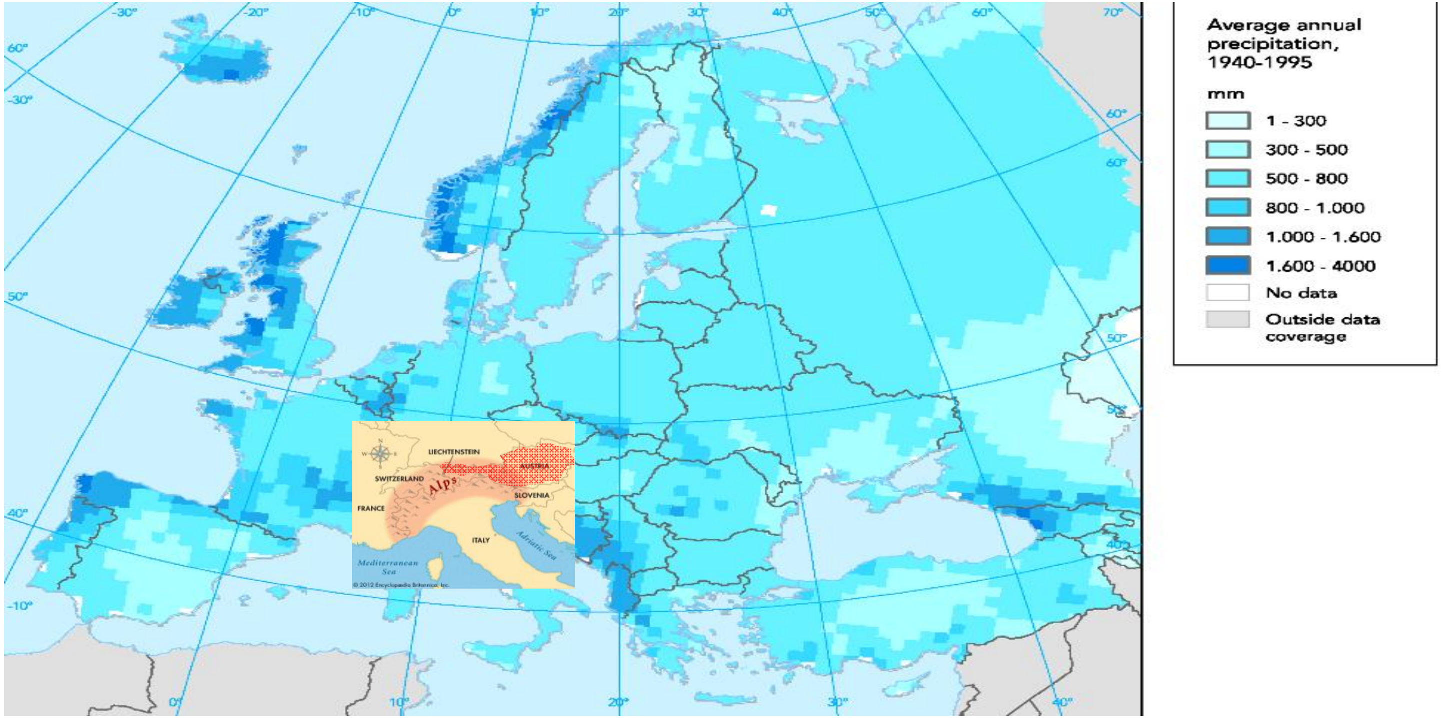
Basics of Pumped Storage EMC Kerala Workshop

Peter Matt

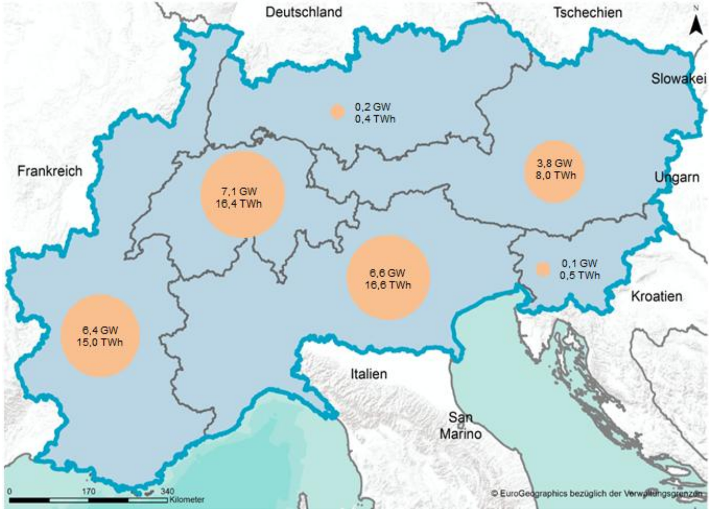
Topics

- Energy transition – requirements to generators and system security
  - Function in grid and benefits
  - Facing the challenges based on huge RES generation in future
- Impacts from the market conditions
- Trade-offs in environmental benefits and impacts
- Financial aspects

Europe Hydropower



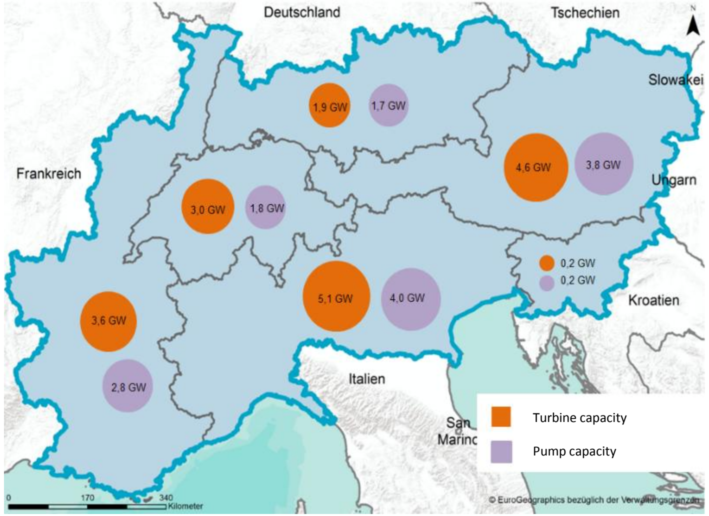
> 300 Alpine Storage Plants offer Flexibility



- **number:** **338**
- **capacity:** **24.1 GW**
- **energy capability:** **56.9 TWh**

- There is a equiparted installed storage capacity in Switzerland, as well as in the French and the Italian Alpine regions.

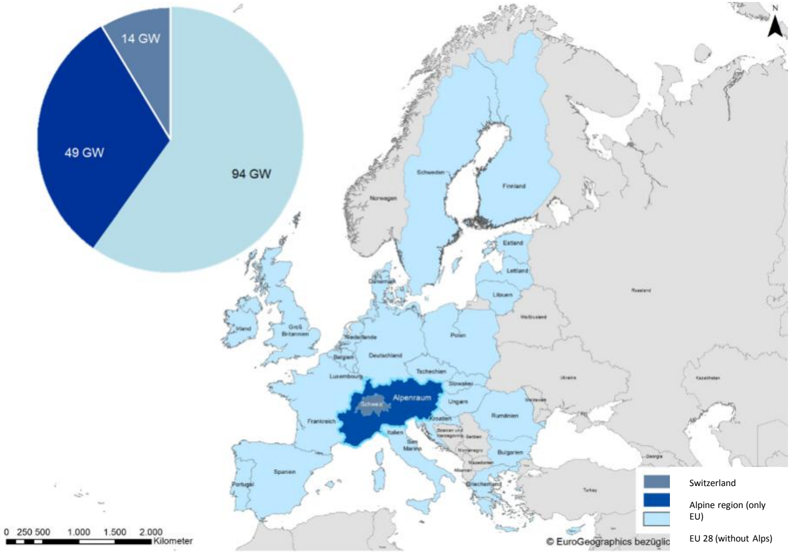
Pumped Storage ist the Asset of Alpine Hydropower



- **number:** **78**
- **Capacity Turbine:** **18 GW**
- **Capacity Pump:** **14 GW**
- **energy storage capabiliy:** **14 TWh**

- Pumped storage plants play a key role in the **integration of volatile renewable energies**

34% of the Hydropower Capacity of EU28 in the Alpine Region



- The total installed hydropower capacity of the European Union amounts to 143 GW
- Only the Alpine region has a hydropower capacity of about 63 GW
- **The hydropower capacity in the Alps - only of European member countries - amounts to 49 GW (34% of EU28)**

Hydropower in Austria



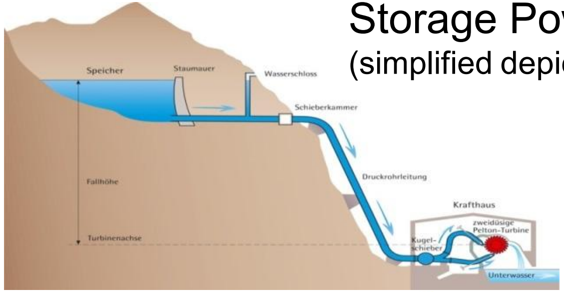

Benefits of Storage Power Plants and Pumped Storage Power Plants

At high demand and/or low renewable production → Production (Turbine)

At low demand and/or high renewable production
→ No production (keep water in high reservoir)
Additional and simultaneous provision of flexibility and ancillary services

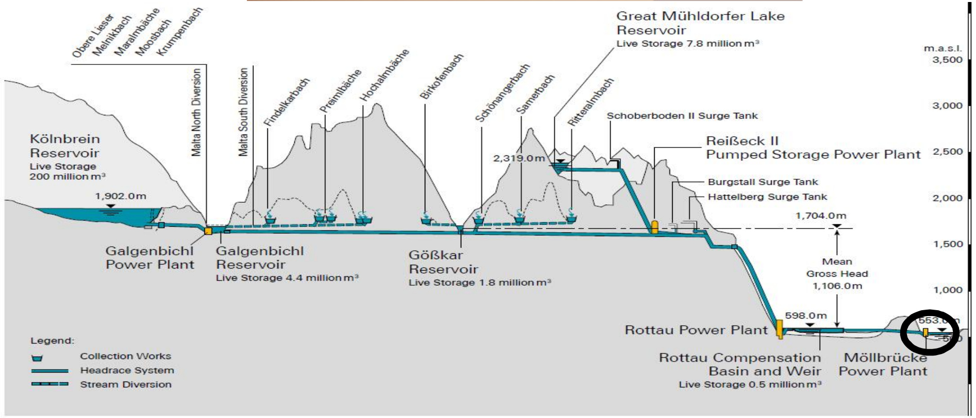
- Operating reserve
- Reactive Power
- Black start Capability
- Congestion Management
- Grid fault management
- …

Storage Power Plant
(simplified depiction)



Storage Power Plant Group (incl. PHS)

- Connected storage and pumped-storage power plants
- Strong interaction between power plants in the group (shared reservoirs, ..)

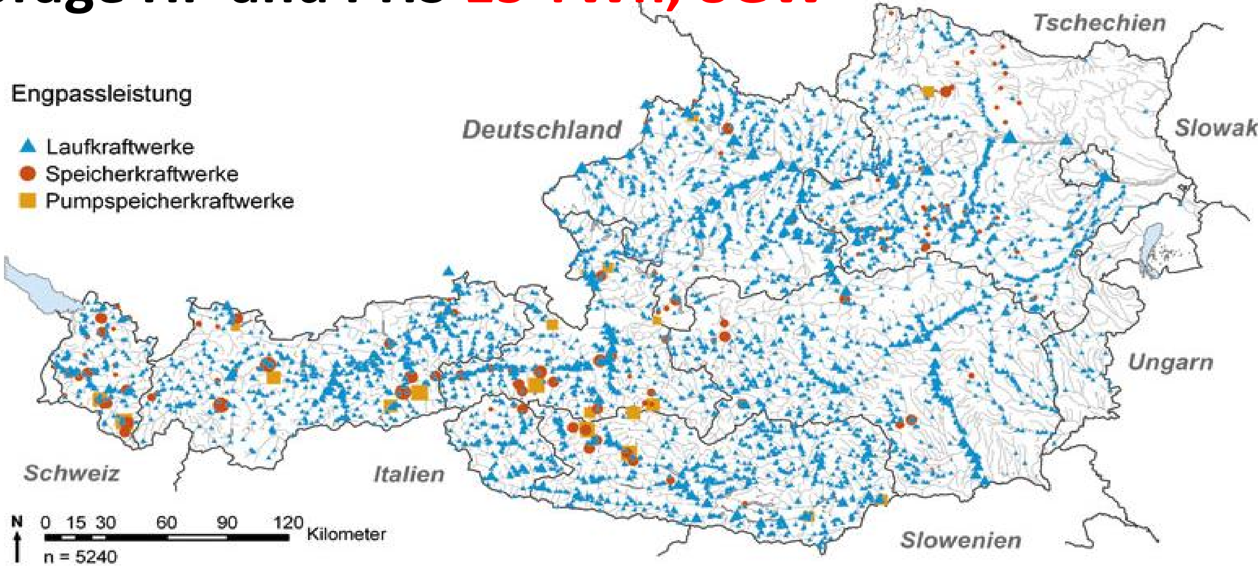


Malta Storage Power Plants, Longitudinal Section

Hydropower in Austria
(67% = 45 TWh)

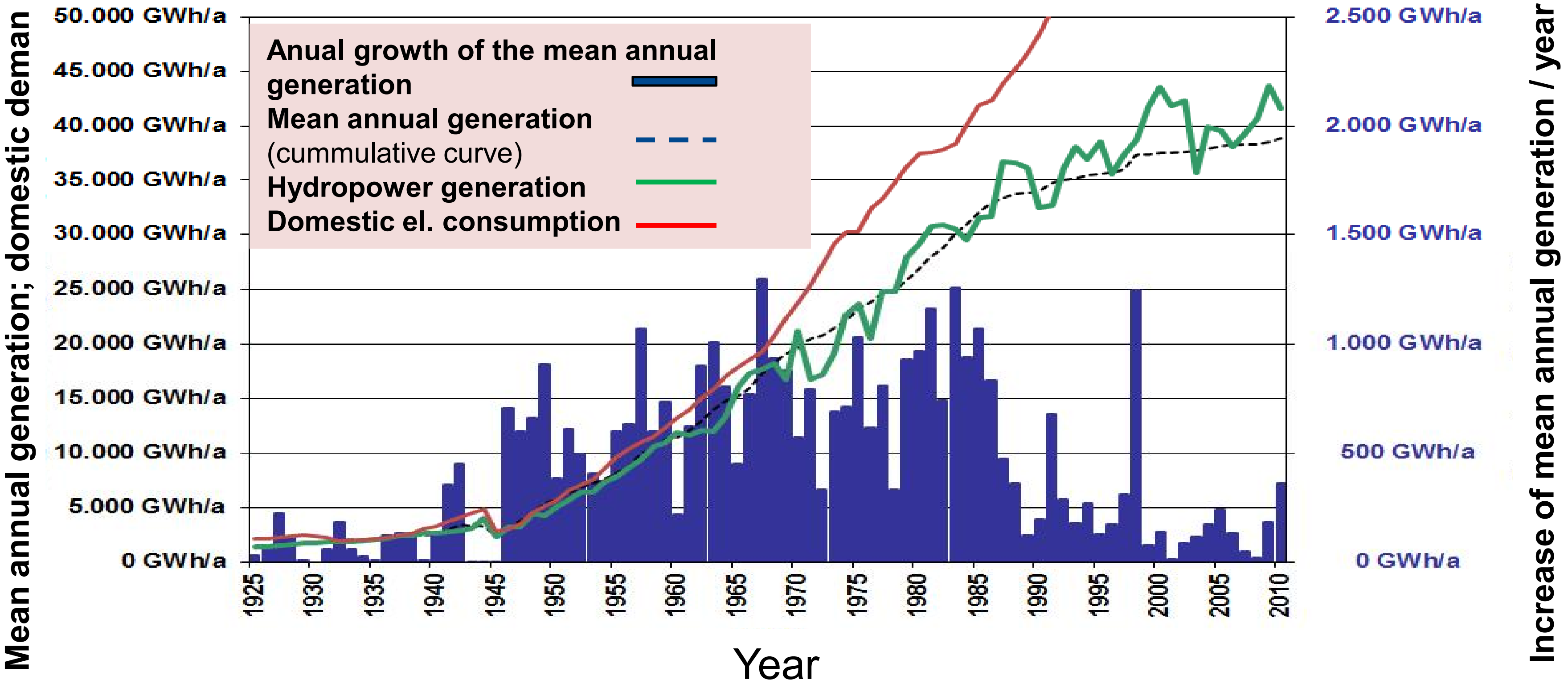
352 Run of River > 1MW; 2500 Run of River < 1MW 30 TWh

112 Storage HP and PHS 15 TWh, 8GW



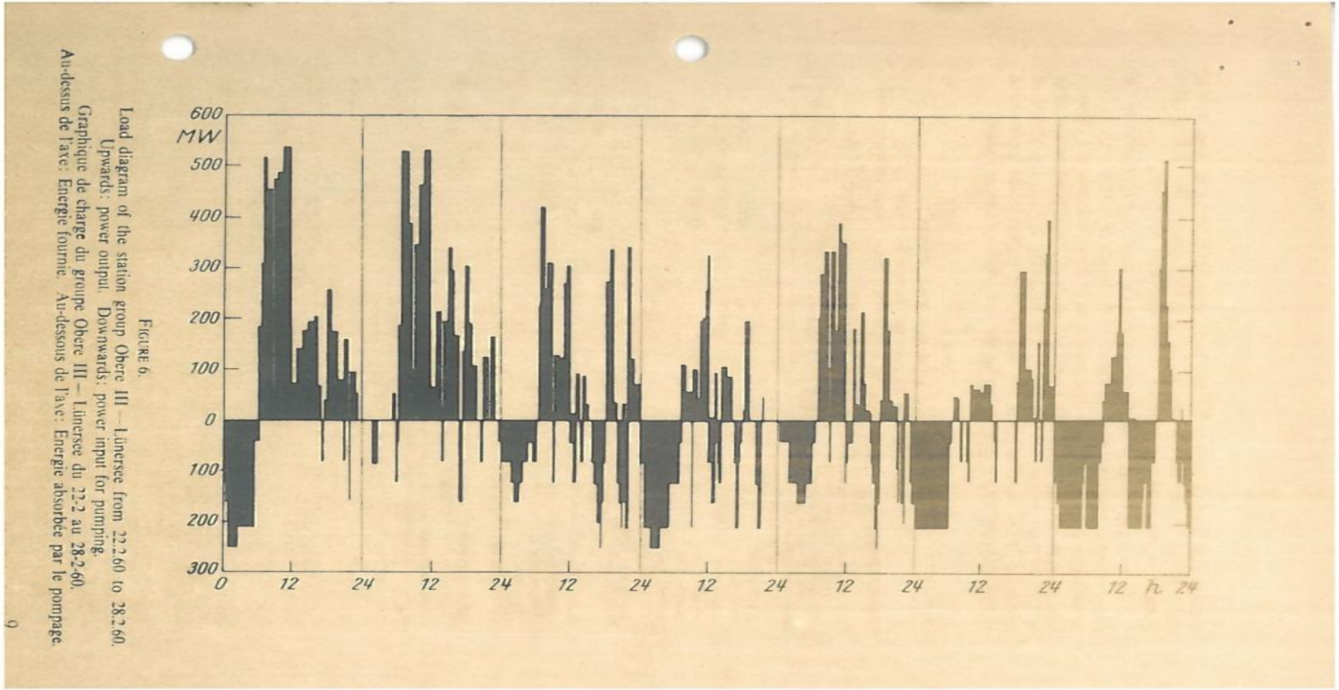
Hydropower Development in Austria
(socio-economic and environmental framework conditions)

Vorarlberger Illwerke AG



Weekly Load Diagramm1960

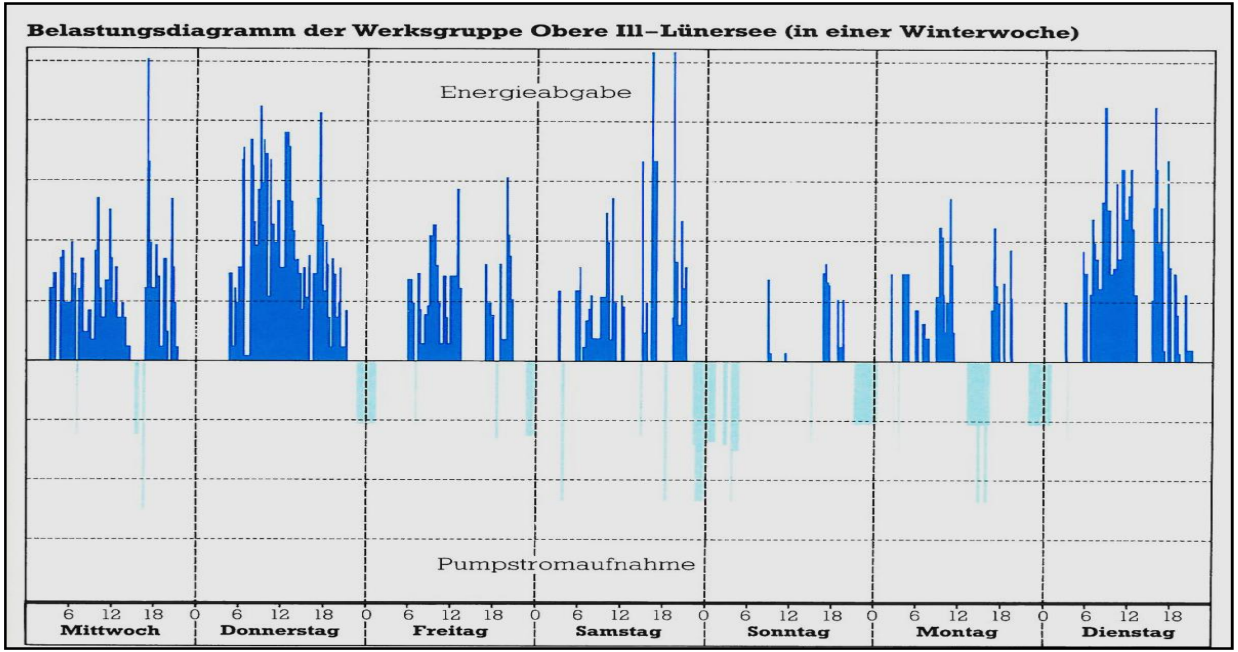
Vorarlberger Illwerke AG



Werksgruppe Obere Ill – Lünersee vom 22.2.1960 bis 28.2.1960

Weekly Load Diagramm 1982

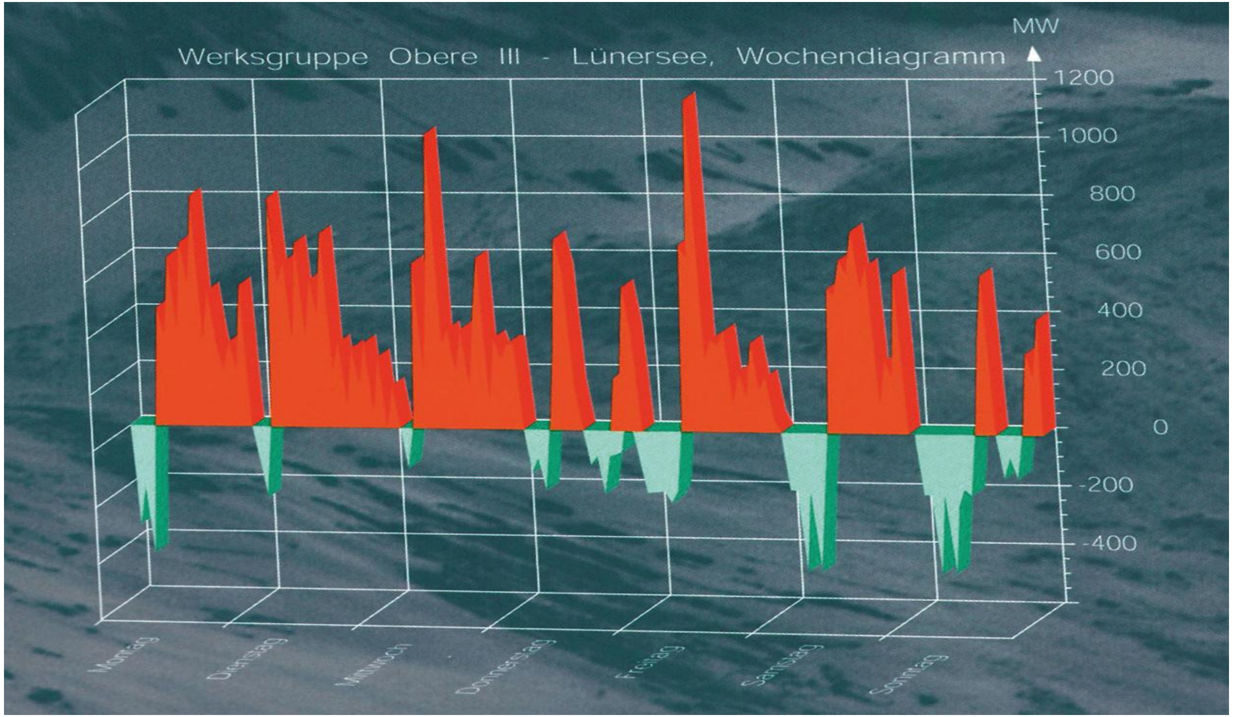
Vorarlberger Illwerke AG



Werksgruppe Obere Ill – Lünersee Winterwoche 1982

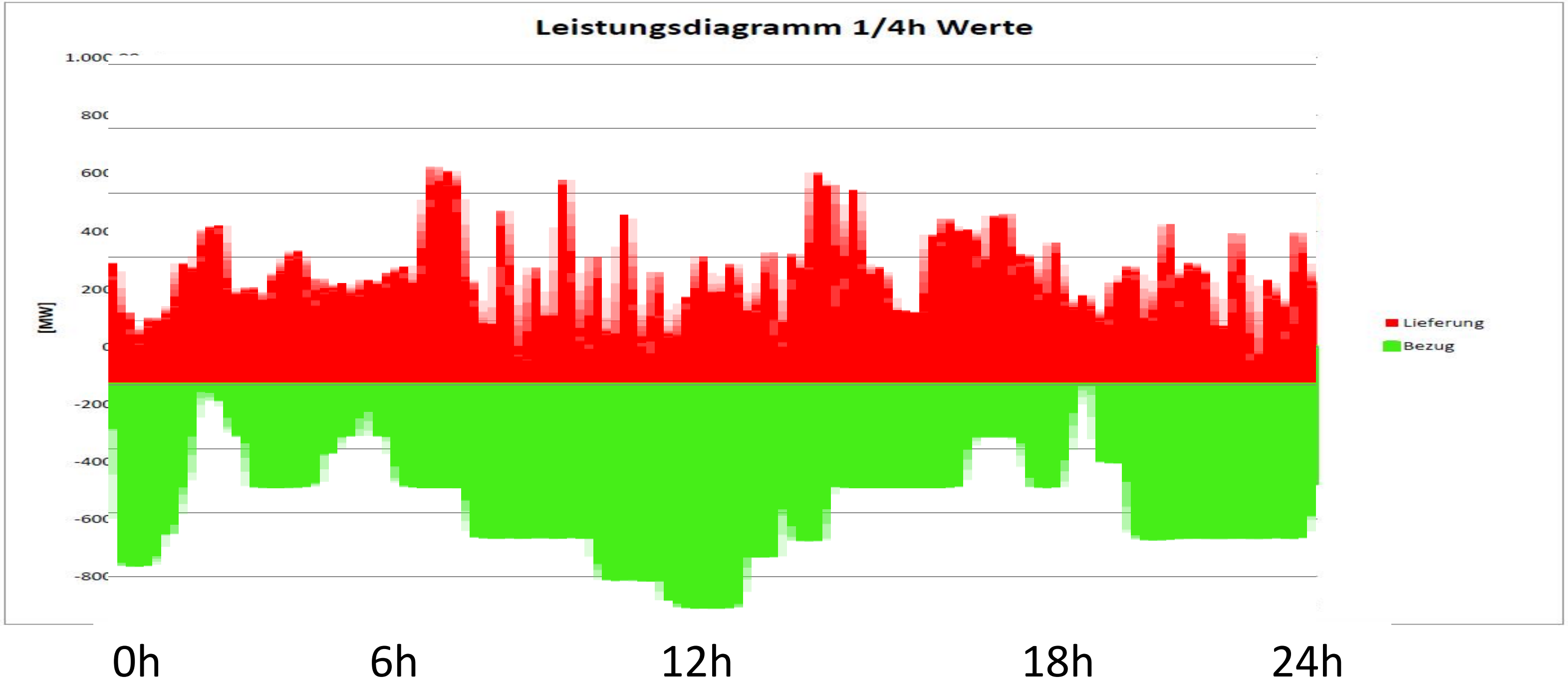
Weekly Load Diagramm 2003

Vorarlberger Illwerke AG



Weekly Load Diagramm 2012

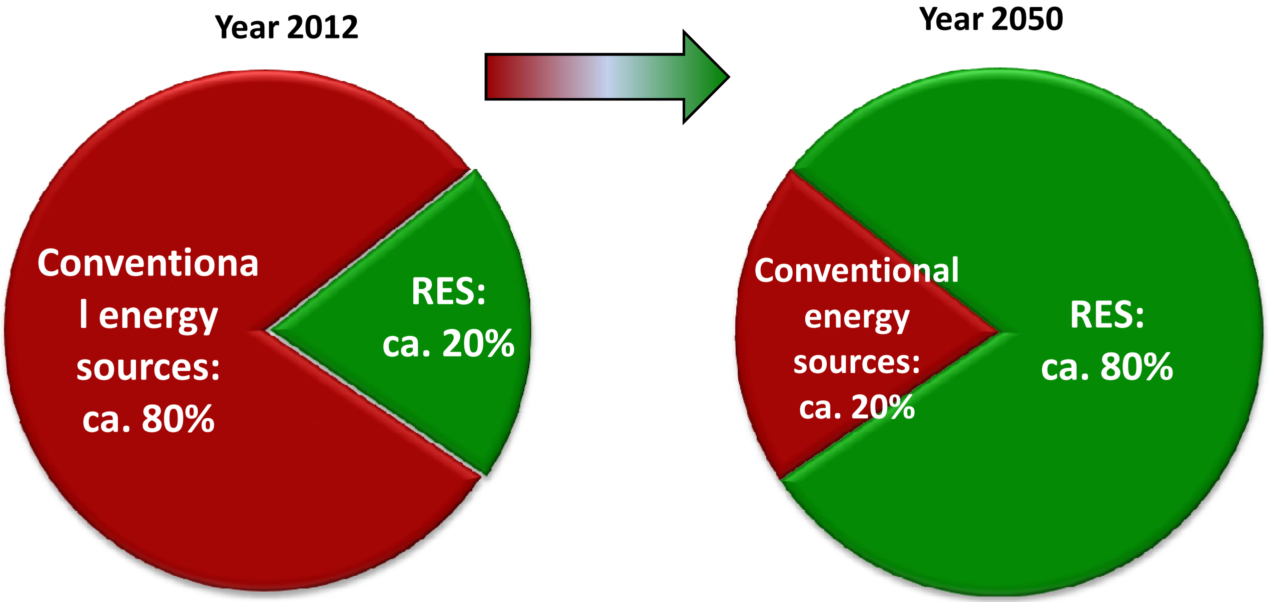
Vorarlberger Illwerke AG



Renewables - Target 2050 "exchange of roles"

Vorarlberger Illwerke AG

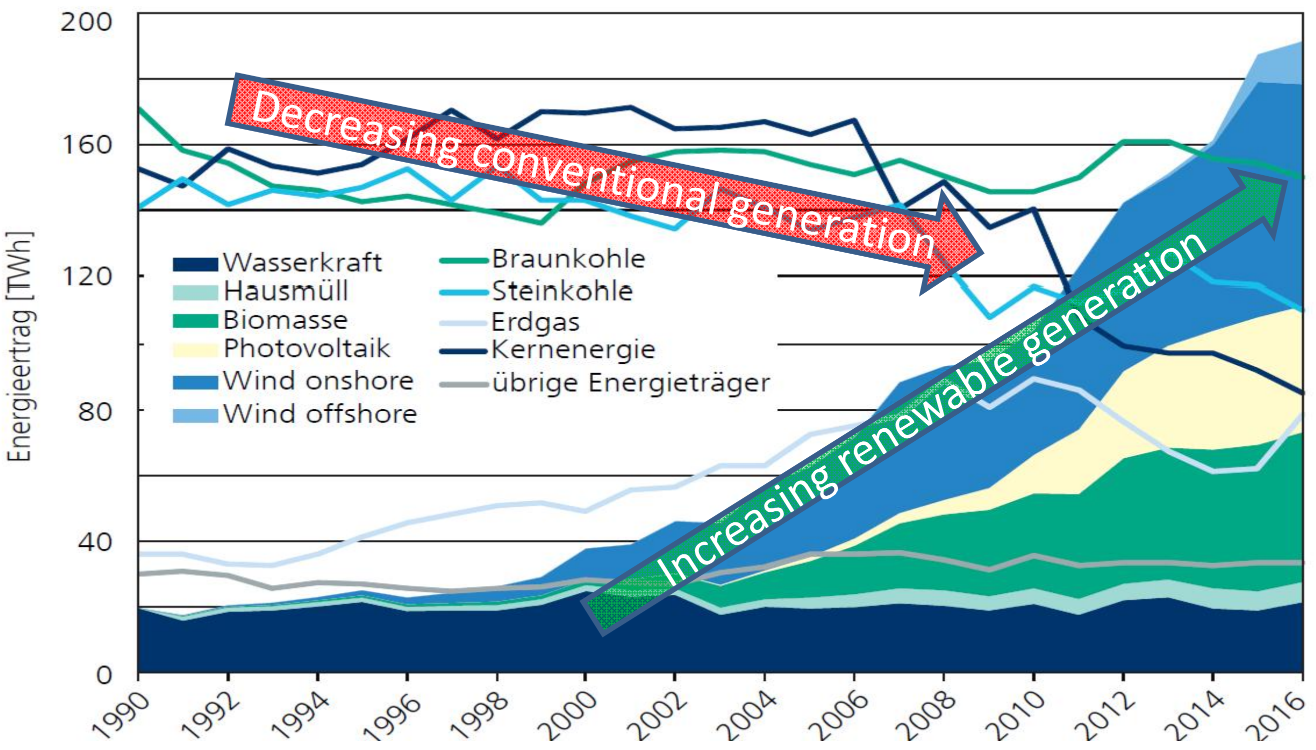
High Share of renewable energies in gross domestic electricity consumption in Germany:
Challenge - integration of wind and PV, while maintaining security of supply



Source: BDEW, AG Energiebilanzen,Stand: 08/2012; Ziele der BR

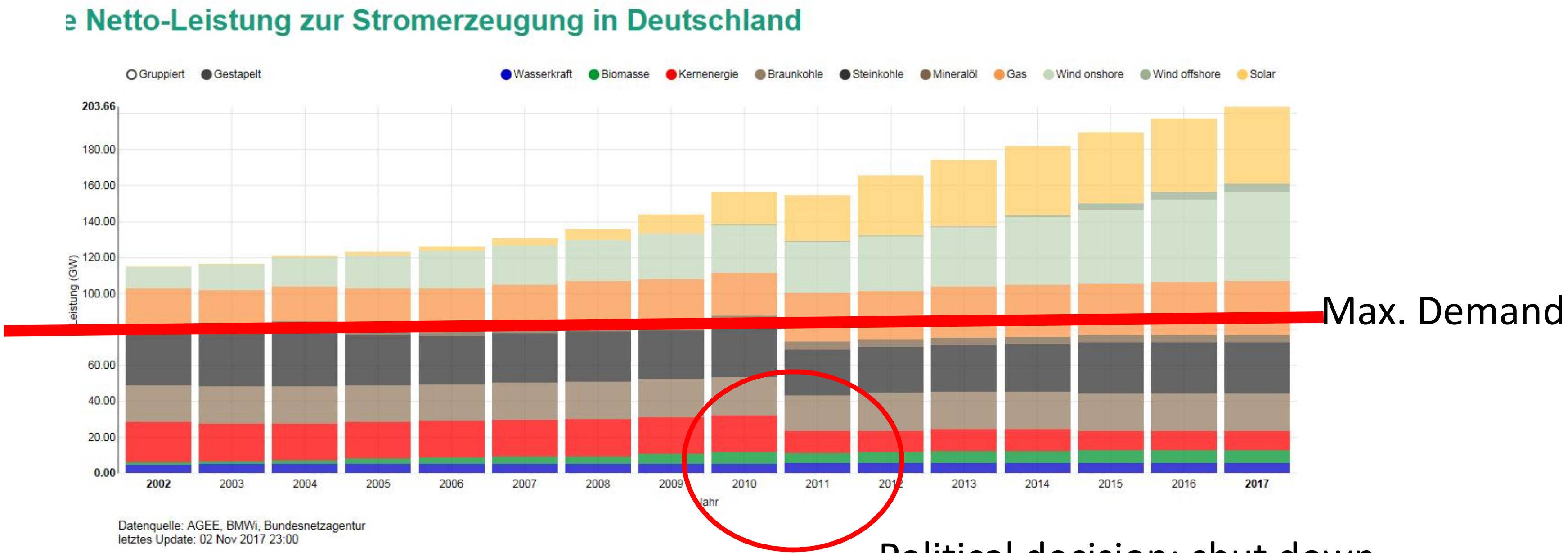
Development Electrical Energy Generation Germany

Vorarlberger Illwerke AG



Source: AG Energiebilanzen

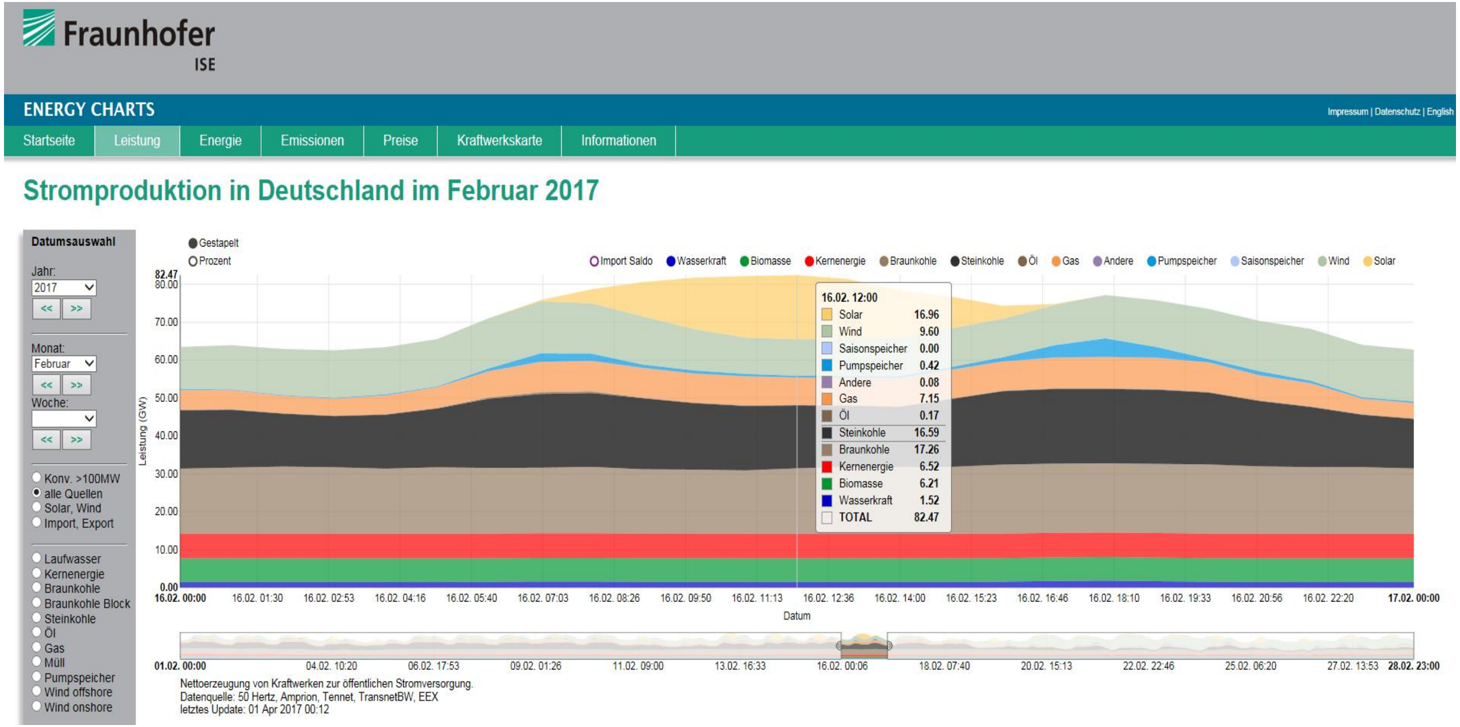
Installed Capacity in Germany



Political decision: shut down nuclear stations until 2030

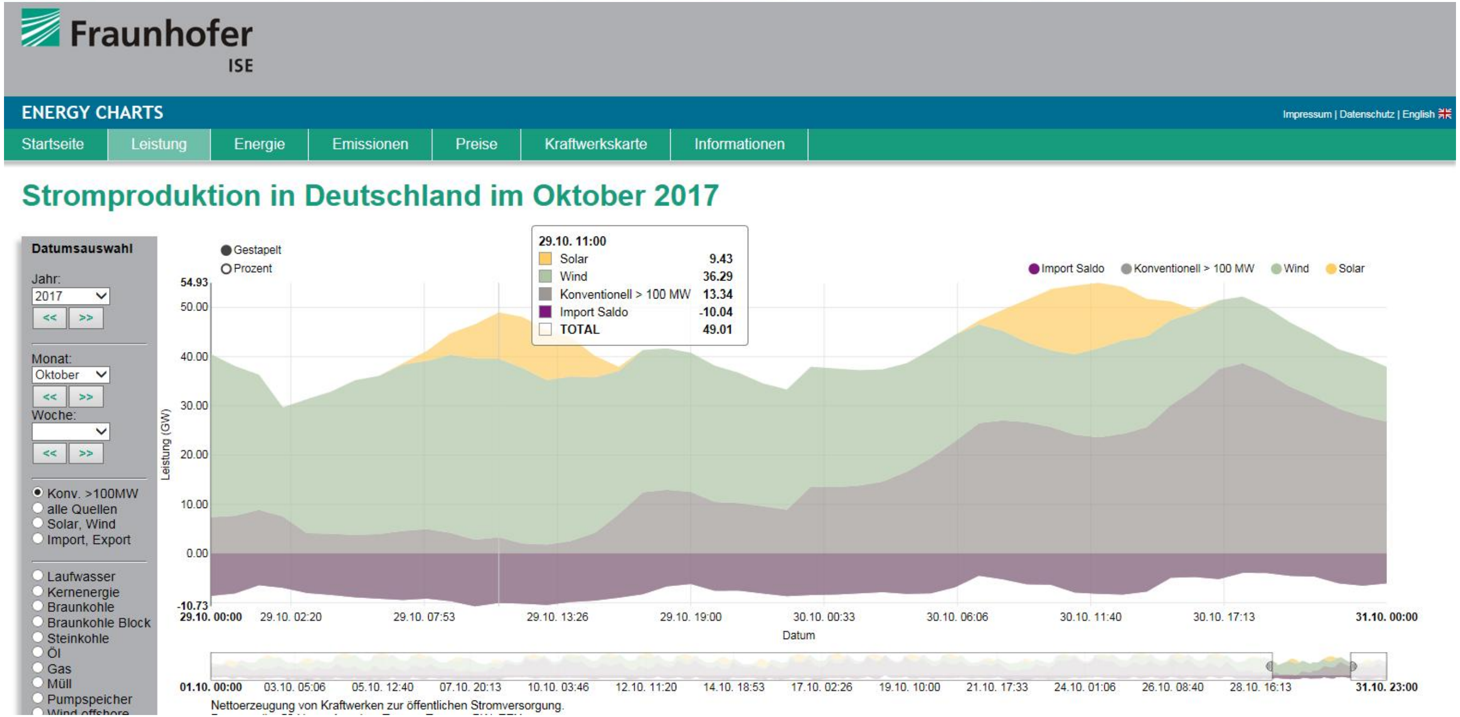
Electrical Energy Generation in Germany

February 2017 (max 40% RES)

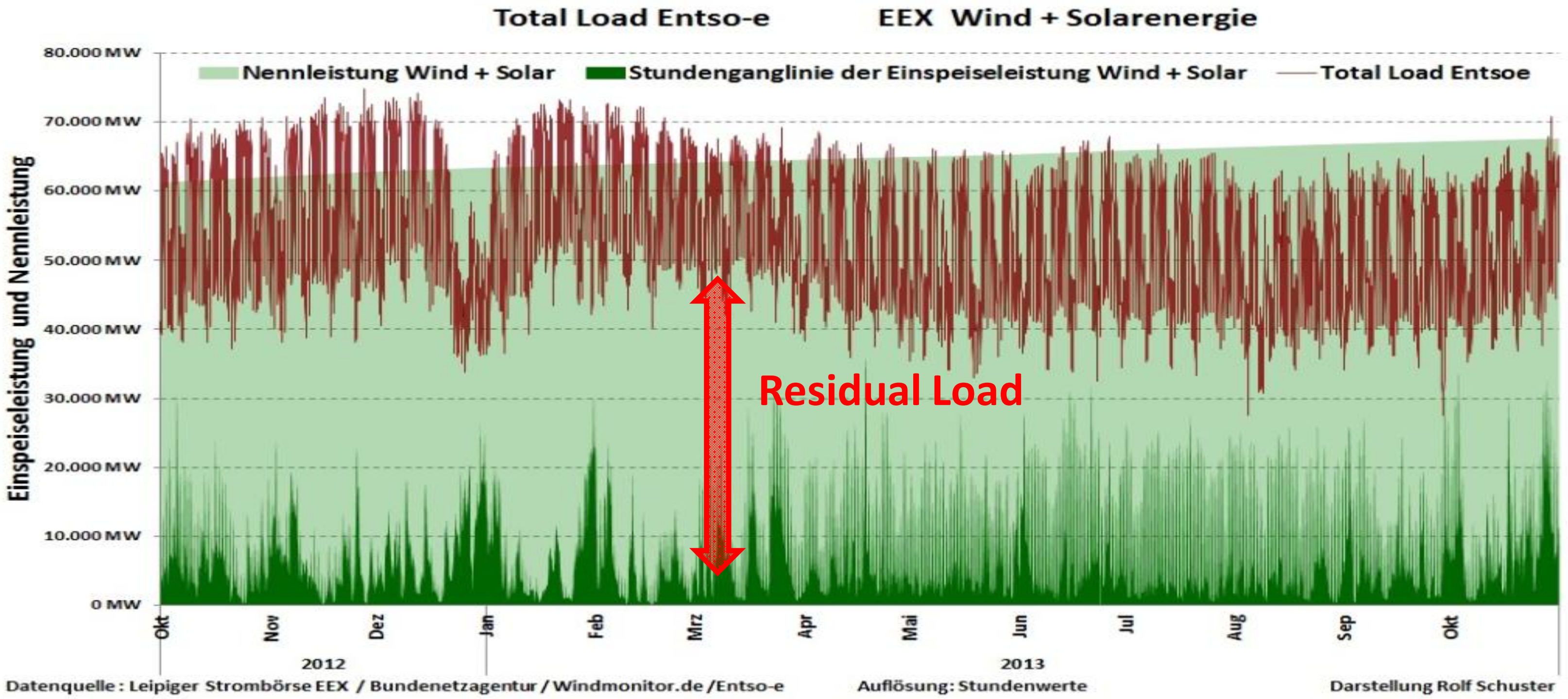


Electrical Energy Generation in Germany
October 2017 (max 93% RES)

Vorarlberger Illwerke AG

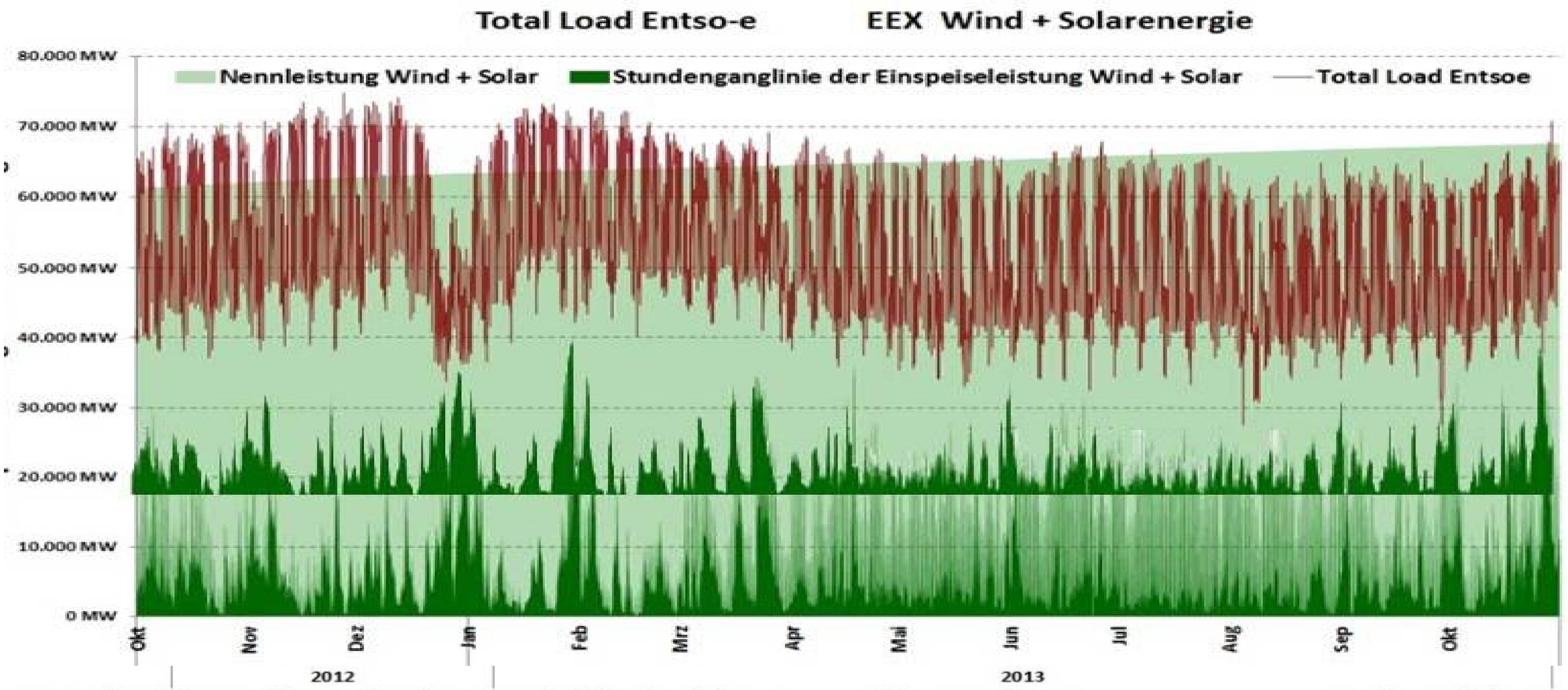


Wind + PV feed in and total installed capacity (Germany)



Wind + PV feed in Simulation 20% RES

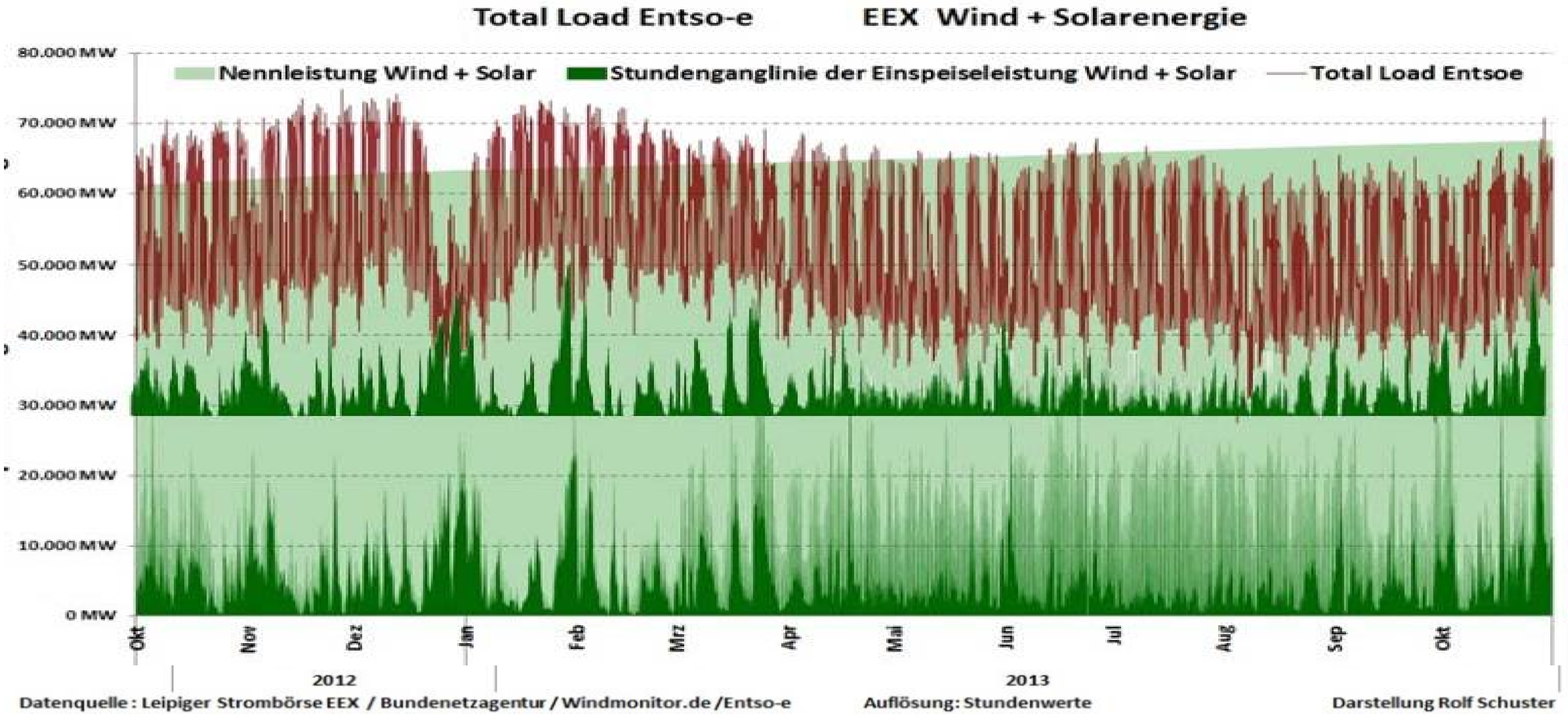
Vorarlberger Illwerke AG



Datenquelle: Leipiger Strombörse EEX / Bundenetzagentur / Windmonitor.de / Entso-e
Auflösung: Stundenwerte
Darstellung Rolf Schuster

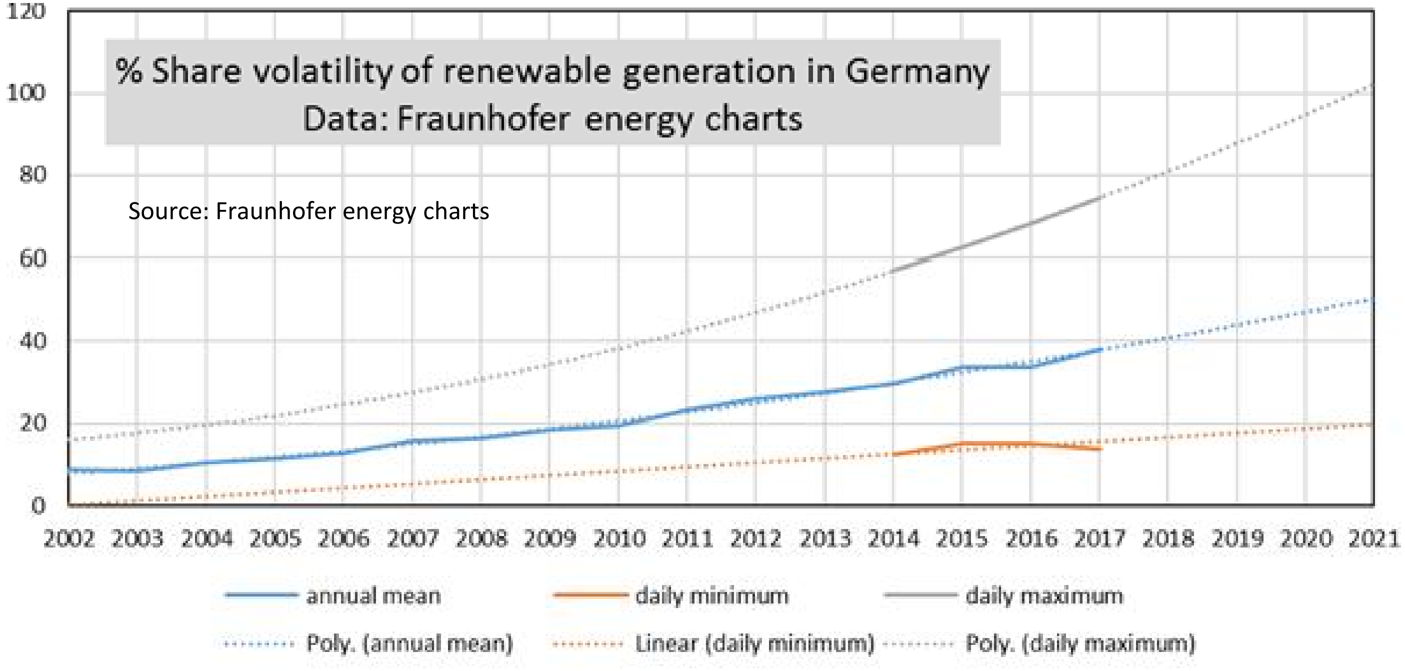
Wind + PV feed in Simulation 40% RES

Vorarlberger Illwerke AG



Daily share of RES - Generation
Renewables in Germany

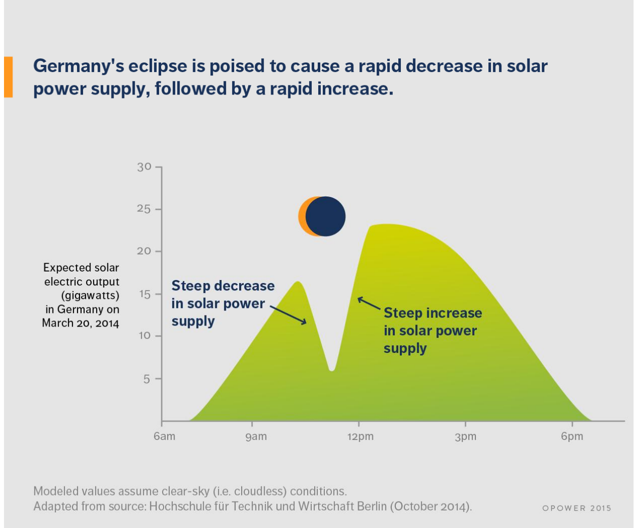
Vorarlberger Illwerke AG

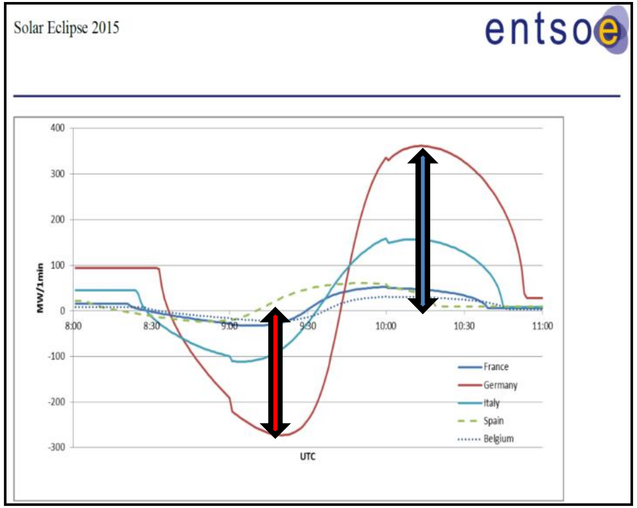


What are the future power gradients?

Vorarlberger Illwerke AG

Example: Impact Analyses Solar Eclipse 2015

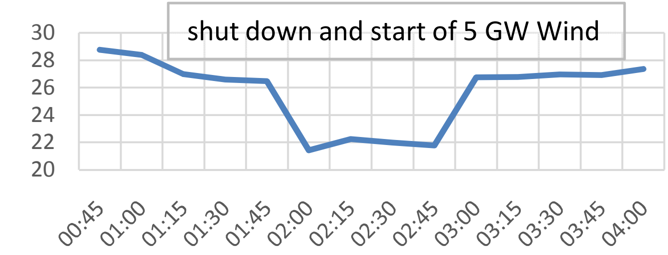


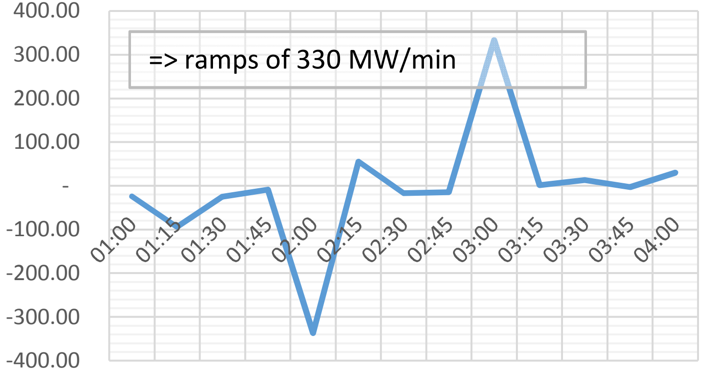


Hydropower the Insurance of Power Supply

Vorarlberger Illwerke AG

Wind capacity during "HERWART" 29th October 2017

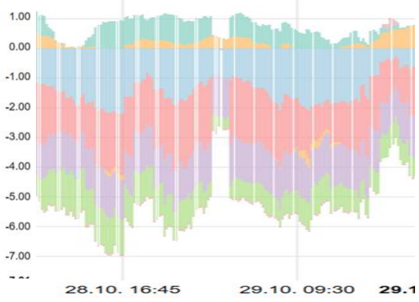




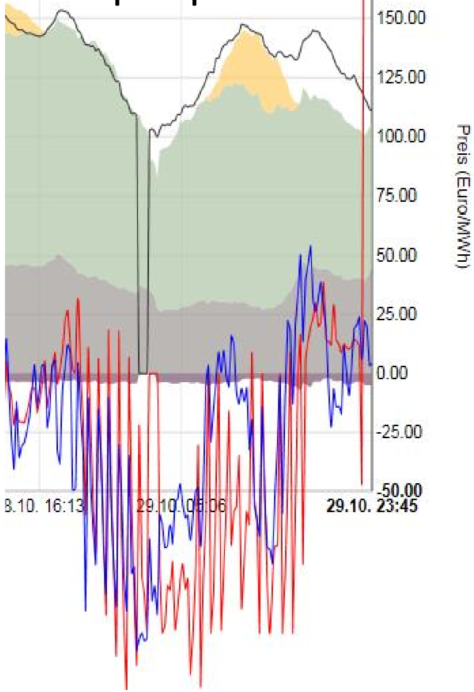
Generation

3,2 GW start and shut down within 15 min

Import Export



Spot prices



Vorarlberger Illwerke AG

Week Load Diagramm
Differences between 2012 and 2016

Vorarlberger Illwerke AG

Installed capacity: Turbine 1995 MW / Pump -1044 MW

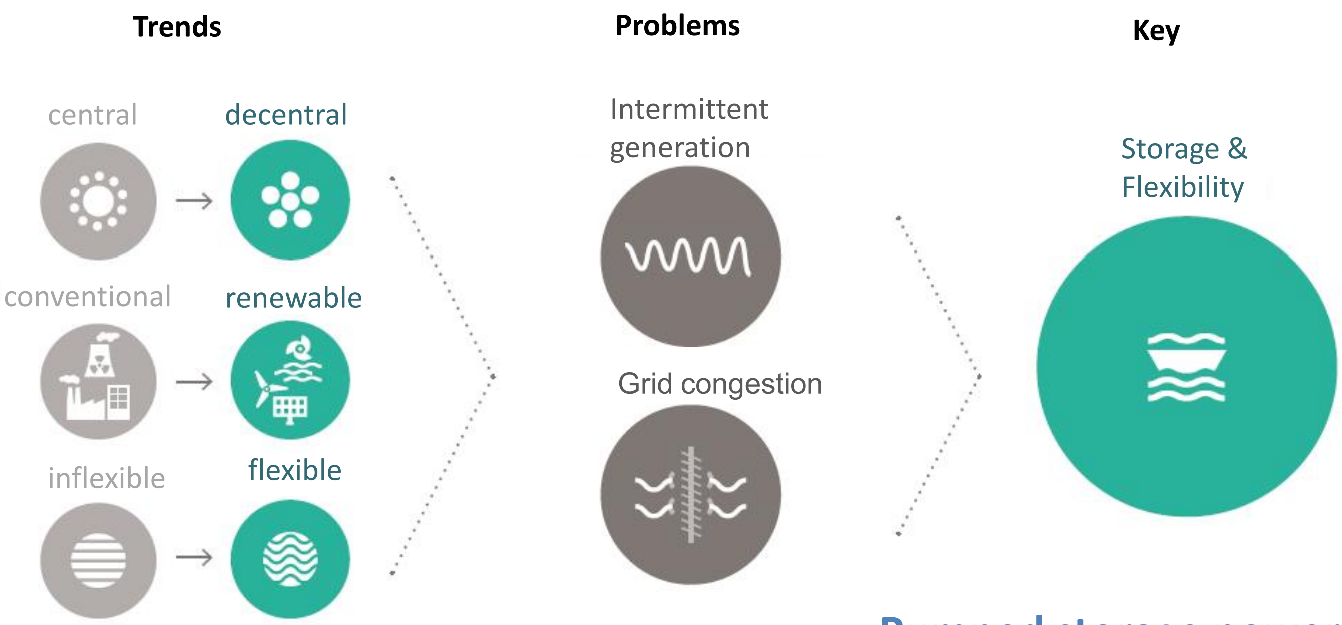
2012	Mean	Peak	Peak/Mean
Positiv Load	**320**	**700**	**2.18**
Negativ Load	**-350**	**750**	**2.14**

2016	Mean	Peak	Peak/Mean
Positiv Load	**250**	**1470**	**5.8**
Negativ Load	**-260**	**820**	**3.2**

- increasing flexibility
- decreasing calls
- shorter generation times

Volatile wind and PV need CO_2-free storage and flexibility

Vorarlberger Illwerke AG

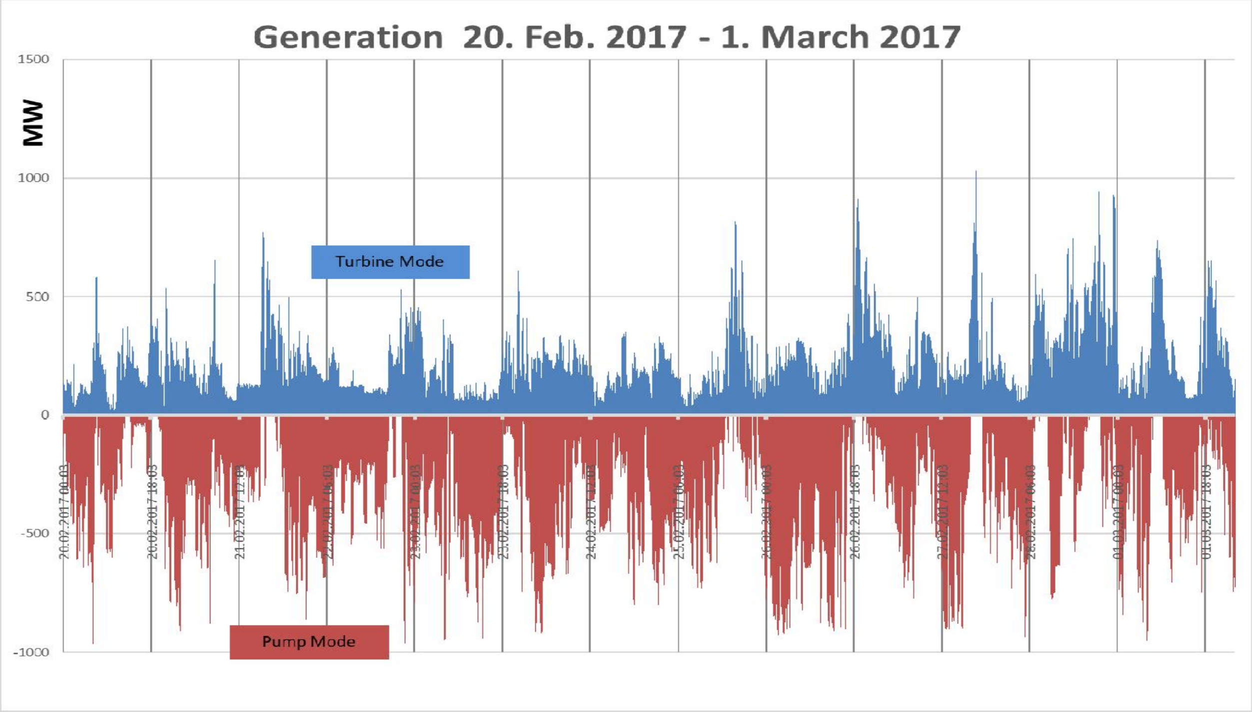


- Pumped storage power plants deliver CO_2-free flexibility in the short-, middle- and long term.
- Hereby, they balance electricity supply and demand over hours, days and even seasons.

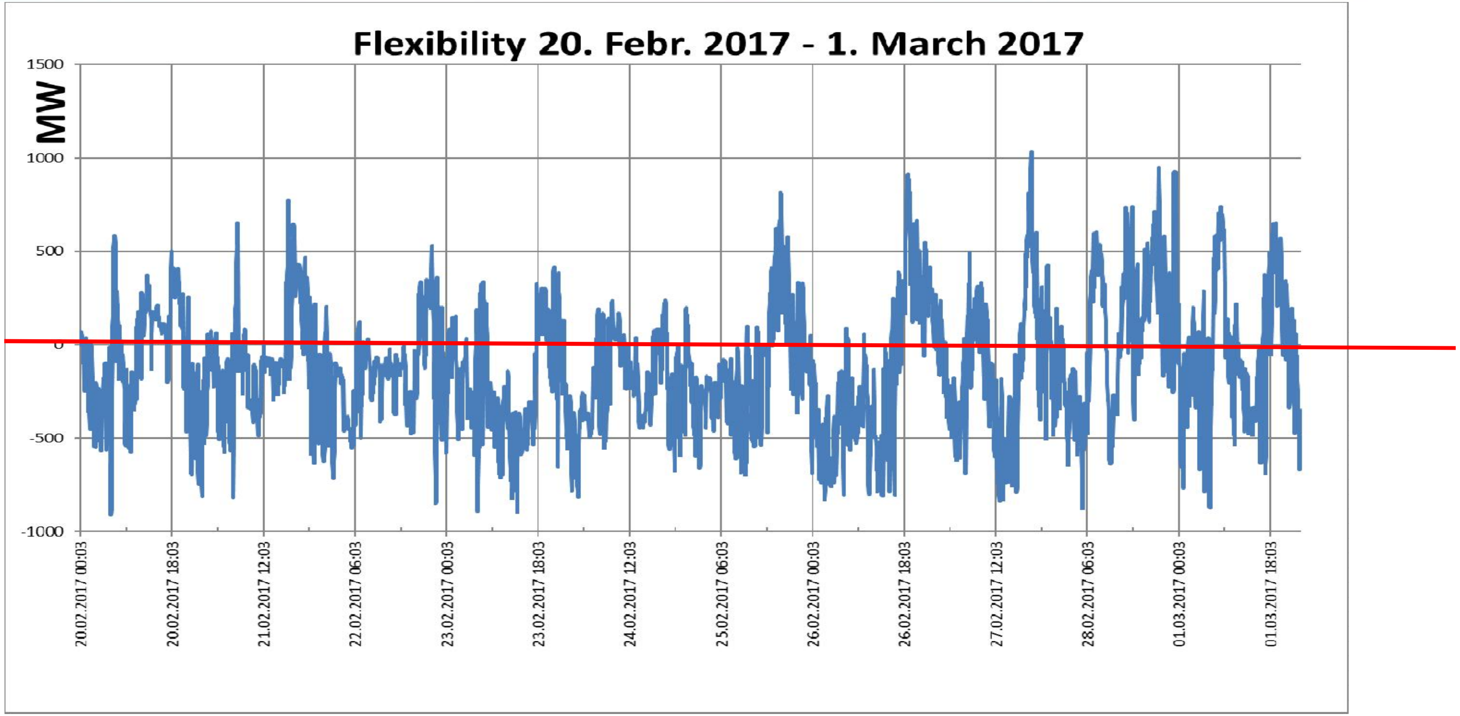
Pumped storage power plants deliver both

Storage plants Vorarlberger Illwerke AG

Vorarlberger Illwerke AG

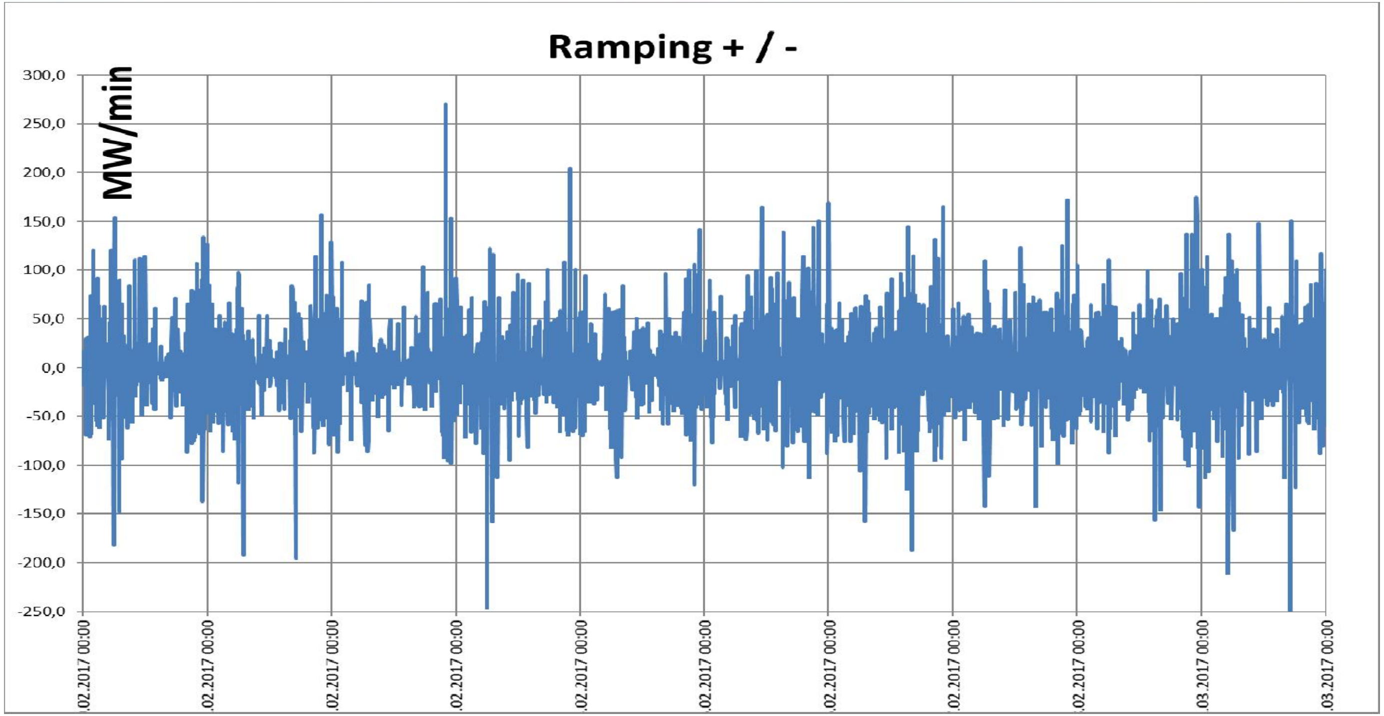


Output to the transmission grid



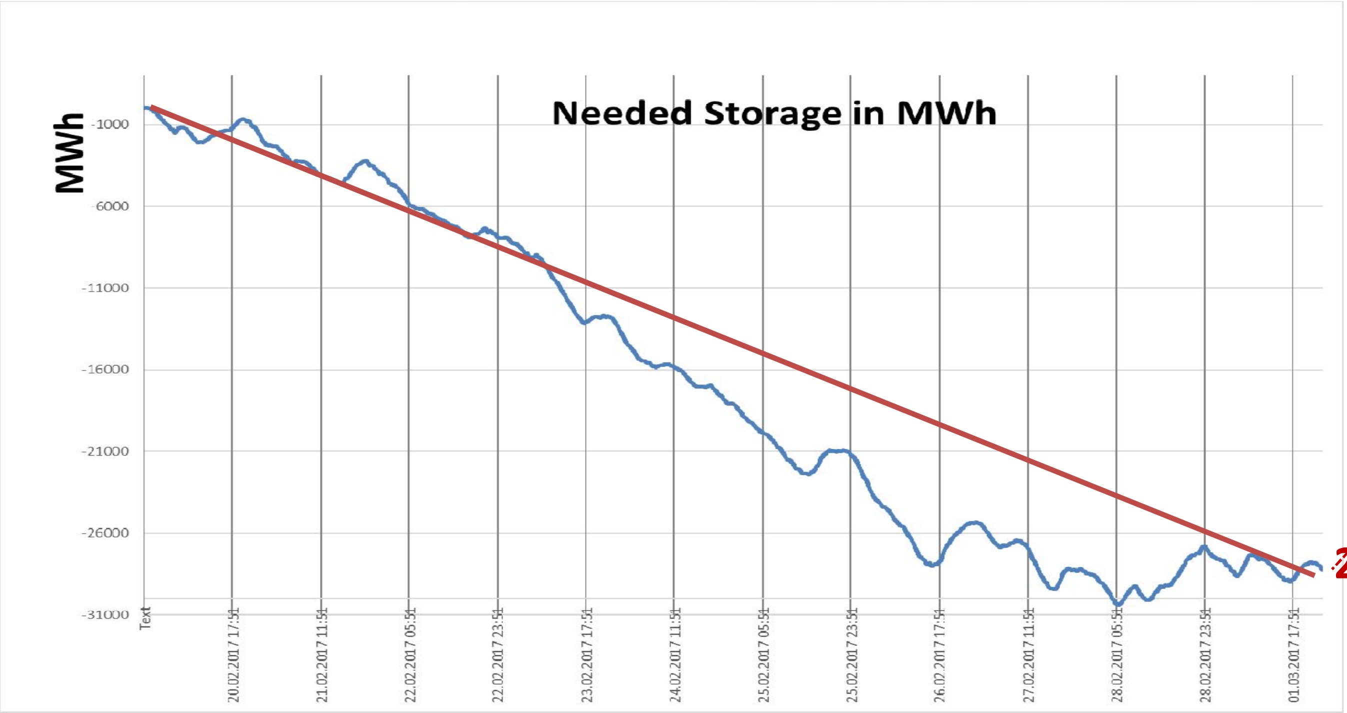
Volatility of Load

Vorarlberger Illwerke AG



Deterministic view: possible linear storage

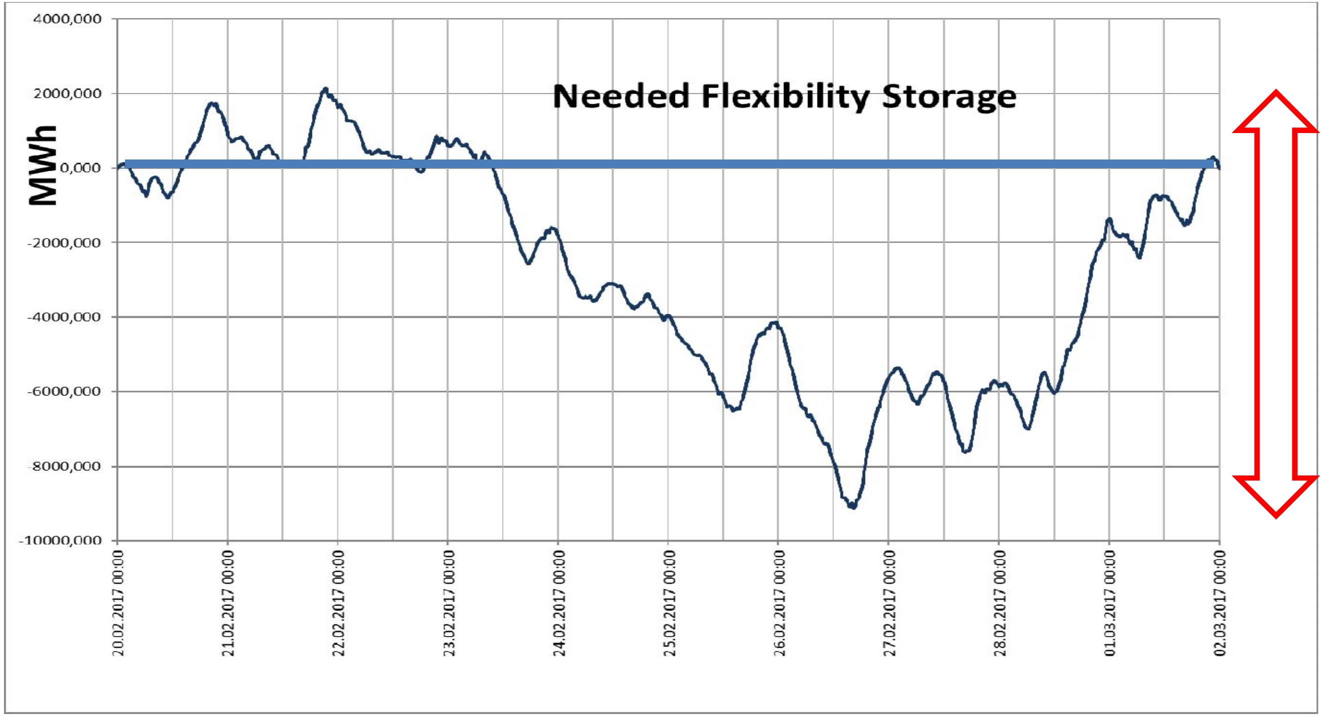
Vorarlberger Illwerke AG



28 GWh Storage

Deterministic view:
Needed Storage for Flexibility

Vorarlberger Illwerke AG



Flexibility - Storage

Vorarlberger Illwerke AG

SHP and PHS plants support integration of wind and PV

- eg. HP-system with 2GW supports
  - Flexibility: - 1GW / + 2GW with ramping +/- 300 MW/min
  - Storage for Flexibility: rd. 10 GWh
  - Storage: rd. 30 GWh
- Extrapolation Alpin Arc – 42 GW SHP and PHS
  - Flexibility: - 14 GW / + 42 GW
  - Storage: rd. 14.000 GWh

„Tomorrows Flexibility“

Vorarlberger Illwerke AG

PCI Prognosis unitl 2030 (Acer TYNDP 2016):

- E- Generation +14 GW
- E- Storage + 14 GW
- E- Storage + 44 GWh

div. Studies	Share RES EE-consumption	needed EES GWh
2025	40%	+ 5 GWh
2030	50%	+50 GWh
2050	60%	+ 100 – 400 GWh
2060	80%	+ 70 TWh

FLEXIBILITY the Future Goal

significant key performance indicators of storge technologies

Vorarlberger Illwerke AG

Source: position paper VGB 6/2017

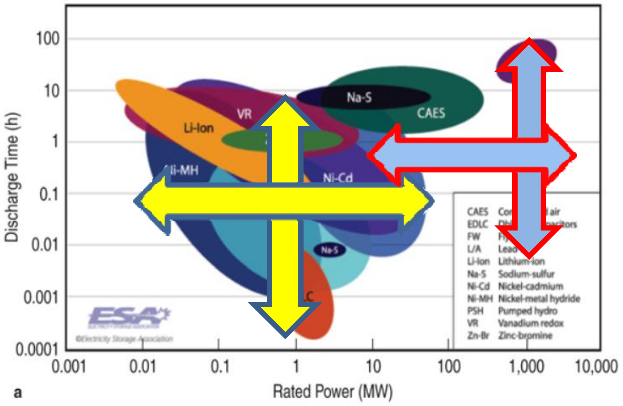
Technology	Current conditions					
	Technology Readiness Level (TRL) (range from 1-9)	Efficiency	Lifetime	Average electricity generation costs	CO_2 neutrality in manufacture and operation	Change-over and Start-up periods
HPP	9	green	green	green	green	green
D-CAES	8 to 9	yellow	green	green	yellow	green
A-CAES	4	yellow	green	yellow	yellow	green
PtGtP(H_2)	8 to 9	red	yellow	yellow	green	green
PtGtP(CH_4)	6	red	yellow	yellow	green	yellow
Batteries	8 to 9	green	red	red	red	green

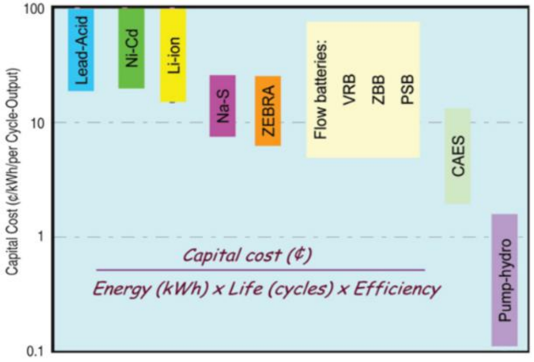
Table 1: VGB (2017) - Comparison of significant key performance indicators of storage technologies

HPP - Hydro Power Plant, D-CAES - Diabatic compressed air storage, A-CAES - Adiabatic compressed air storage, PtGtP (H_2) - Power to gas to power(H_2), PtGtP (CH_4) - Power to gas to power (CH_4)

Qualitative evaluation scale of suitability: green-high, yellow-middle, red-low

Technologies





Range of Batteries: msec -> hours, W -> MW, kWh -> MWh

Range of PHS: sec -> month, MW -> GW, MWh - > GWh

Factor 1 : 1000

SOURCE: ESA; http://www.tms.org/pubs/journals/JOM/1009/fig6.jpg

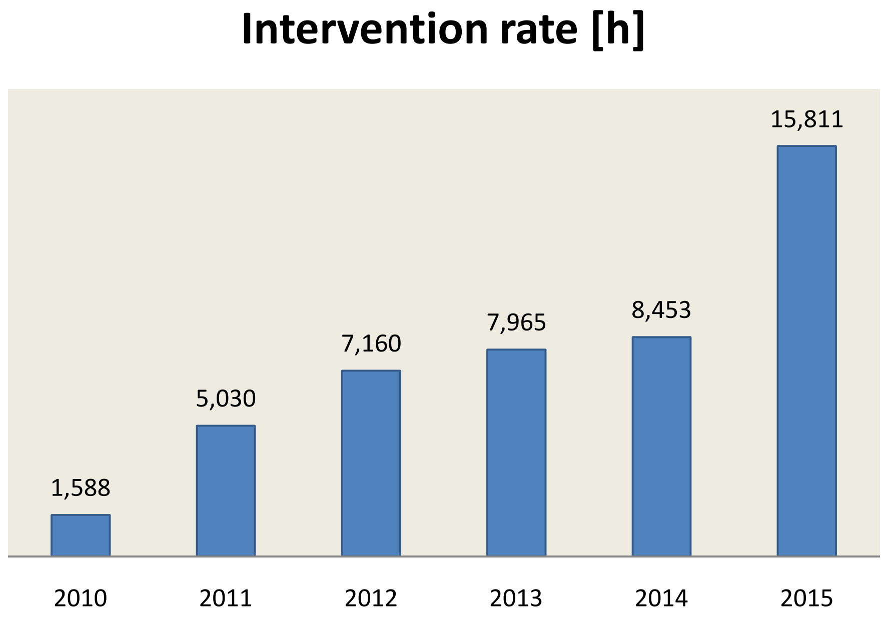
FLEXIBILITY the Future Goal

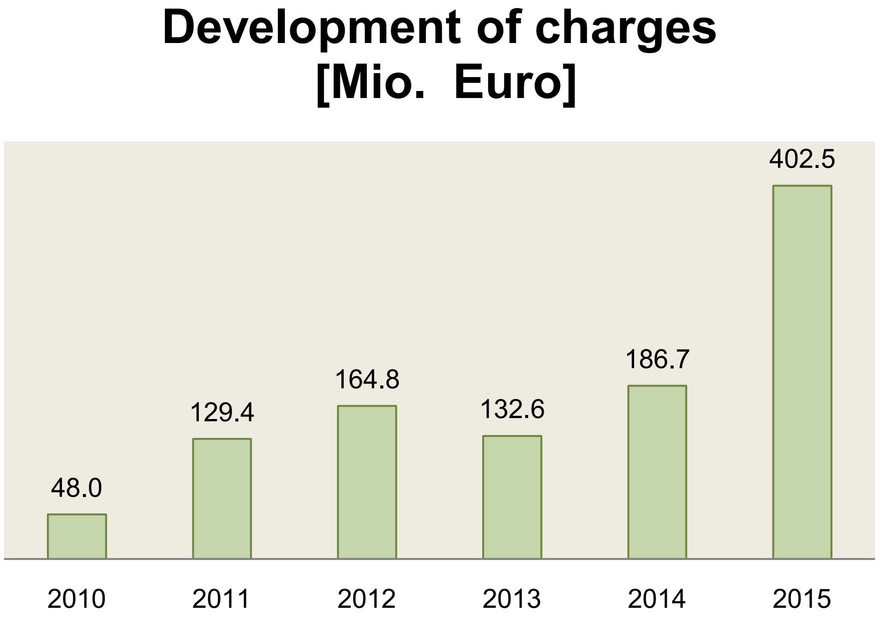
Vorarlberger Illwerke AG

- **Storage:** short term, long term, seasonal, scaling in sec, min, hours, day, month (GWh, TWh)
- **Dynamic:** fast load cycling, (positive and negative ramps > +/- 300 MW/min) quick start facilities, black start facilities, Voltage control with reactive power, primary-, secondary-, tertiary- control energy……
- **Operational Flexibility:** low or no part load limit, high cycle stability, short or no minimum idle time, high effizency over the whole working range
- **Elementary Physics:** Electricity must be available at exactly the moment it is needed.

Redispatch Measures in the German Transmission Network

Vorarlberger Illwerke AG

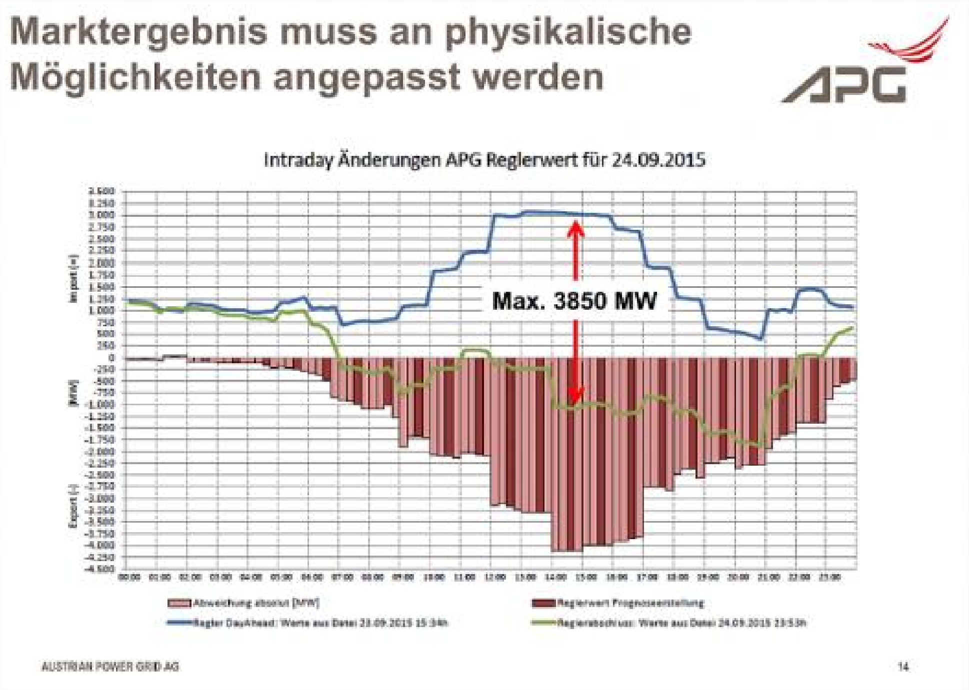




Quelle: Monitoringbericht 2015 Bundeskartellamt BNetzA, 3. Quartalsbericht 2015 zu Netz- und Systemsicherheitsmaßnahmen BNetzA

Current Issues

Vorarlberger Illwerke AG



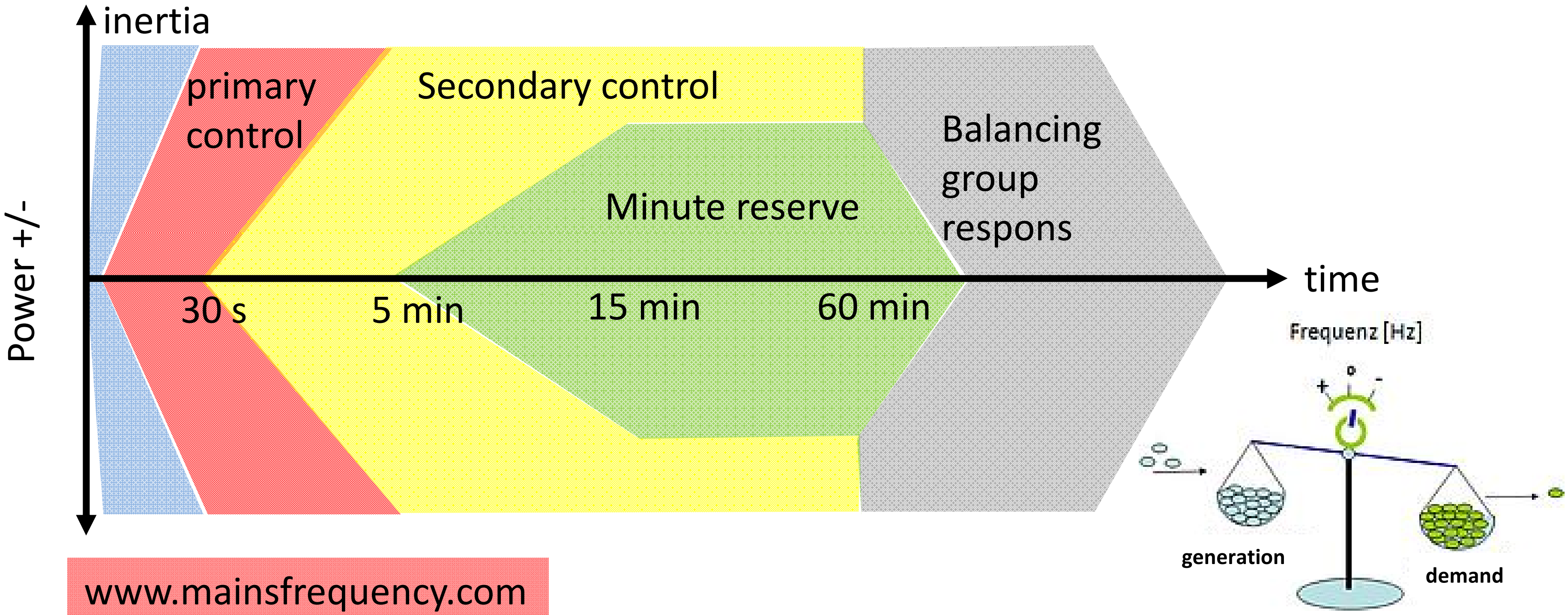
Quelle: APG

Difference between day before prognosis and actual with a delta of 3.850 MW

2:00pm

- Planned: import of 3000 MW
- Actual: export of 850 MW

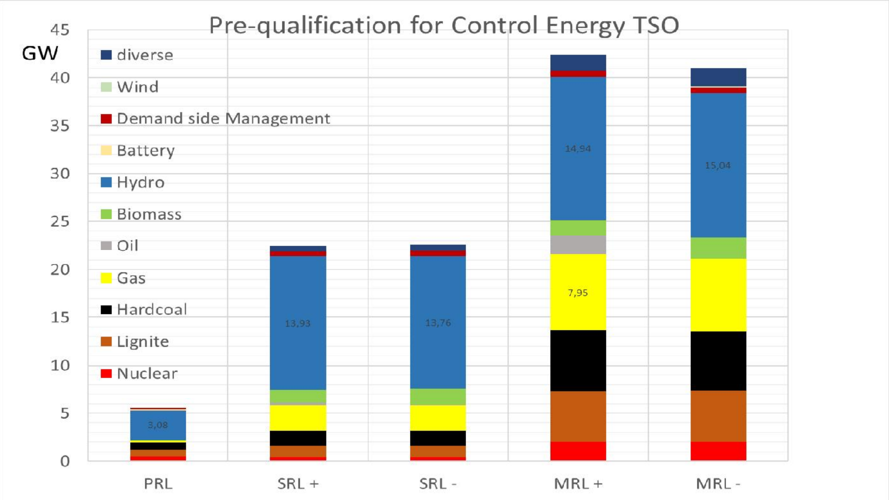
Control energy – frequency control



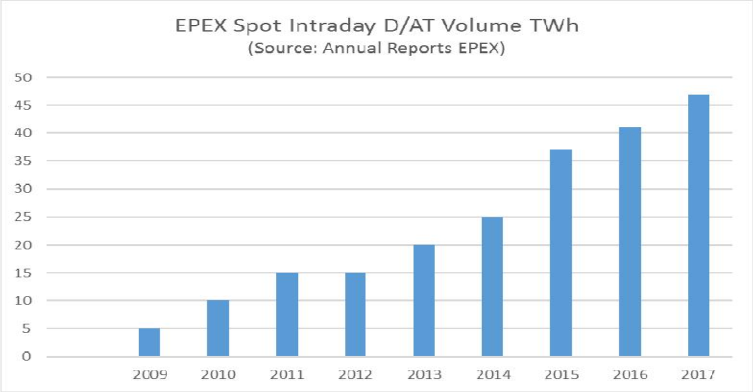
www.mainsfrequency.com

Todays Flexibility

Vorarlberger Illwerke AG



Prequalification of power (GW) for balancing in Germany					
	PRL	SRL +	SRL -	MRL +	MRL -
Nuclear	0,53	0,42	0,42	2,04	2,04
Lignite	0,67	1,24	1,24	5,3	5,34
Hardcoal	0,74	1,49	1,48	6,31	6,15
Gas	0,26	2,67	2,69	7,95	7,56
Oil		0,28	0,02	1,93	0,08
Biomass	0,02	1,36	1,73	1,6	2,17
Hydro	3,08	13,93	13,76	14,94	15,04
Battery	0,16				
Demand side Management	0,07	0,48	0,56	0,67	0,65
Wind					0,09
diverse	0,05	0,59	0,64	1,71	1,86
SUMM GW	**5,58**	**22,46**	**22,54**	**42,45**	**40,98**



Todays tendering for control energy

- PRL +/- 620 MW
- SRL - 1795 MW
- SRL +1869 MW
- MRL +1222 MW
- MRL - 1199 MW

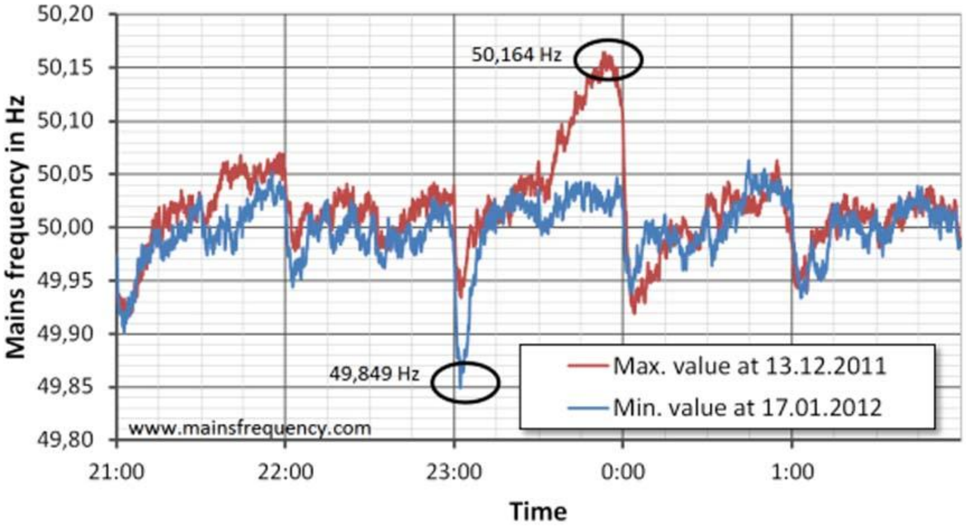
Source:
www.regelleistung.net

Control-energy

Vorarlberger Illwerke AG

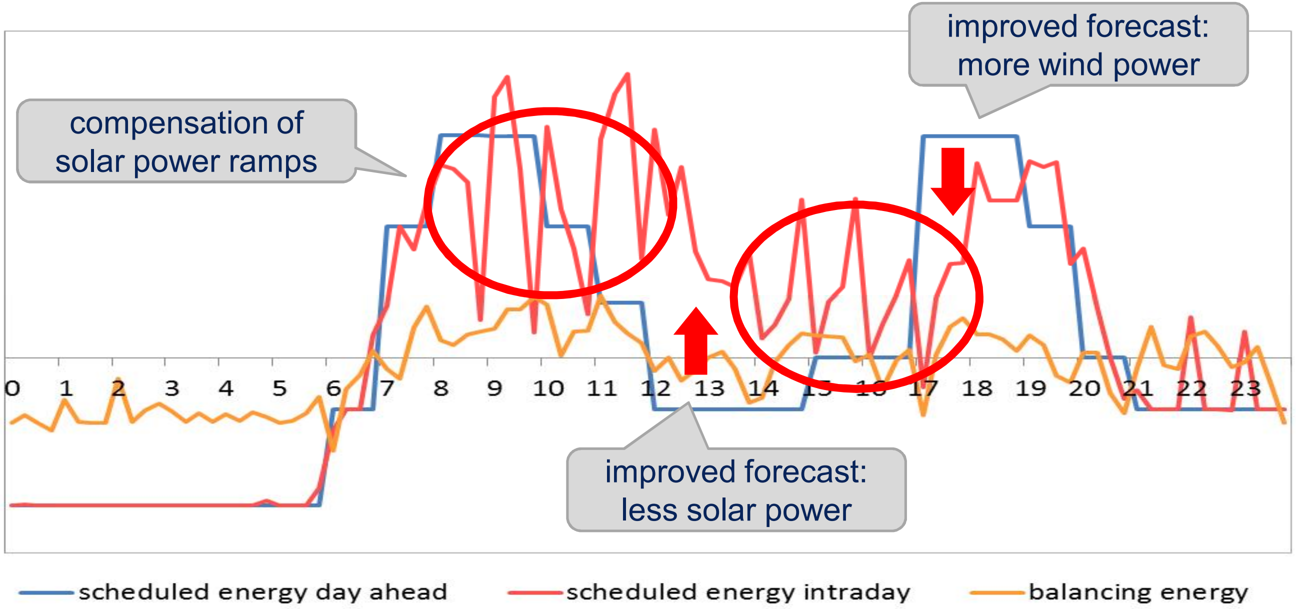
```
* Maximum frequency: 50,164 Hz on tuesday, 13.12.2011, 23:52:54
* Minimum frequency: 49,849 Hz on tuesday, 17.01.2012, 23:02:08
```

The following figure shows the frequency response (average of seconds) for several hours before and after.



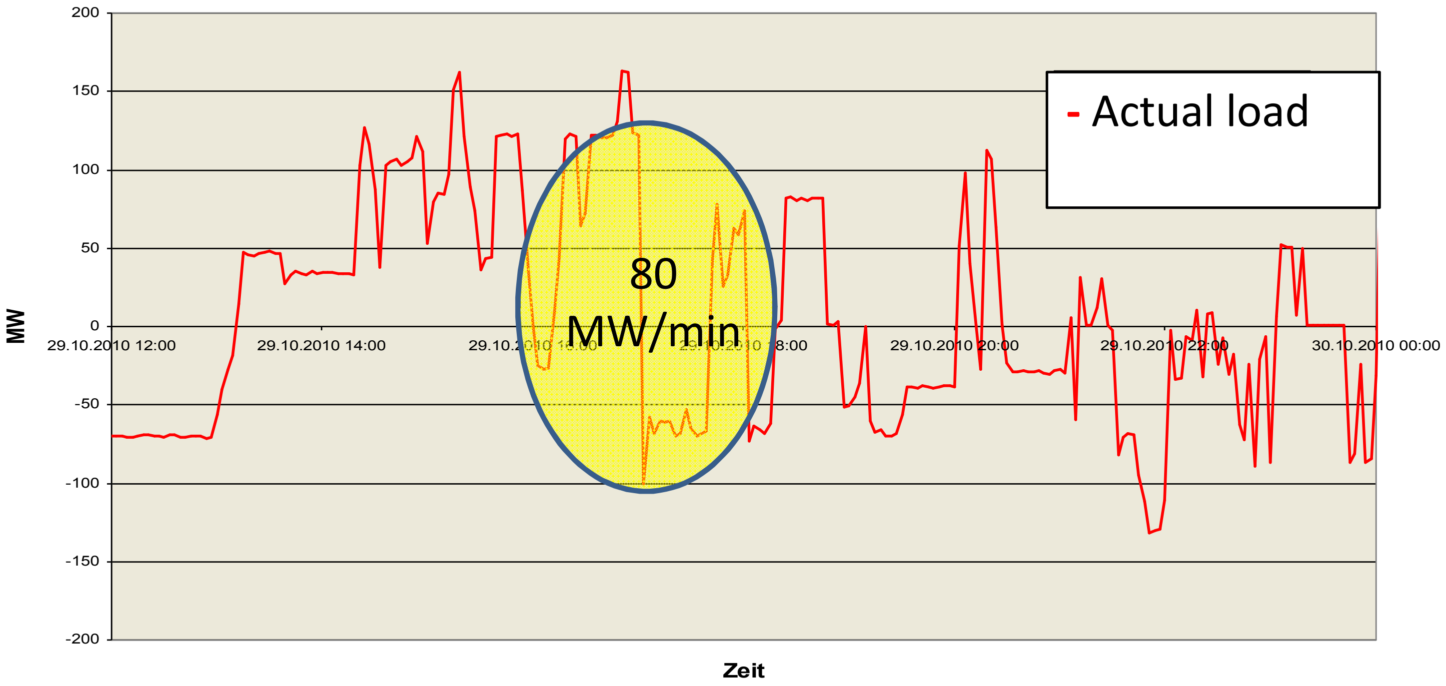
Example of the Dispatch of a PHS

Vorarlberger Illwerke AG



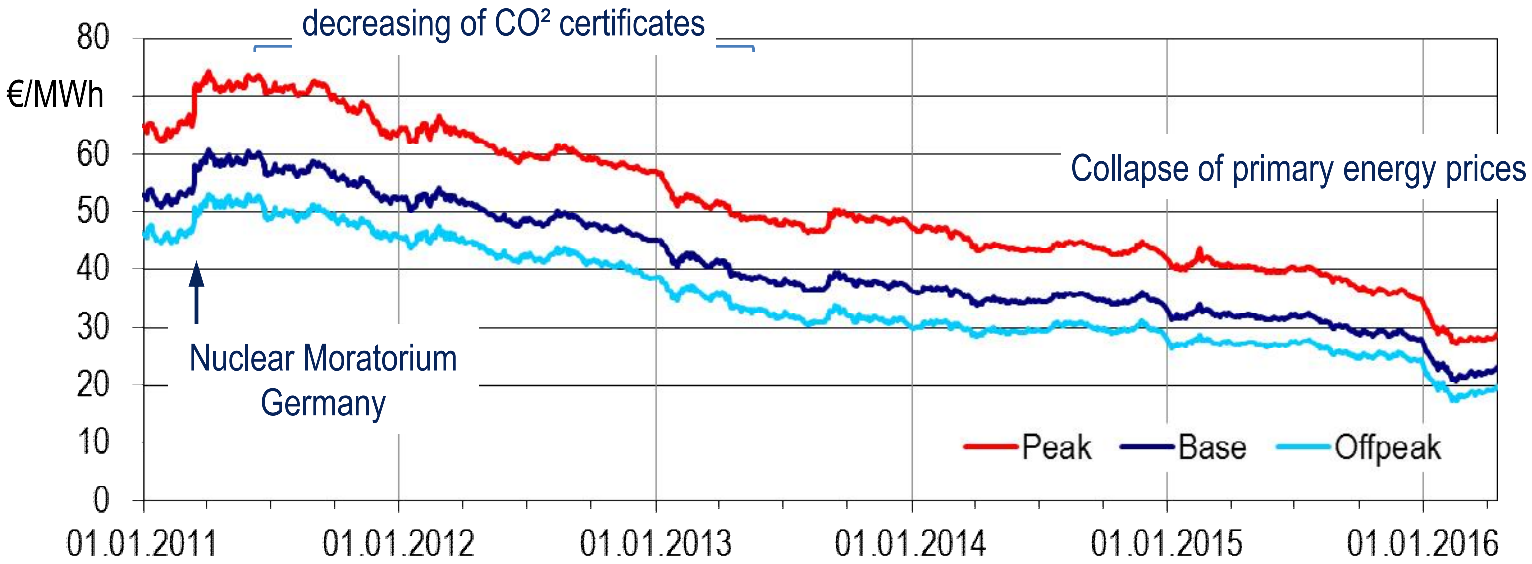
- Already today hydro- and pumped-hydro-stations make a substantial contribution to integrate wind and solar power

Typical Day Ddiagram – one unit Kops II



Development of energy prices

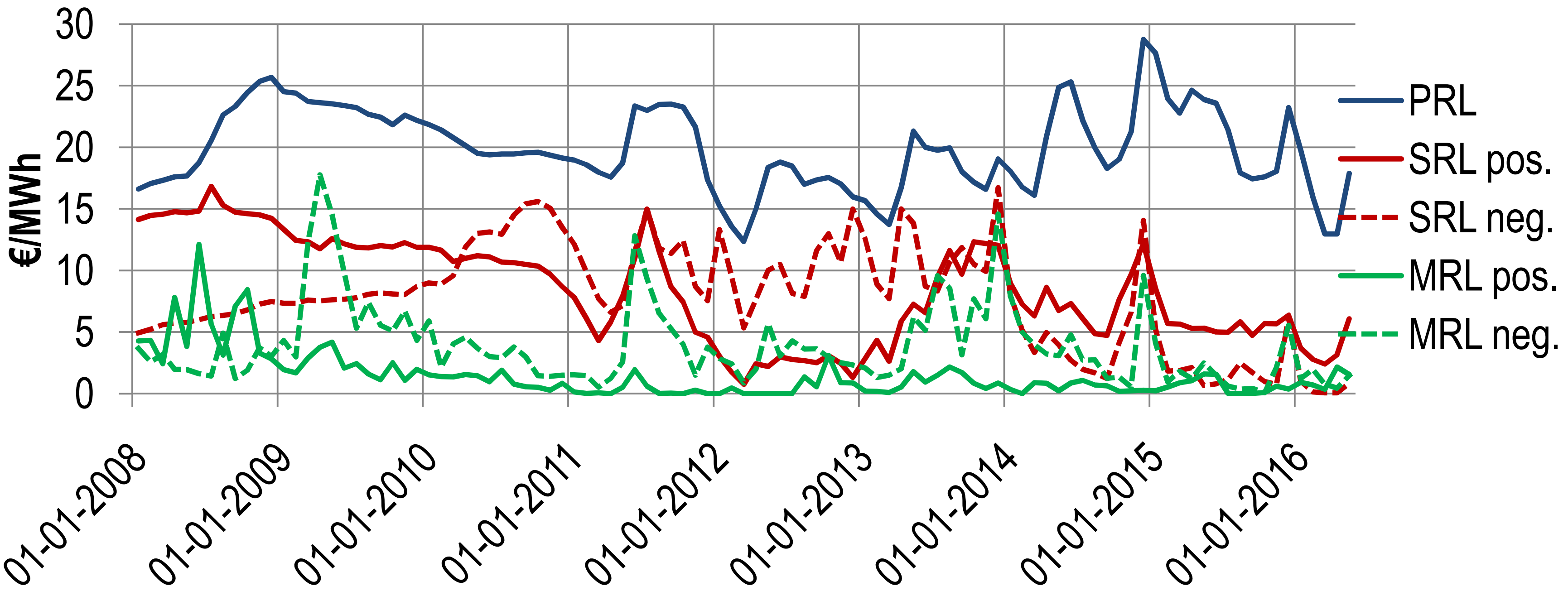
Vorarlberger Illwerke AG



Quelle: eigene Daten

Balancing Energy
Development of prices

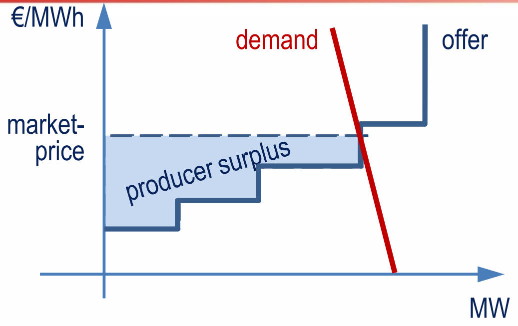
Vorarlberger Illwerke AG



Quelle: eigene Daten

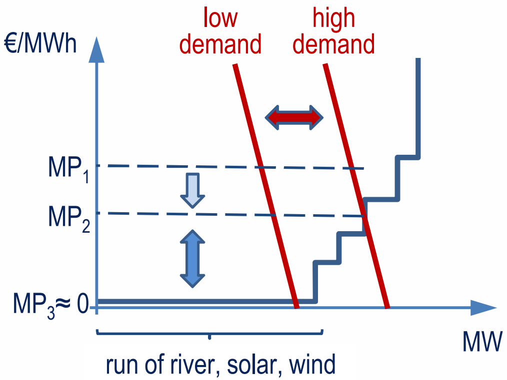
Impacts on the electricity market

merit order principle – impact of subsidies



Demand-offer-curve of a perfect market

- offer at marginal costs
- clearing at the market price
- producer surplus allows to cover fix costs



Electricity market with a high share of renewable energies

- priority purchase and fix feed-in-tariffs
- **independently:** high share of generation capacity with variable costs of almost zero
- force generation units with variable costs out of the market
- decrease of market prices

Status Quo Analyses (Austria)

Vorarlberger Illwerke AG

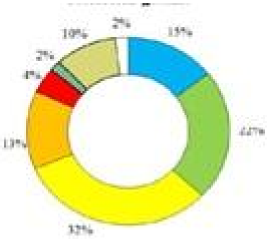
Discontinuity: 32.000
(10% Hydropower)

Morphology 30%

Residual Water 10%

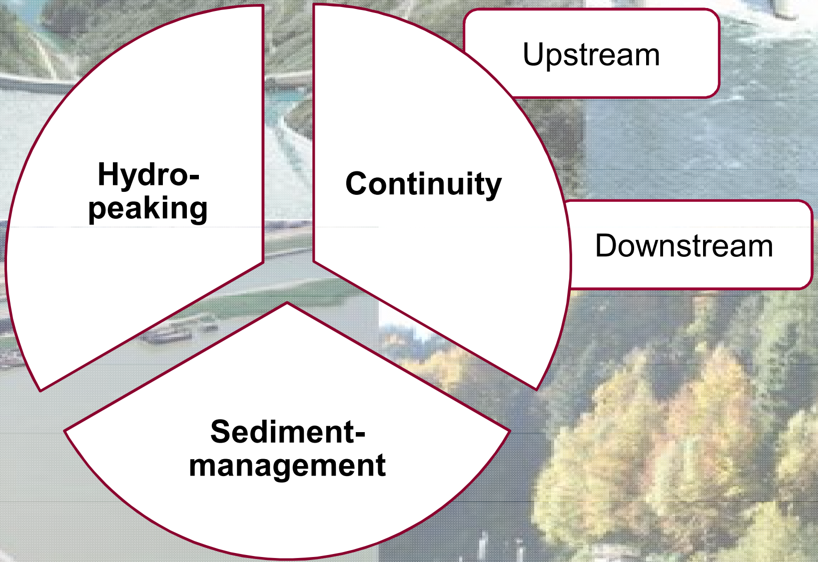
Hydropeaking 2%

Austria total



Run of river plants 4%

Issues for research & development



Hydropeaking: from R&D to smart solutions

Vorarlberger Illwerke AG

200 l/s

40 m³/s

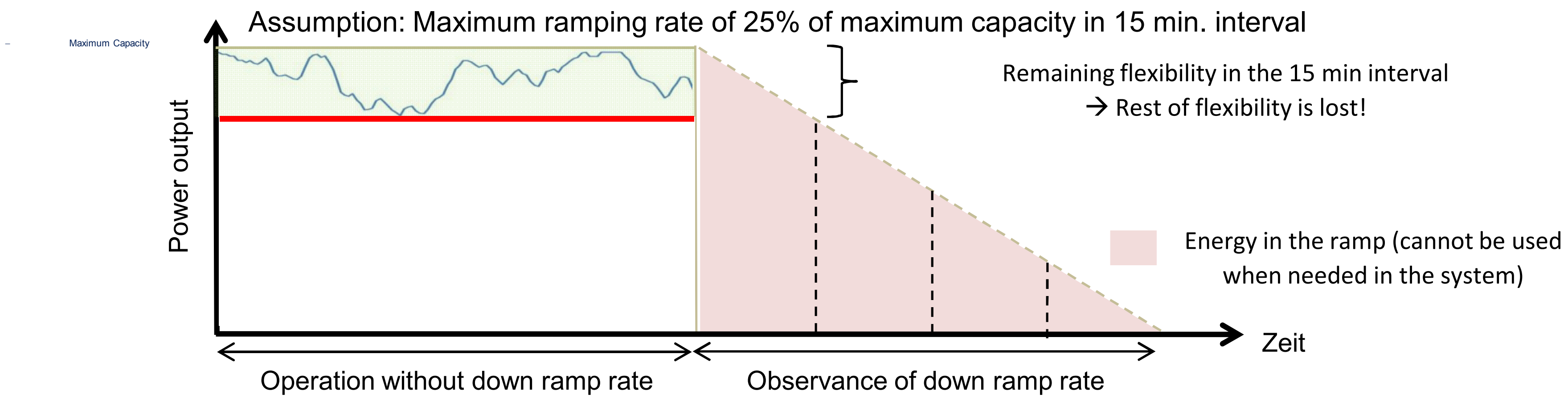
IM Fluss IWHW BOKU

Merging Hydropeaking Projects

		2010
		2011
1. Basic principles	Schwall 2012; Schwallprojekt Prof. Schmutz	2012
		2013
2. Development of Measures	Schwall 2015	2014
		2015
3. economical + ecological. check of measures	SureMma – (über AlpS)	2016
		2017
4. Feasibility studies for smart solutions on real projects	SureMma +	2018
		2019
5. Implementation	Water legislative process	Start 2021

Effects of operational restrictions

Vorarlberger Illwerke AG



Flexibility of storage power plant is highly reduced!

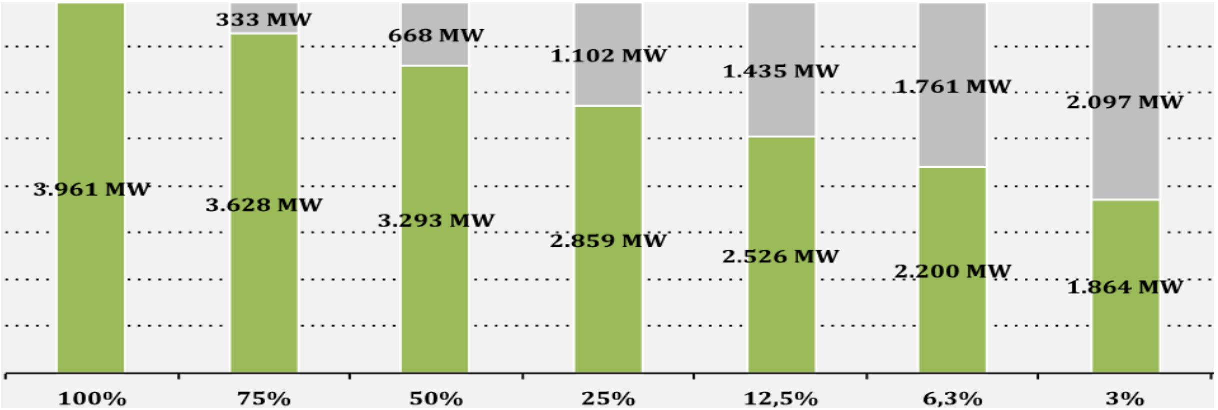
→ Significant negative impact on the electricity system and macro-economic effects

- Security of supply – loss of flexible power
- Climate protection goals
- Additional costs of system operation

→ Very strong negative Micro-economic effects

- Reduction of revenue

Operational restrictions: Loss of flexible Power



Gray: Sum of the lost flexible power of the ten SuREmMa case studies in the in dependence of the intensity of ramping rate attenuation. Green: Sum of remaining flexible Power

<u>More than 50% of flexible power are lost at high ramping rate attenuation!</u>

Projection for all of Austria:

→ <u>Loss of over 50% of flexible power of storage power plant groups</u> at high down ramp rate attenuation (ca.. 4000MW)

→ Comparable to <u>10 big gas fired combine-cycle power plant blocks</u>!

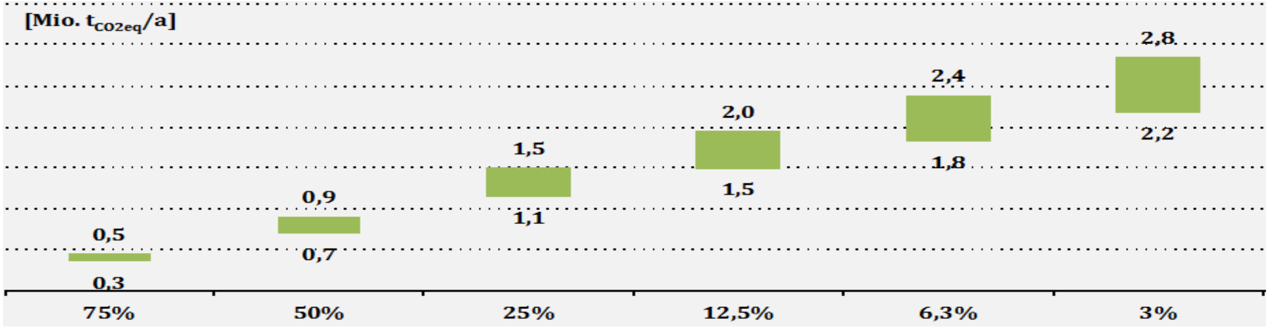
Operational restrictions
Additional CO_2 Emission

Vorarlberger Illwerke AG

Rise of CO_2 emissions in the electricity system due to not integrateable renewable energy (wind and pv).

•Per MW of flexible power 1,5 und 2 MW of fluctuating renewable power can be integrated. Corresponding to 2.600 bis 3.400 MWh per year.

•Quantified as substituting this energy with a modern gas fired combine-cycle power plant



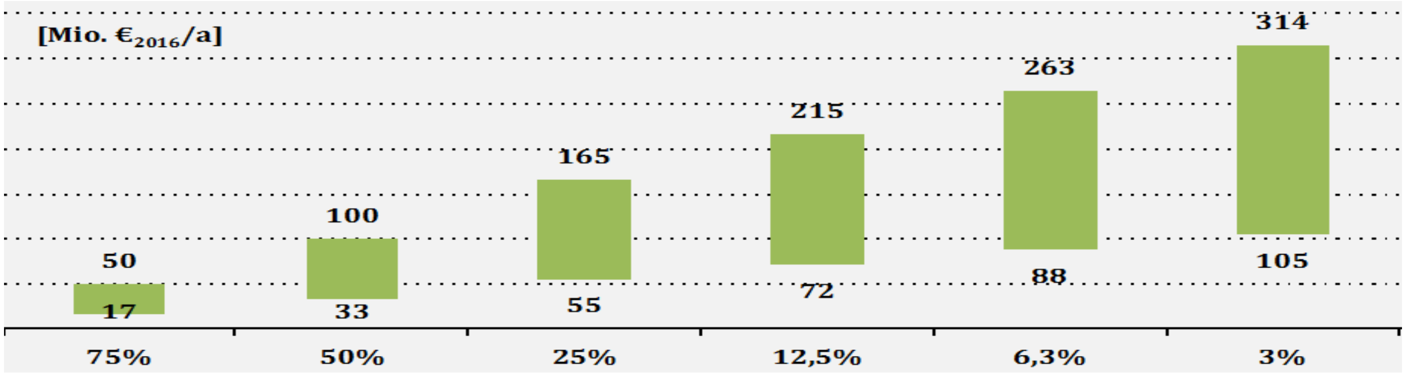
Sum of additional CO_2-emissions of the ten SuREmMa case studies in the in dependence of the intensity of ramping rate attenuation.

- Additional CO_2-emissions of 2,2 -2,8 Mio.t CO_2-equivalent per year in the SuREmMa Case studies at high down ramp rate attenuation!
- Projection for all of Austria:
- → Additional CO_2-emissions comparable to almost 50% of Austrian car traffic (ca. 4,4 – 5,6 Mio.$t_{CO2eq/a}$)

Operational restrictions
Additional costs of system operation

Vorarlberger Illwerke AG

Investment in alternative sources of flexibility leads to a rise in system operation cost.[1)]



Sum of additional costs of system operation of the ten SuREmMa case studies in the in dependence of the intensity of ramping rate attenuation.

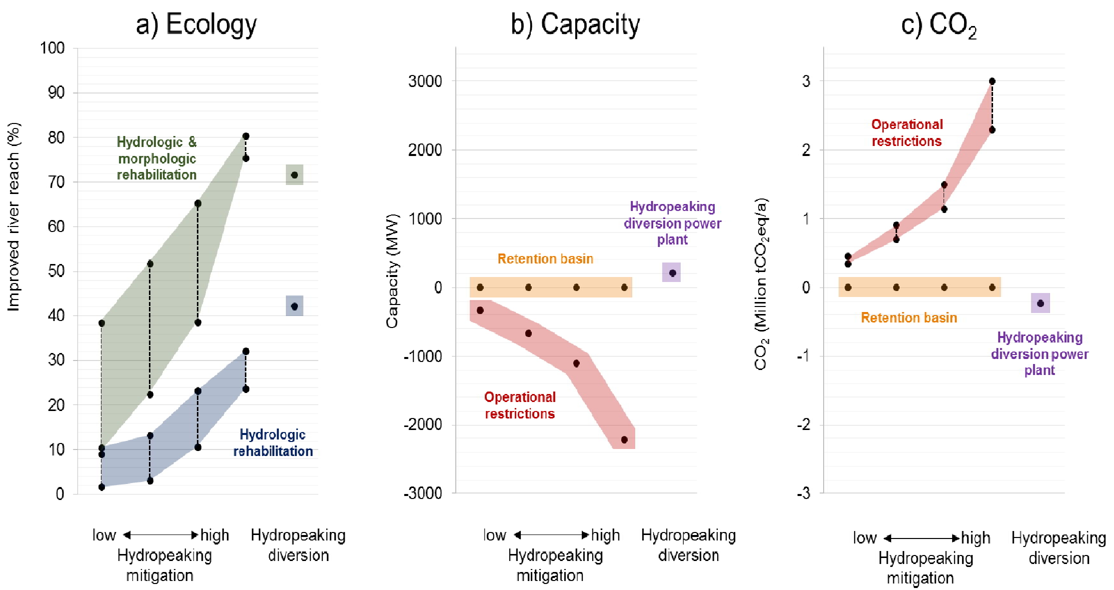
Additional system costs of 105 – 315 Mio. € per year in the SuREmMa Case studies at high down ramp rate attenuation!

Projection for all of Austria:
→ Increase in system operation cost up to 2 ‰ of Austrian GDP (200 – 630 Mio. € per year)

1) Costs of alternative sources of flexibility are between 50.000 – 150.000 €/MW per year.

SuREmMa – final results

Vorarlberger Illwerke AG



a) **Highest ecological improvement**: hydrologic measures together with morphologic rehabilitation.

b) Hydrologic rehabilitation with **operational restrictions cause losses of flexibility up to 50 %.** If possible, retention basins or diversion power plants should be implemented as they have no influence on operational restrictions.

c) **Operational restrictions** for mitigation measures are **contradictory** in achieving the **climate targets**.

Balancing

ecological benefit (incl. CO^2) and proportionality of mitigation measures

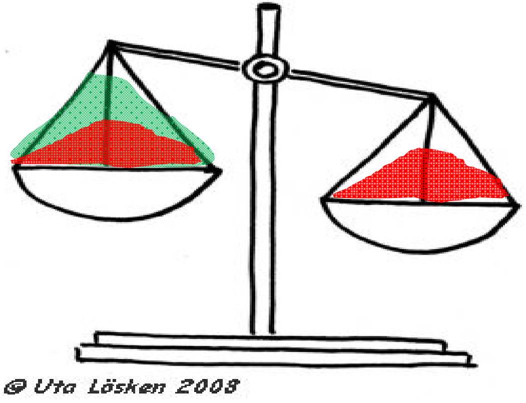
Vorarlberger Illwerke AG

➢Goal:

– **Highest ecological benefit** with the **lowest economical costs**

Ecological benefit

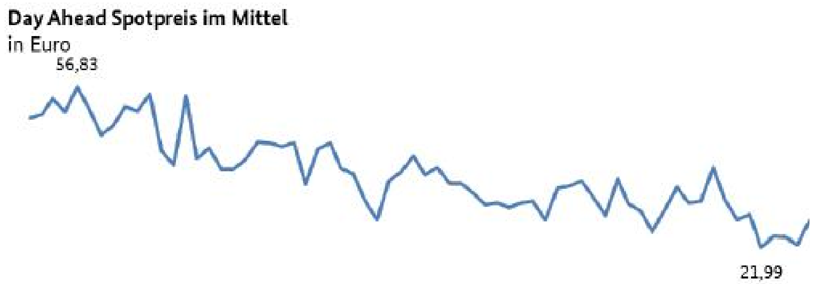
- CO^2 Production

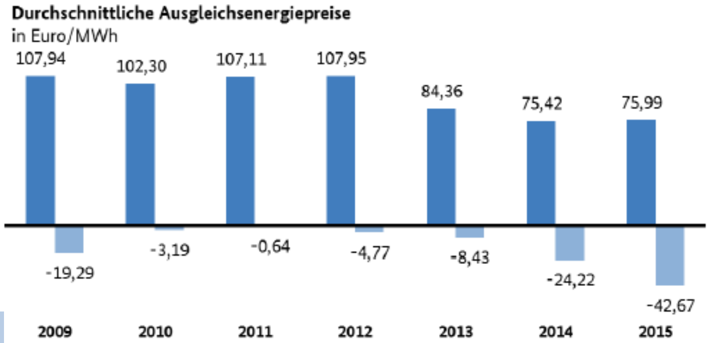


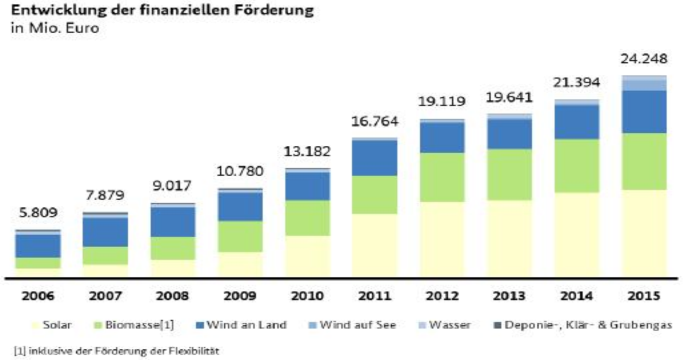
costs

Political settings

(double grid fees, subsidies, different transmission codes…..)







Hydropower, Storage Plants, PHS

- 2-5 years development and design
- > 5 years for approval (EIA)
- 4 years of construction
- > 100 years lifetime
- 700.- /1400.- EUR/kWh
- ROI > 30 years
- CO^2 footprint = lowest of all generators

Role of the Alpine Hydropower

Vorarlberger Illwerke AG

The Alpine Hydropower

with high FLEXIBILITY in Generation (Pump- and Turbine Mode)

plays a indispensable role in a new energy world of EUROPE

- Backbone of the renewable family.
- Enhancing security of supply and system stability.
- Paves the way for tomorrows energy system

Questions?

Please don`t hesitate to contact me

peter.matt@illwerke.at

www.obervermuntwerk2.at

www.kopswerk2.at

Vorarlberger Illwerke AG

National Workshop on
Pump Storage Hydropower Projects
at Thiruvananthapuram
Feb 08-09, 2018

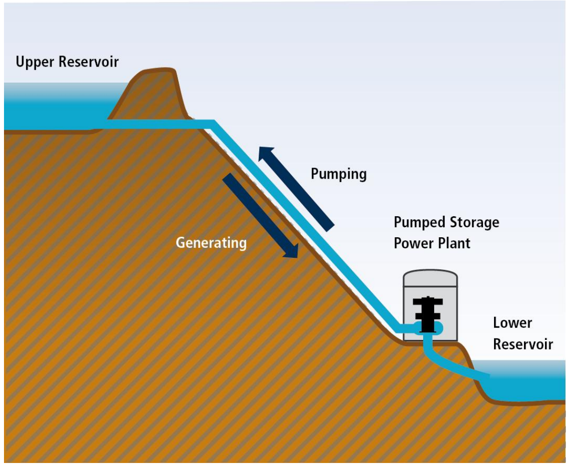
Pump storage Needs paradigm shift

Arun Kumar
Professor and MNRE Chair Professor
Alternate Hydro Energy Centre,
Indian Institute of Technology, Roorkee
Email : akumafah@iitr.ac.in, aheciitr.ak@gmail.com

INTRODUCTION

Pumped Storage Hydropower (PSH)

- A PSH scheme operates by exploiting the difference in height between two water bodies to store energy.
- Energy is stored by pumping water from the lower reservoir to the upper reservoir, and is recovered by releasing the stored water from the upper reservoir.
- It is the most commonly used and most commercially viable large scale electricity storage technology and currently accounts for 99% of the total storage capacity globally.



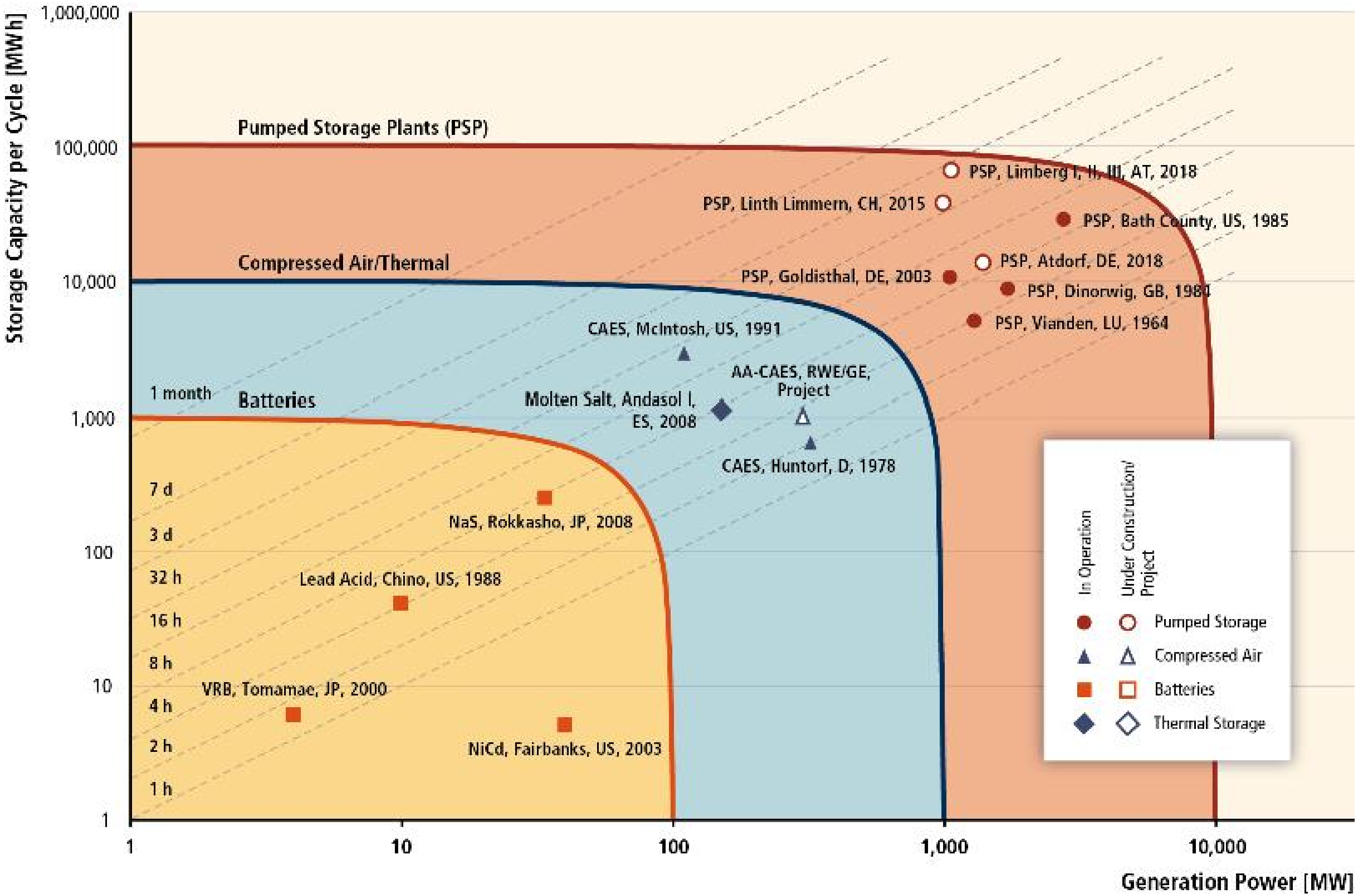
Benefits of Pumped Storage Plants

1. Proven technology, and utility-size storage facilities
2. Provide both Positive and Negative regulation
3. Improve Transient stability (and Inertia),
4. Provide Reactive power (both Lag and Lead),
5. Also, in Motoring mode (generally in off-peak time), may help the grid in mitigating high voltages in night
6. All other benefits of Hydro Power (Energy security, Generating capacity/peaking power, Frequency Regulation, Load following, Reduced transmission congestion, black start etc)

   - *Balancing grid for demand driven variations,*
   - *balancing generation driven variations,*
   - *voltage support and*
   - *grid stability*

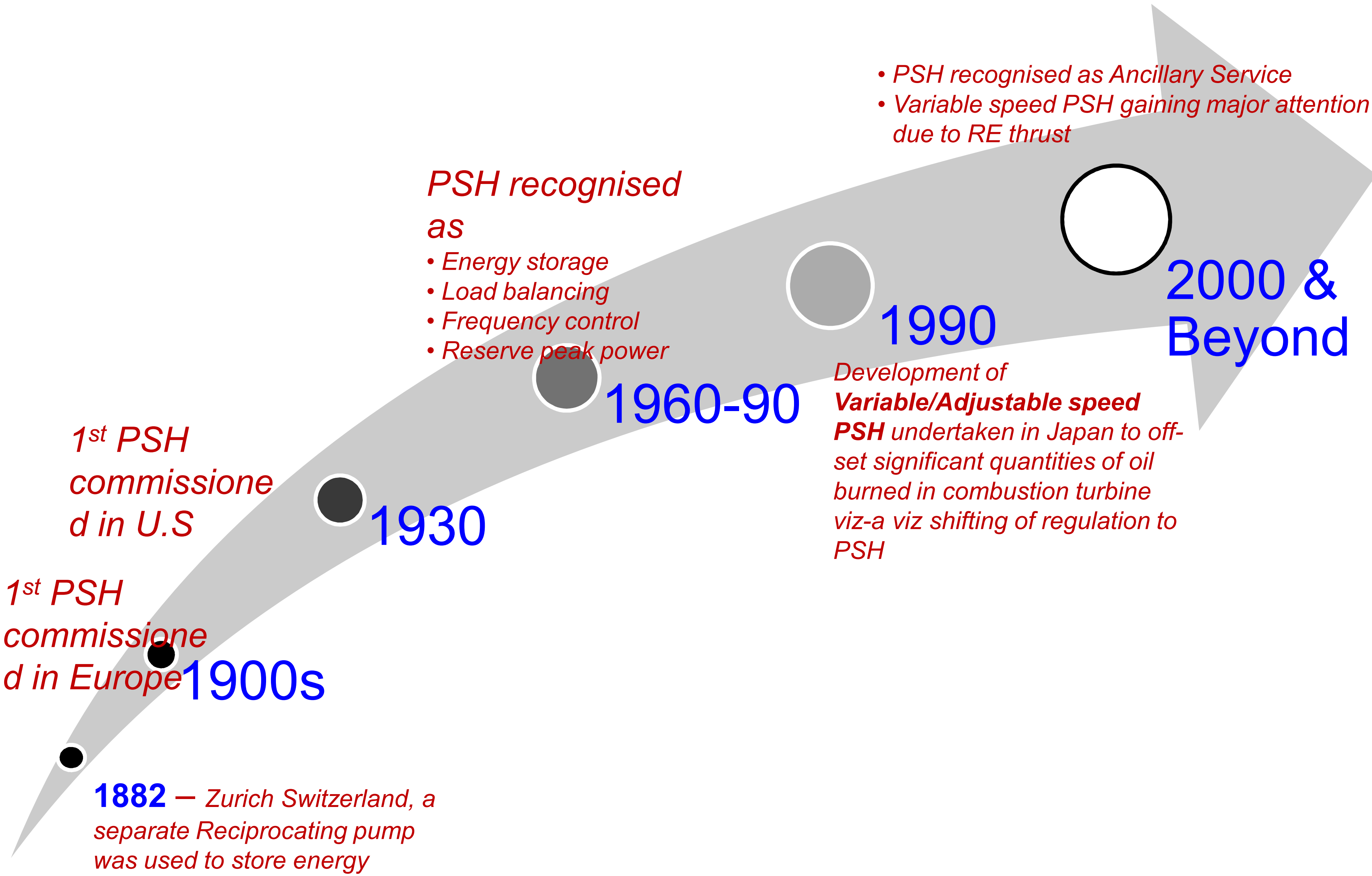
Government of India's ambitious program for Renewable Energy Generation with a target of 175 GW by 2022 comprising of Solar-100 GW, Wind -60 GW

Storage and installed capacity of selected large electricity storage sites



(Vennemann et al., 2010)

HISTORICAL EVOLUTION OF PSP



Courtsy Prabodh Mallick, Marubeni Co.

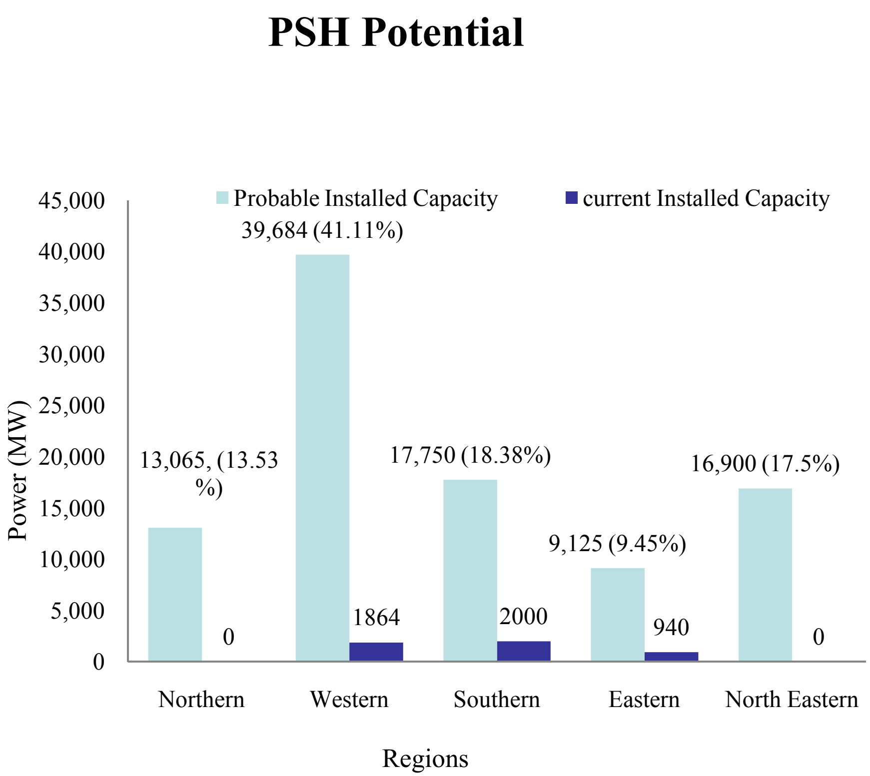
PSH IN INDIA

S. No.	Project name/ state	Installed Capacity		Year of Commission	Type of Plant	Operation in pump mode	Remarks
		No. of units	Total (MW)				
1	Kadana. I &II (Gujarat)	2x60+ 2x60	240	1990-1998	Mixed	Not working	vibration problem
2	Nagarjuna Sagar (Andhra Pradesh)	7x100	700	1980-1985	Mixed	Not working	tail reservoir being constructed
3	Kadamparai (Tamil Nadu)	4x100	400	1987-1989	Mixed	Working	
4	Panchet Hill (Bihar)	1x40	40	1990-1991	Mixed	Not working	tail reservoir being constructed
5	Bhira (Maharashtra)	1x150	150	1995	Mixed	Working	
6	Srisailam (Andhra Pradesh)	6x150	900	2001-2003	Mixed	Working	
7	Sardar Sarovar (Gujarat)	6x200	1200	2006	Mixed	Not working	tail reservoir being constructed
8	Purulia (West Bengal)	4x225	900	2007-2008	Pure	Working	
9	Ghatgar (Maharashtra)	2x125	250	2008	Pure	Working	
10	Paithon (Maharashtra)	1x12	12	1984	Mixed	Working	
11	Ujjani (Maharashtra)	1x12	12	1990	Mixed	Working	
		Total	4,804				

Sl no	Project/ state	Installed Capacity		Remarks
		No. of units	Total (MW)	
1	Tehri Stage-II (Uttarakhand)	4x250	1000	Under Construction
2	Koyna Left Bank (Maharashtra)	2x40	80	Under Construction
3	Kundah (Tamil Nadu)	NA	500	DPR returned due to non-resolution of inter-state aspects
4	Malshej Ghat (Maharashtra)	NA	700	DPR prepared
5	Humbarli (Maharashtra)	NA	400	Survey & investigation being done for DPR preparation
6	Turga (West Bengal)	NA	1000	Survey & investigation being done for DPR preparation
		Total	3680	

- Out of 11 PSH plants (having total installed capacity of 4,804 MW), 3 plants are not operating in pumping mode due to unavailability of lower reservoir while one plant is not operating due to vibration problem.

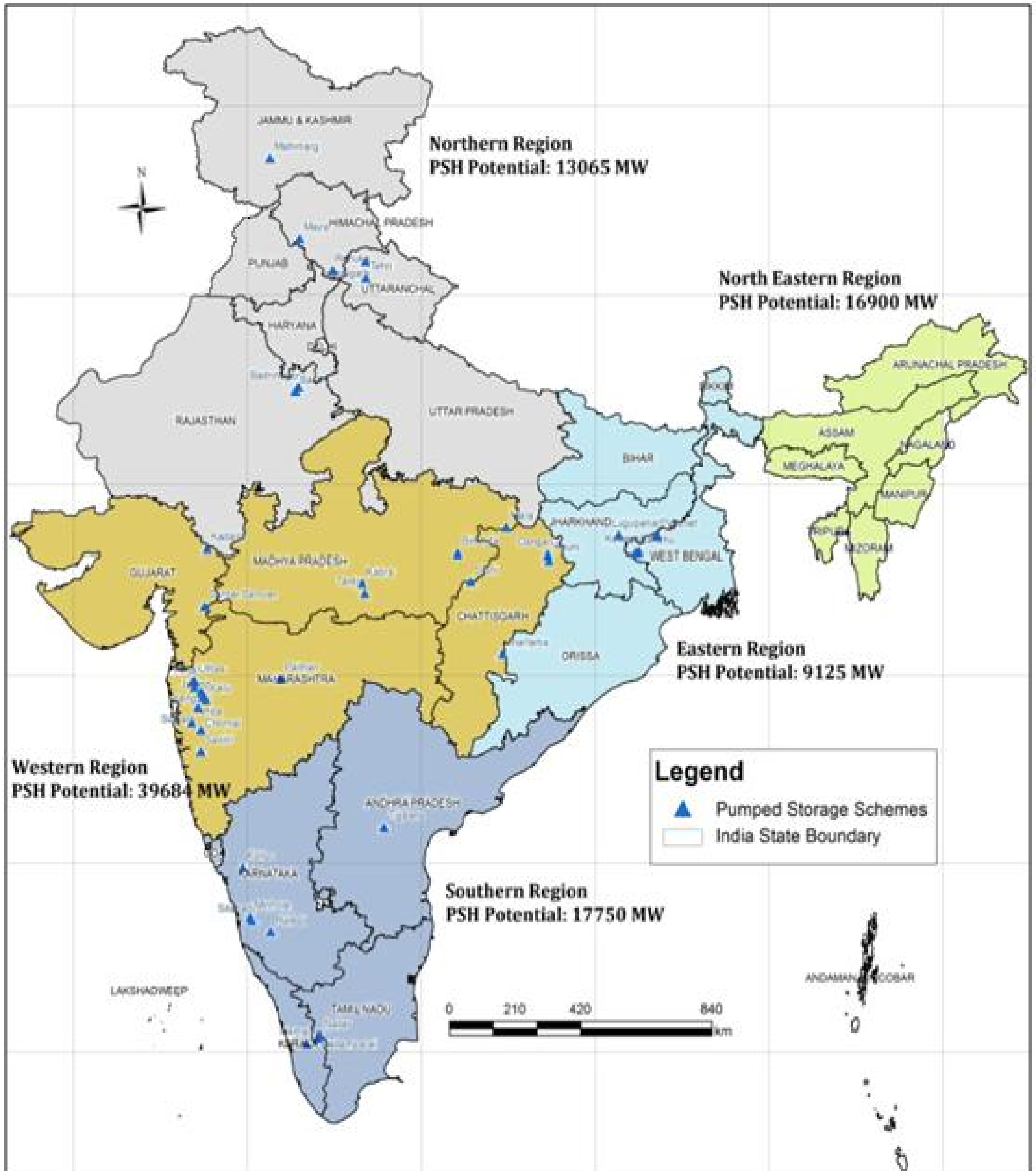
PSH IN INDIA



Region wise distribution of PSH potential and Current PSH installed capacity (MW)

S. No.	Region/State	Probable Installed capacity(MW)
	NORTHERN	
1	JAMMU & KASHMIR	1650
2	HIMACHAL PRADESH	3600
3	UTTAR PRADESH	4035
4	RAJASTHAN	3780
	SUB TOTAL	**13065**
	WESTERN	
1	MADHYA PRADESH	11150
2	MAHARASTRA	27094
3	GUJARAT	1440
	SUB TOTAL	**39684**
	SOUTHERN	
1	ANDHRA PRADESH	2350
2	KARNATAKA	7900
3	KERALA	4400
4	TAMIL NADU	3100
	SUB TOTAL	**17750**
	EASTERN	
1	BIHAR	2800
2	ORISSA	2500
3	WEST BENGAL	3825
	SUB TOTAL	**9125**
	NORTH EASTERN	
1	MANIPUR	4350
2	ASSAM	2100
3	MIZORAM	10450
	SUB TOTAL	**16900**
	TOTAL	**96524**

PSH POTENTIAL SITE LOCATION

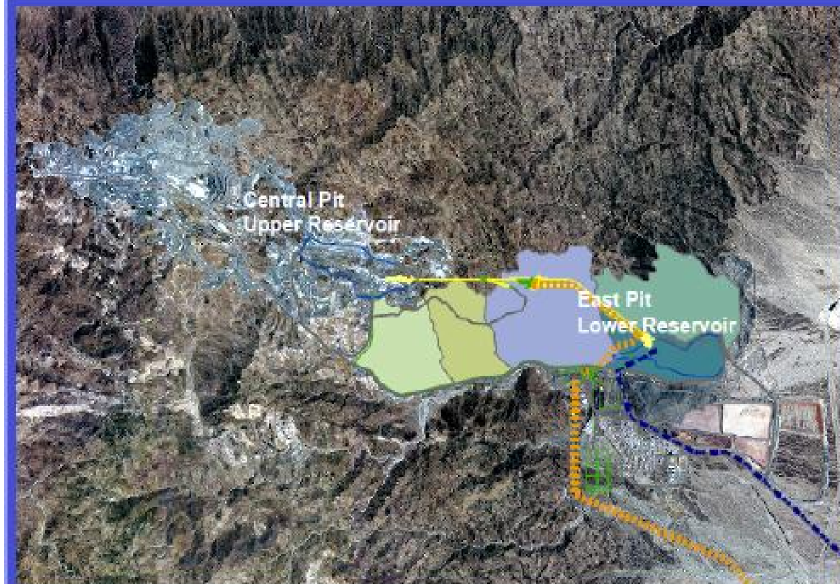


PSH sites	Numbers	Capacity (MW)
Developed	11	4804
Under Development	6	3680
Total Identified	63	96524

Pumped storage projects planned (source: CEA, 2018)

Sl. No.	Name of project	Sate	Installed capacity (MW)	Agency	Present Status
Projects planned on existing hydro projects					
1	Humbarli	Maharashtra	400	NPCIL & THDC	Commitment from GoM awaited.
2	Varahi	Karnataka	700	KPCL	DPR likely by 2022.
3	Idukki	Kerala	300	KSEB Ltd.	Yet to be taken up.
4	Pallivasal	Kerala	600	KSEB Ltd	Yet to be taken up.
5	Upper Indravati	Odisha	600	OHPC	DPR to be prepared by WAPCOS.
6	Ghatghar Stage – II	Maharashtra	125	GoMWRD	
7	Sharavathy	Karnataka	2000	KPCL	TOR for CIA study from MOEF received. DPR under preparation.
8	Sillahalla	Tamil Nadu	2000	TANGEDCO	Survey under progress.
		Sub total	**6,725**		
New Pumped Storage Projects					
9	Malshej Ghat	Maharashtra	700	NPCIL & THDC	TOR for EIA expired. Commitment from GoM awaited.
10	Mutkhel	Maharashtra	110	GoMWRD	Preliminary investigation
11	Warasgaon	Maharashtra	1200	GoMWRD	NHPC explored and found attractive. No Forest land. Commitment from GoM awaited.
12	Atvan	Maharashtra	1200	GoMWRD	NHPC explored and found attractive. Under wild life.
13	Koyna st-VI	Maharashtra	400	GoMWRD	NHPC explored and found attractive. Under wild life.
14	Bandhu	West Bengal	900	WBSEDCL	DPR by 2019.
15	Kulbera	West Bengal	1110	WBSEDCL	Preliminary studies. Likely after Bhandhu.
16	Lugupahar	Jharkhand	2800	DVC	PFR under progress.
		Sub total	**8,420**		
		Total	**15,145**		

Benefits of Closed Loop Pumped Storage System



- Self contained "off-stream" water system
- No need for new dams on main stem rivers
- Uses existing infrastructure
- This sidesteps the constraint of site availability thus minimize environmental impacts

Erzhausen – Pumped Storage, Germany

Outside the Leine River system

Waldeck Pumped Storage Hydroelectric, Germany (920 MW)

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

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.

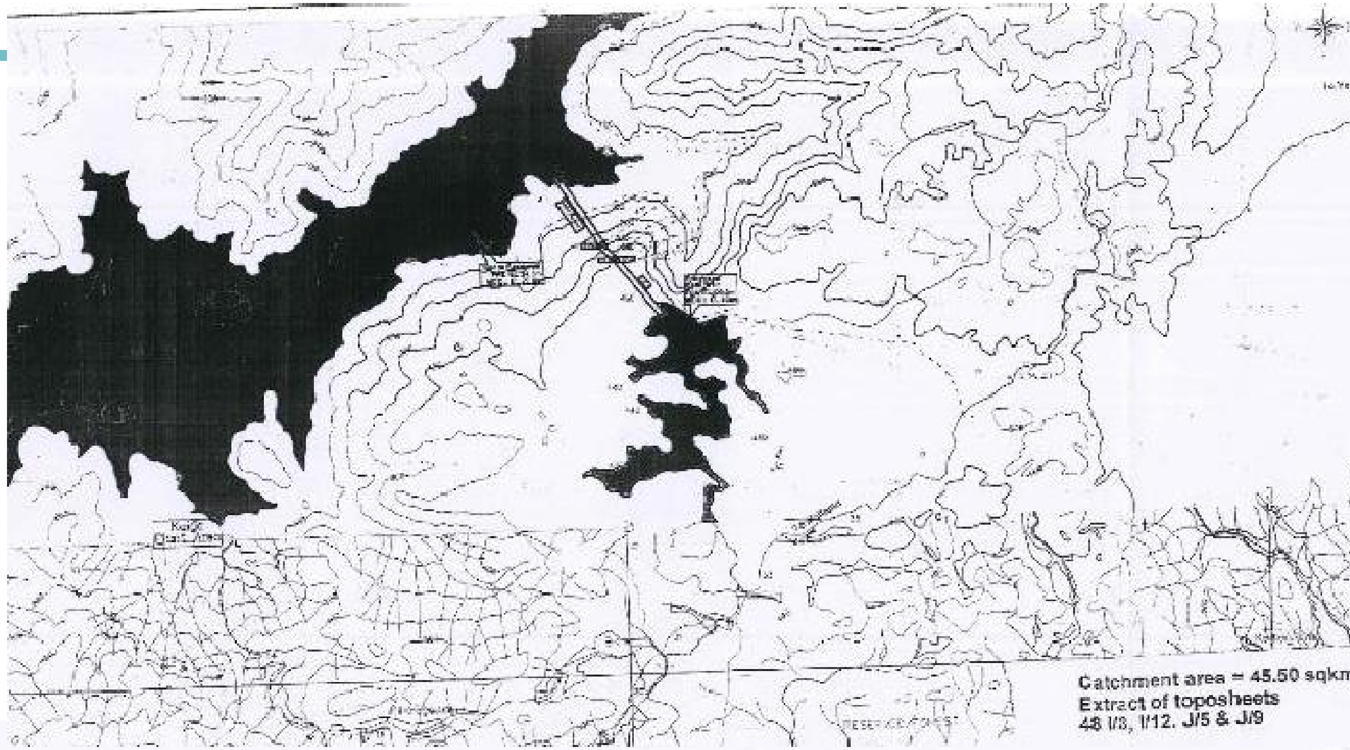
Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

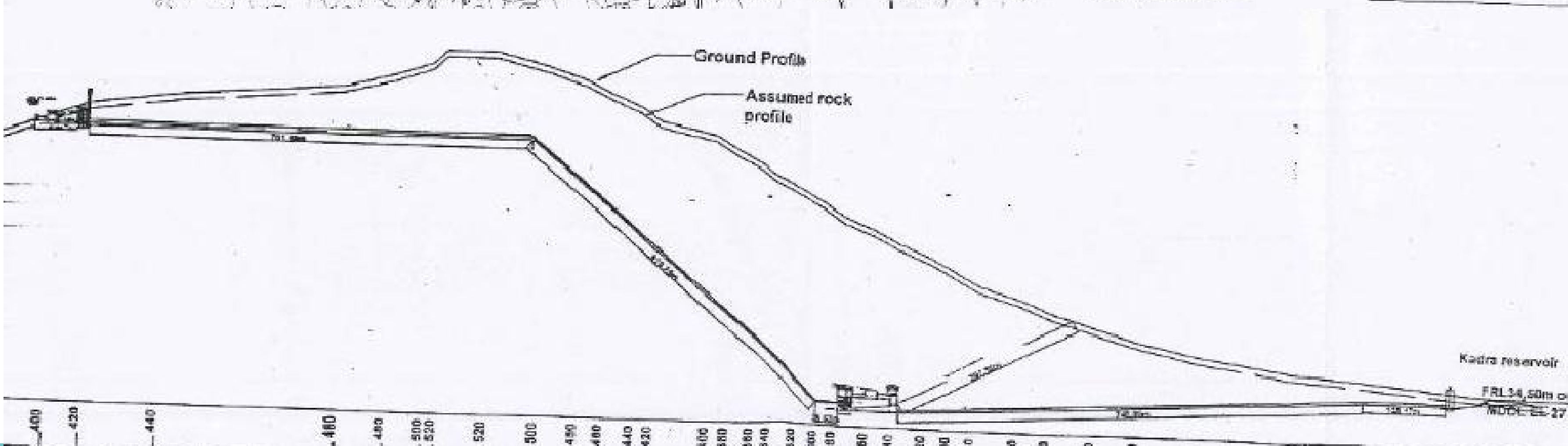
Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963, failed 2005, restarted 2010

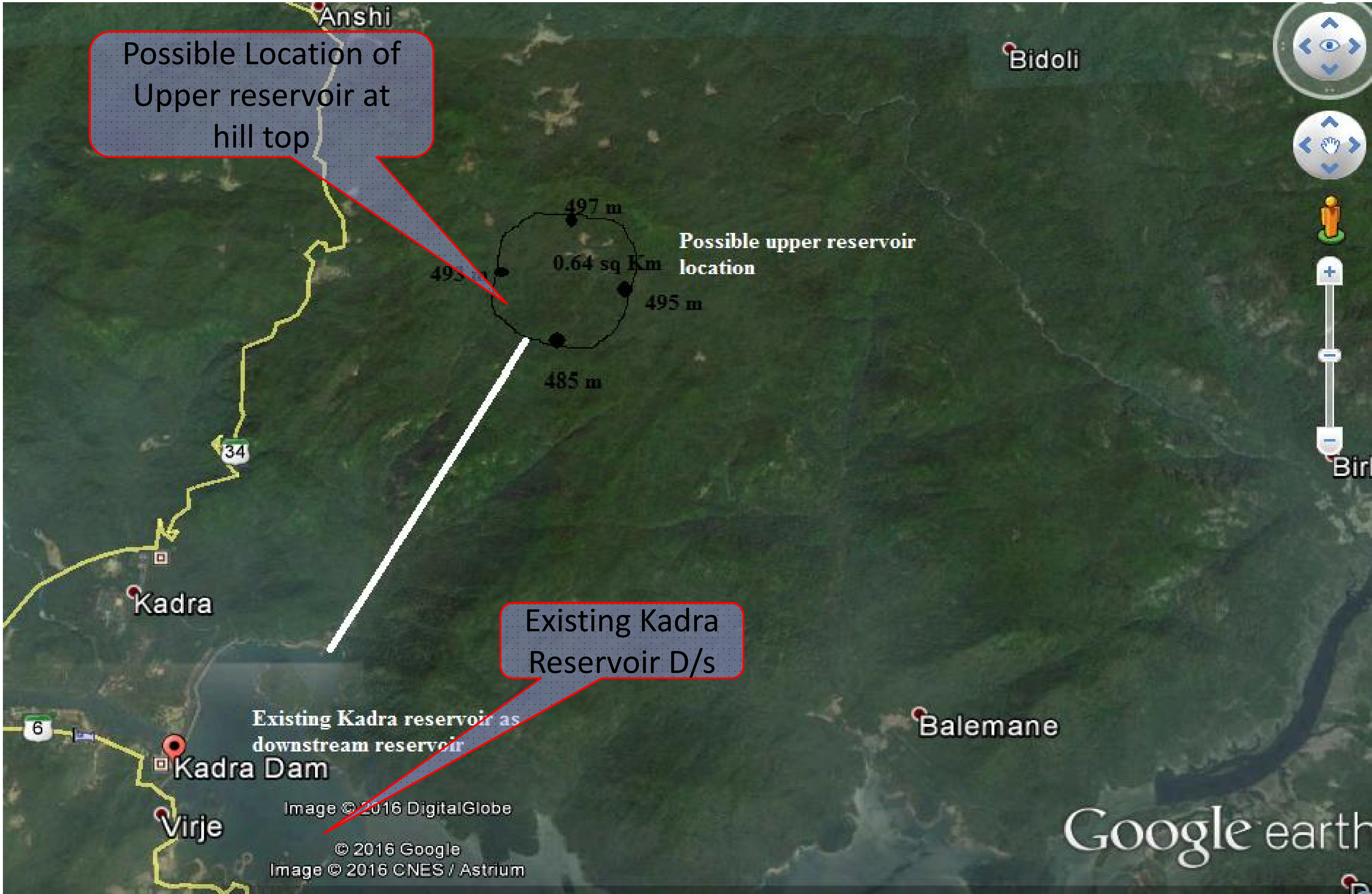
Taum Sauk, 450 MW PSP, Missouri, USA Started in 1963

Kali Pumped Storage Scheme



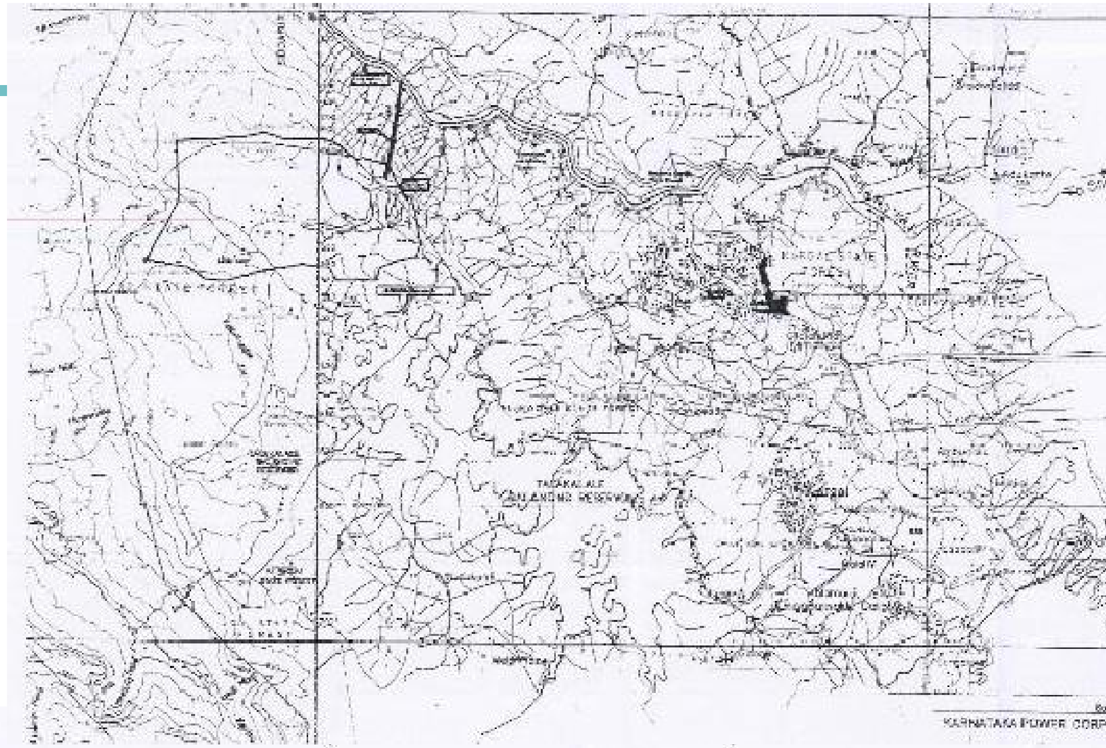


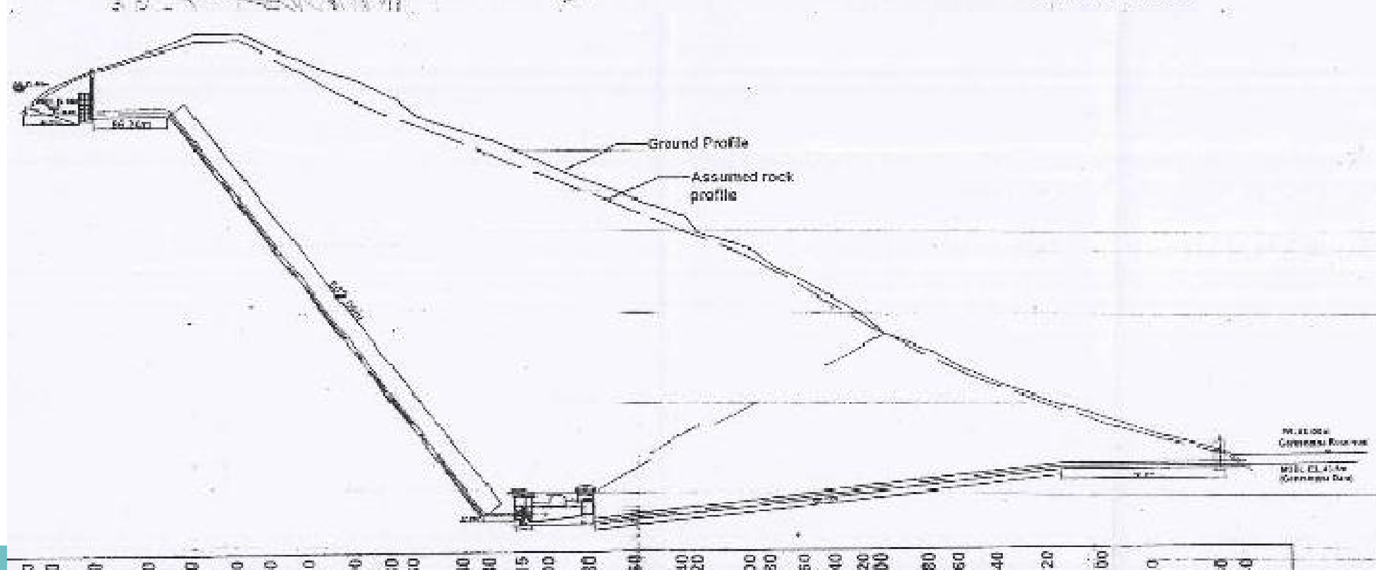
Possible locations of upper reservoir Kali PSP



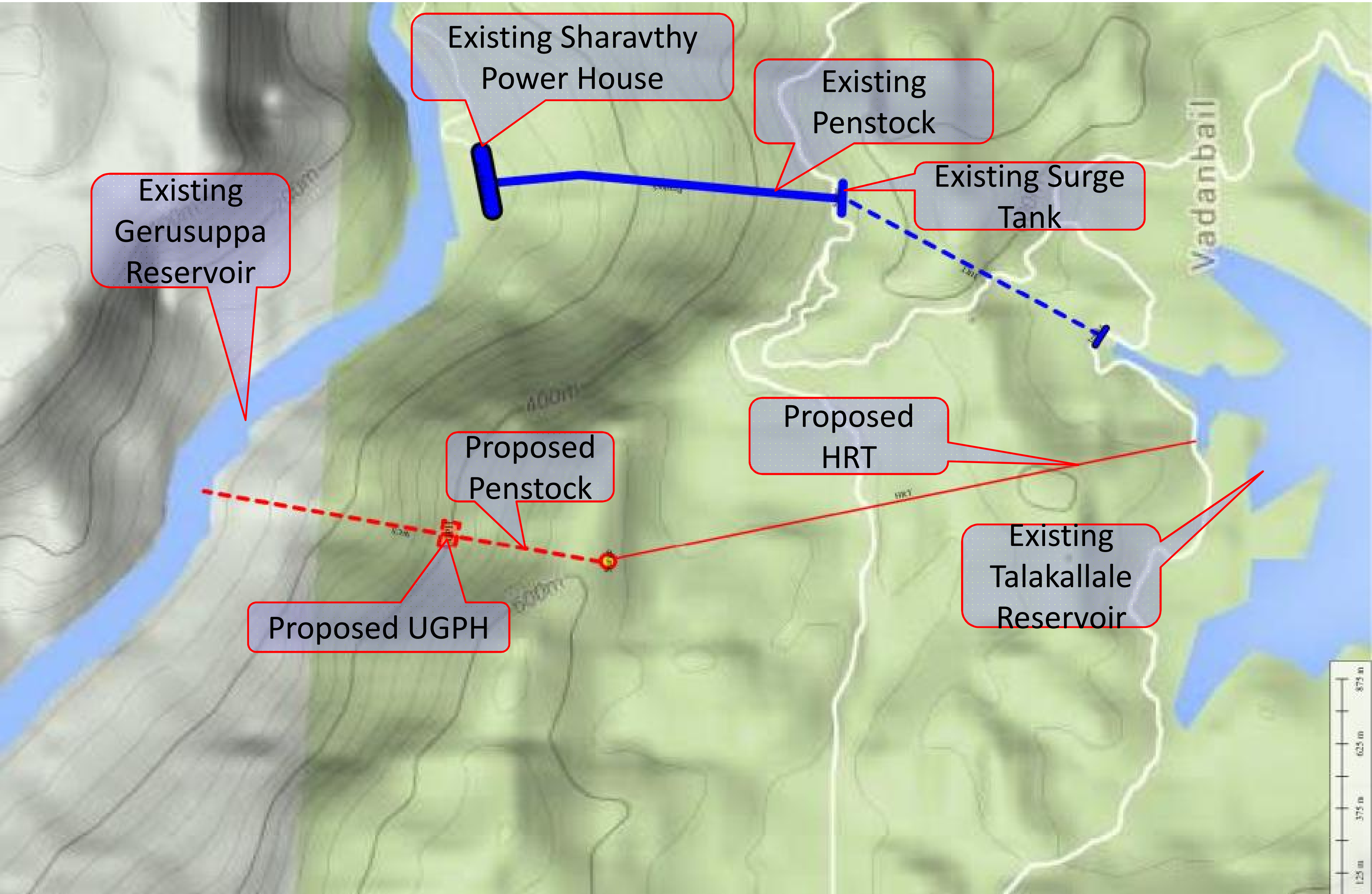
Possible locations of upper reservoir Kali PSP

Sharavathi Pumped Storage Scheme

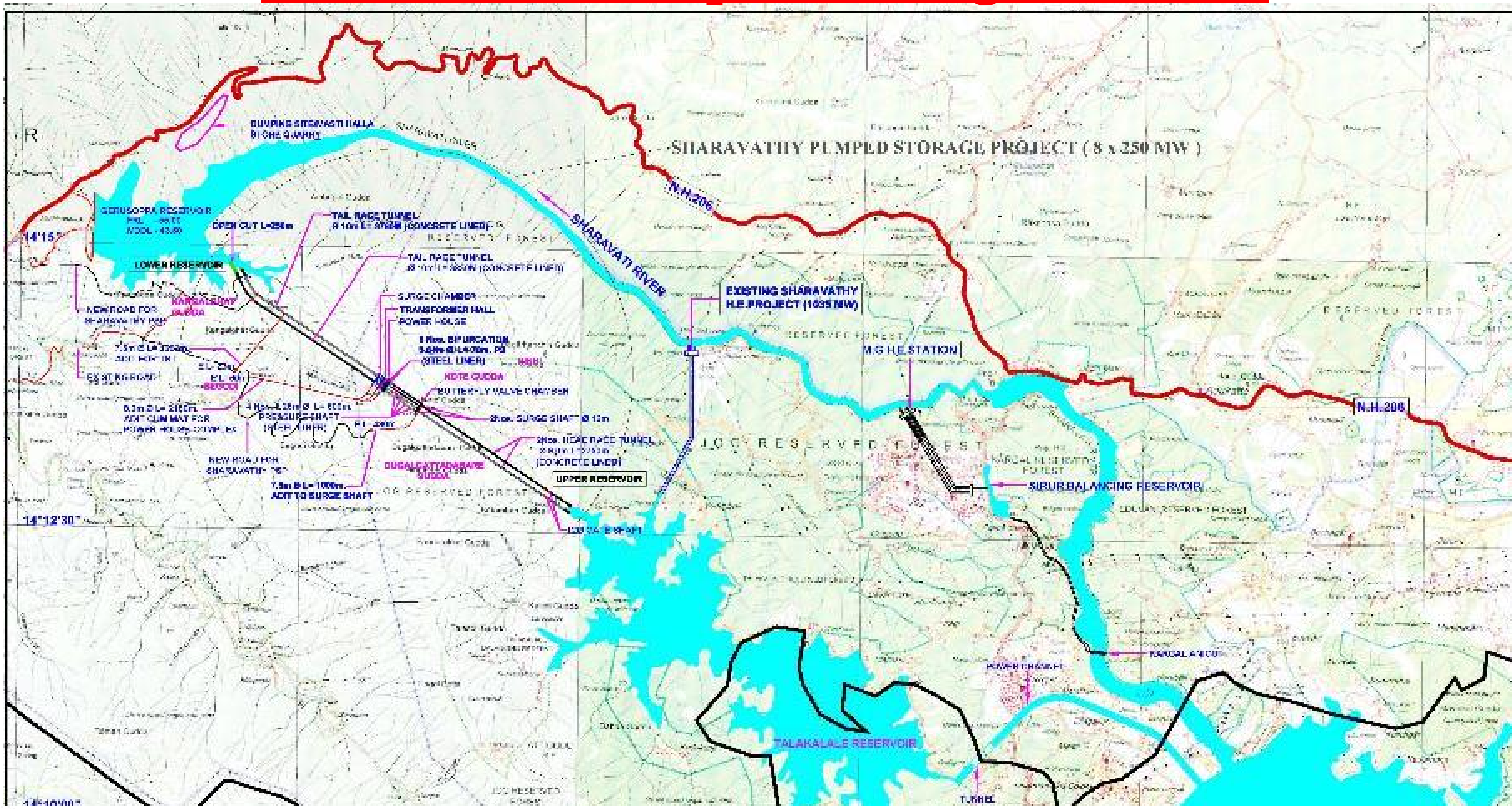


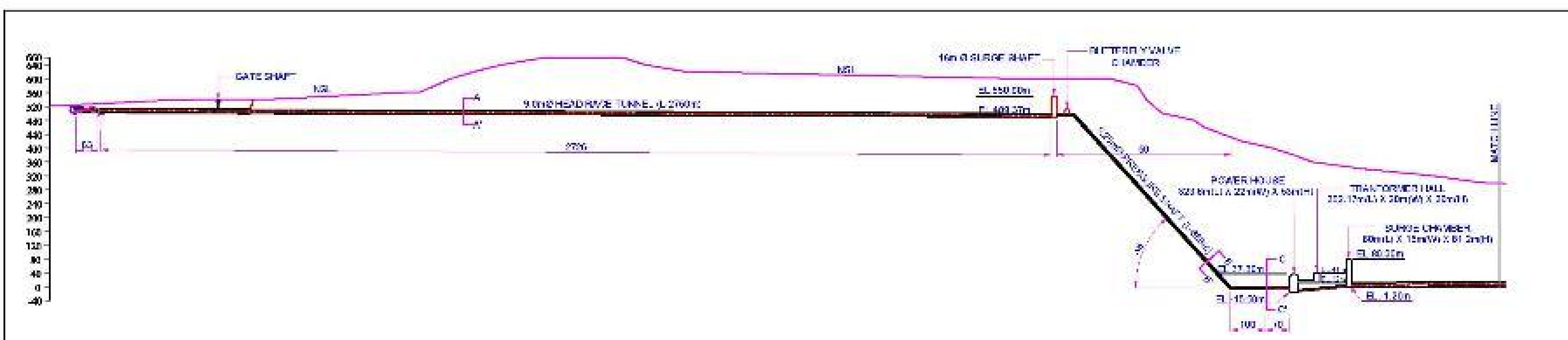


Proposed Sharavathi Pumped Storage Scheme (Option 02)



Sharavathi Pumped Storage Scheme





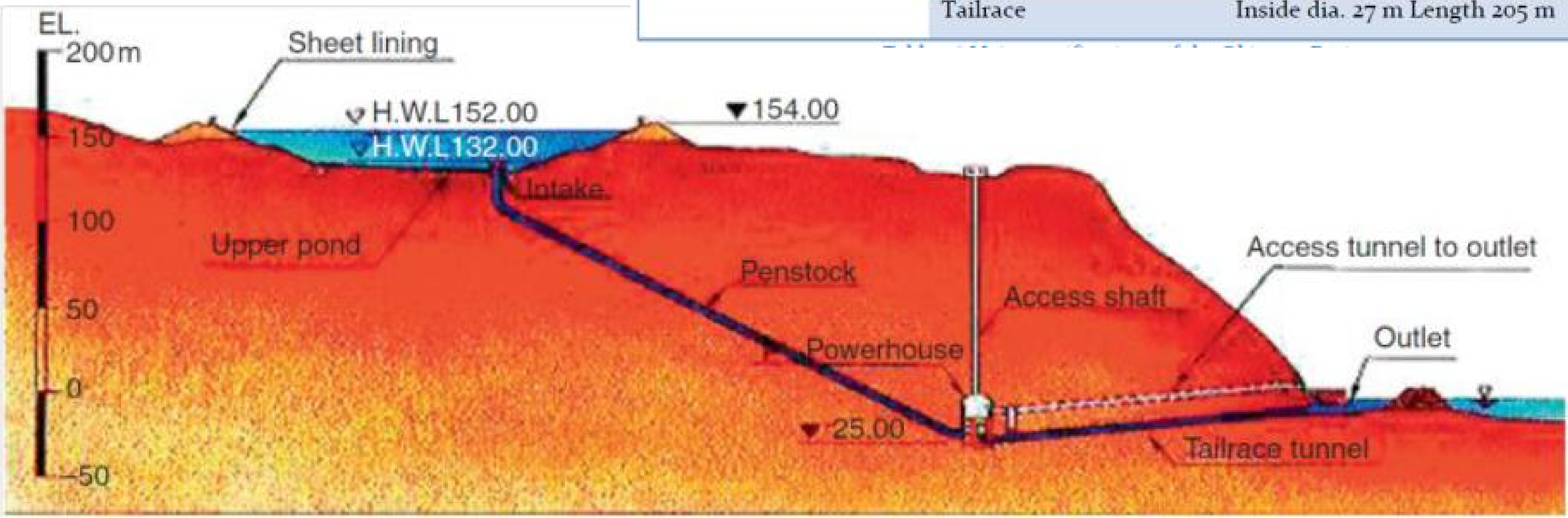
Brookfield Pumped Storage Projects

- Located in California
- 280 MW
- Preliminary Permit granted 10/2007
- Closed Loop system – will not reside on any existing waterways
- Water source identified
- Within one mile of transmission corridor
- Preliminary site control established
- Located in a market where the value of capacity is still evolving

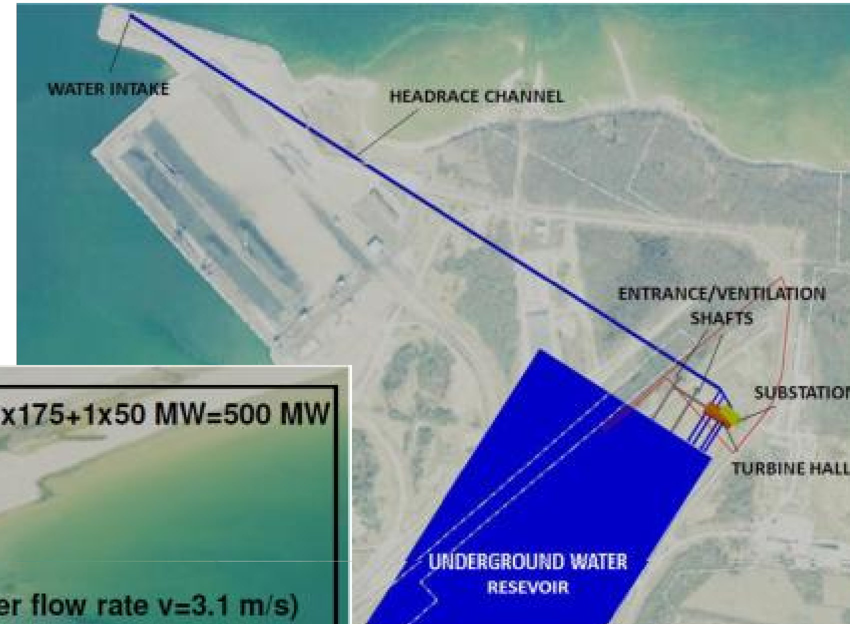
PROJECT LOCATION MAP

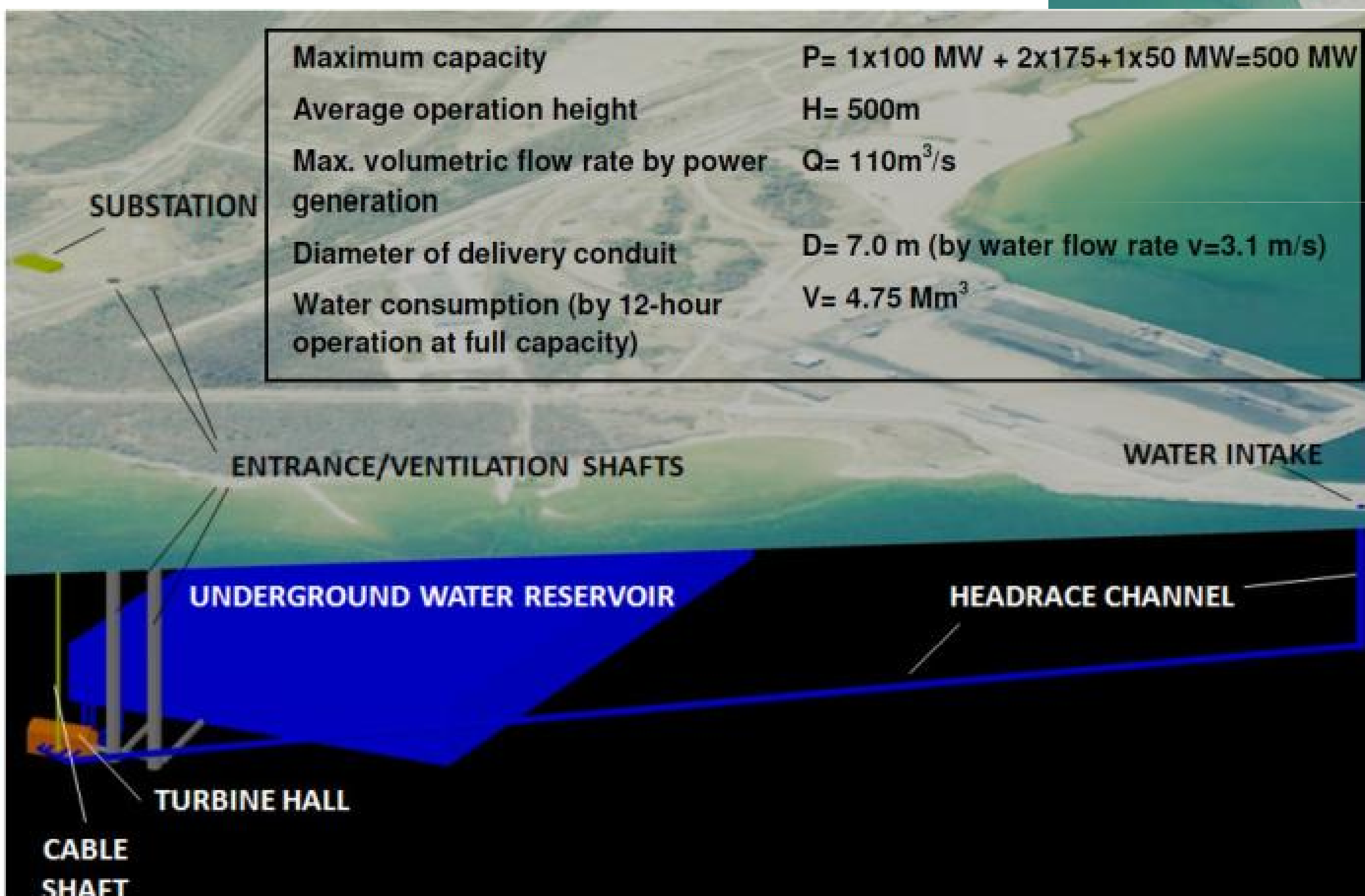
Okinawa Seawater Based PSP, Japan

Okinawa Yanbaru Power Plant		Specification
Power plant	Max. Output	30 MW
	Max. Discharge	26 m^3/s
	Effective head	136 m
Upper regulating pond	Type	Excavated type, Rubber sheet-lined
	Max. embarkment height	25 m
	Crest circumference	848 m
	Max. Width	251.5 m
	Total storage capacity	0.59x106 m^3
	Max. depth	22.8 m
Waterway	Penstock	Inside dia. 24 m Length 314 m
	Tailrace	Inside dia. 27 m Length 205 m



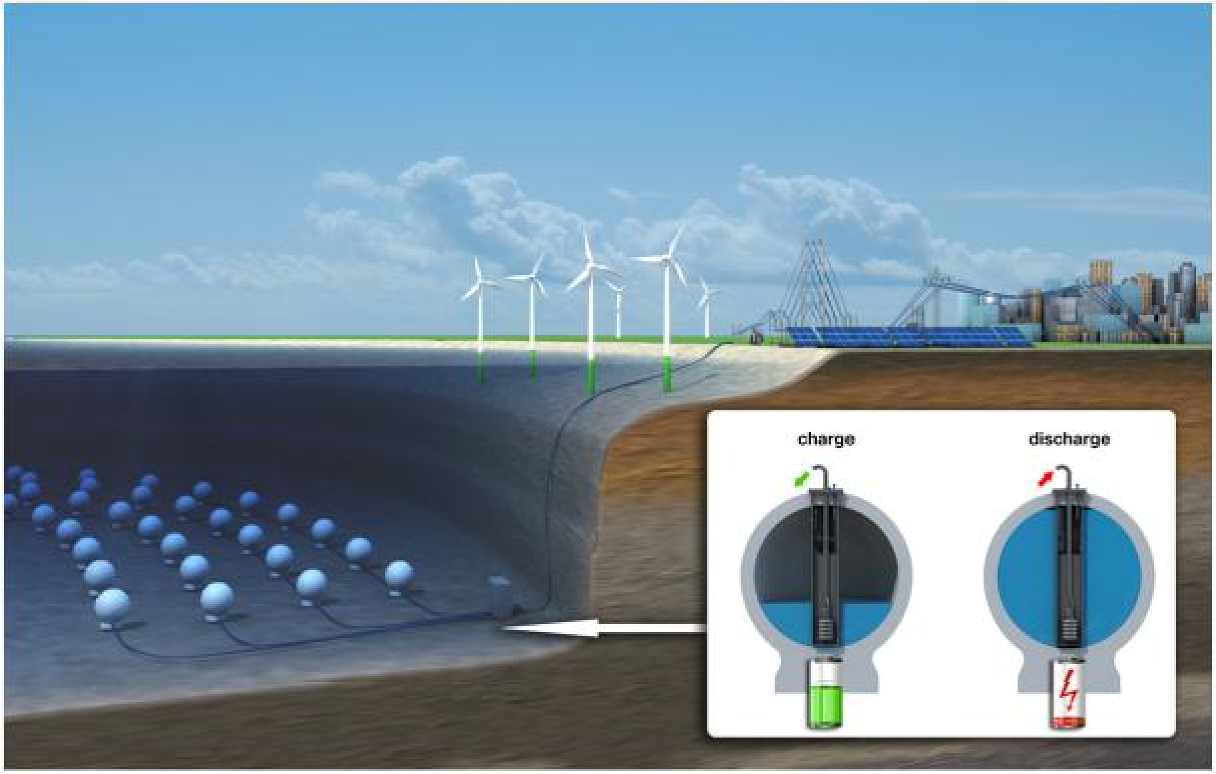
Seawater Muuga PHES (Under construction Completed upto 2020)

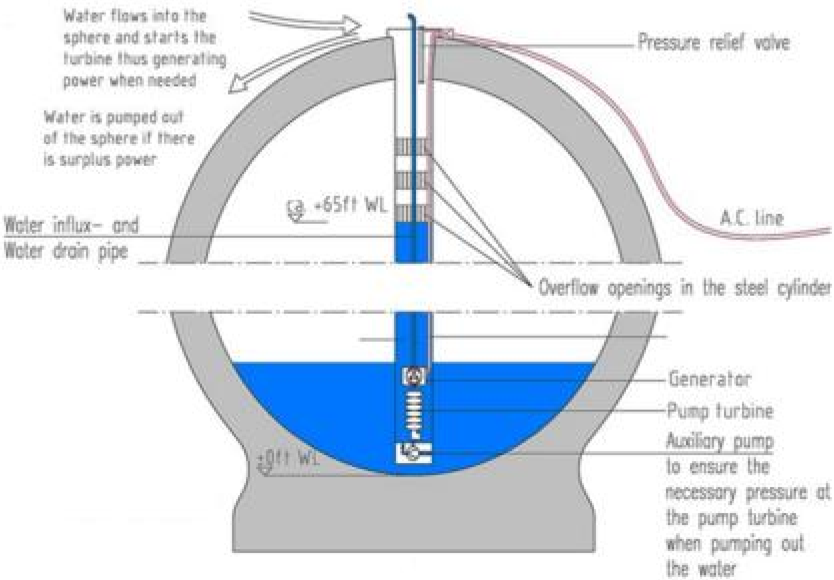




Maximum capacity	P= 1x100 MW + 2x175+1x50 MW=500 MW
Average operation height	H= 500m
Max. volumetric flow rate by power generation	Q= 110m^3/s
Diameter of delivery conduit	D= 7.0 m (by water flow rate v=3.1 m/s)
Water consumption (by 12-hour operation at full capacity)	V= 4.75 Mm^3

Underwater PHS (Stensea project)





Pumps water into 30-meter diameter spheres anchored at the seabed, which can store up to 20 MWh each. Another sea-based alternative solution was proposed in Belgium.

PSH IN DISCARDED MINE SITES

- As per Indian Bureau of Mines, there are 82 abandoned mines in India.
- These discarded mines may be utilized as reservoir for PSH development.
- Mines considered for development are open pit or underground mine.

Main considerations for groundwater reservoir construction:

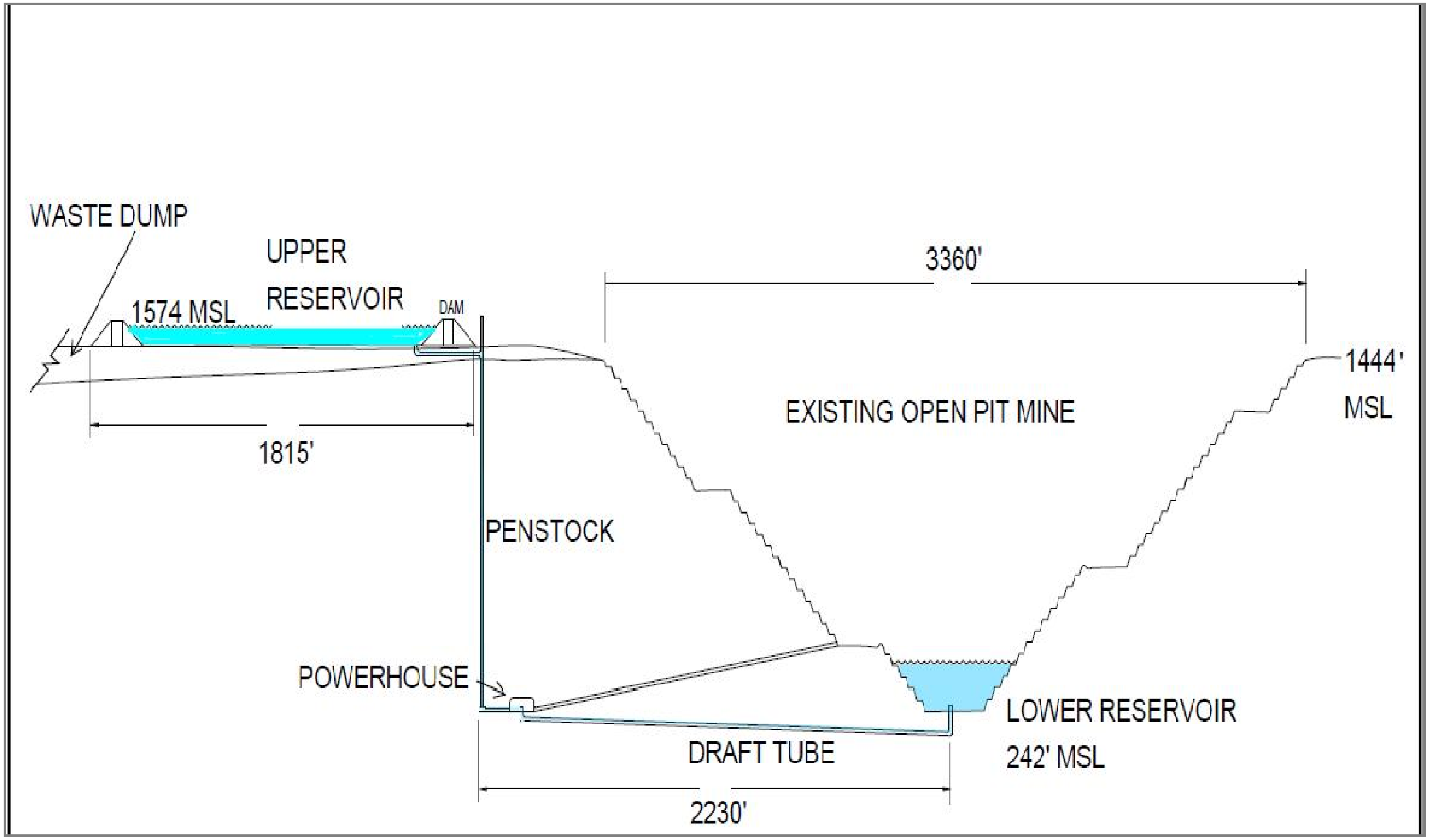
a) large underground storage space
b) nearby source of water.

In addition, other conditions that should also be considered are security, sustainability and the environment

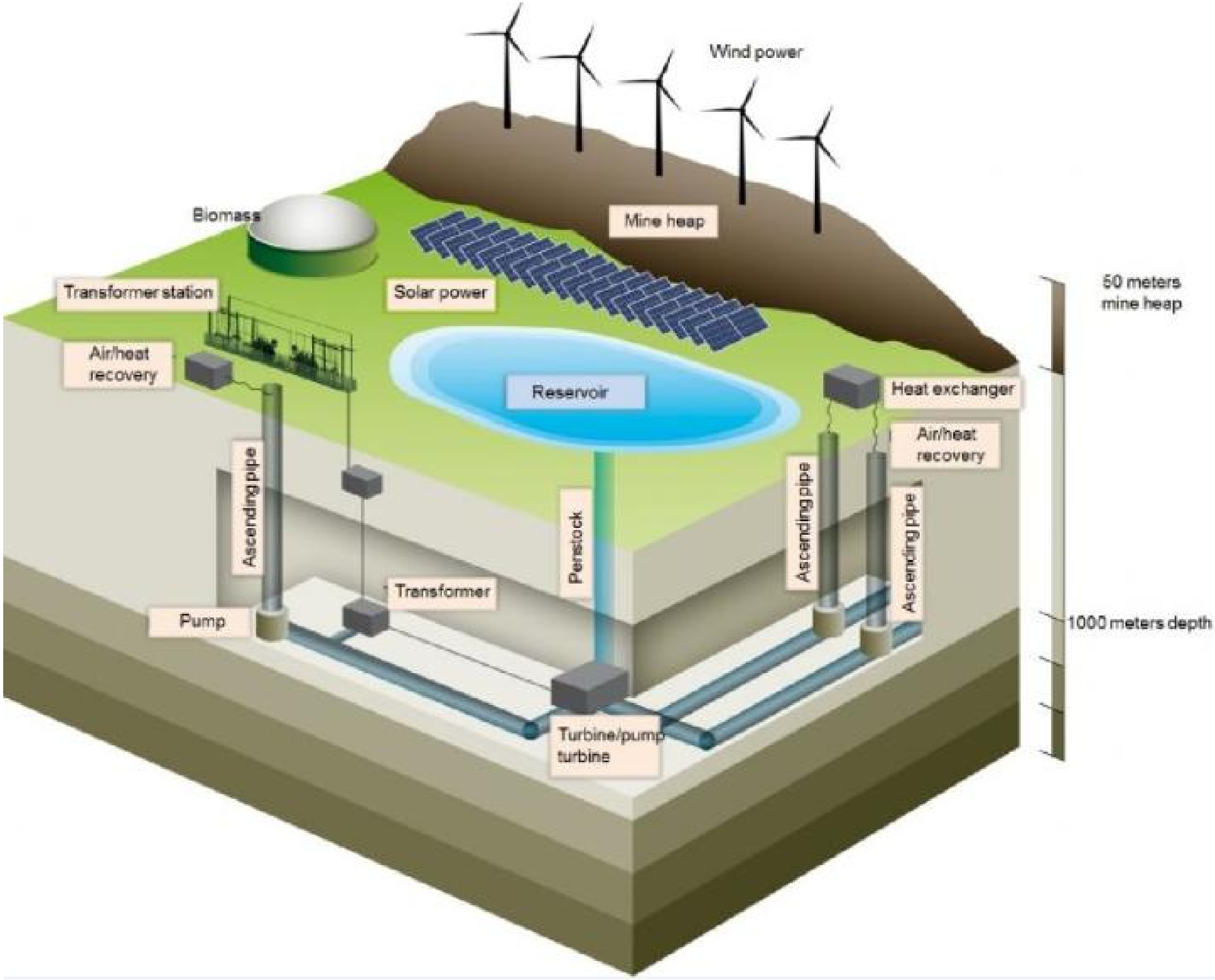
Geotechnical considerations for an underground reservoir:

a) Structural adequacy of the rock mass
b) Water tightness
c) Mineral content and possible contamination
d) Groundwater contamination
e) Disposal of excavated material

PSH IN DISCARDED MINE SITES



The state of North-Rhine Westphalia (Germany) – Prosper-Haniel hard coal mine (600 m deep) 200 MW.



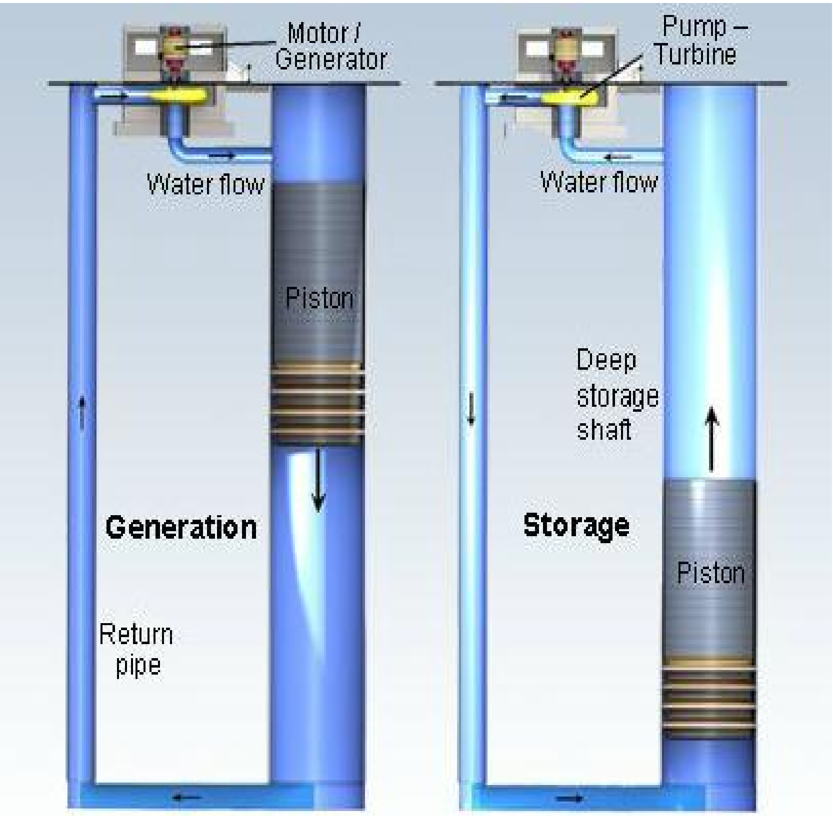
GROUND WATER SITE - GRAVITY POWER MODULE

- Gravity power module (GPM) is the latest technical advancement which is in current development for exploitation of the widely available sites based on PSH
- Suspended large piston made from iron and concrete
- Deep shaft filled with water
- The energy stored by using grid power to force water down and lifting the piston.
- To produce electricity, the piston drops to force water through the turbine, and drives the generator
- The shaft is filled with water once, at the start of operations, but is then sealed and no additional water is required.

Typical GPM Parameters

- 30-100 m diameter storage shaft
- 3-6 m diameter return pipe
- 500-1000 m deep
- 3 acre surface footprint

Advantages: high efficiency; flexible siting; use of existing technology, environmental compatibility, short time from project start to revenue, long lifetime, low cost per megawatt-hour and rapid construction.



(Source: Anthony DA. New energy storage option. Gravity Power 2011)

Patent: Gravity Power

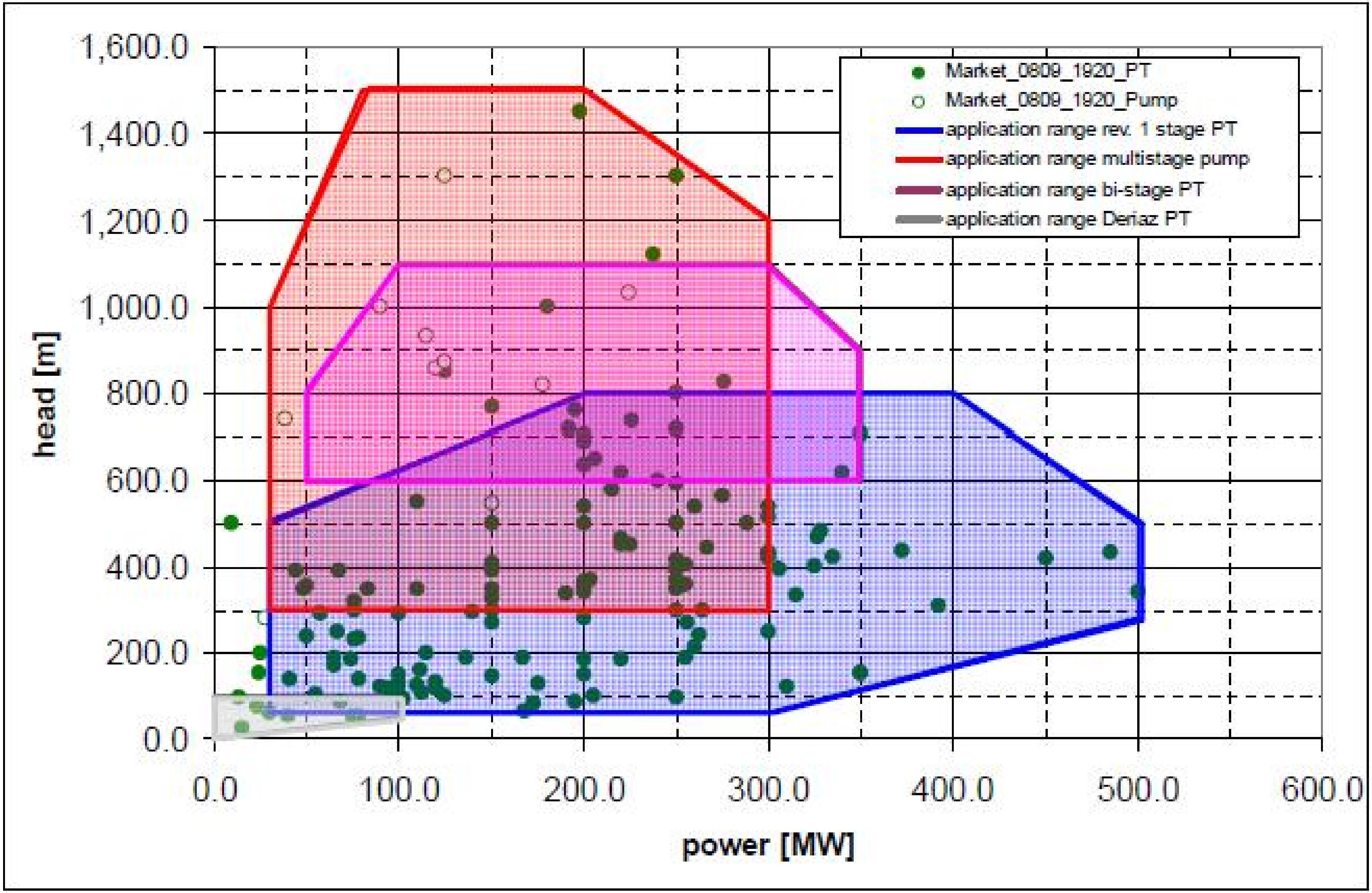
PSP Development Trends

Continuous improvement	• In 40 years, from 70 to 80% cycle efficiency • Availability, Reliability, Cycling
More challenging sites	• Very High or Very Low Head (<50m & >800m) • Head range increase • Underground reservoir • Sea water operation
Flexibility	• Variable Speed offering • Power range increase in turbine mode • Reaction time reduction

PSP Key Facts

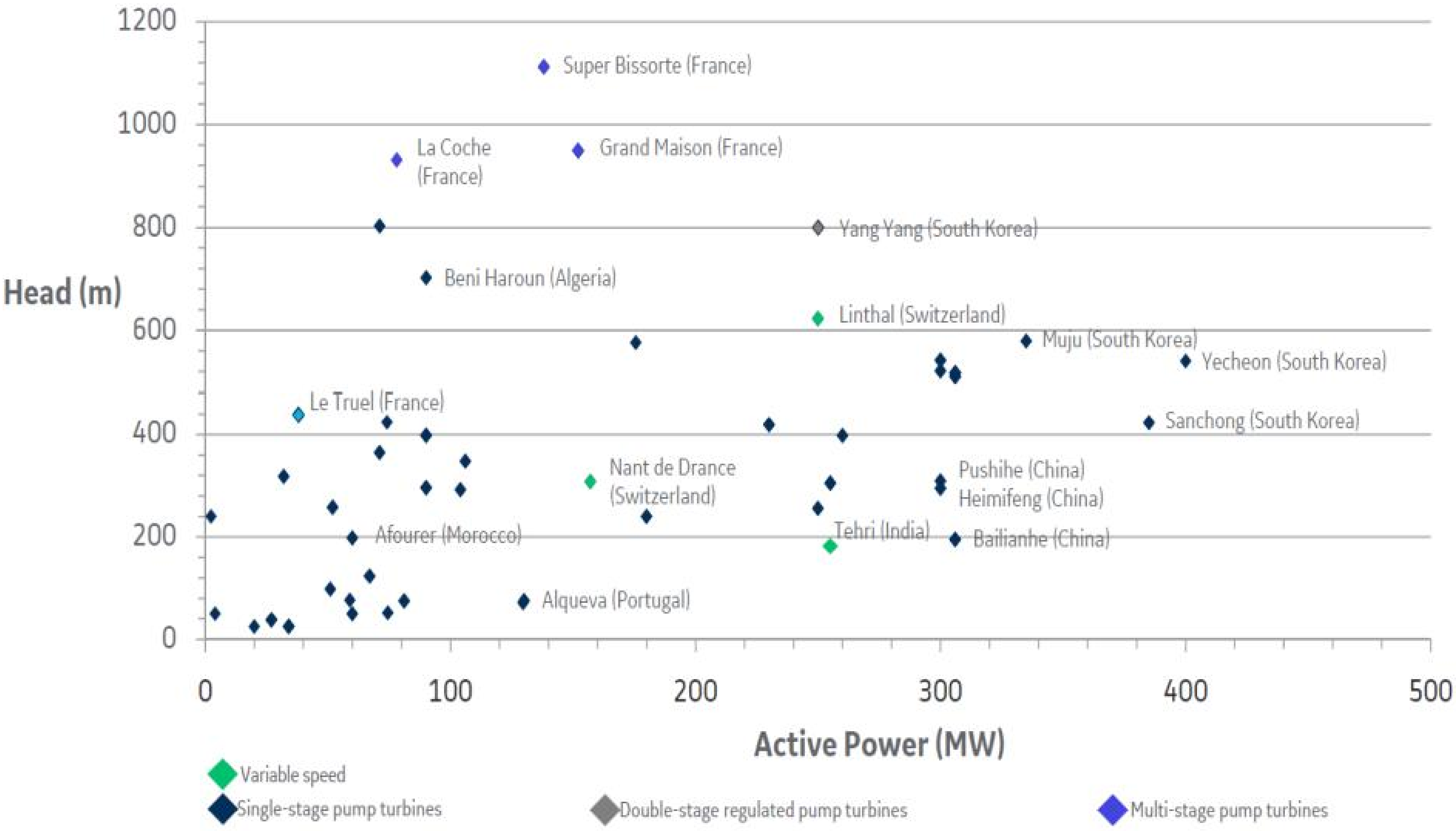
General Performances	**5 to 500 MW**	Output/Input
	> 8 hours full load	Storage capacity
	10 to 2000 m.	Head Range
	> 80%	Cycle efficiency
Reaction Time	**~ 15 s.**	50% to 100% Generation
Ancillary Services	**25% to 100%**	Production adjustment range
	70% to 100%	Pumping power adjustment range (Variable speed machines)

Application Range of Pump Turbines



source: Voith Hydro

Range of PSP – Experience Profile (Alstom)



PSP Technology Comparison

		Fixed speed	Variable speed		Ternary
			Doubly Fed (>100 MW)	Fully Fed (< 100 MW)	
Cost	Integration and equipment	*	**	***	****
Space		Low	Medium	Medum large	Large
Overall efficiency	Turbine mode	Medium	Medium high	High	Medium
	Pump mode	High	Medium	Medium	Low
Regulation flexibility	Turbine power	Medium	Medium high	Medium high	High
	Pump power	Low	Medium	Medium High	High
Transfer time	Pump to Turbine	Medium	Medium	Medium	Fast
	Turbine to pump	Slow	Slow	Medium	Fast
Reaction	50% power swing	Medium	Fast	Fast	Medium
Installations	Global	High	Medium	Low	Low

Variable speed pump-turbines

Feature	Technological Advantages	Economic Advantages
Adjustable pumping power	Frequency regulation in pumping mode by accommodating variable supply	Additional ability to quickly ramp up and down to support more variable renewable energy resources
	More efficient use of equipment, reducing the need for thermal plant cycling; critical for avoiding greenhouse gas emissions	Operations and maintenance cost reduction and increase of equipment lifespan; greenhouse gas offsets if market develops
	Able to take advantage of shifts in grid dynamics to effectively manage variable energy supply and capture and store lower cost energy	Cost minimization and operation of existing units at peak efficiency; support growth of additional renewable energy resources
	There is an increase in energy generation due to the fact that the turbine can be operated at its peak efficiency point a under all head conditions.	This results in an estimated increase in energy generated on the order of 3% annually.
Faster power adjustment and reaction time	Improved balancing of variable energy units (wind/solar) and coordination of overall energy mix	More stable equipment translates into risk reduction and increased reliability of the domestic electric grid

New Technology influencing PHS

- Improved efficiencies with modern reversible pump-turbines
- Adjustable-speed pumped turbines
- New equipment controls such as static frequency converters
- Improved Generator insulation systems
- Improved underground tunneling construction methods and design capabilities
- Overall, the pumping/generating cycle efficiency has increased pump-turbine generator efficiency by as much as 5% in the last 25 years

Pump-Turbine Design: Multi-Objective Optimization

There is large Variety and complexity of requirements for pump-turbines :

Frequent start / stops

Stability over a wide range

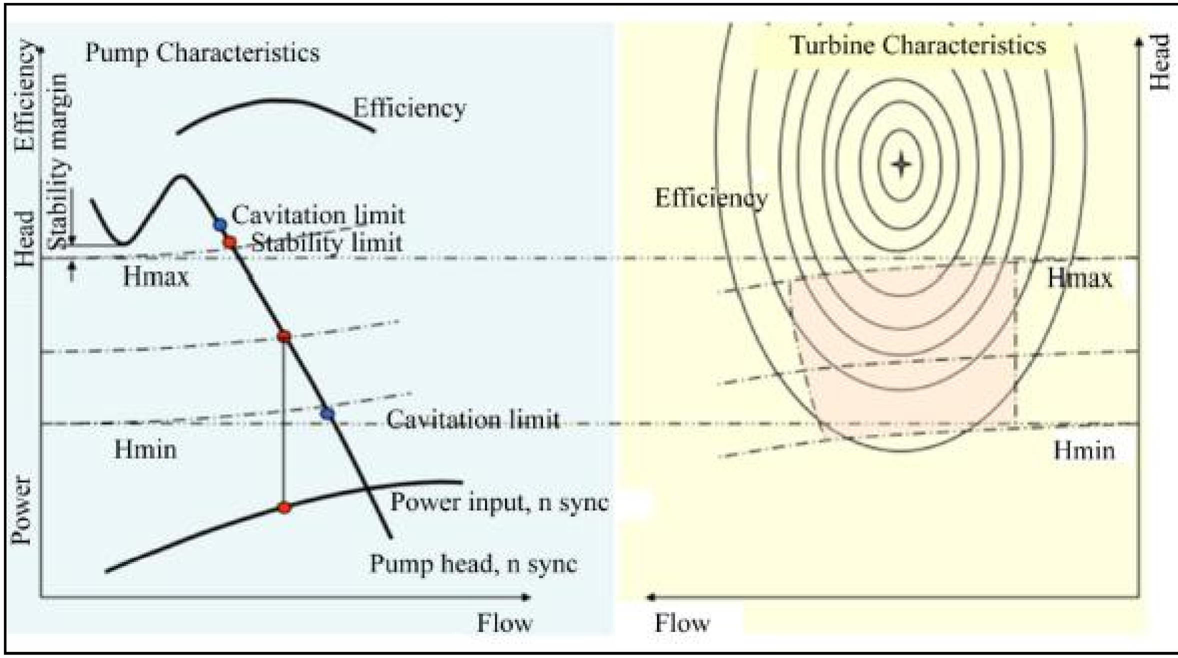
- **Part Load operation**
- **Pump stability at high heads**
- **Dynamic stresses**

Fast changeover times

Safe Operation

High efficiencies

Cost optimized dimensions



Inputs Thankfully Acknowledged

- **BHEL**
- **Voith**
- **Andritz**
- **GE (Alstom)**

Regulatory issues: Pumped Storage Plants

- CERC circulated discussion paper on “power storage devices” but not included PSP as storage even PSP being bulk storage technology.
- PSP are essentially generators in Motoring mode, may not be treated as Consumers (as they are not final consumers) - Need to be taken care in PoC for Drawal charges.
- ToD tariff be implemented to make PSP economically self sustained.
- Incentive tariff for PSP
- Compensation for providing ancillary services
- Off peak power for PSP be made available at attractive price instead of throttling the thermal power plants.

Issues for delibration

- Separate hydro power pumped storage policy and according benefits to PSP as application to RE projects
- Attractive financing for PSPs
- Adjustable speed PSPs for better efficiency
- Operationalization of pump storage projects with not running in PSP mode
- Transmission charges exemption for off-peak energy required by PSPs and energy generated by PSPs
- Re-assessment of PSP potential
- To treat PSP as a regulatory grid management asset
- Incentivized tariff for PSP off-peak as well as peak power and for providing additional benefits like energy security, spinning reserve, black start facility, voltage & power factor regulation etc.

Way forward

- Regulatory treatment and market design is highly critical to capture benefits of PSP.
- Tariff/market design to value ancillary, spinning /non spinning reserve and frequency regulation services, reliable service provider
- Peak power to be compensated
- To value the cost effective source of flexibility and storage
- PSP be treated as Grid rather than generation
- A scheme like "50,000 MW PM initiative" be also launched for PSP.

Thank You

HYDRO

PUMPED STORAGE WAY FORWARD

NATIONAL WORKSHOP ON PUMPED STORAGE / ROHIT UBEROI

FEBRUARY 2018

ANDRITZ

ENGINEERED SUCCESS

CHAPTER OVERVIEW

ANDRITZ: AN OVERVIEW

ANDRITZ is a globally leading supplier of plants, equipment, and services for hydropower stations, the pulp and paper industry, the metal-working and steel industries, and solid/liquid separation in the municipal and industrial sectors.

Headquarters: Graz, Austria

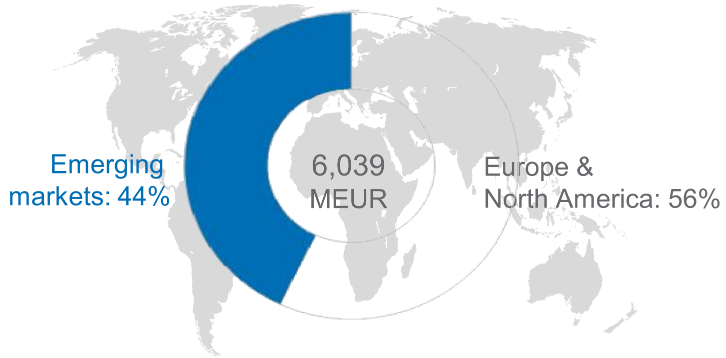
Global presence: over 250 production sites and service/sales companies worldwide

KEY FINANCIAL FIGURES 2016 VS. 2015

	Unit*	2016	2015
Order intake	MEUR	5,568.8	6,017.7
Order backlog (as of end of period)	MEUR	6,789.2	7,324.2
Sales	MEUR	6,039.0	6,377.2
EBITA	MEUR	442.1	429.0
Net income (including non-controlling interests)	MEUR	274.8	270.4
Employees (as of end of period; without apprentices)	-	25,162	24,508

* MEUR = million euros

Sales by region 2016 (%)



	2016	2015
Europe	35	38
North America	21	19
South America	15	14
Asia (without China)	12	13
China	12	12
Africa, Australia	5	4

ANDRITZ: AN OVERVIEW

Worldwide leading position in four business areas

ANDRITZ

ANDRITZ Hydro	ANDRITZ Pulp & Paper	ANDRITZ Metals	ANDRITZ Separation
			
Product offerings: electromechanical equipment for hydropower plants (turbines, generators); pumps; turbo generators	Product offerings: equipment for production of all types of pulp, paper, tissue, and board; energy boilers	Product offerings: presses for metal forming (Schuler); systems for production of stainless steel, carbon steel, and non-ferrous metal strip; industrial furnace plants	Product offerings: equipment for solid/liquid separation for municipalities and various industries; equipment for production of animal feed and biomass pellets

ANDRITZ HYDRO: A BRIEF

We are a global supplier of electro-mechanical systems and services ("from water-to-wire") for hydropower plants and a leader in the world market for hydraulic power generation.

*More than **175 years** of turbine experience (1839)*

*Over **31,600 turbines** (more than 434,600 MW) installed*

*Complete range up to more than **800 MW***

*Over **120 years** electrical equipment experience (1892)*

*Leading in **service and rehabilitation***

*More than **120** Compact Hydro units per year*

ANDRITZ HYDRO: HISTORY

ANDRITZ HYDRO: PUMPED STORAGE PROJECTS

- ANDRITZ HYDRO is a technology leader in the pumped storage technology with more than 10,000MW of installed capacity of Pumped Storage Plants across the globe

- ANDRITZ executed the first variable speed Pumped Storage Project executed outside Japan – GOLDISTHAL PSPs, which has been in successful operation for more than 15 years.

Goldisthal / Germany

Motor Generator

- 2 x 340 MVA DFM and
  2 x 331 MVA fixed speed M/G,
  AC Excitation and Starting - SFC
- 300..346 rpm and 333 rpm

Project Highlights

- two sets of synchronous and
  doubly fed asynchronous M/G
- Central location in the UCTE grid

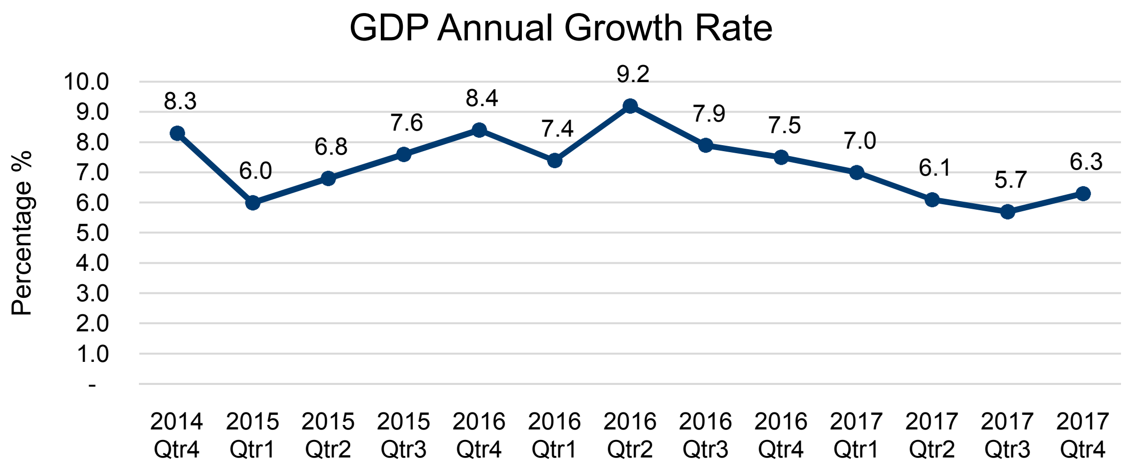
Customer: Vattenfall

Commissioning: 2003

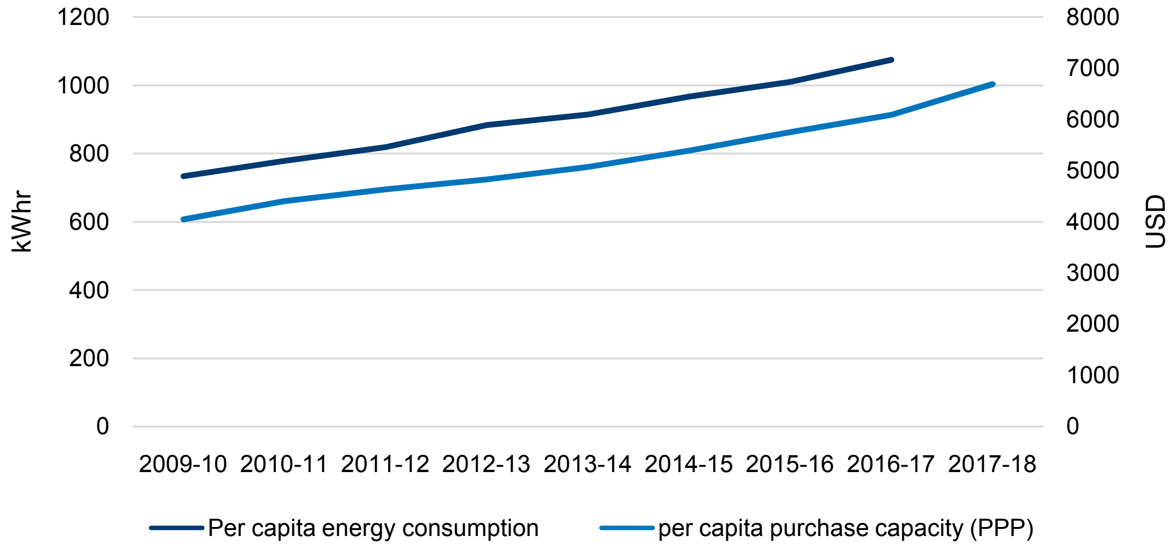
CHAPTER OVERVIEW

INDIA: MACRO ECONOMICS

- India‘s Annual GDP Growth rate is at 6.3%
- Though Demonetisation and GST has impacted the growth, it is still one of the fastest growing economies
- India‘s GDP per capita on PPP basis continues to rise – presently at USD 6092 per person
- Per capita energy consumption stands at 1075kWhr while the global average stands at ~3600kWhr

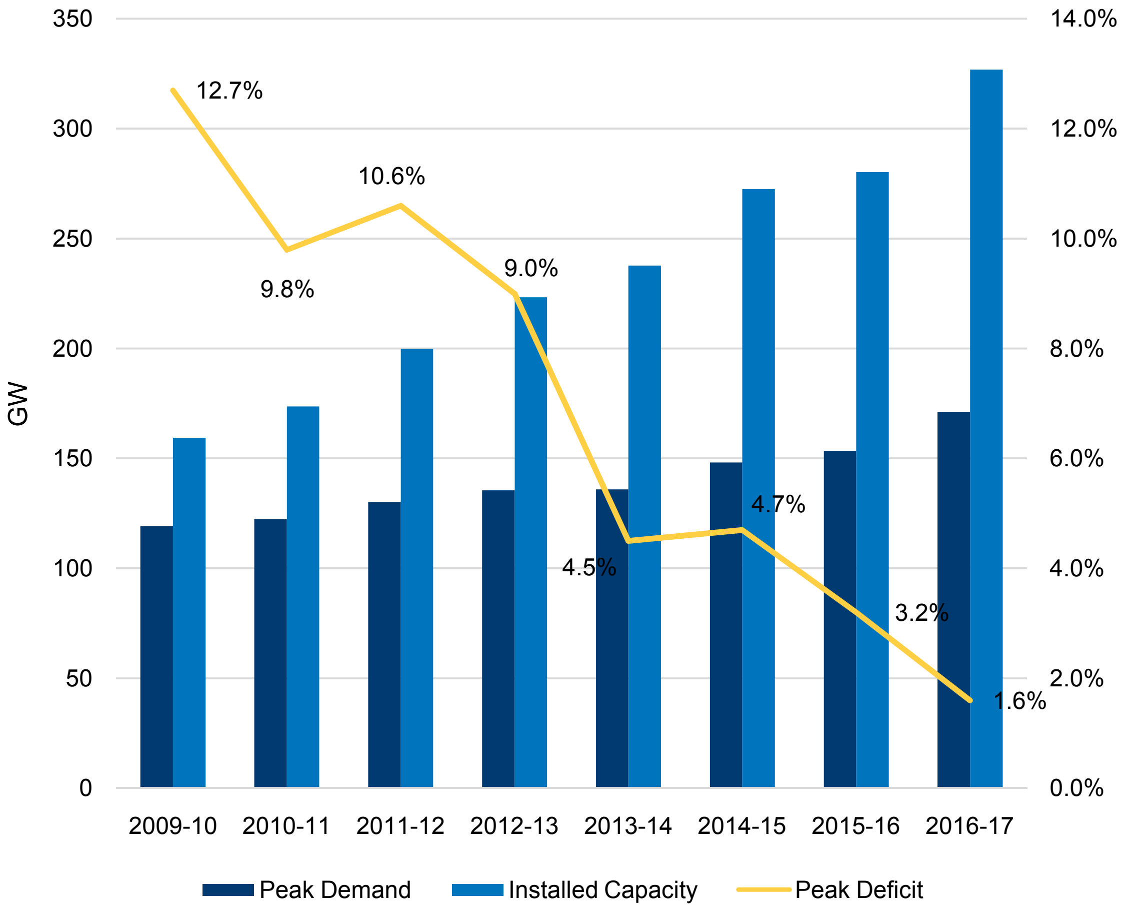


Source: World Bank



ELECTRICITY DEMAND: GROWTH RATE

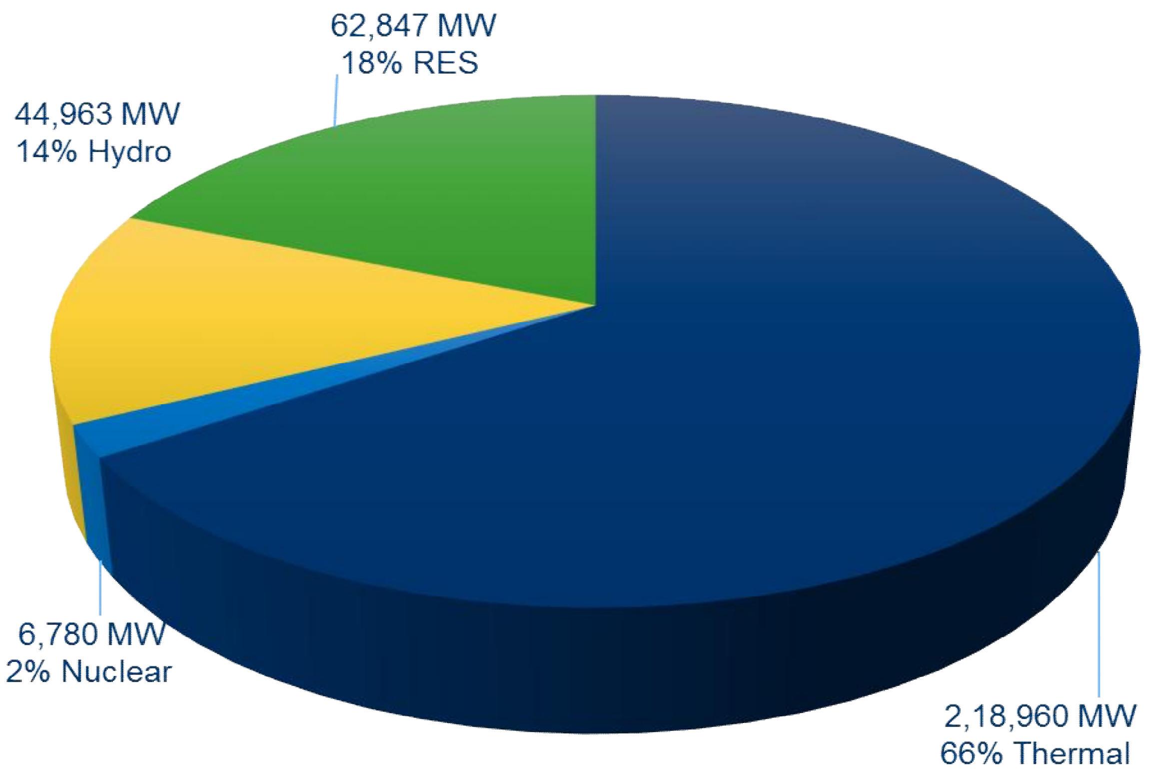
- Installed Capacity has increased at CAGR of ~11% over last 7 years
- The peak demand has only increased at CAGR of ~5.3% over last 7 years
- Deficit gap has reduced from 12.7% to 1.6%
- Realistic view:
    - Per capita energy consumption is low
    - Frequent power cuts are common features
    - Energy growth shall continue to keep pace with the GDP growth rate.



POWER INSTALLATION MIX

INSTALLATION MIX

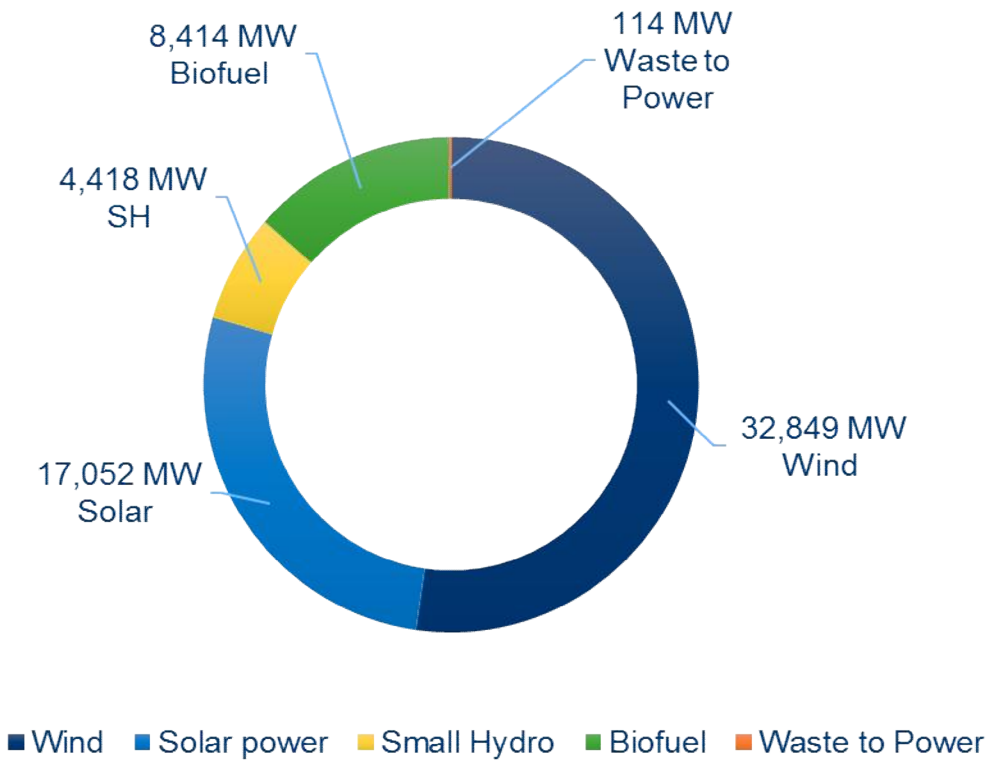
Total: 333,550 MW
As on 31.12.2017



Source: CEA

RENEWABLE MIX

Total: 62,847 MW
As on 31.12.2017

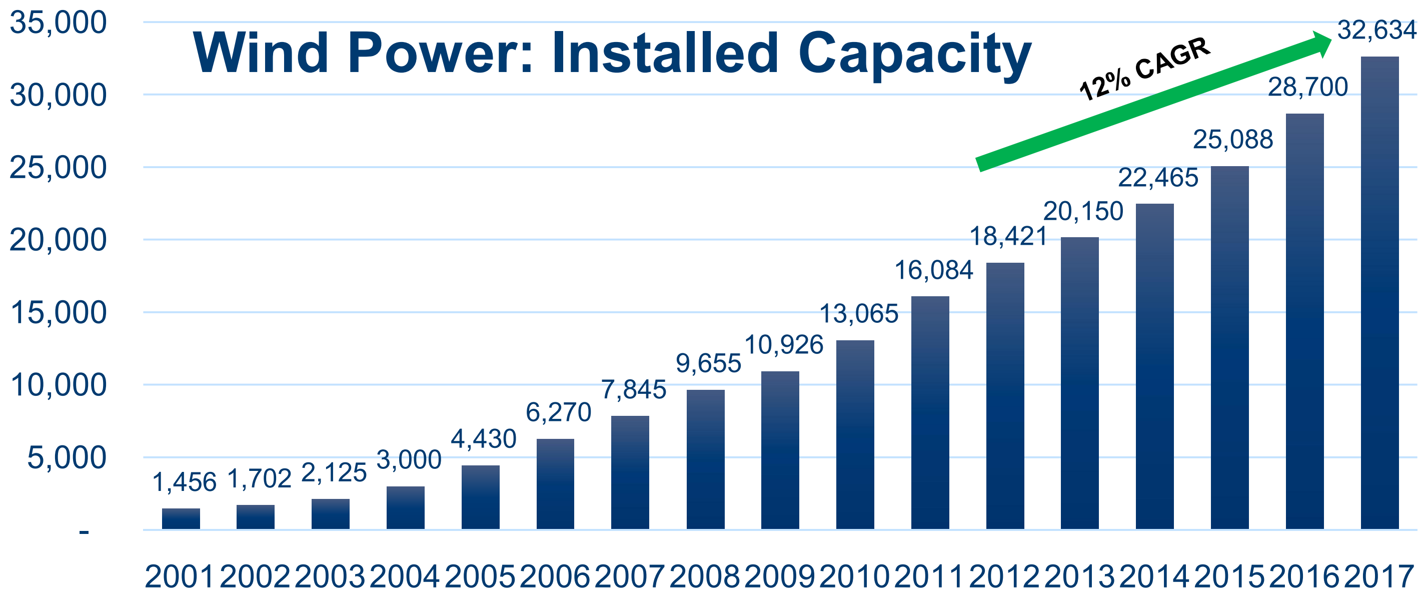


CHAPTER OVERVIEW

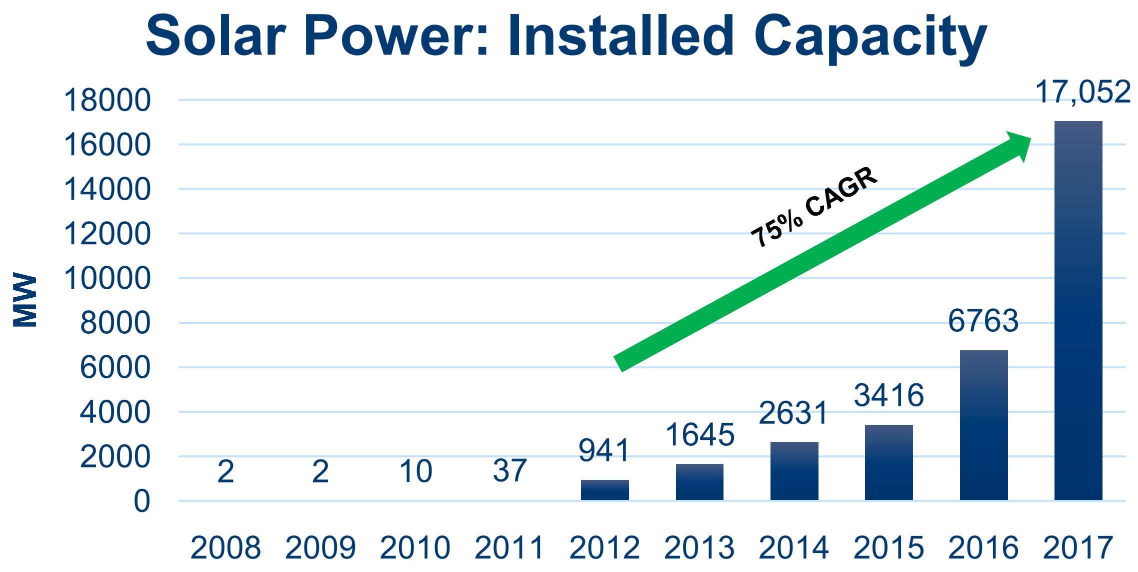
GROWTH OF RENEWABLE INSTALLATION

Wind Power:

- Target for year 2022: 60,000MW
- With a growth rate of ~12% CAGR, the target is feasible.



Source: GWEC

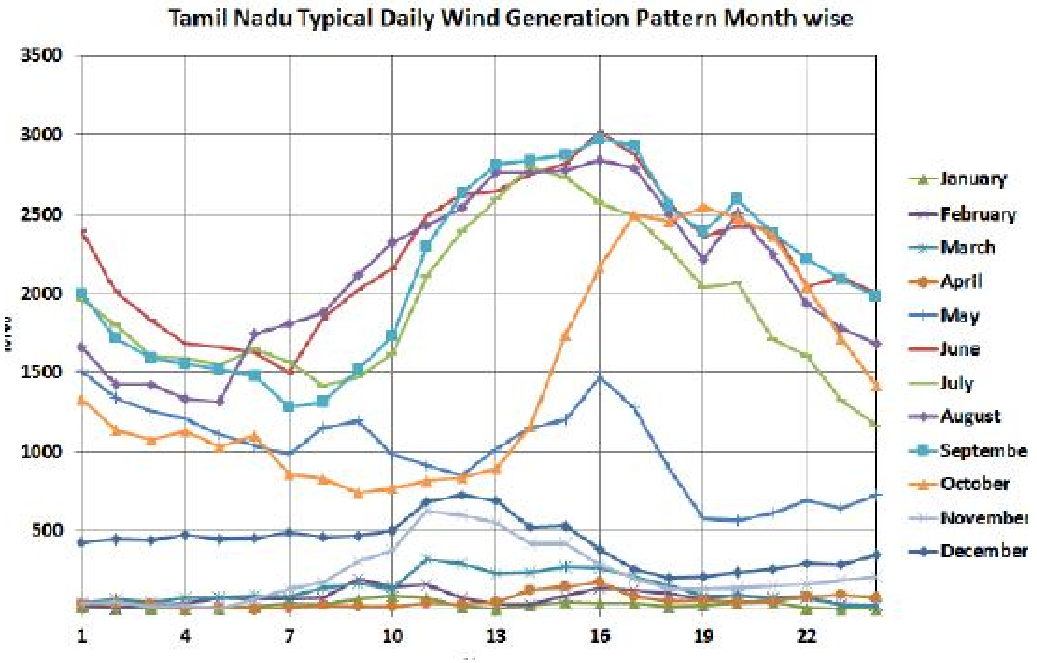


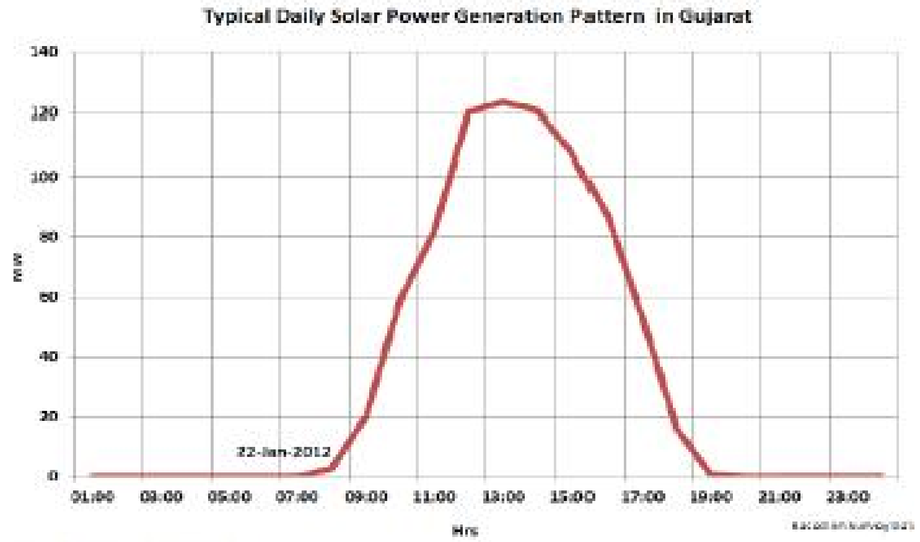
Solar Power

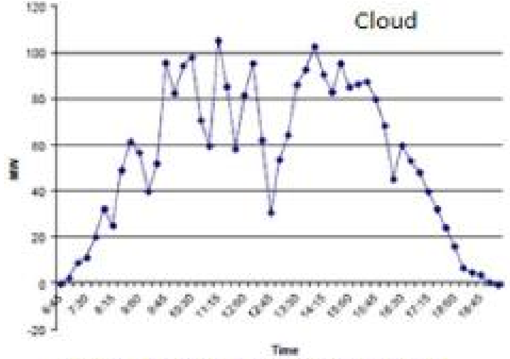
- Target for the year 2022: 100,000MW
- Solar Power installation has been seeing an exponential growth of ~75% CAGR over last 5 years.
- Target could even be exceeded at this growth rate

VARIABILITY AND UNCERTAINITY OF WIND AND SOLAR POWER

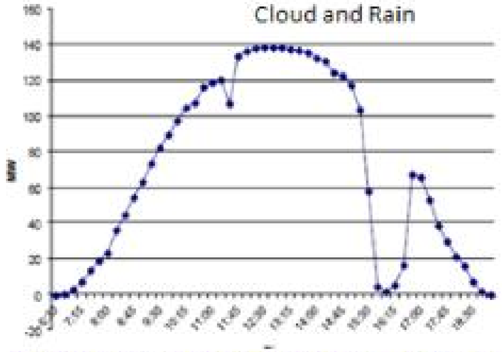
- Wind power and PV Solar are unpredictable depending upon wind speeds, cloud cover, etc.
- Solar can even go to zero in case of cloud / rain event
- Solar energy is dominant during the daytime, when the load requirement is flat







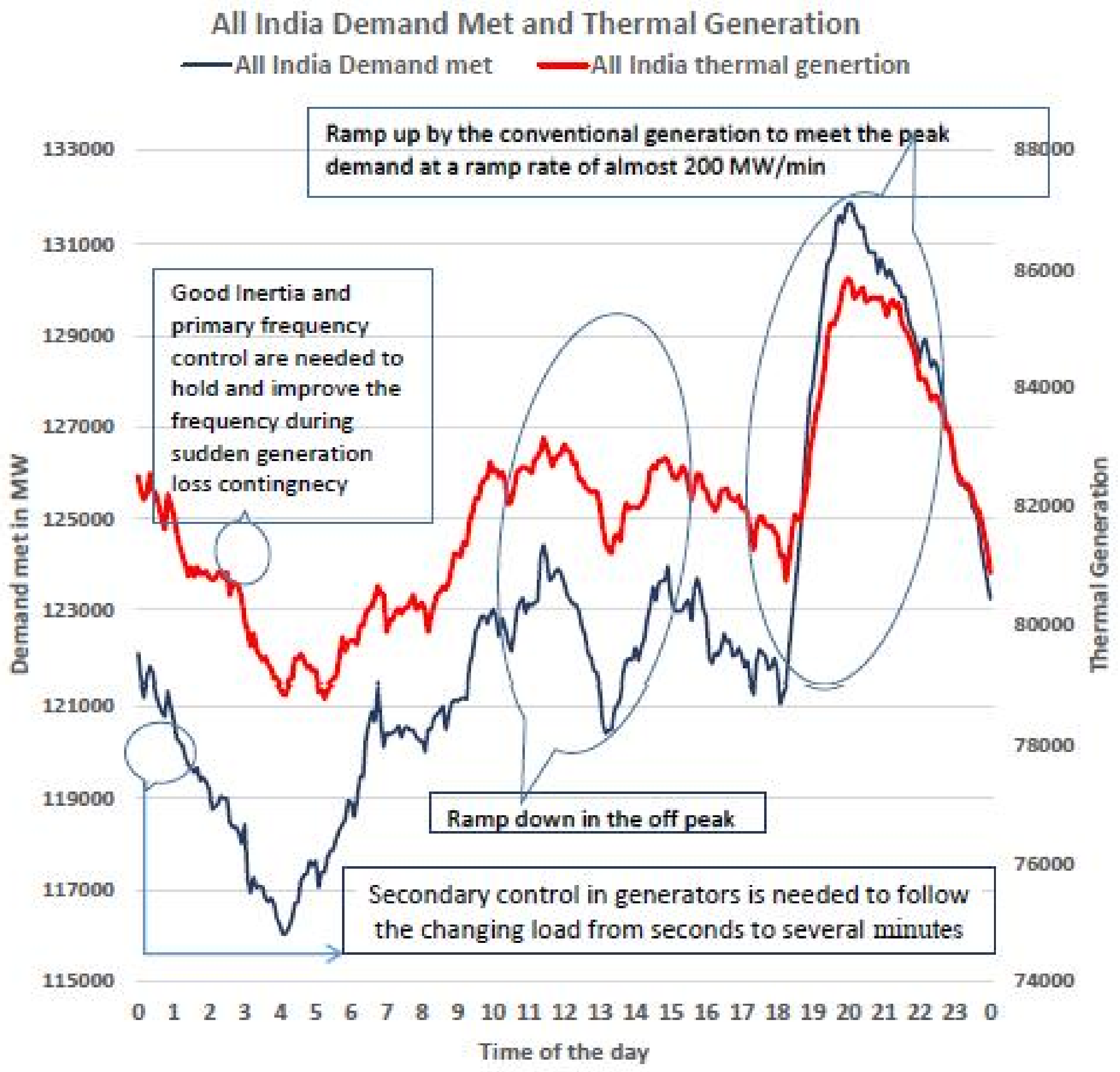
Lot of Variability on account of Cloud



Solar Generation Dropping Zero in Cloud/Rain event

NEED FOR STORAGE PLANTS?

- Load typically peaks in the evening
- Night time is the lean time for energy consumption
- Ramp rates are sharp ~200MW / min, depends upon region to region
- Thermal power plants cannot ramp up at the required pace
- Wind and Solar power is unpredictable
- Solar power is not available during the peak time.
- Flexibility required in the system to cope with the rapid changes and grid stability



NEED FOR STORAGE PLANTS?

- Presently the grid is managed by:
  - balancing the grid every 15 mins
    - Primary Control: through governor operation of the existing plants. Thermal units are being operated at part load of upto 55% during lean time
    - Secondary Control: Automatic Generation Control (Presently only Pilot Project implemented)
    - Tertiary Control: Manual operation (eg.load shedding / backing down of units)
- During the lean time – thermal units are forced to backed down leading to higher heat rates, ie. Higher operational costs and thermal fatigues – reduction in lifetime
- During peak times units are overloaded to technical limits and manual load shedding is resorted.
- At present the forecasting of renewable energy is not accurate – may improve over medium time period.
- Flexibility needed to take care of rapid changes in the demand and overcoming the unpredictability of the renewable sources of energy.

CLEARLY THIS LEADS TO DEMAND FOR STORAGE PLANTS

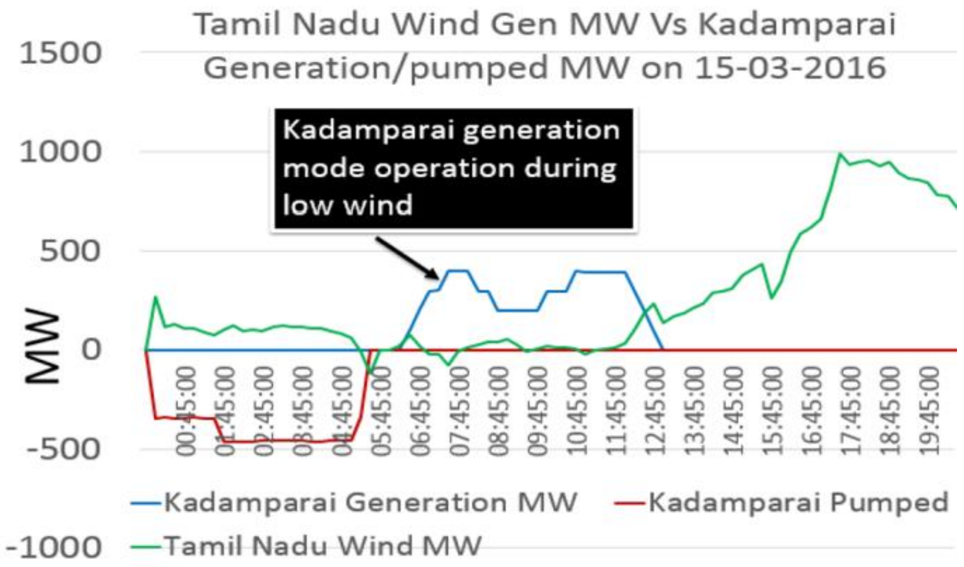
- Hydro Power plants especially Pumped Storage Plants
- Battery storage (new technology)

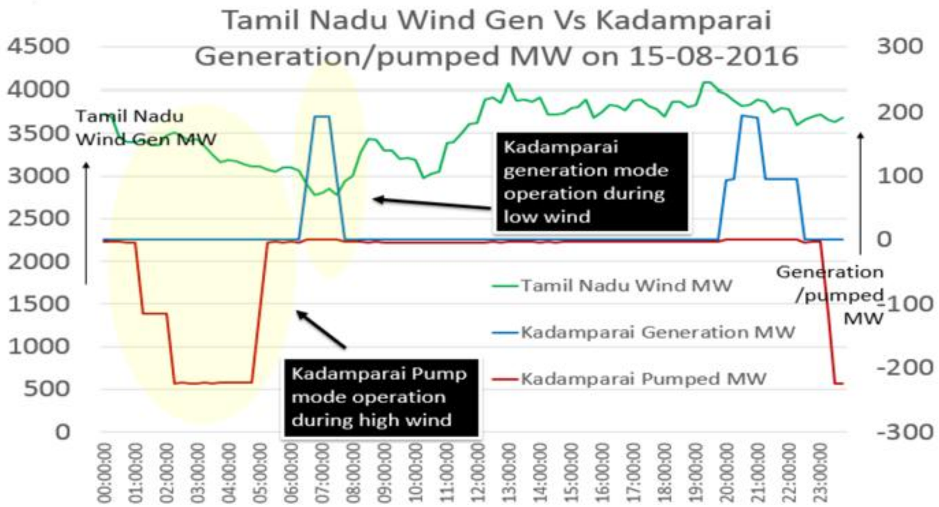
SWOT ANALYSIS: PUMPED STORAGE PLANTS

Strength ▪ Fixed and predicable energy – unaffected by seasonal changes ▪ Provides high inertial response & synchronous condenser mode of operation for reactive power support ▪ Spinning reserve to provide fast response to demand changes ▪ Provides flexibility and stability to the grid ▪ Provides large energy storage, sustainable over long period of time ▪ Minimum lifetime of 40 years	**Weakness** ▪ Hydro is not recognised as renewable source of energy in India ▪ High capital and associated civil costs ▪ Long gestation period ▪ Environmental impact due to inundation
Opportunity ▪ High thrust on solar & wind energy ▪ Recognition of requirement of Storage plants to overcome unreliability and variability of Solar and Wind power ▪ Global instances (eg. Australia) is generating awareness to the need of PSPs to bring in grid stability and flexibility ▪ Recognition to the needs of ancillary services ▪ Existing hydro project reservoirs ▪ Right to energy (Saubhagya scheme)	**Threat** ▪ Strong battery storage lobby ▪ Opposition to reservoirs ▪ Large no. of projects in sensitive environmental zones (Western Ghats) ▪ Govt. & Authorities view that PSPs are expensive. ▪ Lack of tariff structure for ancillary services by PSPs ▪ Limited financing options and poor economic state of Generating Cos. and Discoms. ▪ Peoples' acceptance of prolonged load shedding

PUMPED STORAGE PLANT OPERATION: EXAMPLES

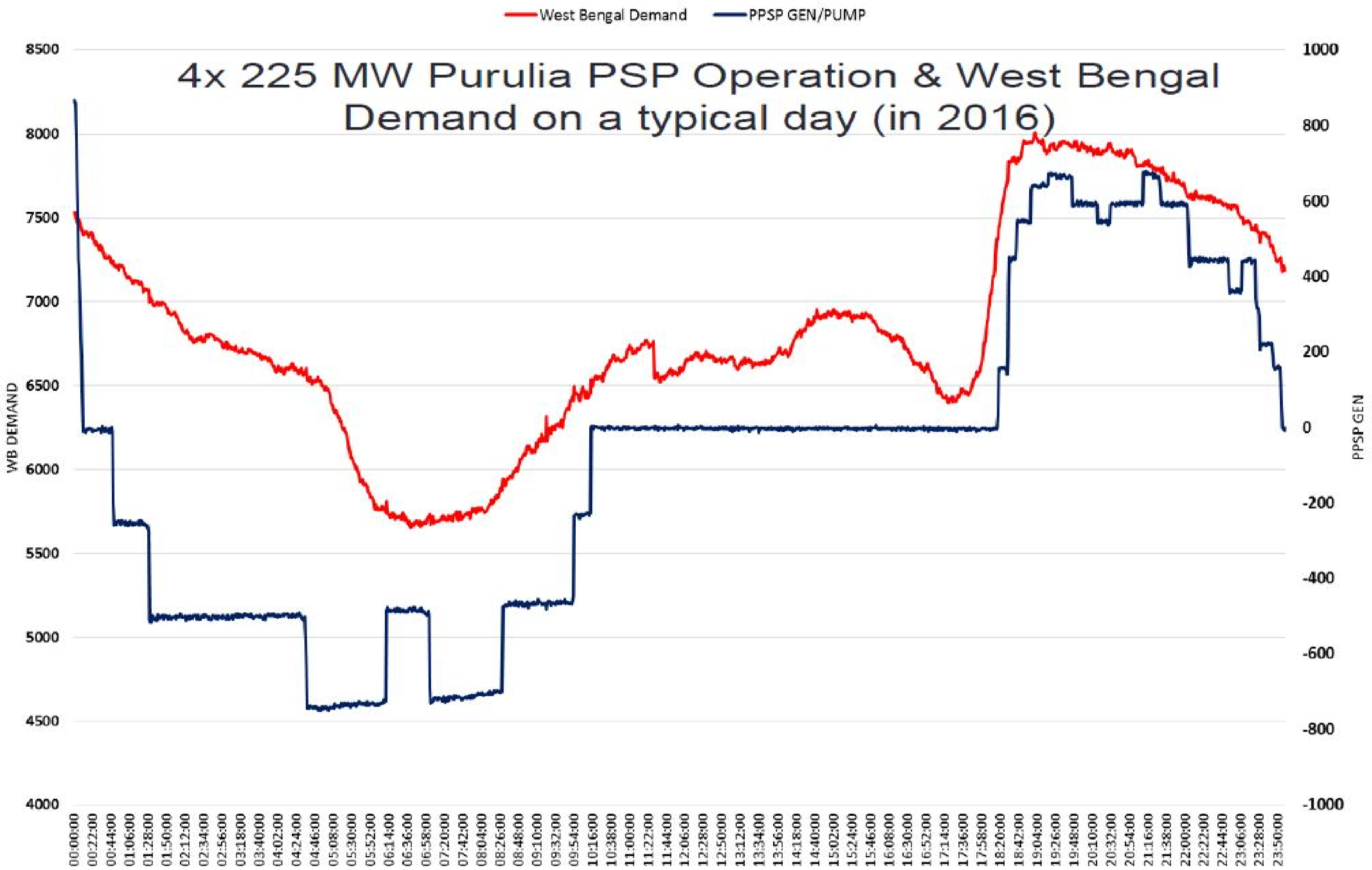
- Tamil Nadu state receives low water intake as well as low rainfall.
- Kadamparai balances the load demand as well as the uncertainty of wind power in the state of Tamil Nadu
- Successfully uses the pumped water to generate energy when required.





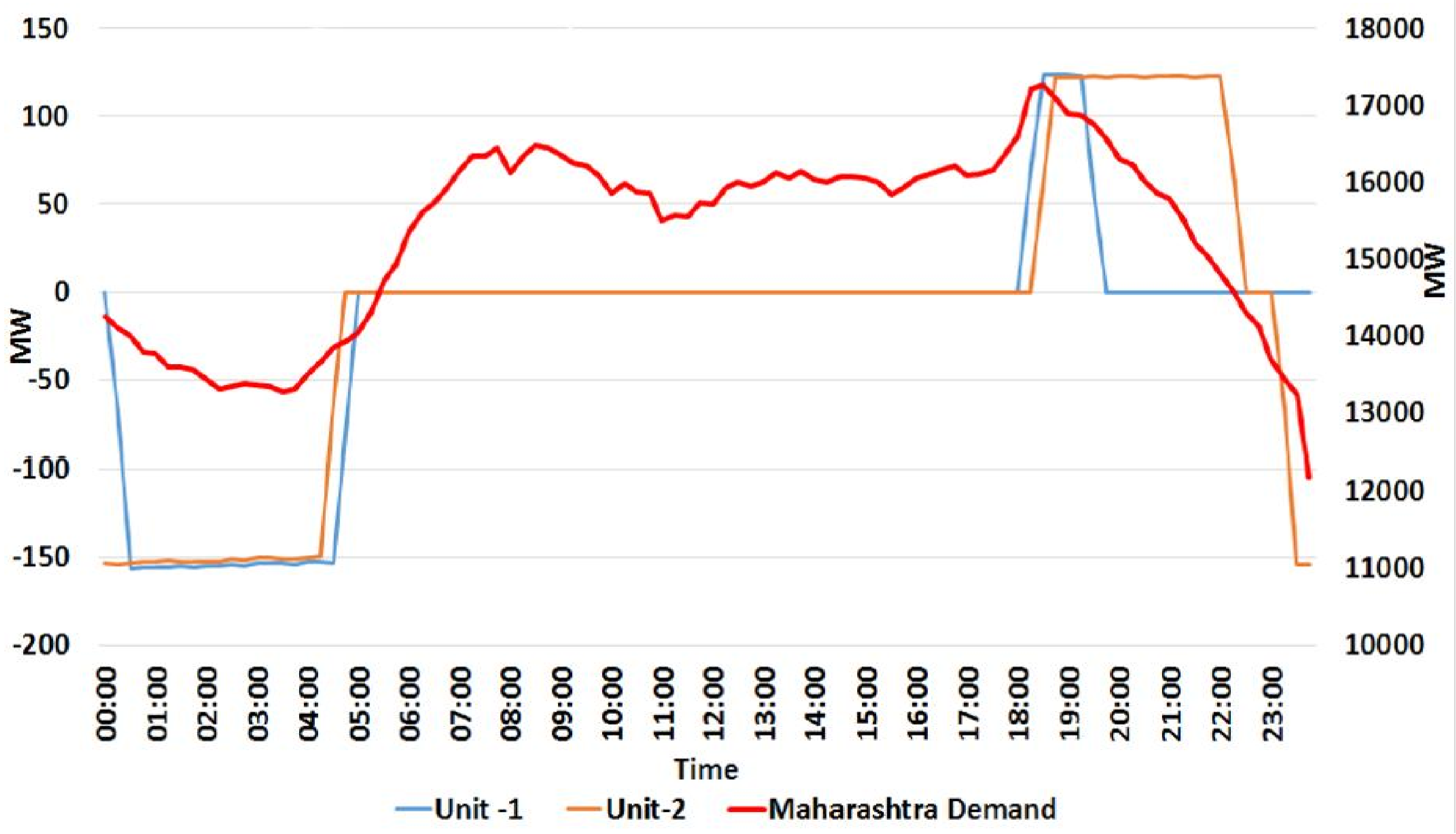
PUMPED STORAGE PLANT OPERATION: EXAMPLES

Purulia Pumped Storage Plant (4 x 225MW) Operation Pattern



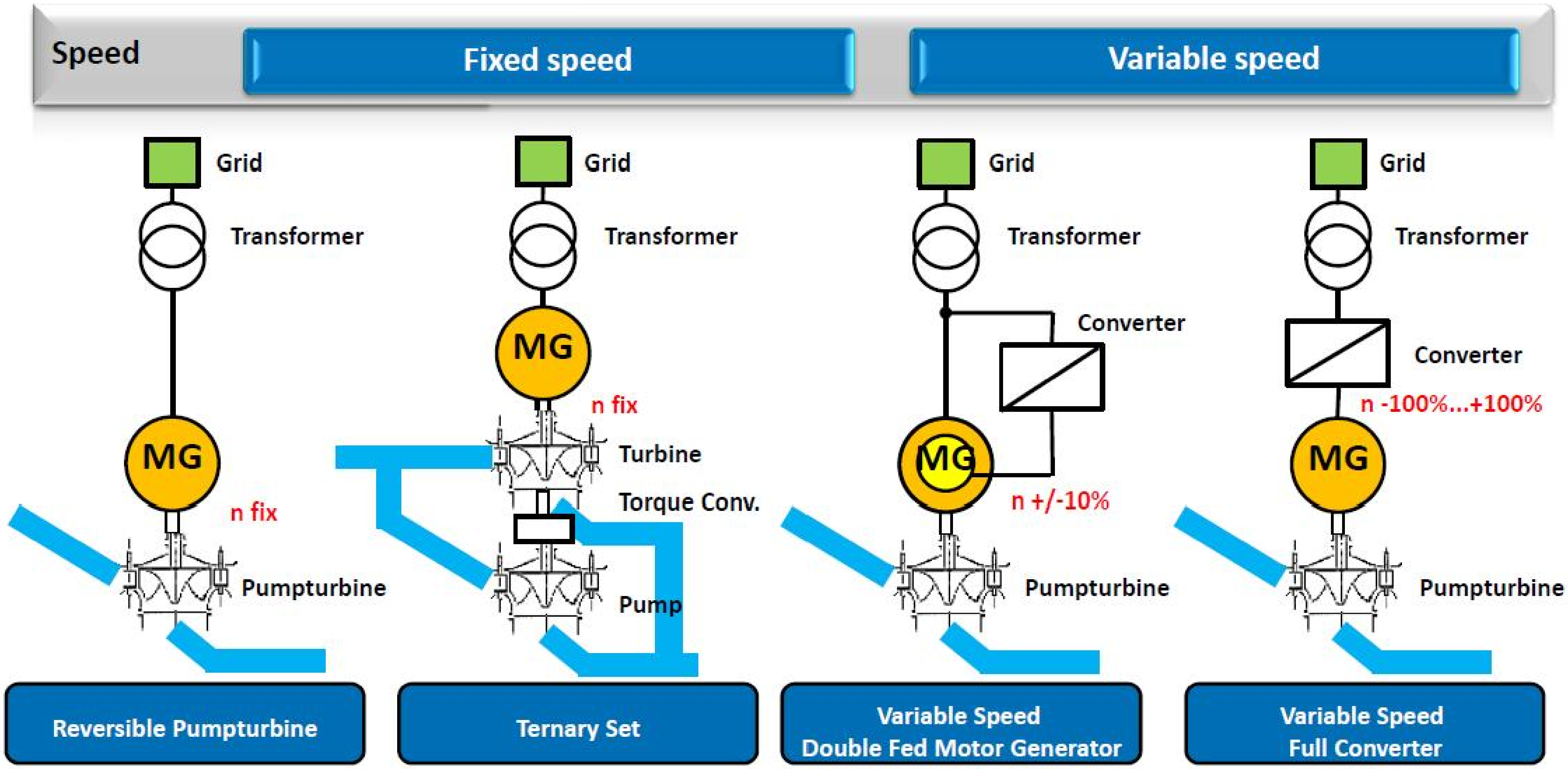
PUMPED STORAGE PLANT OPERATION: EXAMPLES

Ghatghar Pumped Storage Plant (2 x 125MW) Operation Pattern



CHAPTER OVERVIEW

PUMPED STORAGE: SYSTEM OVERVIEW



PUMPED STORAGE: COMPARISON

		Fixed speed		Variable speed	
	🔴 low 🟡 middle 🟢🟡 almost best 🟢 best	**Reversible Pump-Turbine** (w/o Hydraulic Short Circuit)	**Ternary unit**	**DFM** (Doubly fed asynchronous MG)	**FSC** (MG with a full size converter)
	system efficiency	T: 🟢🟡 P: 🟢	T: 🟢 P: 🟢-🔴	T: 🟢🟡 P: 🟢	T: 🟡 P: 🟢
	control range (Power +/- 100%)	🔴	🟢	🟡	🟢🟡
	mode change times	🔴	🟢	🟡	🟢🟡
Grid stability	reaction time on failure (frequency changes)	🟡	🟢	🟡	🟢
	power factor adoption (voltage changes in the grid)	🟡	🟢🟡	🟡	🟢
	synchronous condenser	rotating machine	rotating machine	rotating machine	**in standstill**
	space requirements (Volume)	100%	150%-200%	115%-125%	125%-150%
	world wide references	>300	only a few	>10	less
	costs of the E&M equipment	$	$$$	$$	$$$

CHAPTER OVERVIEW

PUMPED STORAGE: WAY FORWARD

- **Pumped Storage to be recognised as grid asset**
  - The future role for PSPs shall be grid balancing, especially in view of renewable energy dominant grid
  - In absence of suitable tariffs for ancillary services, PSPs under GENCOs cannot prove financial viability
    - No differential tariff exists and the generating/pumping mode on the basis of LDCs request is paid at 0.5 INR/kWhr
  - Incremental increase in wheeling charges would make the investment viable and attract easy financing
  - Integration of the PSPs with RLDCs would help in optimising RE – avoid RE curtailment
- **Integrate PSPs in the "Green Corridor" to balance the renewable energy**
  - Study the impact of integration of PSPs in the "Green Corridor" – Balancing storage close to the RE is the ideal condition – since the interconnection between regions are limited/overloaded.
  - Fortunately, most the 7-RE rich states also have the max. potential for PSPs – Maharashtra, Tamil Nadu, Kerala, Karnataka

PUMPED STORAGE: WAY FORWARD

- **Evaluate most sustainable methodology to adopt Pumped Storage Schemes**
  - Off – river (closed loop) Pumped Storage Projects
    - River course is not affected – minimum impact to the river basin
    - Fixed storage can be created depending on requirement – artificial reservoirs eg. Turkey Nest Reservoirs
  - Utilise existing reservoirs
    - There are several projects between the existing reservoirs – a PSP can be set up between them eg. Sheravathy PSP proposed by KPCL
  - Utilise existing reservoir with an artificial reservoir
    - The artificial reservoir could either be the head pond or tail pond depending upon the location
  - Use discarded or deserted mines as tail pool reservoir
    - Presently, the thought is going about to fill using fly-ash or use as land fill

THANK YOU!

CONTACT:

ROHIT UBEROI
VICE PRESIDENT – BUSINESS DEVELOPMENT
ANDRITZ HYDRO PRIVATE LIMITED
A-24/3, MOHAN CO-OPERATIVE INDUSTRIAL ESTATE,
MATHURA ROAD,
NEW DELHI – 110044
INDIA
p: +91 (11) 49372952
m: +91 9910039610

LEGAL DISCLAIMER

National Workshop on "Pumped Storage Hydropower Projects" 8th & 9th Feb 2018

By S.R. Mishra, ED (Tehri Power Complex)
THDC India Ltd, Tehri Garhwal, Uttrakhand

CONTENTS

1. Potential of Pumped Storage hydro capacity in India

2. Current and upcoming pumped storage hydro capacity in India

3. Capacity Addition Plan Of THDC India Ltd, a brief about under construction, 'Pumped Storage Plant' (PSP) Tehri

4. Key issues and challenges, and outlook for the PSP segment

1. Potential of Pumped Storage hydro capacity in India.

FOCUS ON PUMPED STORAGE PROJECTS

1. Probable installed capacity of pumped storage plants(PSP) in India is 96524 mw

2. There are 63 identified sites in all the five regions of the country.

3. Above potential is excluding the schemes that could be taken up on the existing reservoirs and the proposed schemes on small stream/Nallah.

FOCUS ON PUMPED STORAGE PROJECTS

Name of the region	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Northern	13065(7)	0	1000 (1) Tehri
Western	39684(29)	1840(4)	80 (1) Koyana
Southern	17750(10)	2005.6 (3)	0
Eastern	9125(7)	940 (2)	0
North Eastern	16900(10)	0	0
Total	96524(63)	4785.6 (9)	1080 (2)

FOCUS ON PUMPED STORAGE PROJECTS
Northern Region

State	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Jammu & Kashmir	1650(1)	0	0
Himachal Pradesh	3600(2)	0	0
Uttarakhand	4035(2)	0	1000 (1)
Rajasthan	3780(2)	0	0
Total	13065(7)	0	1000 (1)

FOCUS ON PUMPED STORAGE PROJECTS

Western Region

State	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Madhya Pradesh	6150 (4)	0	0
Chhattisgarh	5000 (3)	0	0
Maharashtra	27094 (20)	400 (2)	80 (1)
Gujarat	1440 (2)	1440 (2)	0
Total	39684 (29)	1840 (4)	80 (1)

FOCUS ON PUMPED STORAGE PROJECTS
Southern Region

State	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Andhra Pradesh & Telangana	2350 (2)	1605.6 (2)	0
Karnataka	7900 (4)	0	0
Kerala	4400 (2)	0	0
Tamil Nadu	3100 (2)	400 (1)	0
Total	17750 (10)	2005.6 (3)	0

FOCUS ON PUMPED STORAGE PROJECTS
Eastern Region

State	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Jharkhand	2800 (1)	0	0
Odisha	2500 (1)	0	0
West Bengal	3825 (4)	940(2)	0
Total	9125 (6)	940 (2)	0

FOCUS ON PUMPED STORAGE PROJECTS

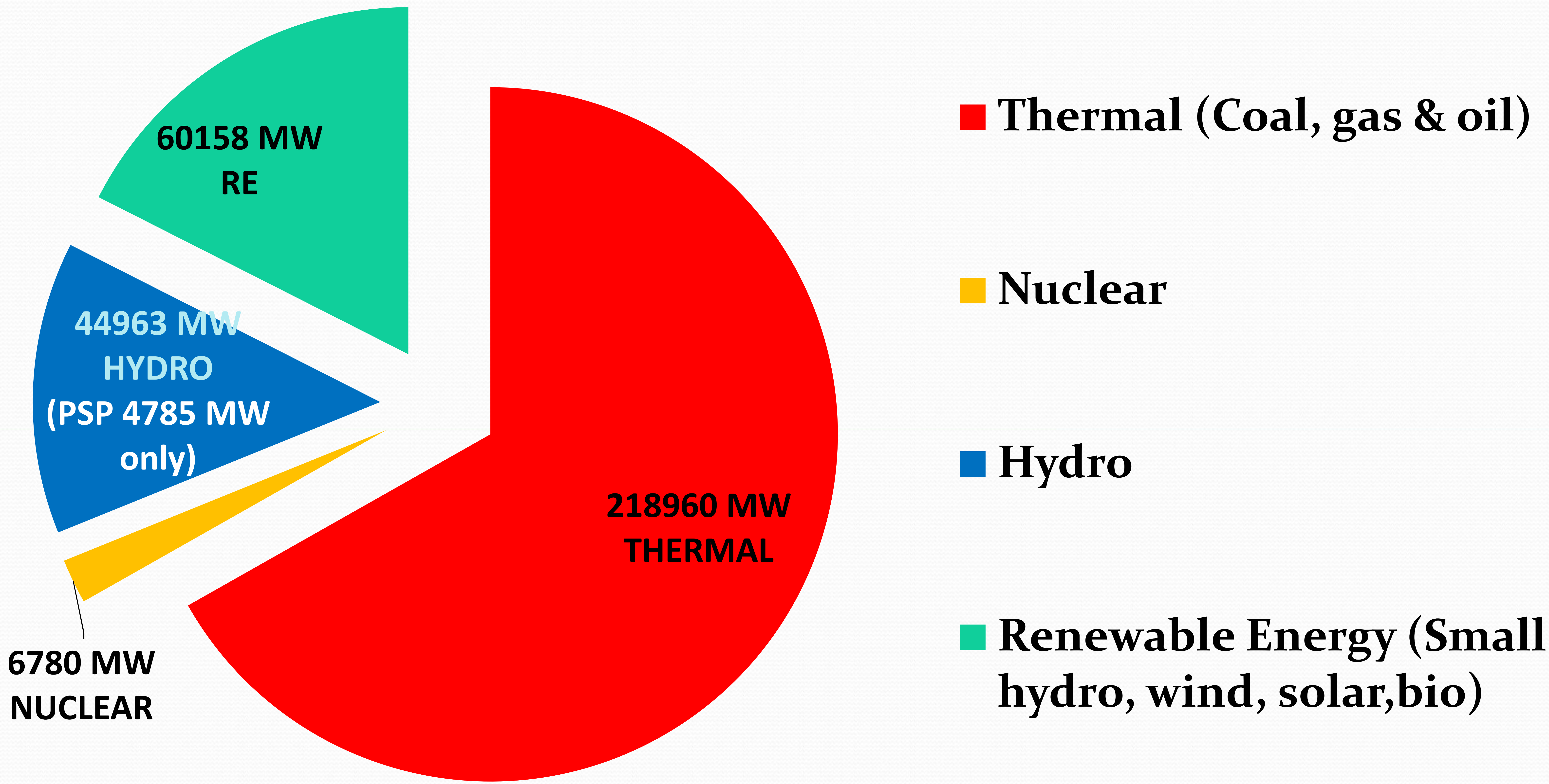
North Eastern Region

State	Potential for Pumped Storage Hydro power plants in MW (No of sites)	Capacity already developed in MW (No of Projects)	Capacity under development in MW (No of projects)
Manipur	4350 (2)	0	0
Assam	2100 (1)	0	0
Mizoram	10450 (7)	0	0
Total	16900 (10)	0	0

2. Current and upcoming Pumped Storage hydro capacity in India.

Installed capacity (MW) in India up to Nov'17 (330861)

COURTESY CEA



FOCUS ON PUMPED STORAGE PROJECTS

EXISTING PUMPED STORAGE PLANTS IN INDIA

1. SARDAR SAROVAR (GUJARAT)	1200 MW
2. SRISAILAM (TELANGANA)	900 MW
3. PURULIA (WEST BENGAL)	900 MW
4. NAGARJUN SAGAR (TELANGANA)	705.6 MW
5. KADAMPARAI (TAMILNADU)	400 MW
6. KADANA St I&II (GUJARAT)	240 MW
7. GHATGHAR (MAHARASTRA)	250 MW
8. BHIRA (MAHARASTRA)	150 MW
9. PANCHET HILL (DVC)	40 MW
TOTAL CAPACITY	4785.6 MW

FOCUS ON PUMPED STORAGE PROJECTS

OUT OF 9 EXISTING PUMPED STORAGE PLANT IN INDIA FOLLOWING 5 PLANTS ARE OPERATIONAL IN PUMPING MODE

➢ SRISAILAM LBPH (TELANGANA)	900 MW
➢ PURULIA (WEST BENGAL)	900 MW
➢ KADAMPARAI (TAMILNADU)	400 MW
➢ GHATGHAR (MAHARASTRA)	250 MW
➢ BHIRA (MAHARASTRA)	150 MW
TOTAL CAPACITY	2600 MW

FOCUS ON PUMPED STORAGE PROJECTS

OUT OF 9 EXISTING PUMPED STORAGE PLANT IN INDIA

FOLLOWING 4 PLANTS ARE NOT OPERATIONAL IN PUMPING MODE

1. **SARDAR SAROVAR (GUJARAT)** (TAIL POOL DAM UNDER CONSTRUCTION)	**1200 MW**
2. **NAGARJUN SAGAR (TELANGANA)** (TAIL POOL DAM NOT CONSTRUCTED)	**705.6 MW**
3. **KADANA St I&II (GUJARAT)** (TURBINE VIBRATION PROBLEM)	**240 MW**
4. **PANCHET HILL (DVC)** (TAIL POOL DAM NOT CONSTRUCTED)	**40 MW**
TOTAL CAPACITY	**2185.6 MW**

FOCUS ON PUMPED STORAGE PROJECTS

UPCOMING PUMPED STORAGE PLANTS IN DIFFERENT STAGE OF DEVELOPMENT

S.N	NAME OF PROJECT	STATE OF LOCATION	INSTALLED CAPACITY (MW)	AGENCY	PRESENT STATUS
1.	TEHRI PSP	UTTARAKHAND	1000	THDC INDIA LTD	UNDER CONSTRUCTION COMMISSIONING DEC 2020
2.	KOYANA LEFT BANK	MAHARASTRA	80	GoMWRD	UNDER CONSTRUCTION COMMISSIONING 2018-19
3.	KUNDAH	TAMIL NADU	500	TANGEDCO	DPR PREPARED, PROJECT TAKEN UP
4.	TURGA	WEST BENGAL	1000	WBSEDCL	DPR CONCURRED BY CEA
5.	MALSHEJ GHAT	MAHARASHTRA	700	THDC & NPCIL	DPR PREPARED BY THDC INDIA LTD

FOCUS ON PUMPED STORAGE PROJECTS

UPCOMING PUMPED STORAGE PLANTS IN DIFFERENT STAGE OF DEVELOPMENT

S.N	NAME OF PROJECT	STATE OF LOCATION	INSTALLED CAPACITY (MW)	AGENCY	PRESENT STATUS
6	LUGUPAHAR	JHARKHAND	2800	DVC	UNDER S&I TO BE TAKEN UP
7.	HUMBARLI	MAHARASHTRA	400	THDC & NPCIL	UNDER SURVEY AND INVESTIGATION
8.	WARASGAON	MAHARASHTRA	1200	GoMWRD	UNDER SURVEY AND INVESTIGATION
9.	CHIKHALDARA	MAHARASHTRA	400	GoMWRD	UNDER SURVEY AND INVESTIGATION
10.	SHARAVATHY	KARNATAKA	450	KPCL	UNDER SURVEY AND INVESTIGATION

FOCUS ON PUMPED STORAGE PROJECTS

UPCOMING PUMPED STORAGE PLANTS IN DIFFERENT STAGE OF DEVELOPMENT

S.N	NAME OF PROJECT	STATE OF LOCATION	INSTALLED CAPACITY (MW)	AGENCY	PRESENT STATUS
11.	SHOLAYAR-I	KERALA	810	KSEB	UNDER S&I TO BE TAKEN UP
12.	SHOLAYAR-II	KERALA	390	KSEB	UNDER SURVEY AND INVESTIGATION
13.	PORINGAL KUTHU	KERALA	80	KSEB	UNDER SURVEY AND INVESTIGATION
14.	VARAHI	KARNATAKA	700	KPCL	UNDER SURVEY AND INVESTIGATION
	TOTAL		10510		

3. Capacity Addition Plan Of THDC India Ltd, a brief about under construction, 'Pumped Storage Plant' (PSP) Tehri.

THDC India Ltd

- THDC India Ltd is a joint venture of Govt. of India and Govt. of Uttar Pradesh incorporated in July 1988.
- Equity is shared in a ratio of 75:25 between GoI and GoUP.
- The company has an authorized share capital of Rs 4000 crores.
- THDC India Ltd is a Mini Ratna Category-I and Schedule-A CPSE under Ministry of Power, Govt. of India .

THDC INDIA LIMITED
(A Joint Venture of Govt. of India & Govt. of U.P.)

THDC India Ltd

Vision

- A world class energy entity with commitment to environment and social values.

Mission

- To plan, develop and operate energy resource efficiently.
- To adopt state of the art technologies.
- To achieve performance excellence by fostering work ethos of learning and innovation
- To build sustainable value based relationship with stakeholders through mutual trust
- To undertake Rehabilitation and Resettlement of project affected persons with human face.

THDC INDIA LIMITED - CAPACITY ADDITION PLAN

- With the commissioning of **Tehri Dam & HPP (1000 MW)** in 2006-07 and **Koteshwar HEP (400 MW)** in 2011-12, THDCIL has contributed 1000 MW and 400 MW of capacity addition during X and XI Plan respectively.

- With the commissioning of **50 MW Wind Power** Plant at Patan, 63 MW Wind Power Project at Dwarka, Gujarat, THDCIL has added 113 MW capacity during XII Plan. Total Installed Capacity of THDCIL at the end of XII Plan is **1513 MW**.

THDC INDIA LIMITED - CAPACITY ADDITION PLAN

THDC proposes to add 3918 MW during 2017-2022 in the Capacity Addition Programme of MOP with the planned commissioning of following Projects:

- Tehri PSP - 1000 MW
- Vishnugad Pipalkoti HEP - 444 MW
- Dhukwan SHP - 24 MW
- Khurja STPP - 1320 MW
- Bunakha HEP - 180 MW
- Malshej Ghat PSP - 700 MW
- Solar Energy Projects - 250 MW

- TOTAL - 3918 MW

THDC INDIA LIMITED - CAPACITY ADDITION PLAN

- Total Installed Capacity of THDC INDIA Ltd by March'2022 is proposed to be 5431 MW.

- THDCIL is also exploring possibilities of development of Hydro Electric and Pumped Storages Schemes in other states viz. Chhattisgarh, Orissa etc and neighboring countries viz. Bhutan, Nepal etc.

- THDCIL is also providing specialized consultancy services in the Hydro Power Sector and other Engineering Works.

A brief about the under construction, 1000 MW ‘Pumped Storage Plant' (PSP) Tehri.

LOCATION OF TEHRI PSP

- It is located in Tehri Garhwal district of Uttarakhand in India, on river Bhagirathi, about 1.5 km downstream of its confluence with river Bhilangana.
- Nearest Railway Station : Rishikesh, 82 km
- Nearest Airport : Dehradun, 110 Km

Tehri Power Complex

Tehri Power complex (2400MW) comprises:-

- **i) Tehri HPP (1000MW) (2006-07)**
- **ii) Koteshwar HEP (400MW) (2011-12)**
- **iii) Tehri PSP (1000MW) (Dec 2020)**

(First pumped storage plant in central sector of the country)

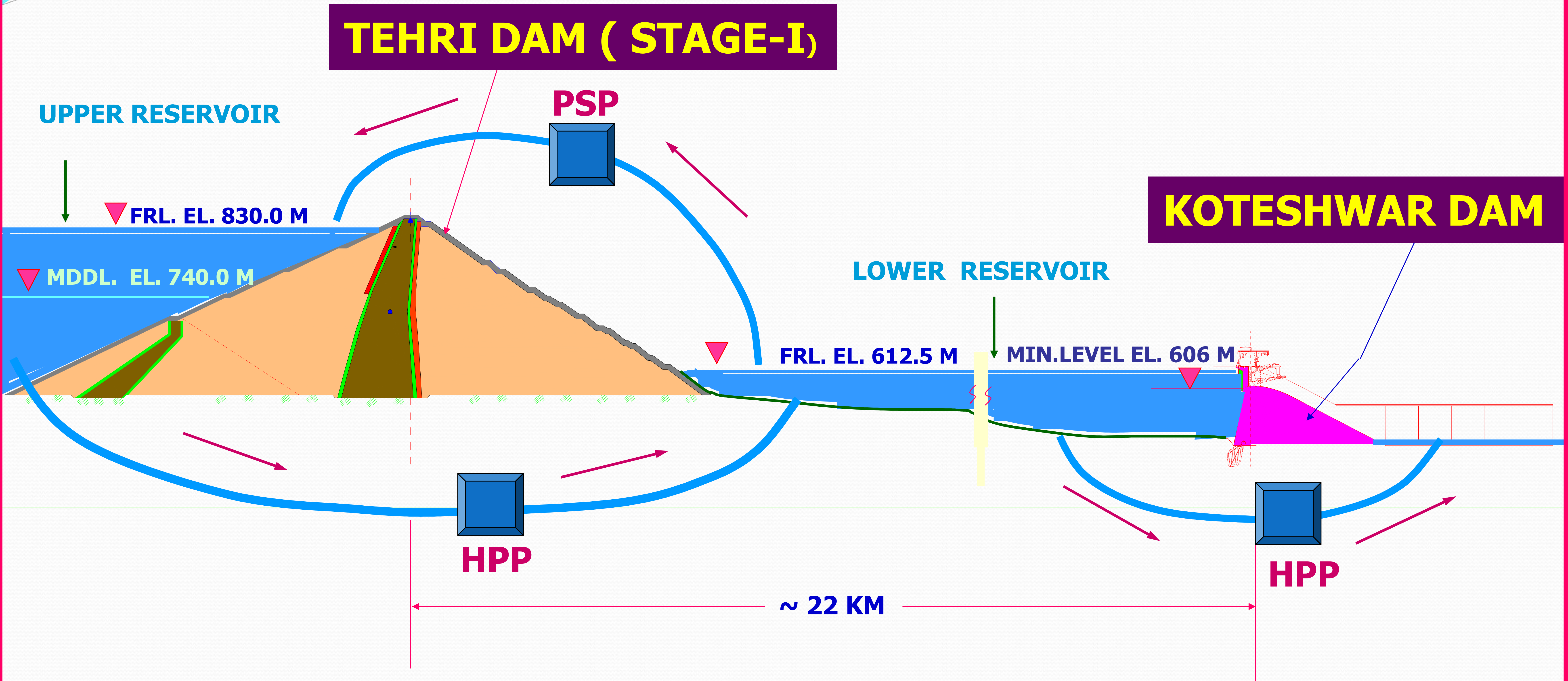
CONCEPT BEHIND TEHRI PSP

- The operation of Tehri PSP is based on the concept of recycling of water discharged between upper reservoir and lower reservoir.

- Tehri Dam reservoir shall function as the upper reservoir.

- Koteshwar reservoir as the lower balancing reservoir.

TEHRI PROJECT: L-Section

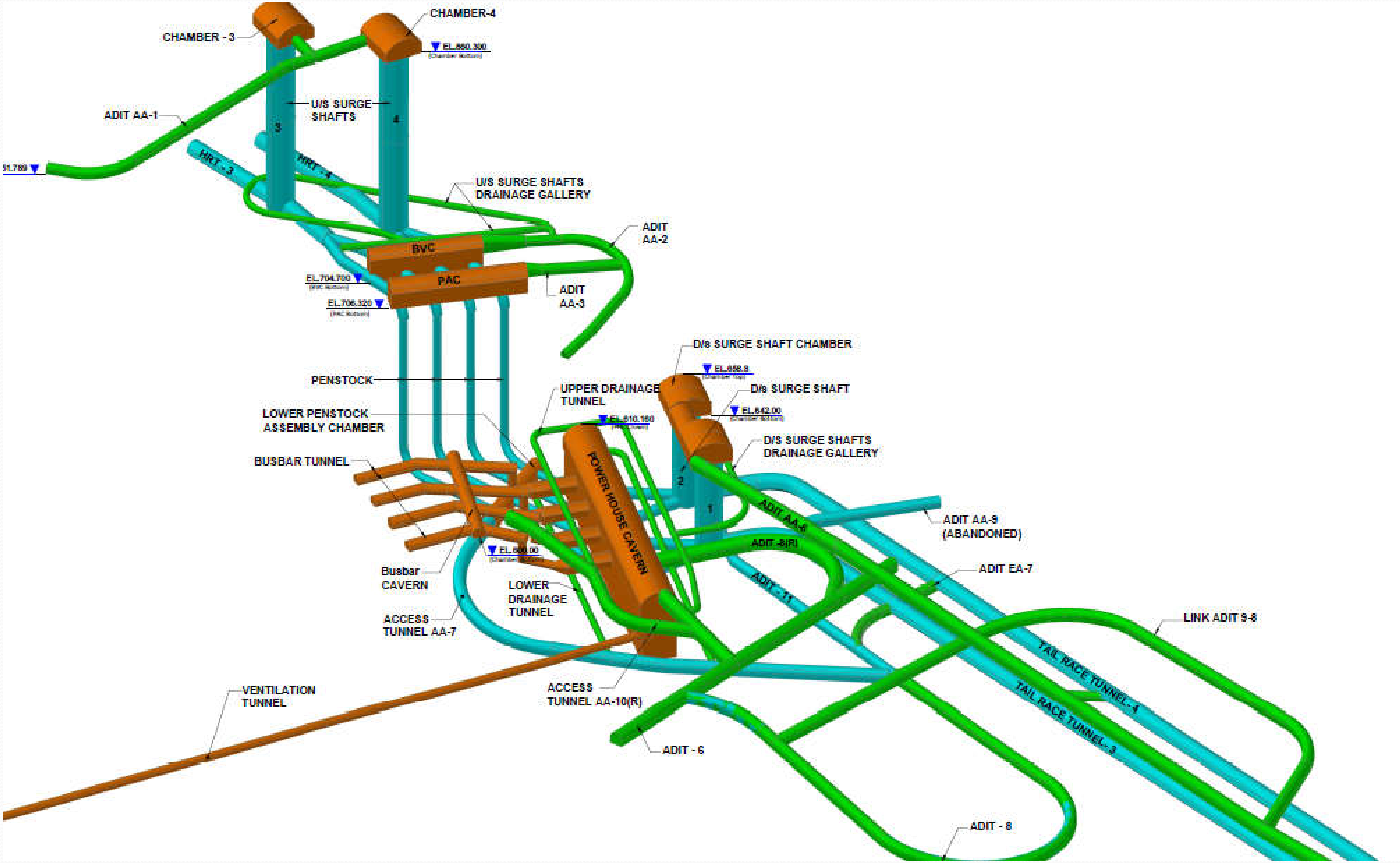


L-SECTION OF UPPER AND LOWER RESERVOIR OF TEHRI PSP

OPERATION OF TEHRI PSP

- 90 m head variation from max to min head
- For pumping operation of reversible units during off-peak hours, the energy requirement will be of the order of 1600 MU limited to maximum of 1000 MW during off-peak hours
- PPA has been done with four states Delhi (600MW), Haryana(100MW), Uttarakhand (200MW) and Rajasthan(100MW) to get power in off peak hours.

3D LAYOUT OF TEHRI PSP



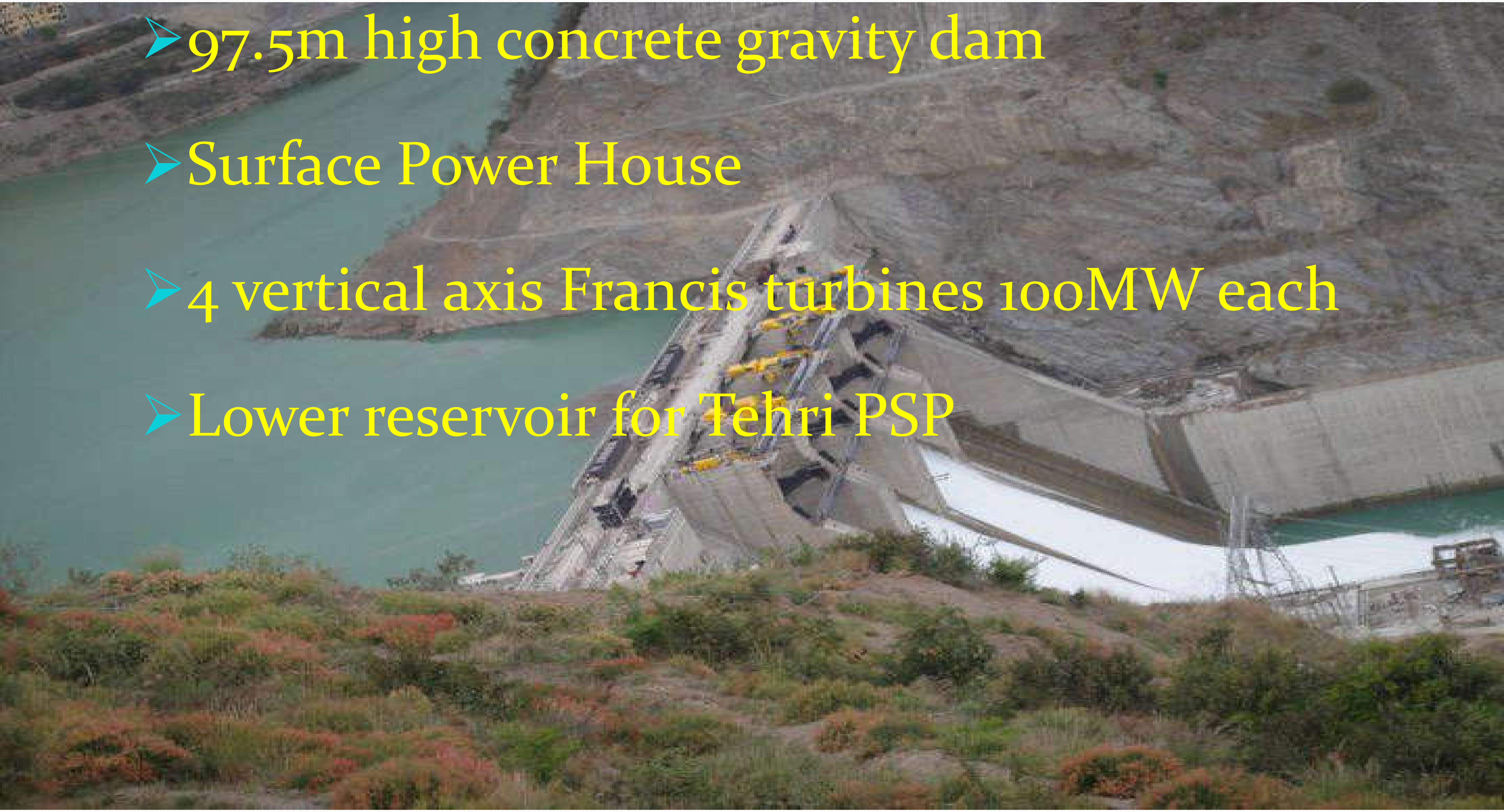
WORKING OF TEHRI PSP

PUMPED STORAGE PLANT -1000 MW
CROSS SECTION THROUGH WATER WAY

TEHRI UPPER RESERVOIR AND TEHRI HPP POWER HOUSE

- 260.5m high earthen rock fill dam
- Under ground Power House
- 4 vertical axis Francis turbines 250MW each
- Spillway System designed for PMF of 15,540 cumecs
- Upper reservoir for Tehri PSP

LOWER RESERVOIR & KOTESHWAR HEP



- 97.5m high concrete gravity dam
- Surface Power House
- 4 vertical axis Francis turbines 100MW each
- Lower reservoir for Tehri PSP

TEHRI PUMPED STORAGE PLANT(4X250MW)

SALIENT FEATURES:

1.	Upstream Reservoir		Tehri Dam Reservoir (Already commissioned)
2.	Downstream Reservoir		Koteshwar Dam Reservoir (Already commissioned)
3.	Head Water Levels		
		Maximum	830 m
		Minimum	740 m
4.	Head Race Tunnels		Two Nos concrete lined HRTs (HRT-3 & HRT-4) Already constructed.
		Diameter	8.5 M
		Length HRT-3	932 m
		Length HRT–4	1060 m

TEHRI PUMPED STORAGE PLANT(4X250MW)

5.	Upstream Surge Shaft		
		Location Type	End of HRT Restricted Orifice
		Numbers	02 Nos.
		Diameter	20.92 m
		Penstock Bifurcation	At the base of surge shaft
6.	**Penstocks**		
		Numbers	04
		Diameter	6.0 m
		Type	Steel lined

TEHRI PUMPED STORAGE PLANT(4X250MW)

7.	**Power House**		
		Type	Underground
		Size of Machine hall	
		Max. width	25.0 m
		Height	55 m
		Length	203 m
		Location	Left Bank
		Rated unit capacity	250 MW
		Installed capacity	1000 MW
		Number of units	04 nos.
		Type of Machine	Variable speed vertical Francis type reversible Turbine.
		Turbine Net Head Range	120.4m to 219.4 m
		Pump delivery Head Range	130.5m to 229.5 m
		Design Head	188 m
		Rotational Speed	Variable speed

TEHRI PUMPED STORAGE PLANT(4X250MW)

8.	**Output**		
		-Nominal value	278 MVA
		-Maximum capacity	306 MVA
		Rated electrical power output	250 MW at about 188m WC of rated net Head
9.	**Downstream Surge Shaft**		
		Numbers	02
		Diameter	18.44 m
		Height	Approx. 80 m
10.	**Tail Race Tunnels**		
		Numbers	02
		Diameter	9.1 m
		Length	
		TRT-3	1151.00 m
		TRT-4	1255.00 m
11.	**Tail Water Levels**		
		Maximum	612.5 m
		Minimum (in pump mode)	606 m
		Minimum (in turbine mode)	603 m
		Average	609.5 m

BENEFITS FROM TEHRI PSP

- **1000 MW, peaking power, will be added to the Northern Region**

- **Annual generation of 1268 million units**

- **Stabilization of Grid (load balancing)**

AWARD OF MAJOR WORKS

- **Under Single EPC Contract**

- **Consortium of GE Hydro France(formerly Alstom Hydro-France) Hindustan Construction Co. Ltd. and GE Power India Ltd (formerly Alstom India Ltd)**

- **Awarded on 23.07.2011**

MAJOR STRUCTURE – EPC CONTRACT

- **Balance Works of Head Race Tunnel (HRT-3 & 4)**
- **Butterfly Valve Chamber**
- **Penstock Assembly Chamber & 04 nos. Penstocks**
- **Four Surge Shafts- Two upstream & two downstream**
- **Machine Hall**
- **Bus bar cavern and 04 no. bus bar galleries**
- **Tail Race Tunnels (TRT-3 & 4) & Outlet Structure**

CONSTRUCTION DETAILS

(A) UNDERGROUND EXCAVATION:

- UNDER GROUND EXCAVATION AT THE PROJECT IS BEING DONE WITH DRILLING BLASTING METHOD.
- TOTAL EIGHT BOOMERS (WITH TWO BOOMS) ARE BEING USED FOR DRILLING AT TEHRI PSP.

CONSTRUCTION DETAILS

(B) STABILIZATION MEASURES

As Per Site Requirement Following Stabilization Measures Are Being Taken At Tehri Psp

1. 25/32/36 mm DIA ROCK BOLTS/ANCHORS
2. Cable anchors
3. Structural steel supports
4. Shotcrete with wire mesh
5. Steel fibres reinforced shotcrete
6. Lattice girders with self drilling anchors/forepoles

CONSTRUCTION DETAILS

(C) CONCRETE WORK

1. **CEMENT**: OPC-43 grade and OPC 53 grade
2. **FINE AGGREGATE**: Grading zone-II & III
3. **COARSE AGGREGATE**: MAX SIZE OF 40m
4. **CONCRETE** : Grade between m15 and m40
5. **SUPER PLASTICIZERS**: To have economy and better workability concrete mixes have been designed with super plasticizers

FINANCIAL STATUS

W.r.t. to Contract Value

Sl. No.	Contract/Value	Present status till Jan'18	% completion
	Overall EPC Contract: (INR : 1843.49 Crs.)	1101.71 Crs.	59.76%
1.	PDE Contract : INR : 39.54 Crs. (EURO 5125765+INR 65740936)	20.78 Crs.	52.57%
2.	Civil Work Contract : (INR : 661.47 Crs)	375.00 Crs.	56.69%
3.	Off - Shore components Contract : (Supply of EM & HM Plant & Machinery INR : 532.75 Crs. (EURO : 82841152)	399.48 Crs.	74.98%
4.	On - Shore components Contracts : (Supply of EM & HM Plant & Machinery INR : 524.72 Crs)	291.76 Crs.	55.60%
5.	Transportation - Services Contract : INR: 85.01 Crs. (EURO : 880200 + INR 79.35 Crs)	14.69 Crs.	17.28 %

Power House

Barrier wall in Draft tube

POWER HOUSE –Control room

U/S Surge Shaft Upper Chamber- 3

U/S Surge Shaft Upper Chamber- 4

Butterfly Valve Chamber

Drainage gallery around BVC

Upper Bus Bar 8 : Lining

Lower Bus Bar 8

TRT 3 U/s Overt Reinforcement Works

TRT 3 U/s Overt Concrete Works

TRT- 3 D/s Heading

TRT- 4 D/s Heading

TRT - 4 U/s invert lining

Key issues and challenges, and outlook for the PSP segment

Why do we need power storage?

- In addition to the upcoming Thermal and Hydro power plants Govt of India has planned to install 175 GW capacity from renewable energy sources by the year 2022.
- By 2022 it is expected that total installed capacity (all forms) in the country will be about 535 GW.
- In spite of so high installed capacity , 24x7 power will not be ensured, and grid will not be stable due to variability in the generation
- To ensure 24x7 power supply and to ensure grid stability, storage of power is required which can be used as and when required as per the demand.

How to Store the power?

- **Batteries?** - Not economical in totality, having its limitations, not environment friendly, disposal issues etc.
- **Pumped Storage Plants?** - Yes, This is the most reliable, economical and best available method for storage of electricity

FOCUS ON PUMPED STORAGE PROJECTS

Now, the need of the hour is to implement the Pumped storage plants along with RE segment projects.

But how can we implement it faster ?

To ensure fast implementation of the Pumped Storage Plants following issues need to be addressed-

1. **Land Acquisition/Transfer:** Smooth and time bound transfer of land for the project can be achieved by providing specific clause for such projects in the land acquisition act.

FOCUS ON PUMPED STORAGE PROJECTS

2. **Environment/Forest/Other clearances:** During initial stage of implementation of the project related clearances shall be provided in a time bound manner by the Govt bodies. It can be achieved by setting on-line time bound procedure.

3. **Law and order:** During construction stage project work is stopped on trivial issues very frequently due to ineffective law and order situation towards the hydro projects. It can be made effective through a special task force having special powers for directing state authorities.

4. **Risk Register:** There are contractual disputes and tall claims which hamper the work in the form of time and cost overrun. It can be resolved in a smooth and fast manner by sharing the risks as per the pre defined risk register.

5. **All hydro projects under RE segment :** Govt shall take a decision to bring all hydro projects in the RE segment so that benefits of RE projects could be availed by PSP to make these projects viable.

6. PSP as Grid Asset:

- To make PSP's viable and qualify in merit order dispatch, it shall be treated as Grid Asset because PSP stabilizes the grid as other components.

- A substantial portion of its capital cost (75-80%) shall be subsumed and it shall be recovered through wheeling charges.

- Beneficiaries who provide off- peak power will be returned with peak power after accounting for losses and will have to bear balance 20-25 % of the capital cost.

- This will help DISCOMS to opt for pump storage system which is fully make in India and a green system

PSP Advantages:

- *Mature Technology.*
- *Load balancing in the grid.*
- *Limited impact on the environment.*
- *Service life is very high.*
- *Flexible and fast acting plant.*

Conclusion:

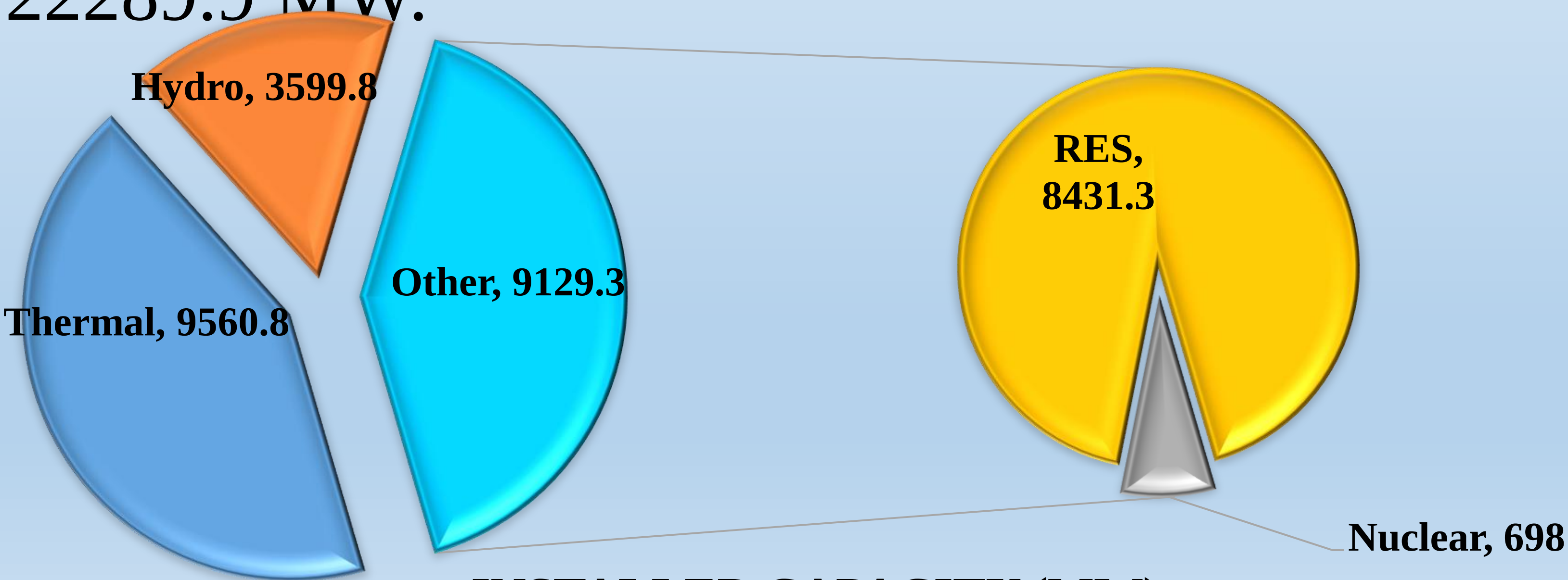
To fulfill the government of India's initiative 24x7 assured power for all and to see our country in the front line of the developed country, pump storage plants is the best available solution in combination with existing installed power projects and upcoming RES power projects with a stability in the grid.


THANK YOU
FOR LISTENING

KARNATAKA POWER CORPORATION LIMITED

Sharavathy Pumped Storage Scheme in State of Karnataka

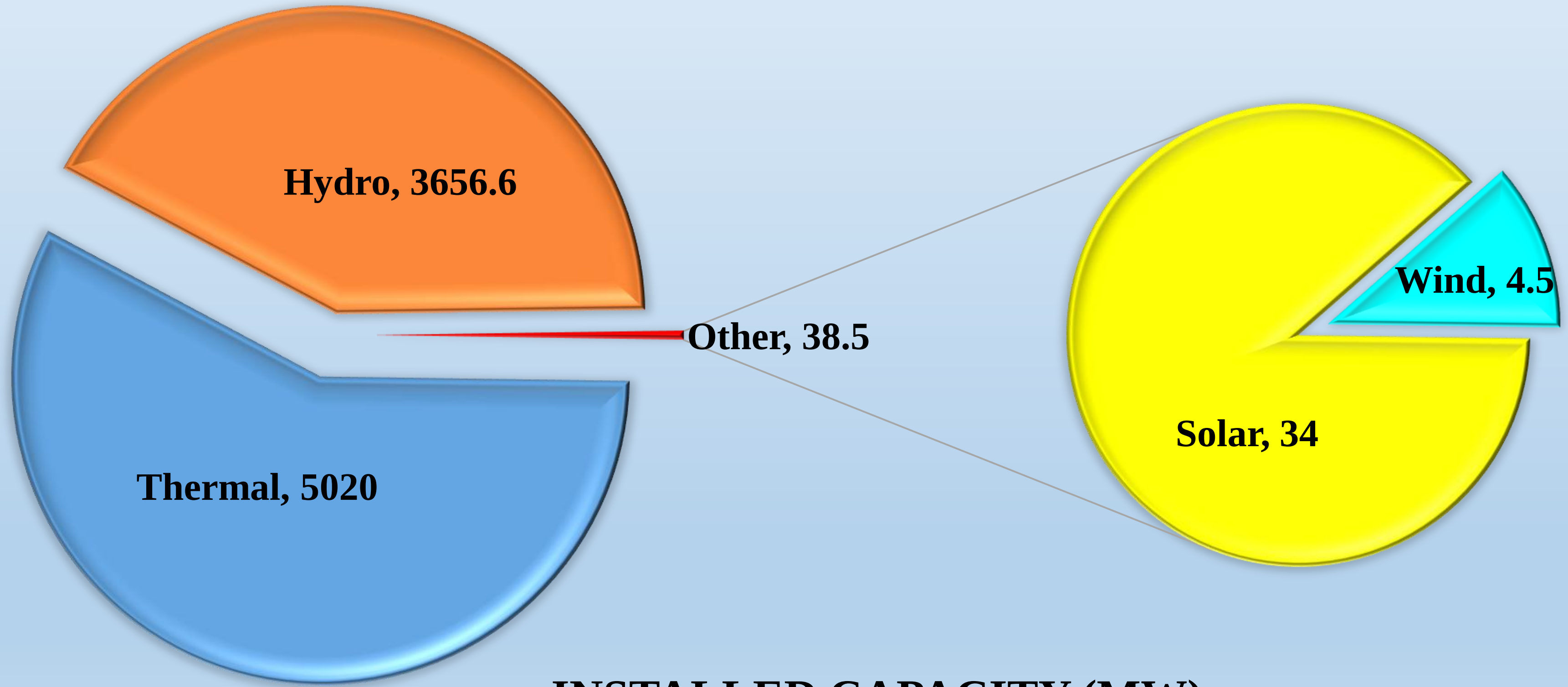
- Karnataka Power Corporation Limited (KPCL), a Government of Karnataka undertaking.
- It is a premier power generating company of Karnataka.
- Total installed capacity in Karnataka State - 22289.9 MW.



INSTALLED CAPACITY (MW)

Source: CEA Dec-2017

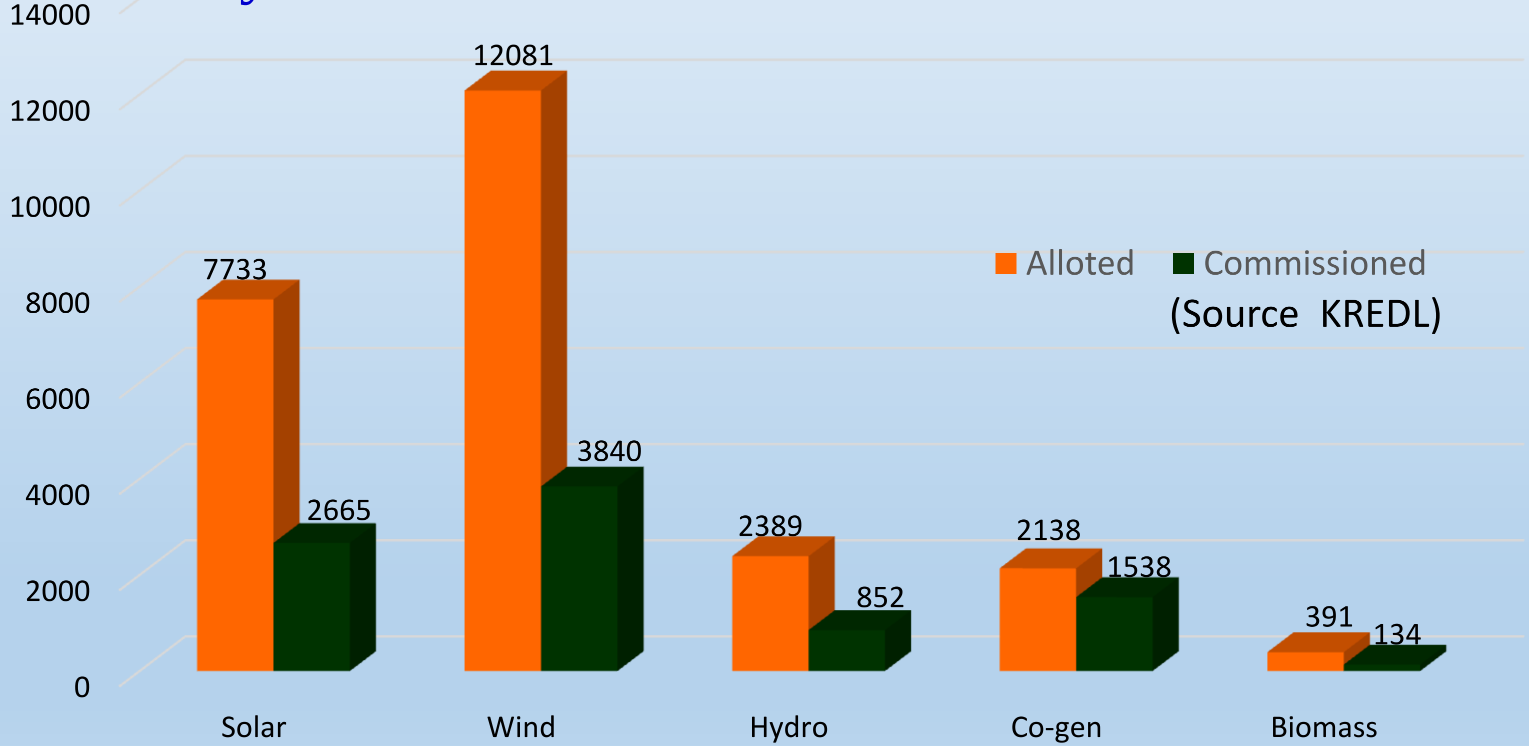
- Total installed capacity of KPCL - 8715 MW.



INSTALLED CAPACITY (MW)

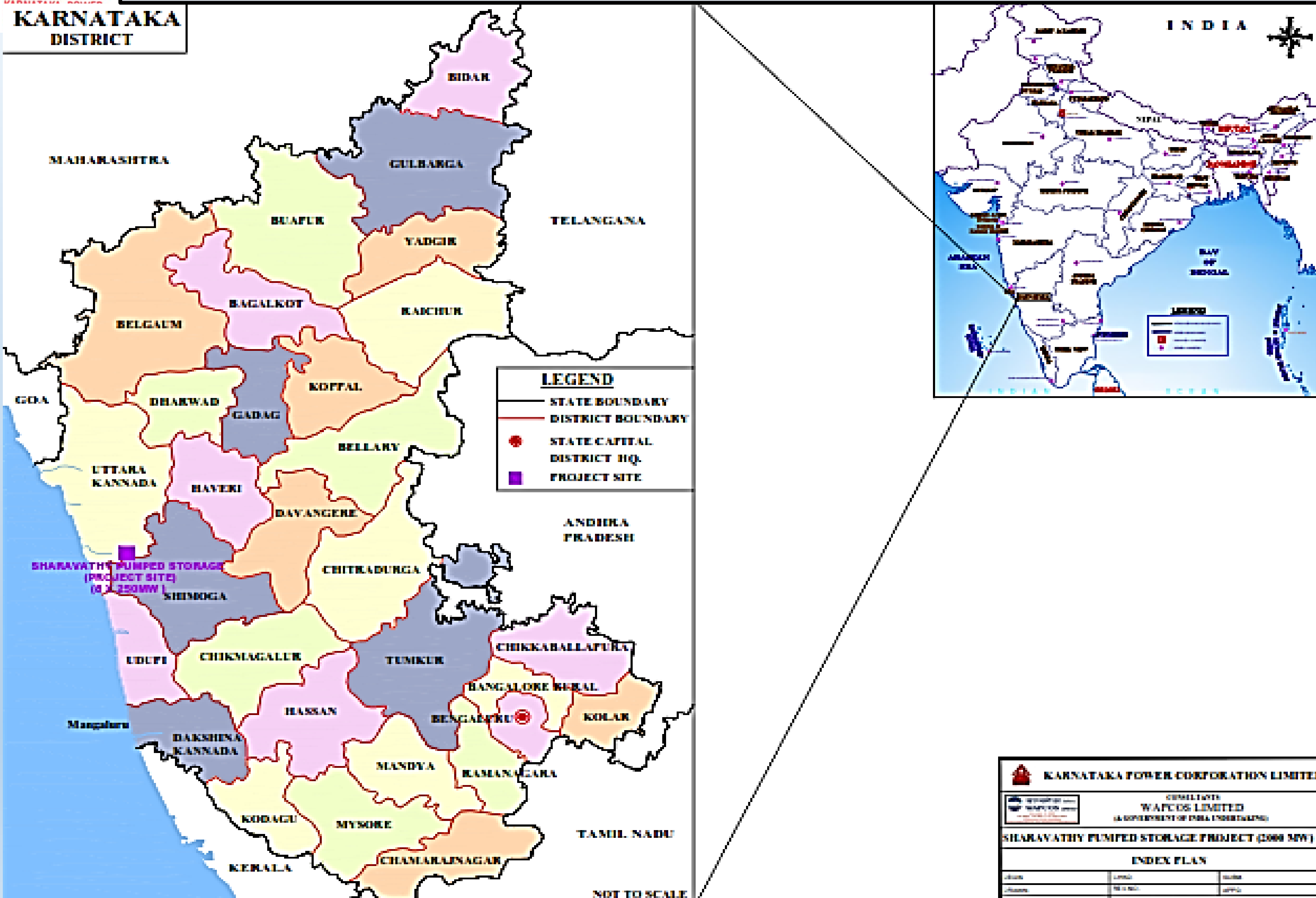
Need for Pumped Storage Scheme in State of Karnataka

- Policy of GoI & GoK- capacity addition in renewable energy sector is encouraged
- Present status of the capacity addition in renewable energy sector as on January 2018 in Karnataka is as follows:

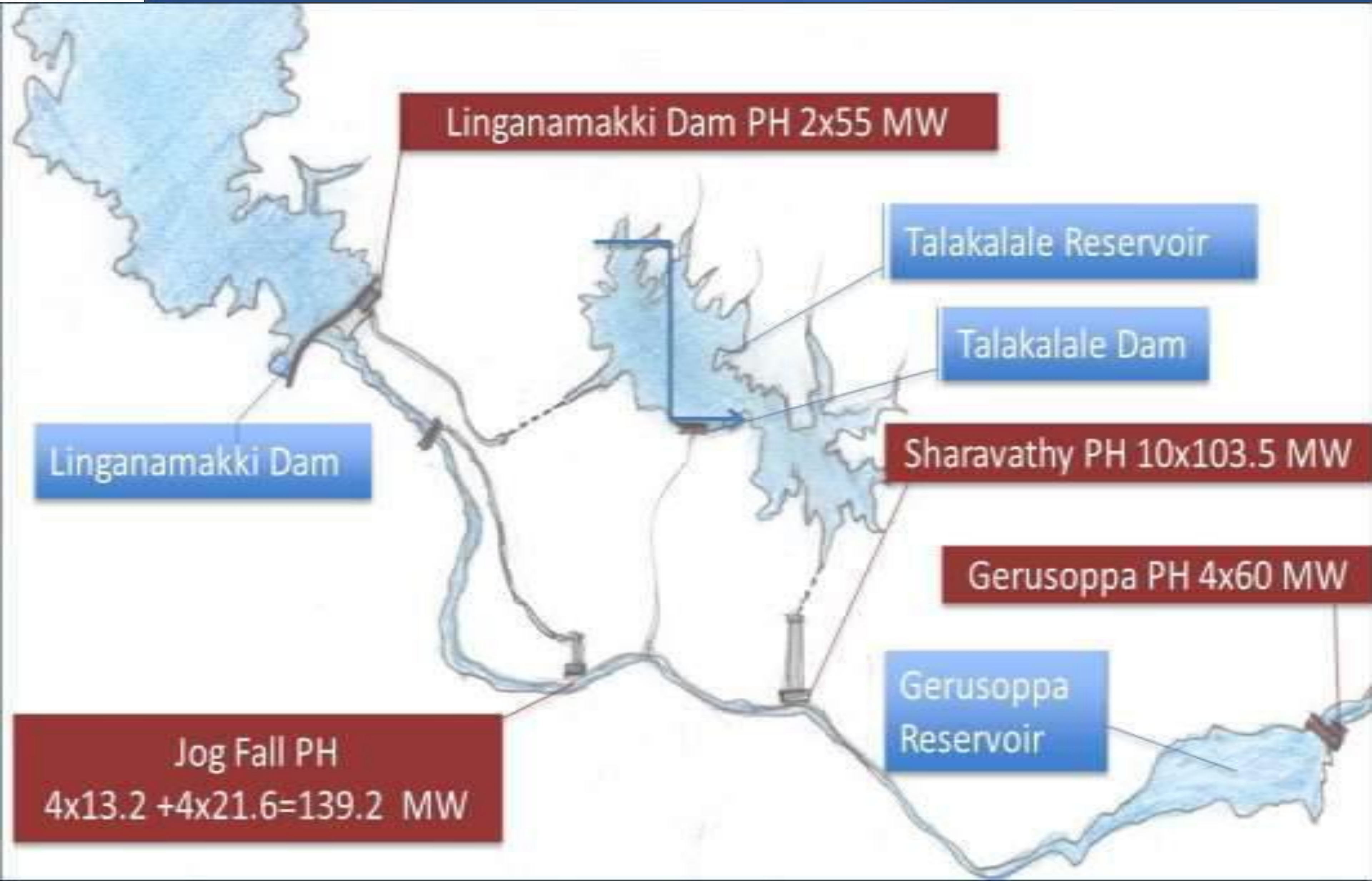


- Total Allotted RE sources : 24732 MW
- Already Commissioned RE Sources : 9029 MW

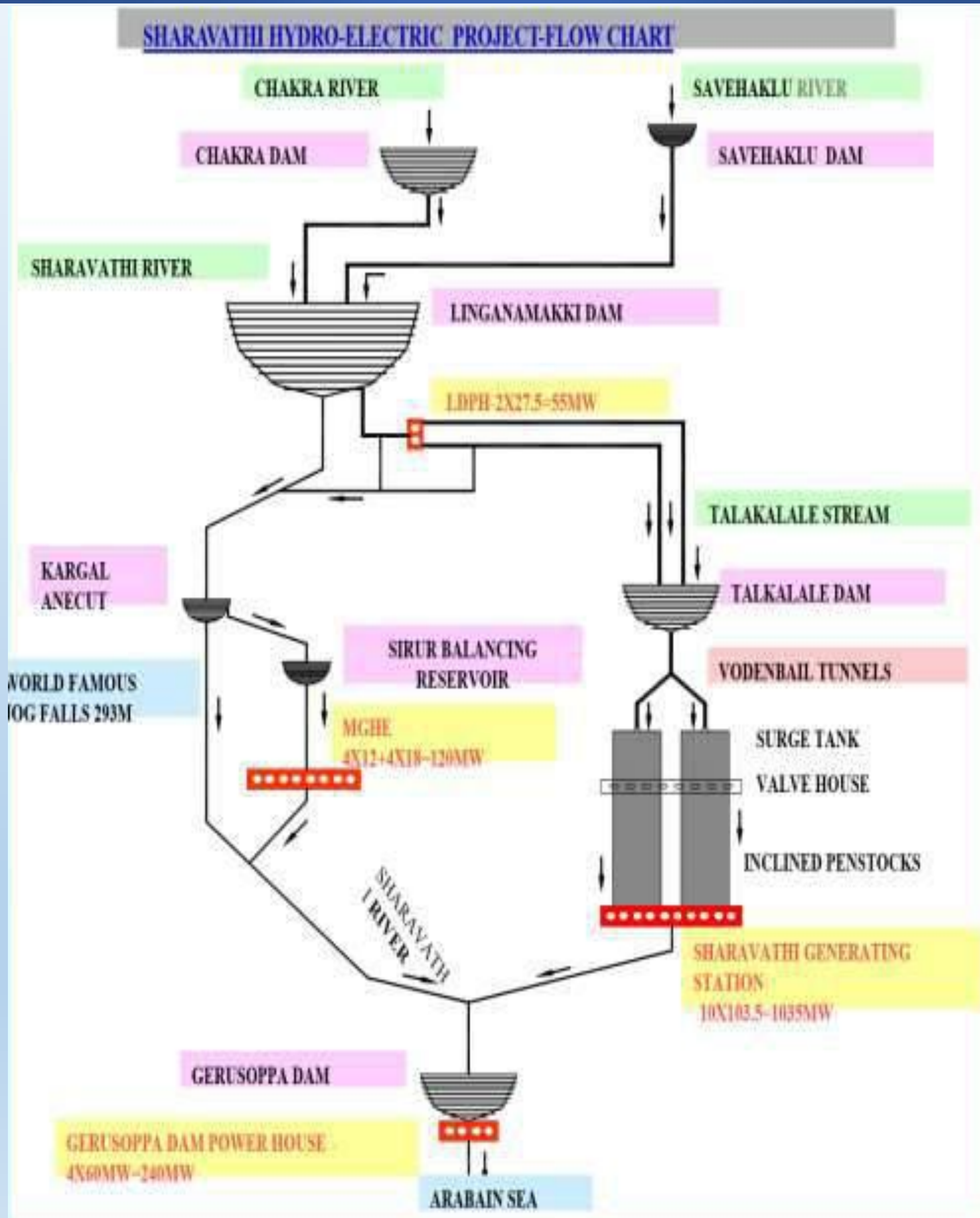
Project Location



Sharavathy Pumped Storage Scheme in State of Karnataka



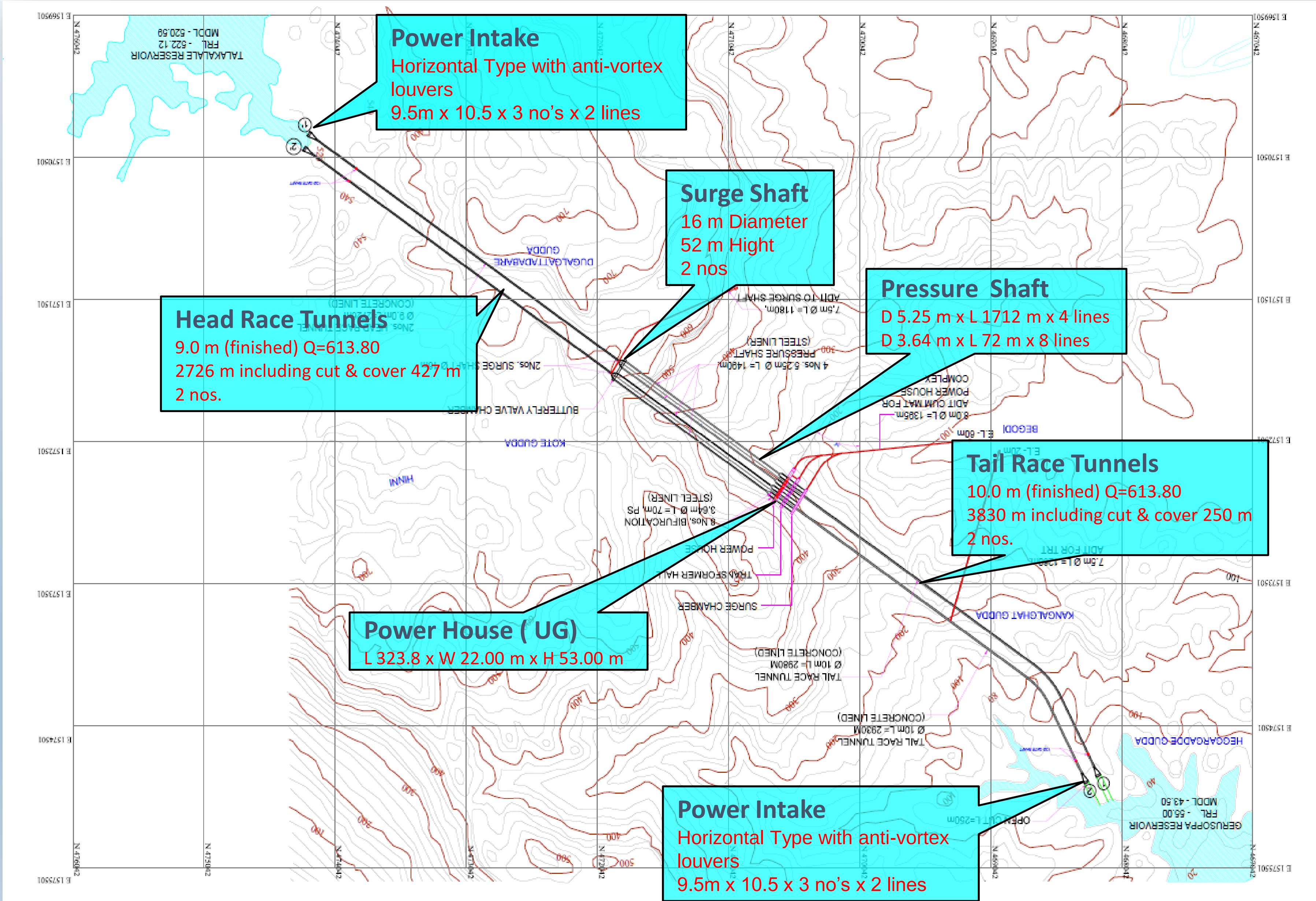
Sharavathy Pumped Storage Scheme in State of Karnataka



Sharavathy Pumped Storage Scheme in State of Karnataka

- The Sharavathy pumped Storage H.E Project is planned between existing Talakalale and Gerusoppa reservoir which are situated at downstream of Liganamakki reservoir on Sharavathy river.
- The present scheme is a very attractive scheme both in terms of technical feasibility and from economical consideration.
- The scheme envisages utilization of the waters of the Sharavathy River released from Linganamakki dam through dam toe Power house by a hydel channel in to Talakalale reservoir, which is a balancing reservoir for existing Sharavathy H.E. project of 1035 MW.
- The proposed pumped scheme envisages power generation on a Pumped storage type development, harnessing a head of about 460+ m between Talakalale as upper reservoir and Gerusoppa as Lower reservoir.

Sharavathy Pumped Storage Scheme in State of Karnataka



Sharavathy Pumped Storage Scheme in State of Karnataka

- The proposed Pumped storage scheme envisages the construction of:
  - 2 (two) No. intake with trash racks having mechanical raking arrangement.
  - 2 (two) No. 2.726 Km long, 9 m diameter circular concrete lined headrace tunnels including cut & cover.
  - 2 (two) No. 0.828 Km long, 5.25m diameter inclined circular steel lined (including horizontal) pressure shafts
  - 2(two) no. 16m dia circular Surge Shafts 52m high.
  - An underground power house having an installation of 8 Francis type reversible pump-turbine driven generating units of 250MW capacity each.
  - 2 (two) no. 3.780 Km & 3.830 Km long concrete lined tail race tunnels to carry the power house releases to lower reservoir.

- The factors influencing the installed capacity of pumped storage scheme at a site are:
  - the requirement of daily peaking hours of operation;
  - operating head,
  - live pondage in the reservoirs
  - and their area capacity characteristics.

Sharavathy Pumped Storage Scheme in State of Karnataka

- The details are summarized below:
  - Installed Capacity (MW) : 2000
  - No of units : 8
  - Unit Size (MW) : 250
  - Head (max)- Generating : 478 m
  - Head (Min)- Generating : 476 m
  - Hours of daily Peaking Operation : 6
  - Energy Generation (MWh) : 12000
  - Pumping Energy (MWh) : 14833
  - Cycle Efficiency : 80.90%

➢ Power Evacuation Arrangement :

- The 2000 MW power generated at 18 kV will be stepped up to 400 kV.
- This power shall be further evacuated by two 400 kV D/C transmission lines (Approx. 60 KM).

- **Estimates of the Cost:**
  - The preliminary cost estimate of the project has been prepared as per guidelines of CEA / CWC.
  - The break down of the cost estimates is given below:

Item Estimated	Cost (Rs. Lacs)
Civil Works	273980.38
Electro-mechanical Works	227764.24
Total	**501744.62**

- **Financial Aspects:**
  - The Sharavathy Pumped Storage extension project, with an estimated cost (Generation only) of Rs. 5017.44 Crores and design peak energy generation of 4380 GWh is proposed to be completed in a period of 5 years.
  - The tariff has been worked out considering a debt-equity ratio of 70:30, and annual interest rate on loan at 12.50%.
  - Tariff: The cost of energy at bus bar as given below:

Sl No	Off peak Energy rate(Rs/kWh)	First year Tariff (Rs/kWh)	Levelized Tariff(Rs/kWh)
1	1	4.38	3.98
2	2	5.73	5.33
3	3	7.07	6.67

- **Present status of the Project:**
  - PFR has been completed.
  - MoEF & CC has issued ToR for conducting EIA & EMP studies and given approval for pre-construction activities.
  - Detailed Survey and Investigations are under progress.
  - Expected date for completion of DPR – Dec 2018

Conclusion & Recommendation:

- The proposed Sharavathy Pumped Storage Project would perhaps be one of the biggest Pumped storage Schemes in the range of 2000 MW in India.
- Dams are existing and the powerhouse complex is underground.
- Sharavathy Pumped Storage Project involves minimum civil works and could be completed in 5 years.
- The cost per MW installed works out as Rs. 2.50 Crores


HEARTY WELCOMES TO
EVERY ONE PRESENT
OVER HERE…

KADAMPARAI POWER HOUSE
4 X 100 MW.

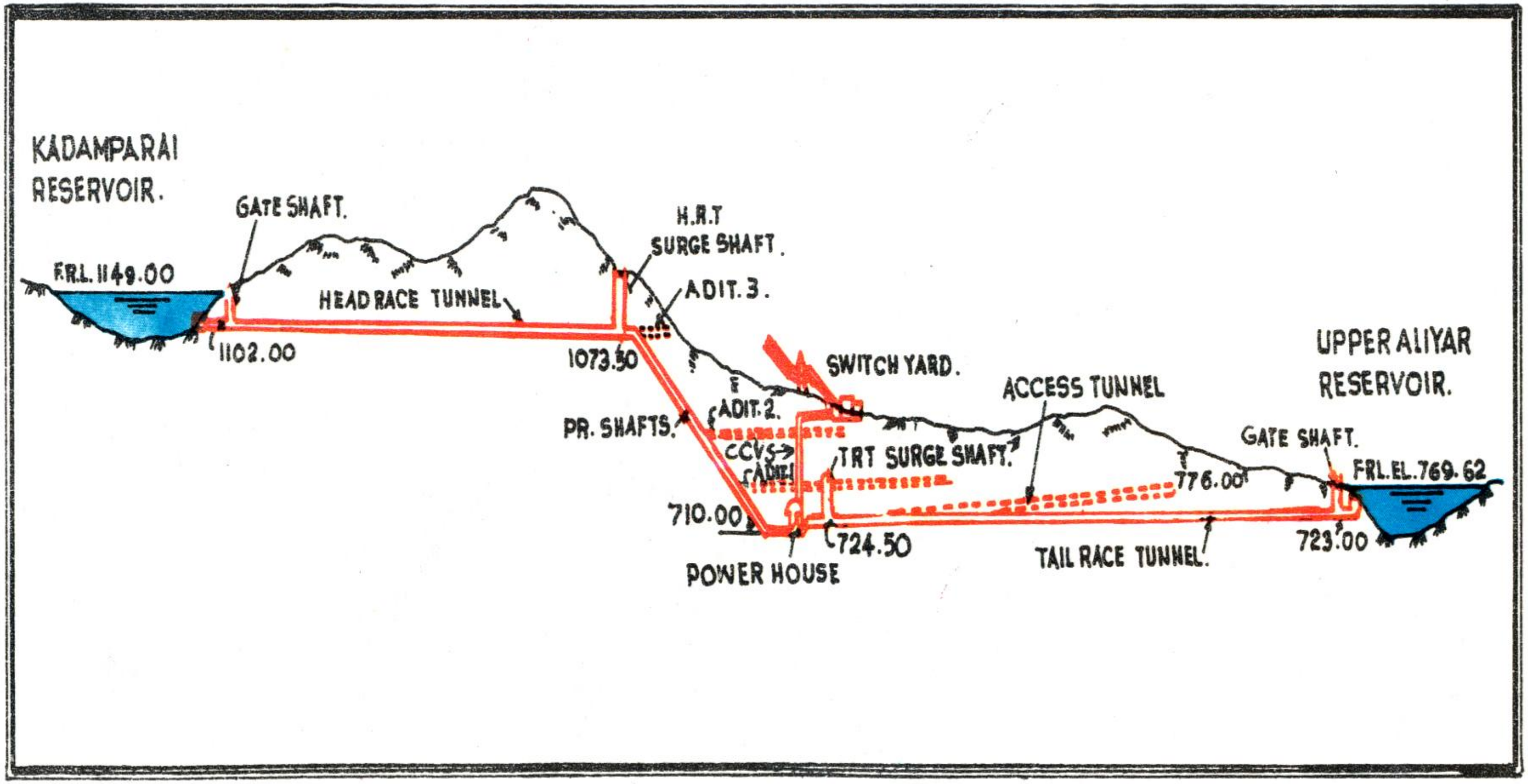
Presentation–by

Er.N.S.Namasivayam,SE/HYDRO-RMU/TANGEDCO,

"Challenges faced in the operation and maintenance of Kadamparai pumped storage POWER HOUSE in the southern regional grid."

KADAMPARAI -"A boon for power availability in the southern grid".

kadamparai pumped storage



KADAMPARAI TO UPPER ALIYAR RESERVOIR — PROFILE

- The first unit (1x100MW) was commissioned on 17.10.1987.Subsequently the other Units were Commissioned on the respective dates.
- Unit II-26.02.1988,
- Unit III – 12.04.1989
- Unit IV- 16.12.1988.
- The capital cost of the Scheme is Rs 18050 Lakhs
- This is the first underground pumped Storage Scheme in Tamil Nadu Electricity Board and the biggest Hydro capacity.

POWERHOUSE Commissioning Particulars

	-
Number & Capacity of the Machine	**4 X 100 MW**
Date of commissioning of Units	1) 17.10.1987
	2) 26.02.1988
	3) 12.04.1989
	4) 16.12.1988

Turbine Operating Parameters

Make of Generator / Turbine	
	UNIT 1 GEC BOVING UNITED KINGDOM
	UNIT 2,3&4 BHEL INDIA
Type of Turbine	Francis Reaction Reversible
HEAD for each Power House	
a)Maximum	1) 395 mts (GENERATOR MODE)
	2) 413 mts (PUMP MODE)
b)Minimum	1) 323 mts (GENERATOR MODE)
	2) 341 mts (PUMP MODE)
Speed of Machine	500 rpm

Generation Capacity of one UNIT

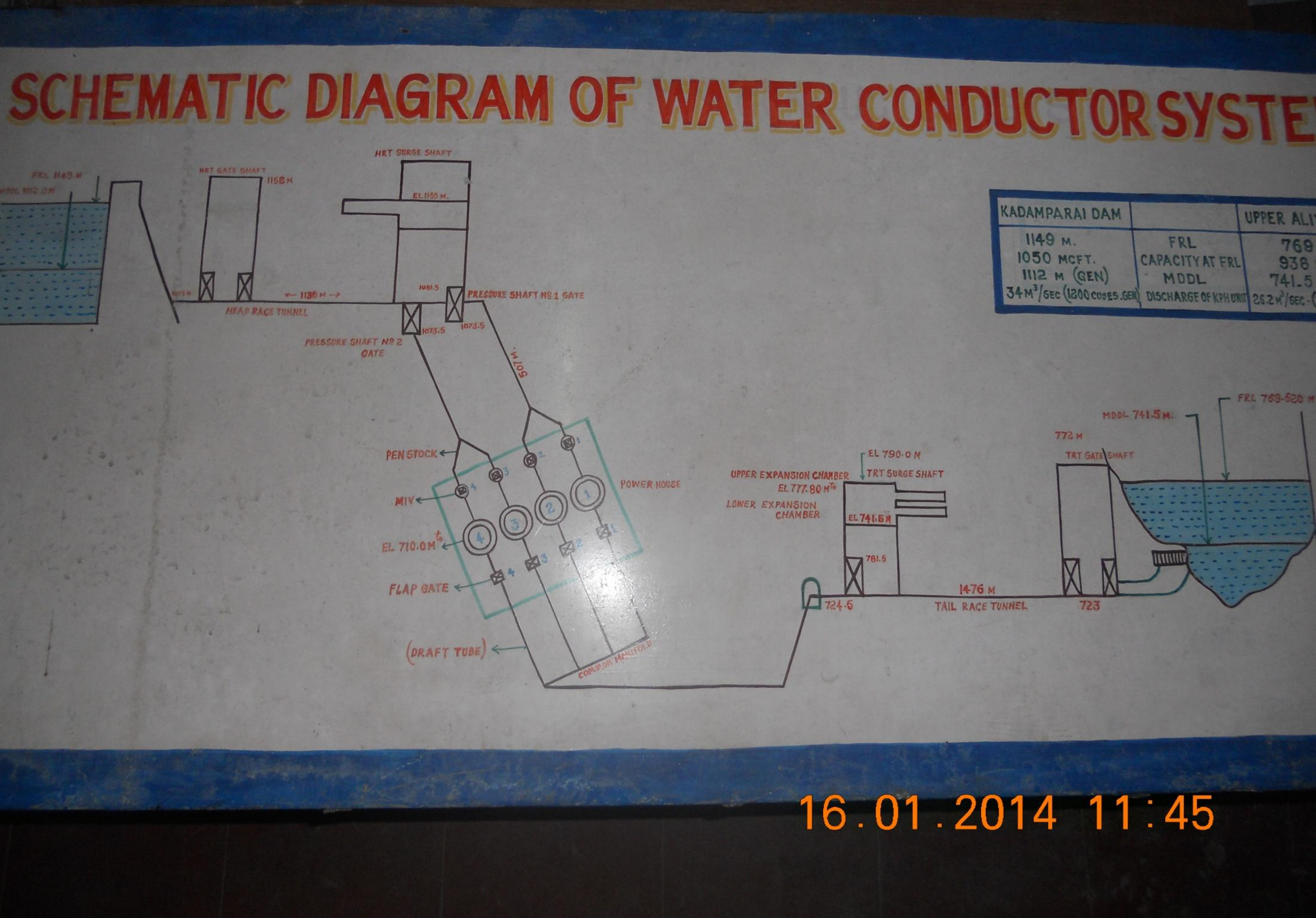
Generation Details	Generation in Lakh Unit	Water discharge in Mcft
Per Unit /Hour Generation @full load (100 MW)	1 Lakh Units	3.7 Mcft
All the four Units run between 18.00 Hrs to 22.00 Hrs (i.e. 04 Hours)	16.00 L.U	59.2 Mcft.
Equivalent water Pumped Details	**Consumption in Lakh Unit**	**Water Stored**
Per Unit/ hour consumption and water stored	1.1 Lakh Units.	3.00 Mcft
If four Units are run as PUMP mode the time required for the above discharge (59.2 Mcft) Pump Running Hours 05 Hrs	22 L.U.	59.2 Mcft

Kadamparai Dam Particulars (Upper Reservoir)

Height of dam in Ft.	221.45
FRL in Ft.	3770
Storage in Mcft.	1089
MDDL in feet	3648
Dead storage in Mcft	140.57

Upper Aliyar Dam (Bottom Reservoir) Particulars

Height of the Dam	**265**
Full Reservoir level in feet	**2525**
Storage in MCft	**937.89**
Dead Storage in MCft	**23.1**
Minimum Draw Down Level for pump operation at 2445 feet and dead storage is 209 MCft at upper Aliyar Dam	



SCHEMATIC DIAGRAM OF WATER CONDUCTOR SYSTE
HRT SURGE SHAFT
HRT GATE SHAFT
1158 M
EL 1160 M.
1081.5
PRESSURE SHAFT Nº 1 GATE
← 1130 M →
HEAD RACE TUNNEL
1073.5
1073.5
PRESSURE SHAFT Nº 2 GATE
507 M.
KADAMPARAI DAM
1149 M.
1050 MCFT.
1112 M (GEN)
34 M3/SEC (1200 CUSES.GEN)
FRL
CAPACITY AT FRL
MDDL
DISCHARGE OF KPH UNIT
UPPER ALI
769
938
741.5
26.2 M3/SEC -
PEN STOCK
MIV
EL 710.0 Mts
FLAP GATE
POWER HOUSE
(DRAFT TUBE)
COMMON MANIFOLD
EL 790.0 M
UPPER EXPANSION CHAMBER
TRT SURGE SHAFT
EL 777.80 Mts
LOWER EXPANSION CHAMBER
EL 741.6 M
781.6
724.6
1476 M
TAIL RACE TUNNEL
723
772 M
TRT GATE SHAFT
MDDL 741.5 M.
FRL 769.620 M
16.01.2014 11:45

Grid frequency prior to 2002

- Grid was operated at lower frequency [i.e between 48.5Hz&49.0Hz for more times till 2002 and less surplus power was available during off peak time.

- Surplus power was available in the grid during National holidays,& on Sundays by which time two or three units were utilized as pump at Kadamparai.

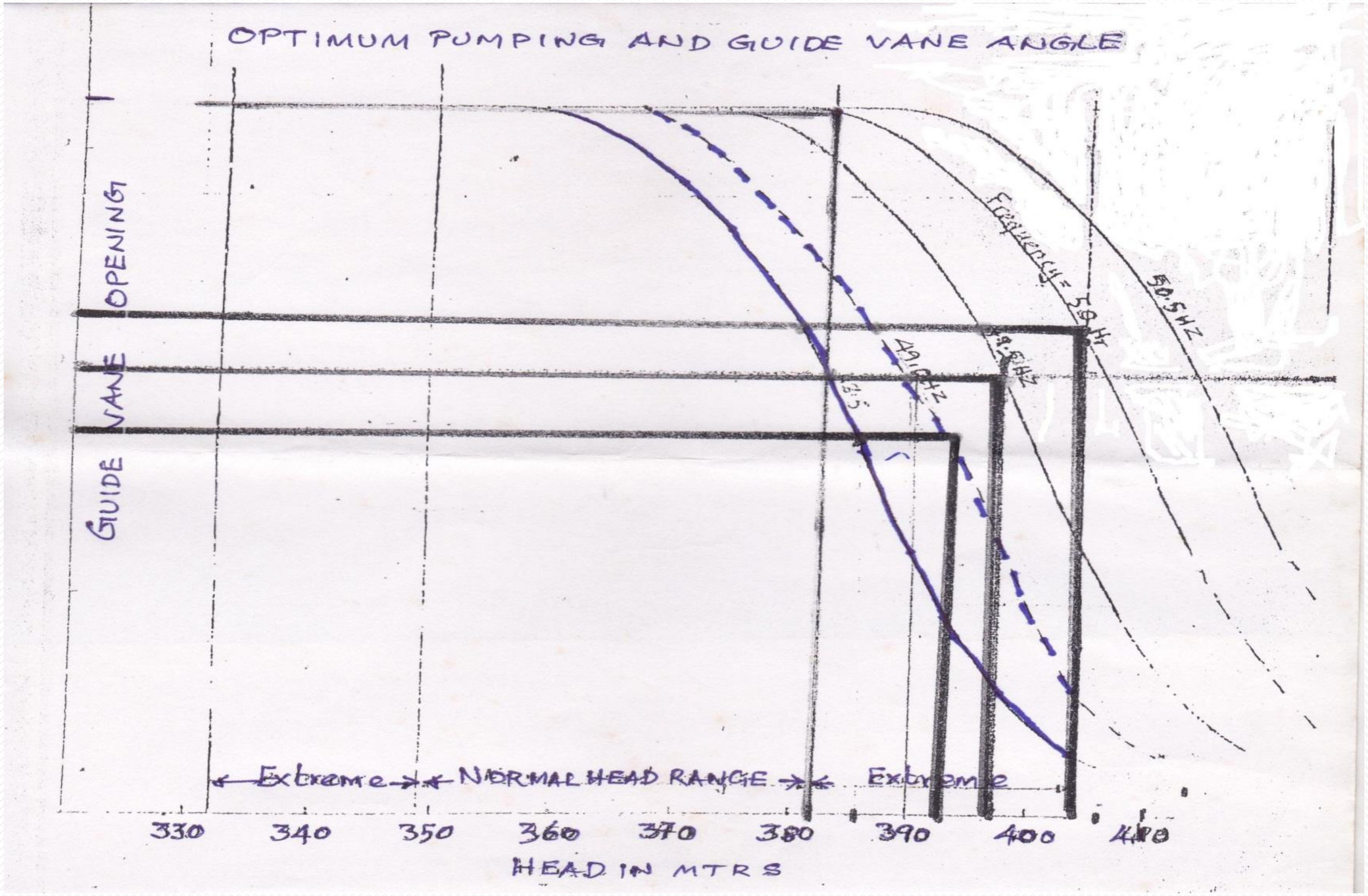
Frequency limitation for pump operation at Kadamparai.

- Frequency for pump operation at Kadamparai is designed between 49.5hz and 50.5hz .The motor input required is about 109 mw at rated speed. If all the four units are operated as pump, then the power input required at station end is about 440 MW. First time, on 12-02-2003 only all the four units were put on pump mode though the station was commissioned in 1989.

Low frequency pump operation

- For low frequency operation below 49.5 Hz and upto 48.5 Hz , the designer have recommended to limit the dynamic operating head to 381 m and to reduce the guide vane opening by 60 %.
- As the operating head and frequency was not matched as per their recommendation, this aspect was not tried at KPH.
- Radial feeder from a thermal station[MTPS] to KPH was tried and as it involves more switching isolation in all Sub stations ,this was not tried as a regular feature .
- TNEB has also checked the feasibility of using big size converter for one unit so as to increase pump running hours and to use the water for meeting peak demand. But due to economic reasons this idea was dropped.

Optimum pumping & frequency.



Performance during 1989-97.

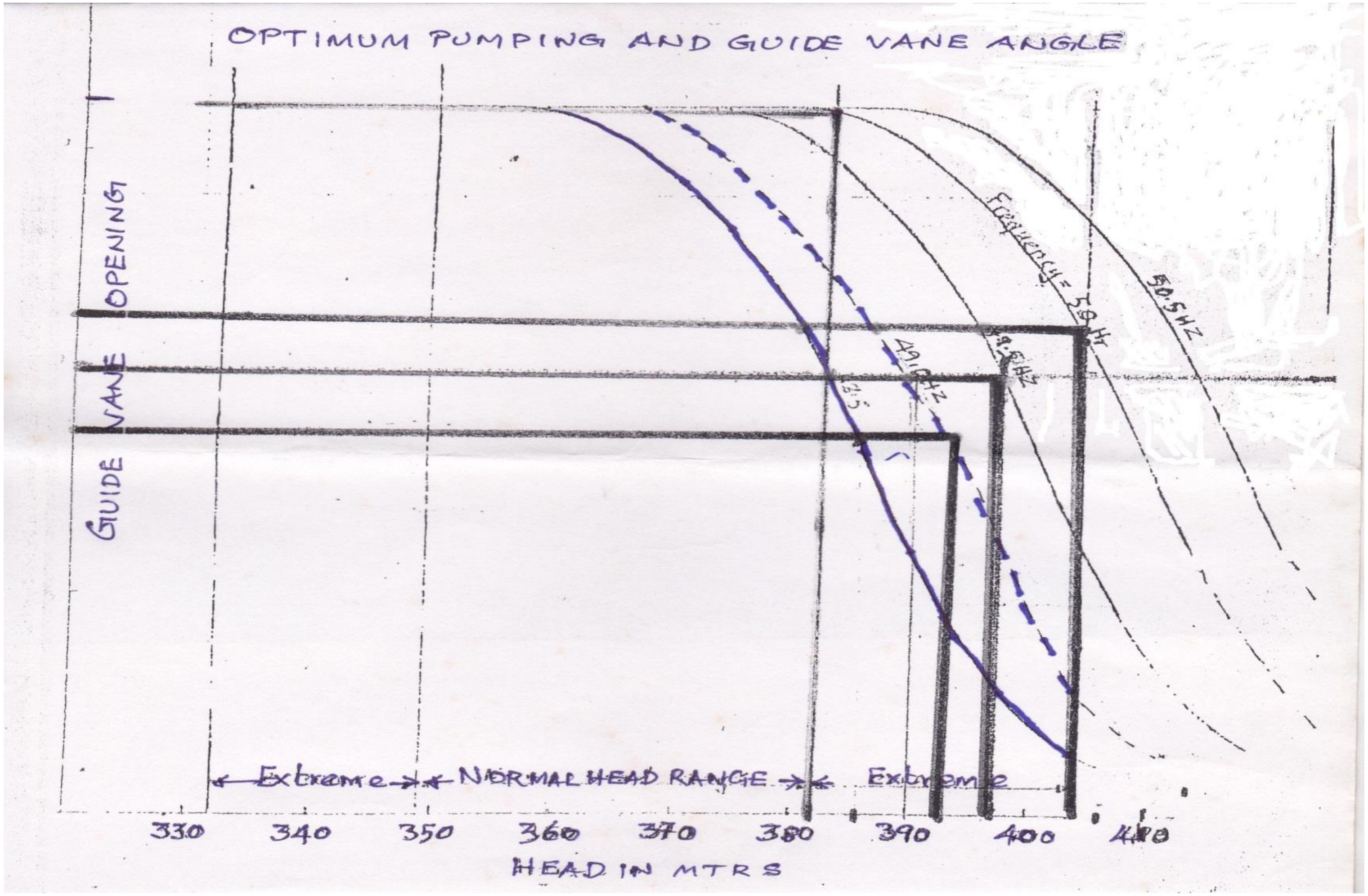
- From 1989 to 1997 the generation obtained by recycling was very minimum and the reason for poor pumping was due to the fact that only one unit was in service. Units 3 & 4 were in forced outage due to fire accident & unit 2 was due to 230 KV power cable fault.
- Frequency of the southern regional grid was operated less than 49.0 Hz for most of the time in a day and caused a limitation on pump operation.

KADAMPARAI MACHINE FLOOR

Low frequency pump operation

- For low frequency operation below 49.5 Hz and upto 48.5 Hz , the designer have recommended to limit the dynamic operating head to 381m and to reduce the guide vane opening by 60 %.
- As the operating head and frequency was not matched as per their recommendation, this aspect was not tried at KPH.Radial feeder from a thermal station[MTPS] to KPH was tried and as it involves more switching isolation in all Sub stations ,this was not tried as a regular feature .
- TNEB has also checked the feasibility of using big size converter for one unit so as to increase pump running hours and to use the water for meeting peak demand. But due to economic reasons this idea was dropped.

Optimum pumping & frequency.



Performance during 1989-97.

- From 1989 to 1997 the generation obtained by recycling was very minimum and the reason for poor pumping was due to the fact that only one unit was in service. Units 3 & 4 were in forced outage due to fire accident & unit 2 was due to 230 KV power cable fault.
- Frequency of the southern regional grid was operated less than 49.0 Hz for most of the time in a day and caused a limitation on pump operation.

Operating frequency

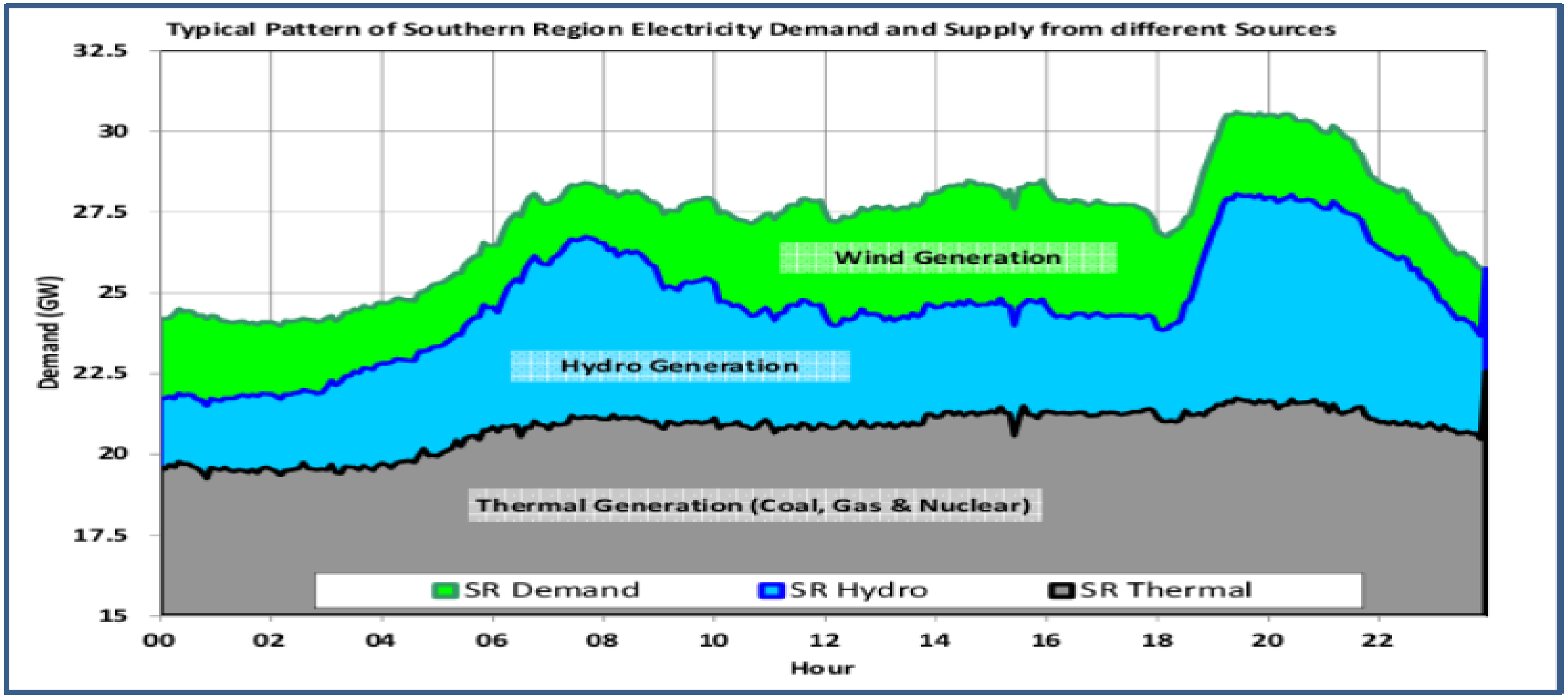
- Frequency range was narrowed from+/- 3 % to 1.0 % in 2003 and imposed the penal mechanism of deviation from schedule known as the UI mechanism in southern region.[ABT]
- This is only a commercial mechanism but this method has improved the operating frequency of southern region for longer duration above 49.5Hz .[REFER SLIDE-4]

Pump operation after 2003.

- Pump operation at kadamparai have increased during off peak hours and this was possible due to gradual wind power capacity addition in Tamil Nadu.Wind had also helped for better performance of the station after 2003.

Wind in SR Grid.

Management of Intermittency & Variability in Wind generation-
Southern Region (July 2011)



Performance of Pump operation after 2003.

- 2003-04----471MU --WIND CAP-1361MW
- 2004-05----232MU*---DO---------2040MW
- 2005-06----555MU---DO----------2898MW
- 2006.07----416MU----DO---------3476MW
- 2007-08----403MU-----DO--------3857MW
- 2008-09----237MU**-----DO------4288MW
- 2009-10----485MU-----DO--------4890MW
- Reason for low performance
- *DAM GEOMEMBRANE WORK-8 MONTHS- TOTAL SHUTDOWN.** POWER CUT IMPOSED IN TAMILNADU DUE TO SHORTAGE OF POWER.

Pump performance-contd

2010-11--611MU-------WIND CAP--5887MW

2011-12--533MU-------DO--------------6970MW

2012-13---335 MU----DO---------------7165MW

2013-14---497 MU----DO---------------7275MW

2014-15---511 MU ----DO--------------7345MW

2015-16---420 MU-----DO----- ~7500MW [tentative data]

S.No	YEAR	GENERATION in MU	WATER PUMPED in MCFT	CONSUMED in MU
1	2010-11	572.140	17664.00	619.789
2	2011-12	510.537	15521.54	544.615
3	2012-13	302.063	9611.75	337.254
4	2013-14	505.190	14188.61	497.846
5	2014-15	502.470	14571.40	511.277
6	2015-16	413.410	11662.01	409.193
7	2016-17	289.115	9392.31	328.575
8	2017-18 Till Jan'18	298.81	11257.98	303.38
TOTAL		8083.72MU	200153.97 MCFT	3551.931MU

Reservoir regulation.

- During south west monsoon season, both upper and lower reservoirs i.e. Upper Aliyar & Kadamprai are filled up to their maximum level. Wind and inflow are peak at that period.Any operation of pumping due to high wind energy had resulted less spill in the lower reservoir.No spill in upper reservoir.
- Whenever KPH is used on generation mode due to sudden outage of thermal/nuclear, and if lower reservoir is kept very near to FRL, spill had occurred.

Challenges faced

- Dam leakage -reservoir level regulation and geomembrane installation.
- upper dam filling through pump operation after geomembrane installation.
- Frequent start/stop-components failure in stator/turbine.
- Removal of 25 ton mass rock over the control room due to a crack in the crown.

Major rehablitation works after fire accident

. **E & M works**

- **Renovation works in unit 2, 3, & 4 and its auxiliaries are cable laying in both vertical shafts,unit transformers & bus duct erection , crane erection ,lift erection, excitation panel replacement in unit 3 & 4 testing and commissioning.**
- **[civil works]**
- **cable shaft 1 & 2- concrete lining.**
- **Access tunnel shotcreting works due to rock fall and dust control during the process of work.Besides carbon/smoke dust, cement dust also gave problem in the control panel circuits of unit 1 during renovation perid.**
- **Unit 3 & 4 transformer bay re-construction**

.

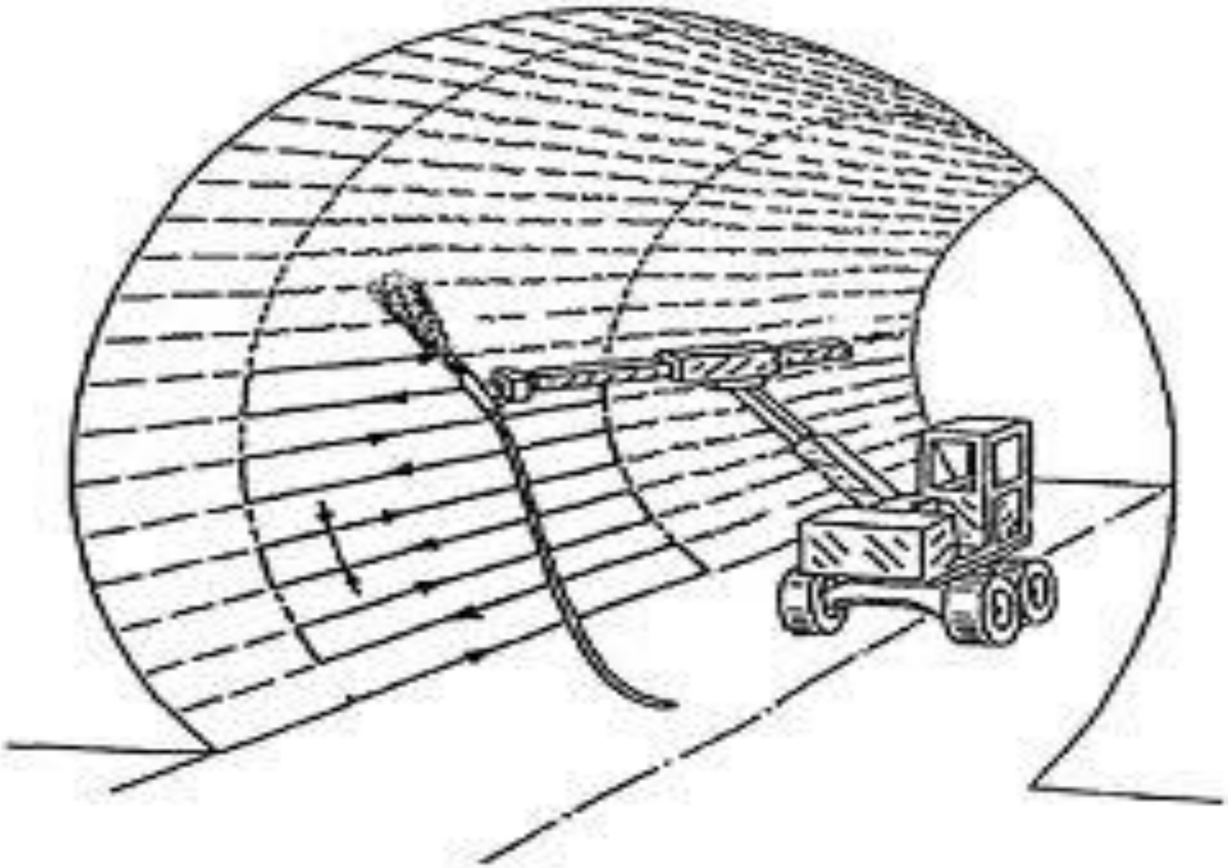
Problems faced.

- 230 kv cable failure due to fall of conduit.
- Thrust runner disc insulation failure.
- Brake track disc rubbing.
- power transformer neutral bushing crack.
- Runner uplift.
- Rotor earth fault -dynamic condition
- MIV struckup-flow reversal-sudden stop of unit during shutdown from pump mode

View of access tunnel, upper and lower reservoirs

Rock fall in access tunnel.

Removal of loose rocks and rock bolting shotcreting works in access tunnel.



Rock mass removal

- crack noticed on the crown of the power house above unit 3 and one portion was hanging.
- structural arrangements were made and rock mass about 25 Tons- lowered on the structure.
- Remedial measures - Rock bolting-& Shot-creting done in the crown portion.

crack in the crown -chain link fence provided after rock bolt provision

Unit 2.- Runner uplift.

- During commissioning & testing of unit 2 in 1989 , the governor was adjusted for settings in turbine mode.
- The unit 2 rapidly began to over speed which caused excessive up thrust and the runner came to rest suddenly and seized.
- Repairs to the runner and spiral casing - done by BHEL and commissioned.

unit 2-230 KV cable fault

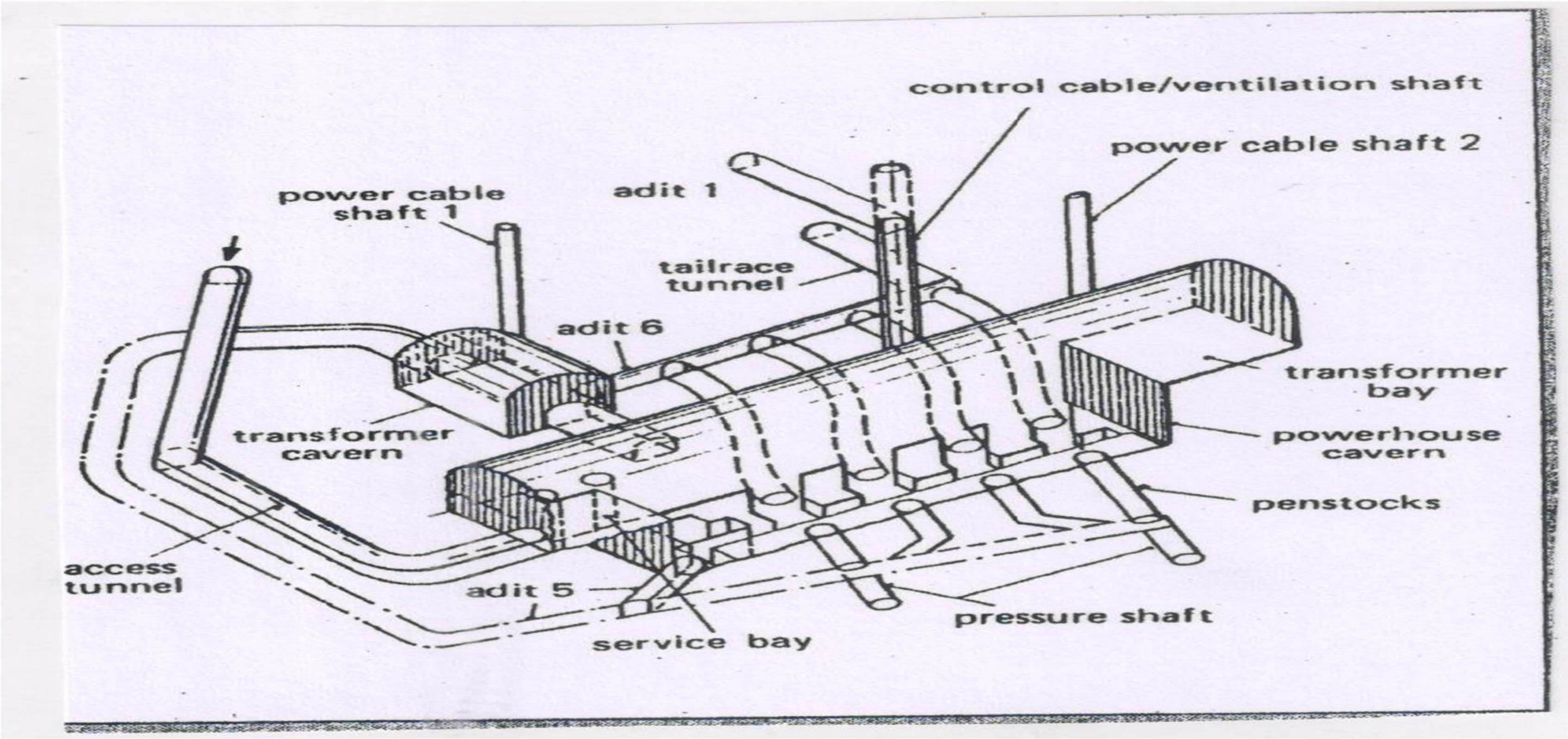
In june 1990,conduit pipes fixed in the vertical power cable shaft for lighting [200 m-depth] fell on the 230 kv cable and damaged the cable insulation at many locations in all seven cables.

unlined vertical shaft and seepage was present.Corosion on clamping material caused failure and be one of the reasons for fall of conduit pipes on the power cables.

Repairs to Silec cable.

- The power cable shaft 1 was inspected and all the conduits were removed . Damages on the cables were assessed.
- Connection between cables by means of joint was also checked .Due to space limitation in the vertical shaft this idea was dropped.
- Out of 7 runs ,only three cables were found healthy, though outer sheath were damaged at many locations.Insulations applied on the three cables and unit 1 was put into service.

cavern with three vertical shafts.



cable lowering in power cable shaft

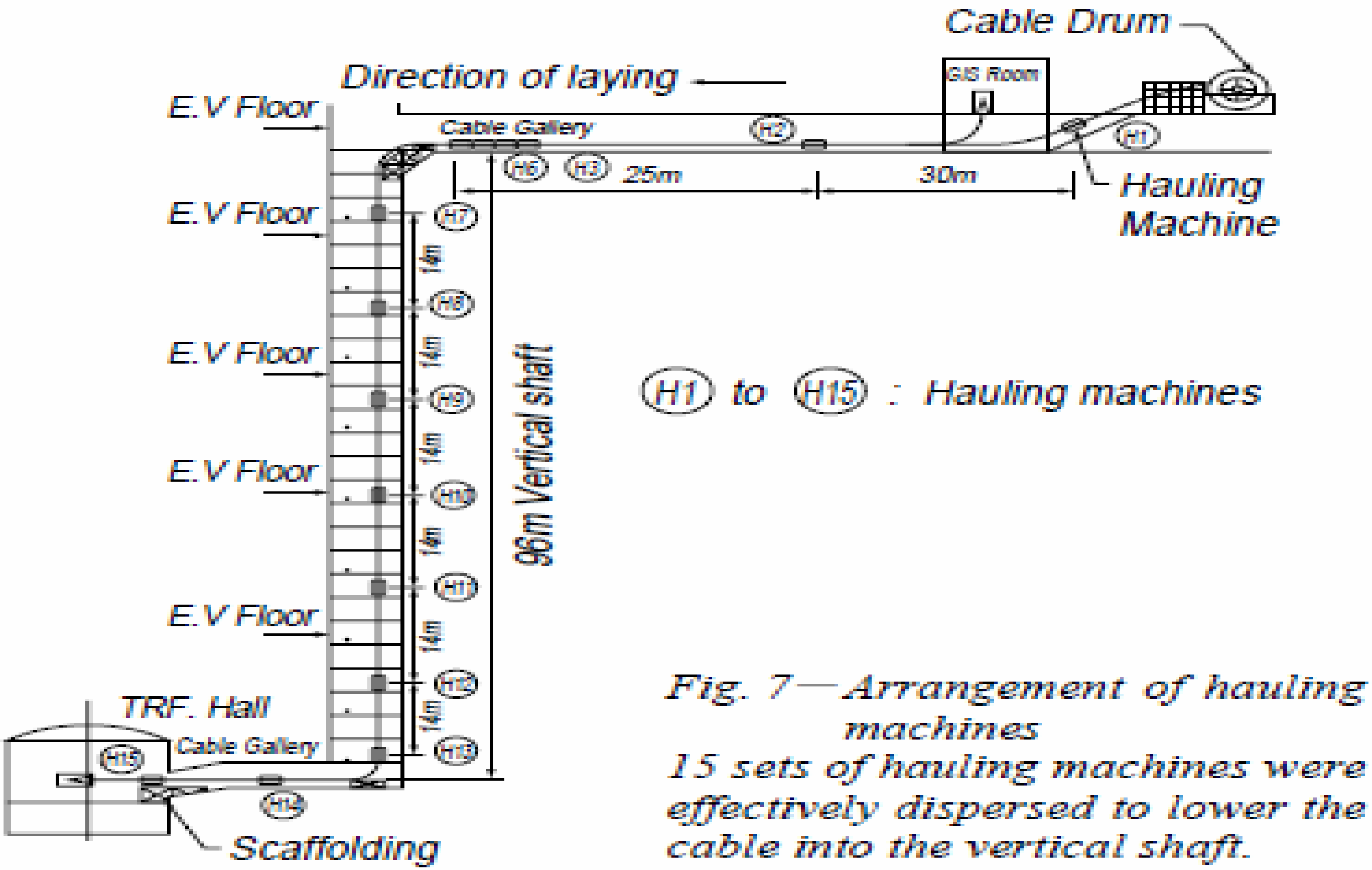
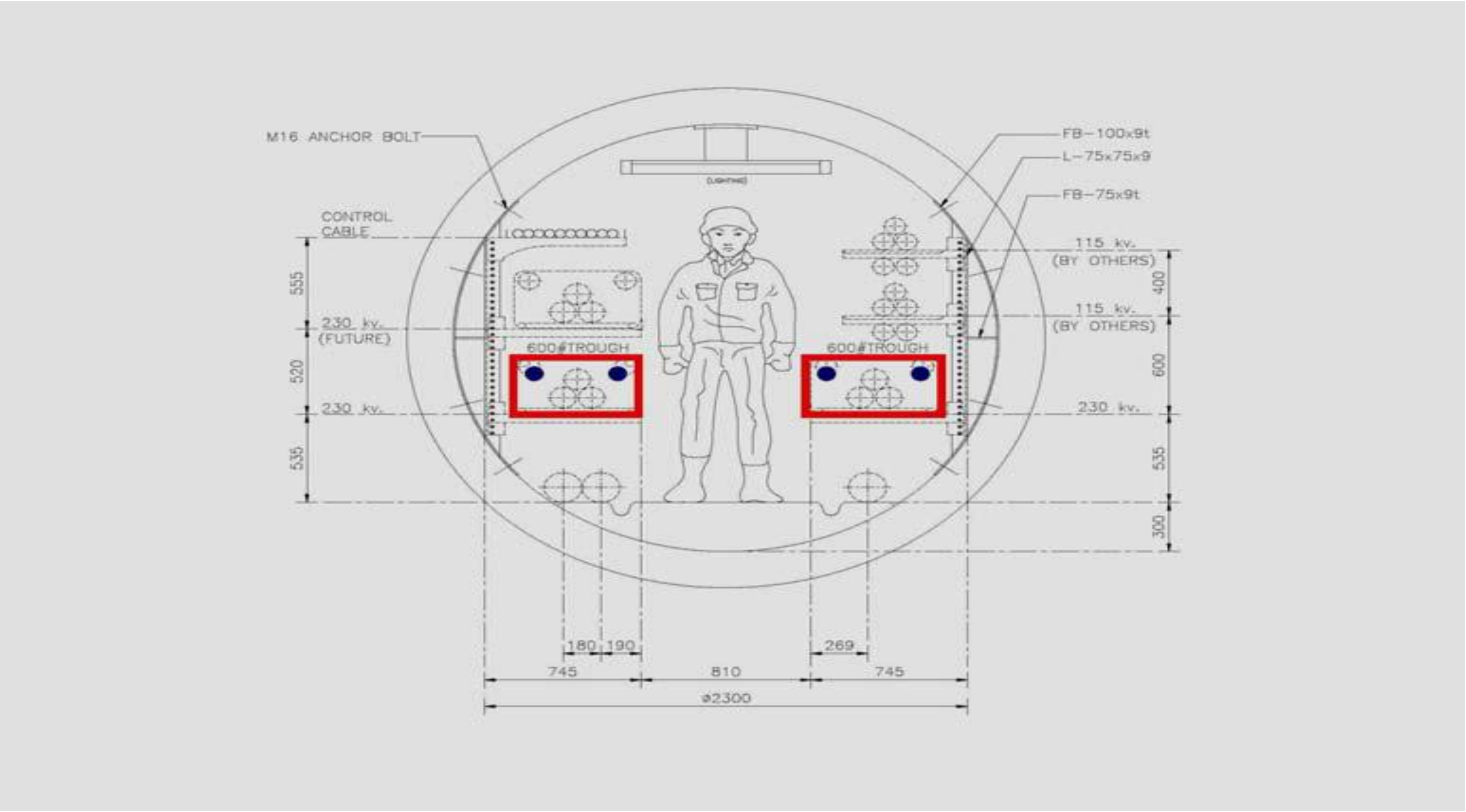


Fig. 7— Arrangement of hauling machines
15 sets of hauling machines were effectively dispersed to lower the cable into the vertical shaft.

cable in horizontal shaft



view of vertical portion of power cable shaft 2

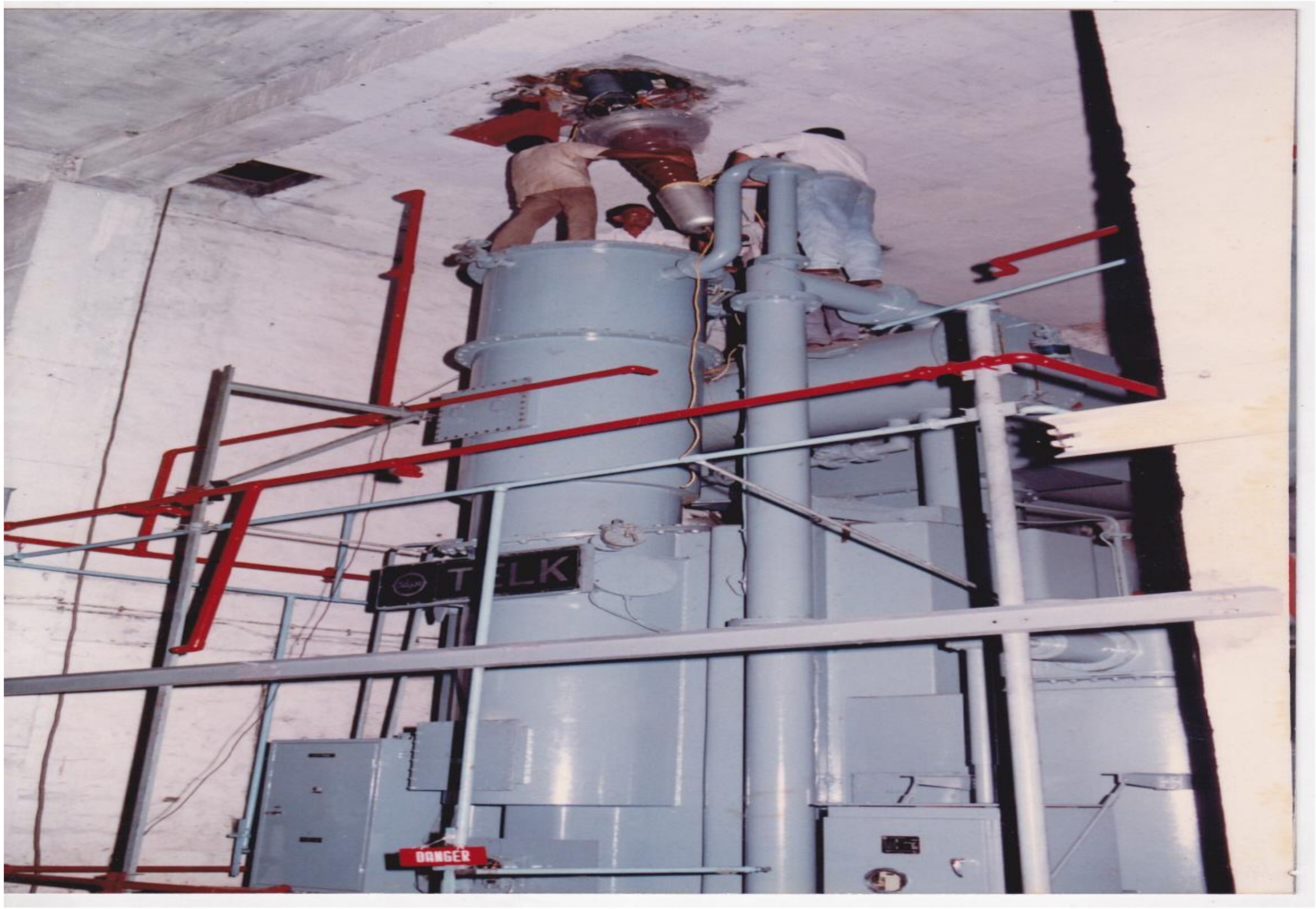
view of horizontal portion of cable tunnel.

Low IR value on 230 KV cable.

- .Due to seepage of water in the cable gallery inside power house, low IR value in one phase of the cable was reported due to water entry into the indoor pot head.

- To rectify the defect,assistance of the cable jointer from Silec/France was utilized and defect rectified in 1993.

Erection of indoor termination in transformer pot head tank.



Fire in transformer bay

- The main transformer bay of underground hydropower station is constructed deeply underground and connected with the switch yard through power cable shaft .Transport passage is called as access tunnel and is of 1 km in length . The transformers placed in two locations inside the cavern. Unit 3&4 transformers were damaged in a fire accident in Oct'90.

Fire fighting

- **When the fire occurred , the visibility inside cavern was poor. Approach to tr bay was difficult for carrying out fire fighting operation since the combustion process was fast & dense.**
- **The fire spread quickly because of the smooth air flow in the underground hydropower station through access tunnel . Vertical shafts acted as chimney.**
- **The smoke volume was exhausted naturally through the power cable shafts and through ventilation tunnel.As a measure of fire fighting , water pumped inside cavern upto generator floor so as to avoid damage to other equipments.**
- **Hence up upto generator floor , flood situation was created.**

Equipments damaged in fire

- 7 Nos unit power transformers ,single phase, 45 MVA: 11kv/230kv were damaged
- 230KV cables-7 runs-length each about 300m connected between transformer and switchyard in power cable shaft 2 were damaged
- EOT Crane
- unit 3 & 4 bus duct
- Power house lift and switchyard lift.

Laying of power cable

Power Generated is transferred through 230 kv single core cable of 500 sq mm to outside switchyard. 7 runs of 230 KV Cables and 2 runs of 22 KV cables were Laid in power cable shaft 2 .

Supply of cables were by CCI and terminations at switchyard and indoor were by Kabeldon /Sweden. Installation was done by M/S Cable Corporation of India in 1994.

The cable laying in the vertical shaft was a challenging job since the weight of cable per metre is about 14 Kgs and each run about 350 m

Forces acted on the cable due to an earth fault at the station.

- One day ,when units 3 & 4 were running at full load, tripped due to an earth fault in the 230 KV switch yard.This was happened due to sanp of the Kundah conductor connected to the line isolator and main bus .
- On inspection of vertical shaft the loose provision gave near the mouth of the vertical shaft was found straightened.This was due to high mechanical forces acted on the cable due to an earth fault.

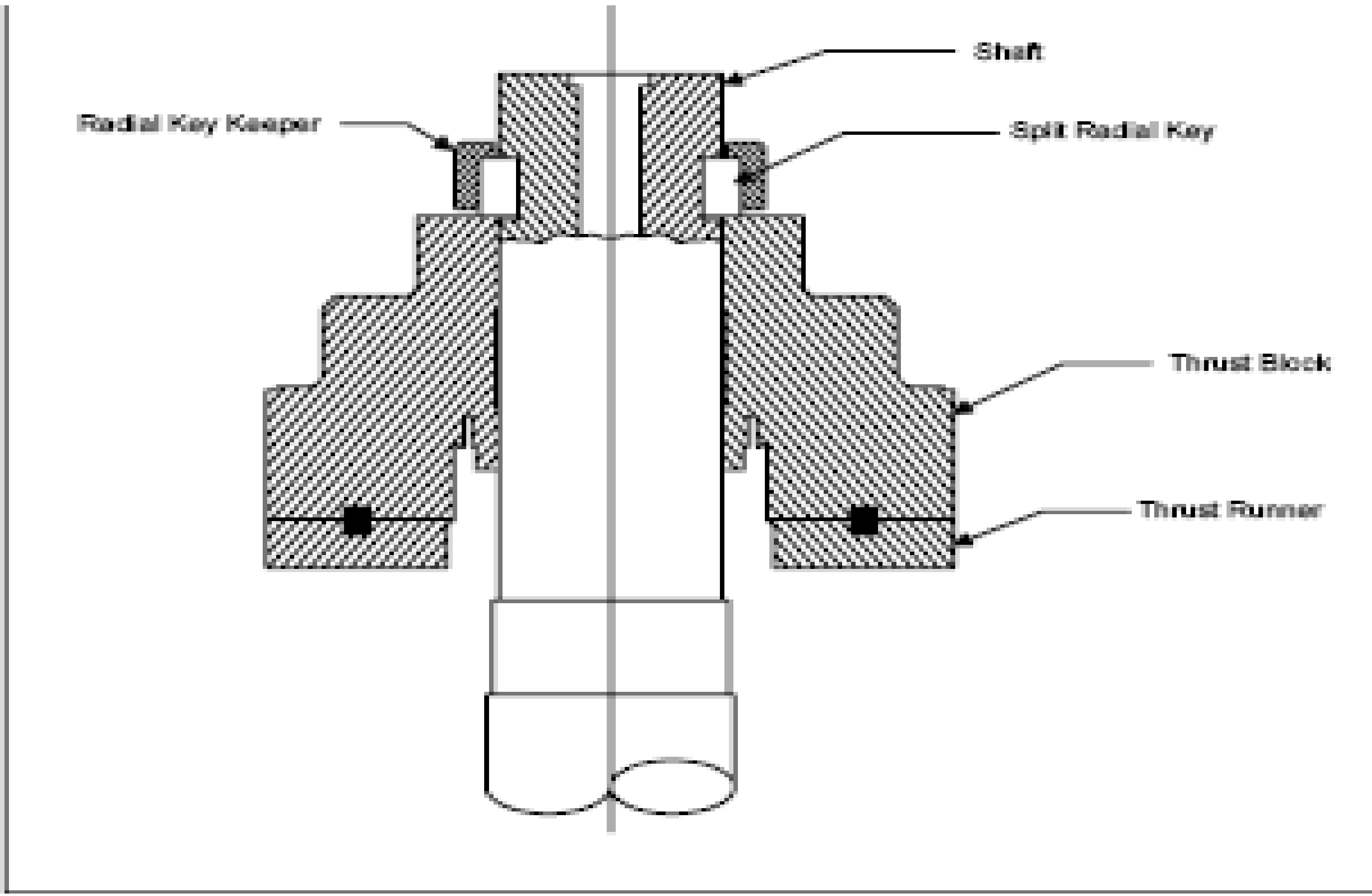
view of clamps fitted in the vertical shaft.

view of outdoor end termination after erection.

Thrust runner disc insulation failure

- Scoring marks on thrust collar runner disc was noticed at KPH during voltage builtup after completion of renovation.The reason for this defect was due to the low insulation value of the insulation disc fitted between runner disc and thrust collar.
- As per CIGRE report ,such failure occurs in the units where static excitation is used which induces spikes in the shaft voltage and cause and breakdown of oil film if the oil is contaminated.

View of thrust block



Method adopted.

- The insulation disc was supplied and works supervised by BHEL.
- Insulation is being checked on regular intervals and oil is changed as and when required to avoid failure of insulation in thrust and guide bearing.

Brake track rubbing.

- One day when unit was running as generator, the generator brake track disc assembly got contact with brake shoe and created noise and spark .
- The unit was brought to shutdown due to rubbing.The incident was happened due to failure of bolt fitted with the brake disc and rotor rim at one location
- .As the replacement requires dismantling of the generator and its reassembly , as an immedite measure the brake track disc was welded with generator rim and unit brought into service.
- Regular inspection of welded clamp WASdone.

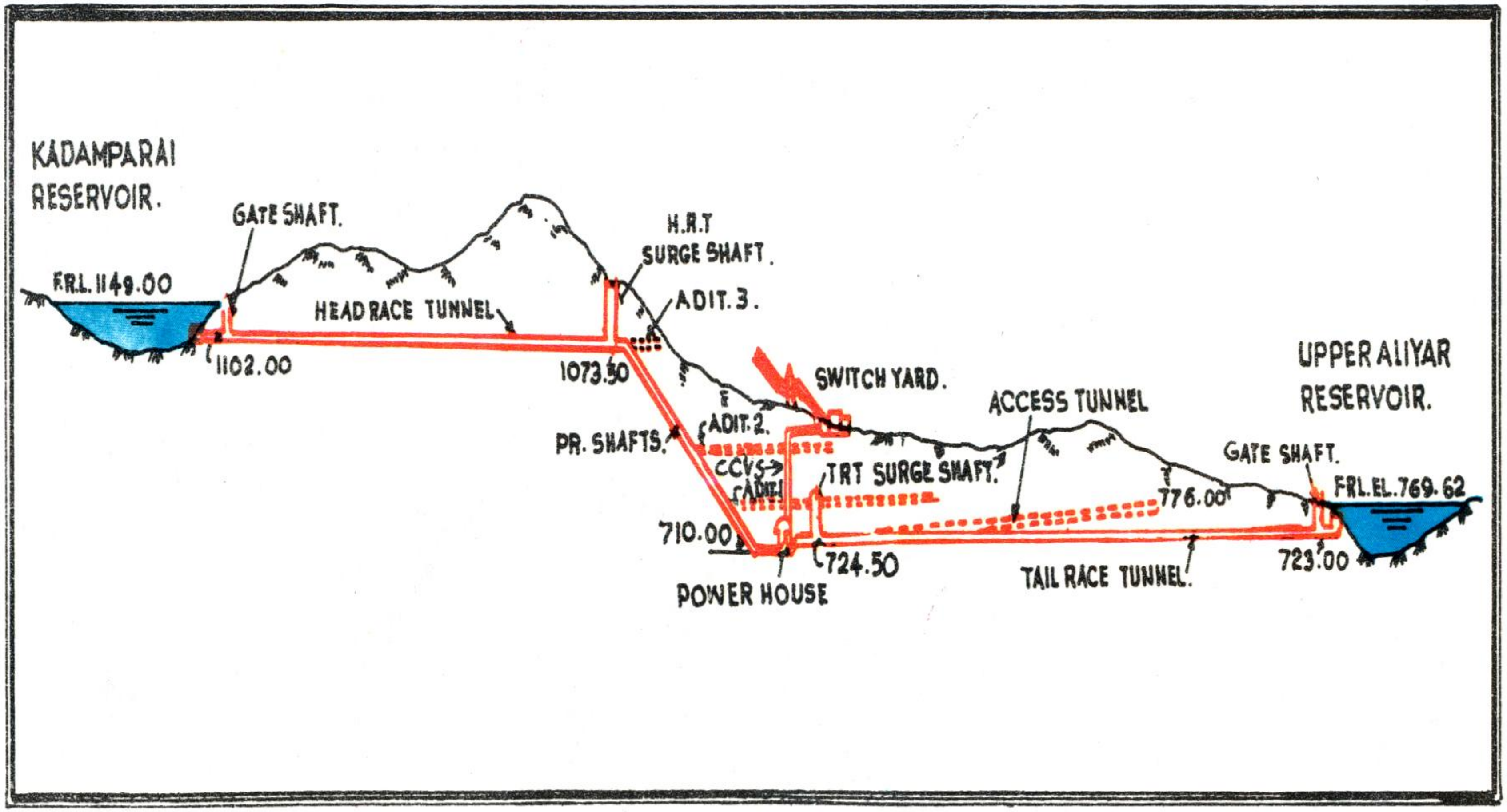
mechanism box components failure

- The unit breakers are operated 6 to 8 times at KPH in a day. Back to back operation is preferred during pump selection since short duration when compared with SFC start.Frequent start-stop is also one of the reasons for the wear and tear on the control valve,and bearings in the breaker mechanism box.
- In one occassion ,field coil failure,and FDR burnt was happened due to non-opening of one phase of the unit breaker for a shorter duration due to struckup of the opening mechanism latch in one phase.

Outage in stator .

- Due to frequent start and stop operation of units on both directions[clockwise & anti-clockwise] have increased the vibration in the machines and caused outage of stator in all four units.The the machine availabilty was found reduced between2009 &2015.Fall of loose component in unit 2 & rotor contact with stator in unit 4 have caused outage of units for longer duration. Stator earthfault was faced in unit 1 & 3 due to aging of insulation ,oil vapour carbon dust & coil vibration.

Leak in adit 1 & 2.



KADAMPARAI TO UPPER ALIYAR RESERVOIR — PROFILE

Leakage and reservoir level

- However, over the years, the seepage increased and in 2003 the maximum operating level was pegged at 75 % of maximum height to limit the seepage.In 2003 the leakage was around 15,000 Lpm and rose to 25,000 Lpm in 2004.
- Hence upper reservoir regulated at a lower level and it was according to inflow& pump operation.

geomembrane installation

- Various methods adopted in kadamparai dam to reduce the leakage had not given any fruitful result ,instead the leakage was increased from 1000 to 4000 Lpm. It was further increased from 4000 Lpm to10000 Lpm in 2002-03.Then it went to 15000 Lpm. Maximum leakage recorded was about 25,000 Lpm in july -Aug 2004.Hence it was decided to go for geomembrane installation instead of conventional methods.

.

Dam empty

- For fixing Geomembrane in the upstream face of kadamparai dam,the upper reservoir was emptied in Sept 2004 and water stored in the lower reservoir to its full capacity with a program to use the water in summer 2005. [i.e.,after completion of geomembrane installation work].

view of Kadamparai dam -empty condition.

work in progress

- The PVC geocomposite was laid over the antipuncturing geotextile

geomembrane installation work in progress.

Upper reservoir filling

- First time one unit was operated as pump in April 2005 using SFC for filling water in Kadamparai dam after completion of geomembrane work.
- Being summer period and as there was no inflow to kadamparai dam ,water was filled by pumping from the lower reservoir.
- This was an achievement and useful record in the operation history of the power house.
- The summer demand was met in 2005 by utilizing Kadamparai pumped storage.

VIEW OF HRT INTAKE-WATER FLOW

View of dam after installation of geomembrane and intial filling .

Full level at Kadamparai dam.

Effect of geomembrane

- The installation of the exposed PVC geocomposite provided as a rehabilitation measure proved efficient in the control of leakage.
- Seepage was less than 100 lpm when measured at FRL in 2005 monsoon.[i.e., after installation of geomembrane].

Area & cost

- Geomembrane fixed in the upstream face was for 17500 sq m and at an expenditure of 12 crores.
- The Kadamparai dam is operated at FRL after this work and the leakage is very minimum .
- No repairs done on geomembrane at kadamparai.

Lessons learnt.

1. Locating main step-up transformers in a separate underground cavern and providing extensive heat exhaust system .

Adequate reliable dewatering system is required for an underground power station.Better to have a flood drainage tunnel if topography permits.

In Tamilnadu, while constructing PUSHEP these points are conssidered.

2. Total shutdown is required for any work in the wcs on tailrace side due to common manifold system at KPH. In future, minimum 2 tunnels on tailrace side is to be provided if more units are programmed.

3.Flap gate on DT is not recommended for future pss since the flap gate which used at KPH is not reliable.

Buckling in Pressure Shaft 1&2

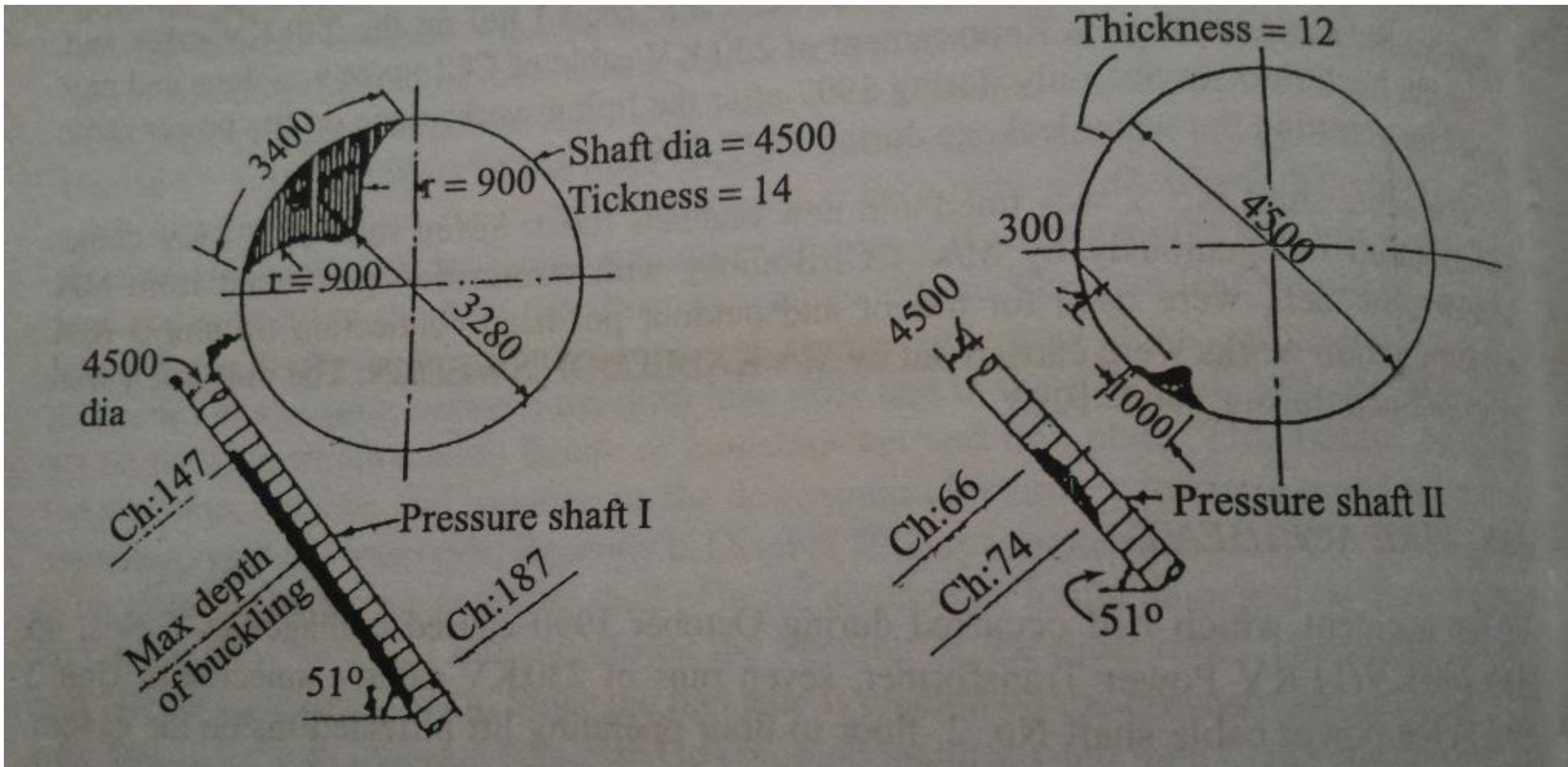


Fig 1 Details of Buckling in Pressure Shafts.

Flap gate problem

- FLAP GATE-EXCESSIVE VIBRATION DURING INTIAL COMMISSIONG.
- VIBRATION WAS DUE TO PLY IN BETWEEN WORM WHEELS FIXED IN THE GEAR BOX-WORM WHEEL CHANGED WITH HARD MATERIAL AND PLY ADJUSTED.VIBRATION REDUCED.
- HINGE PIN/BRACKET FAILURE AND LINK FAILURE.
- Due to link failure ,flap gate was closed while the machine was running. pump operation was affected, but generator operation was performed with this defect till rectification.

flap gate-contd

- Failure of hinge/bracket obstructed the proper closure of flap gate .Hence isolation of unit for runner inspection and for flap gate rectification works total shutdown was availed everytime.
- For any emergency in the tailrace water conductor system TRSS is closed for isolation,thereby four units are not available for operation.

2 additional hinges with bracket provided in the flap gate as an improvement measure.

DRAFT TUBE LINER PIECE
broken view

LINER PIECES COLLECTED NEAR TRSS GATE

PIECES COLLECTED BELOW THE RUNNER

A PLATE GOT STRUCK IN THE RUNNER

VIEW OF RUNNER


THANK you
...
A YOUNG MAN WHO WAS GRADUATED YESTERDAY
AND STOPPED LEARNING TODAY
WILL BE UNEDUCATED TOMORROW
-Swami Vivekananda
Let us learn, learn and continue to learn
till the last Nano second of our life

Role of Pumped Storage Plants in Large Scale RE Integration

By
Shri B. B. CHAUHAN
Managing Director

Gujarat Energy Transmission Corporation Limited
Vadodara, Gujarat

RE Scenario in India

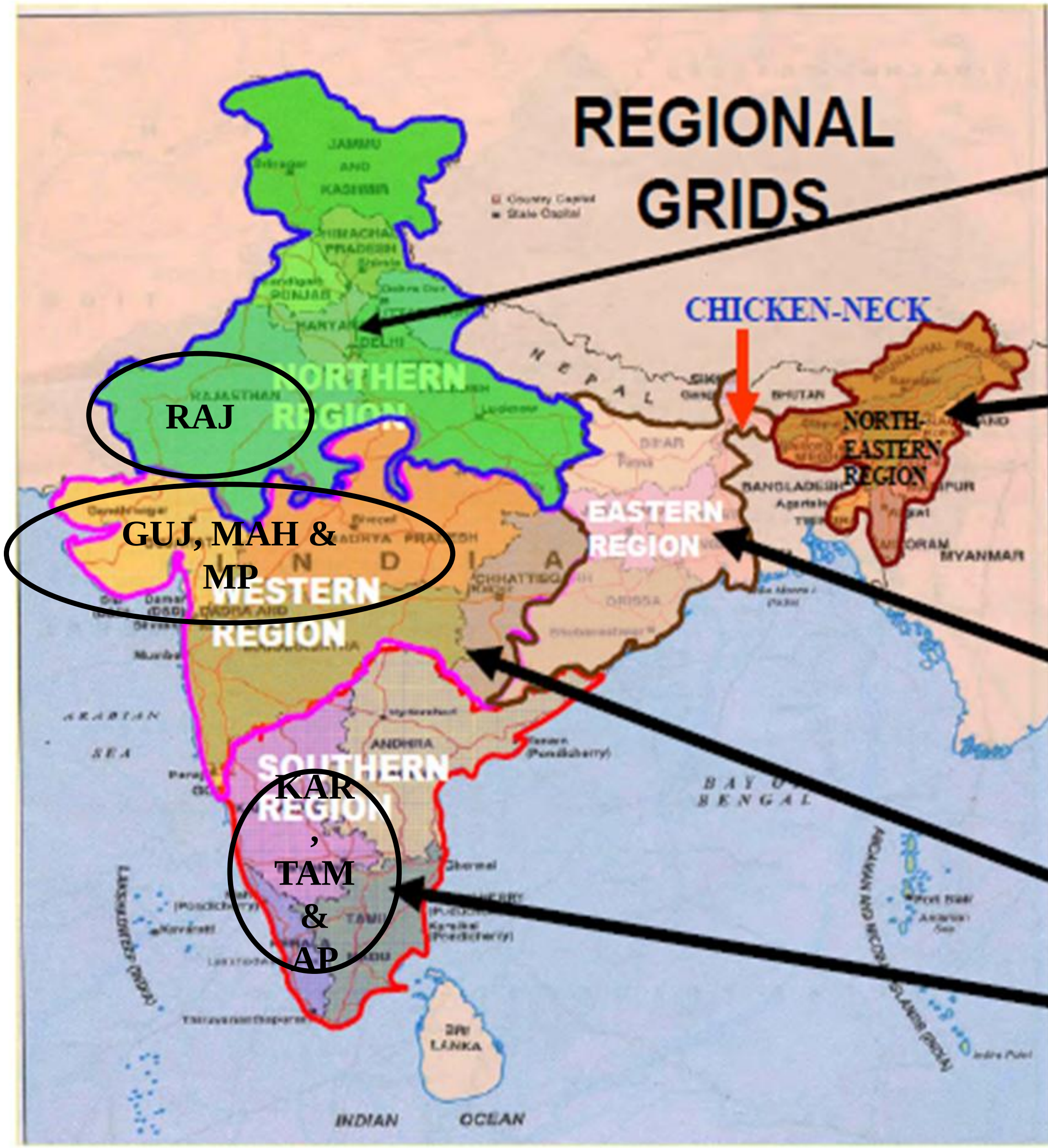
Renewable Energy Installed in India at Glance

RE Sources	Installed Capacity (MW)	Target 2020 -22 (MW)
Wind Energy	**32848**	**60000**
Solar Energy + Rooftop	**16070 + 982**	**100000 (60000 + 40000)**
Biomass Energy	8414	10000
Waste to Energy	114	
Small Hydro Energy	4418	5000
Total	**62847**	**175000**

- **Target is 175 GW against actual RE energy 62 GW**

* Source MNRE Dec 17

Sector wise RE potential



Deficit Region

Snow fed - run-of -the -river hydro

Highly weather sensitive load

Adverse weather conditions: Fog & Dust Storm

Very low load

High hydro potential

Evacuation problems

Low load

High coal reserves

Pit head base load plants

Industrial load and agricultural load

High load (40% agricultural load)

Monsoon dependent hydro

RE Scenario in Gujarat

RE Growth ... till today & RE Target

Target of Solar Energy by 2022 as per MNRE

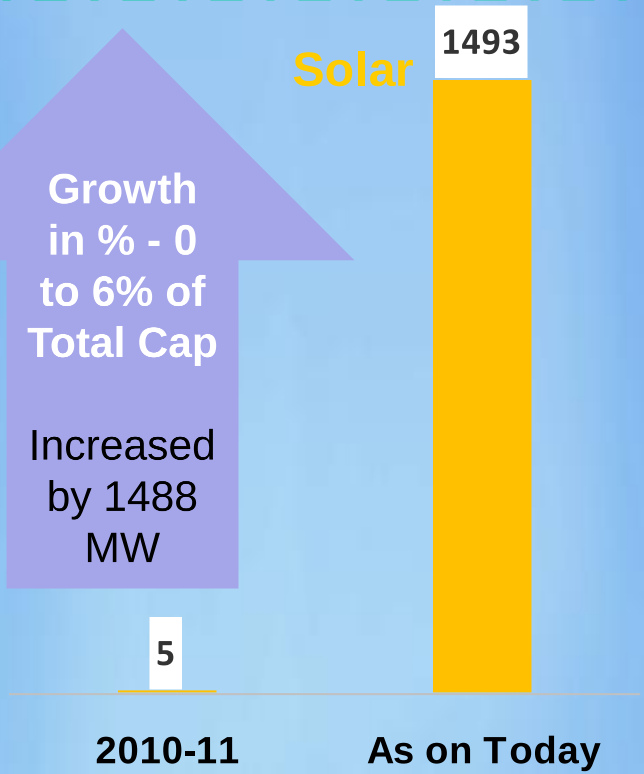
8020 MW

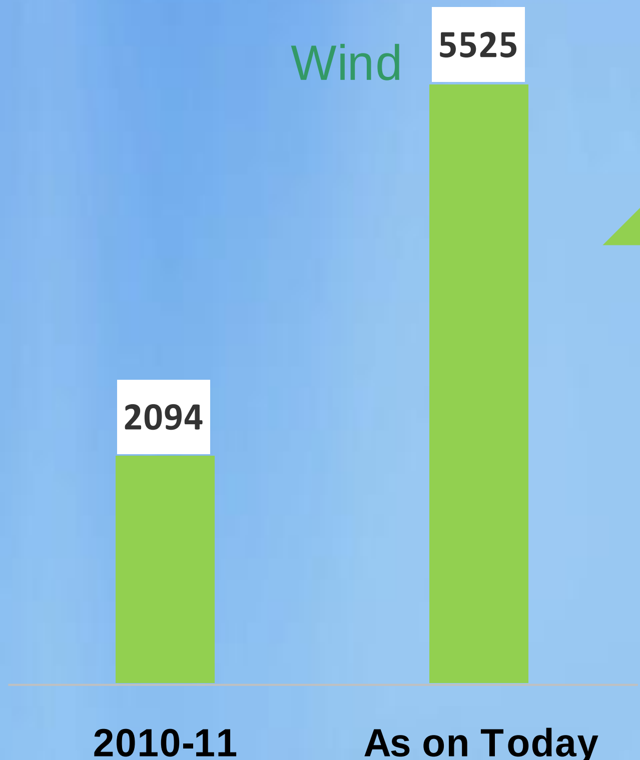
8800 MW

Target of Wind Energy by 2022 as per MNRE

Growth in % - 0 to 6% of Total Cap

Increased by 1488 MW



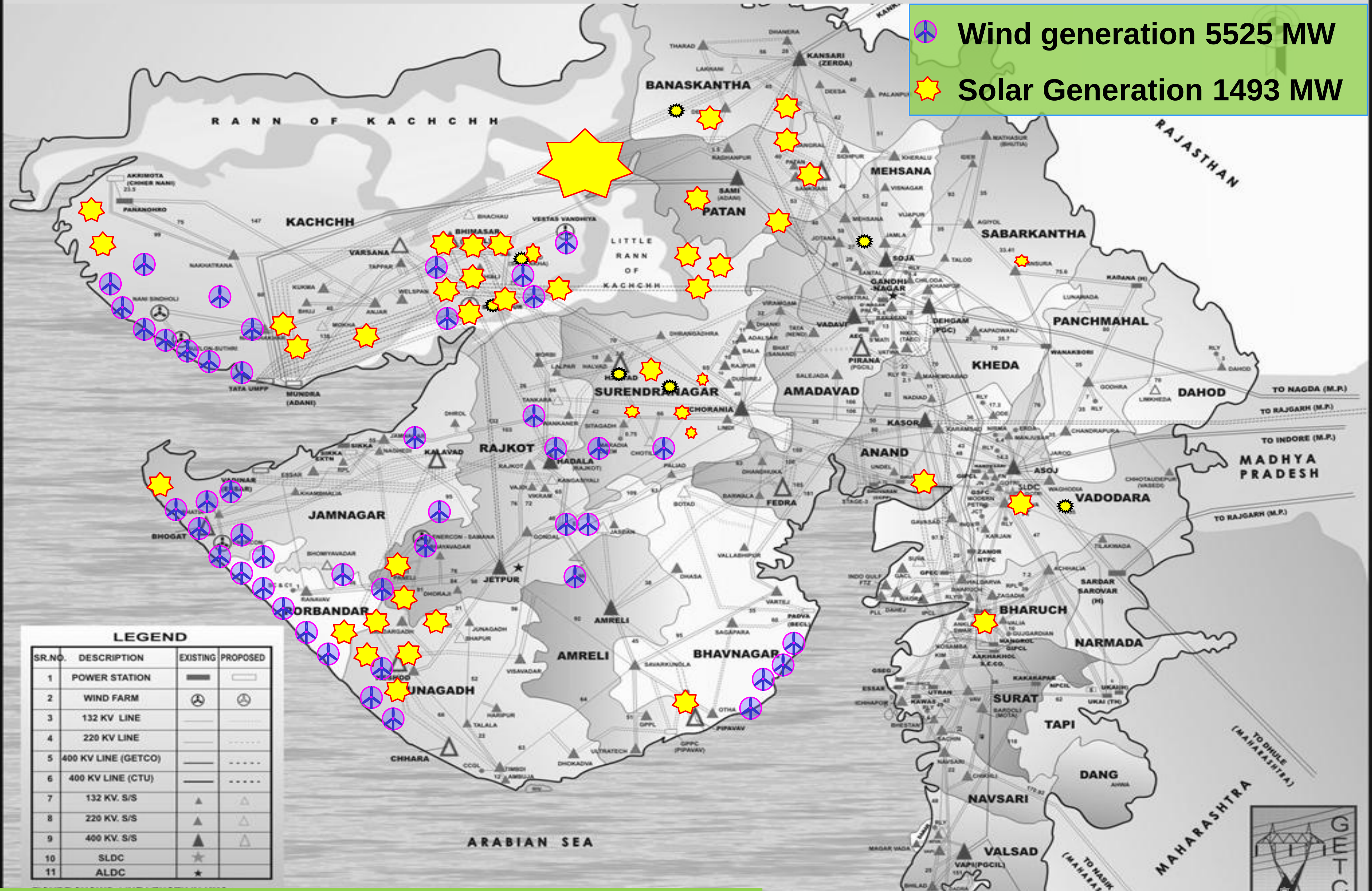


Growth in % - 14 to 20% of Total Cap

Increased by 3431 MW

Data in MW

Gujarat Renewable Power Location



Coastal Area –that gives challenges for network

RE Integration & Challenges in Gujarat

Need of Pump Storage Plant

Need of Balancing Sources for RE Rich State

Coal Generation
(58 %)
Not Effective

Gas Generation
(9 %)
Costlier & not easily available

RE (23 %)
Wind + Solar energy
Variable, intermittent & uncertain energy

Nuclear Generation
(2 %)
Must Run

Hydro Generation
(9 %)
Not available as per need

RE Integration : challenges

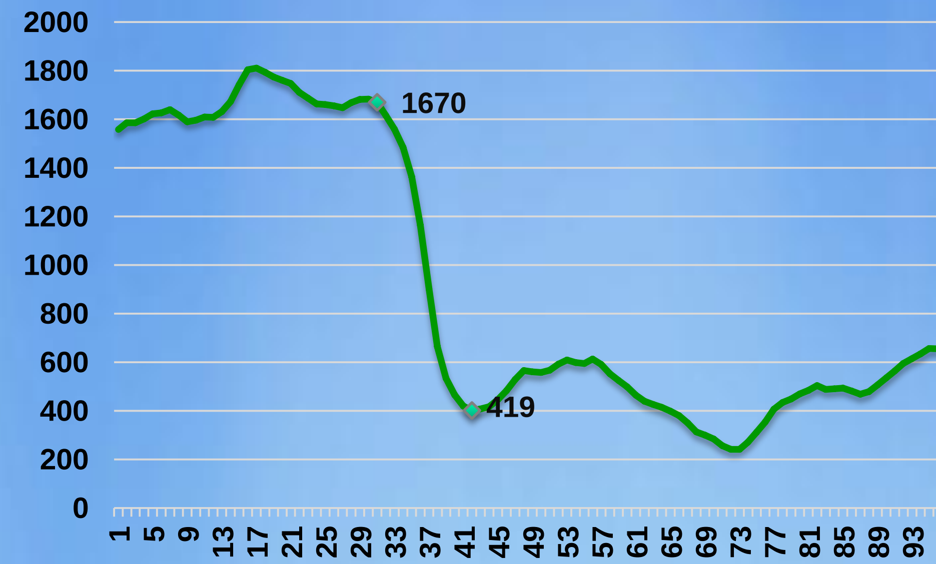
- Variable (Seasonal)
- Intermittent
- Uncertain
- Reactive Power
- DSM Violation
- Remotely located
- Forecasting
- Balancing Mechanism
- Over-rule Merit Order
- Impacting Conventional Plants
- Network Inadequacy

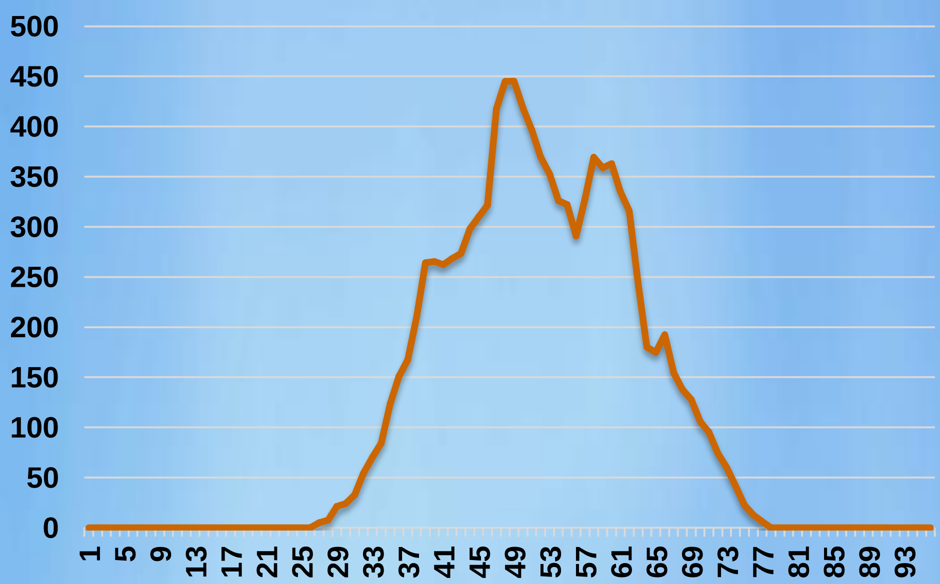
But, the biggest one is "Must Run Status"

RE Generation Variation in Sys Operation

10.06.2016 (Variation of 963 MW in 2 hrs)

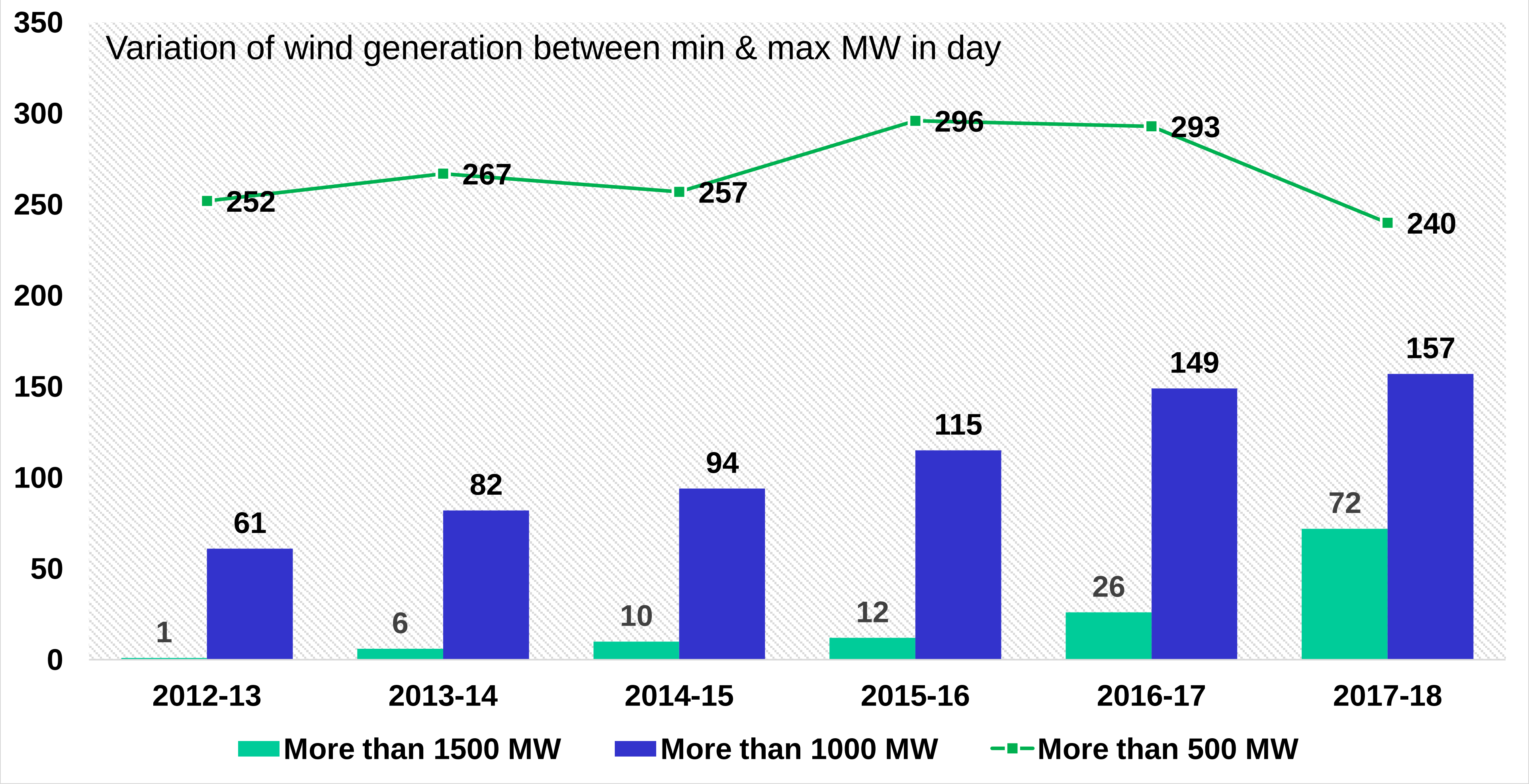
10.01.2016 (1253 MW in 3 hrs)



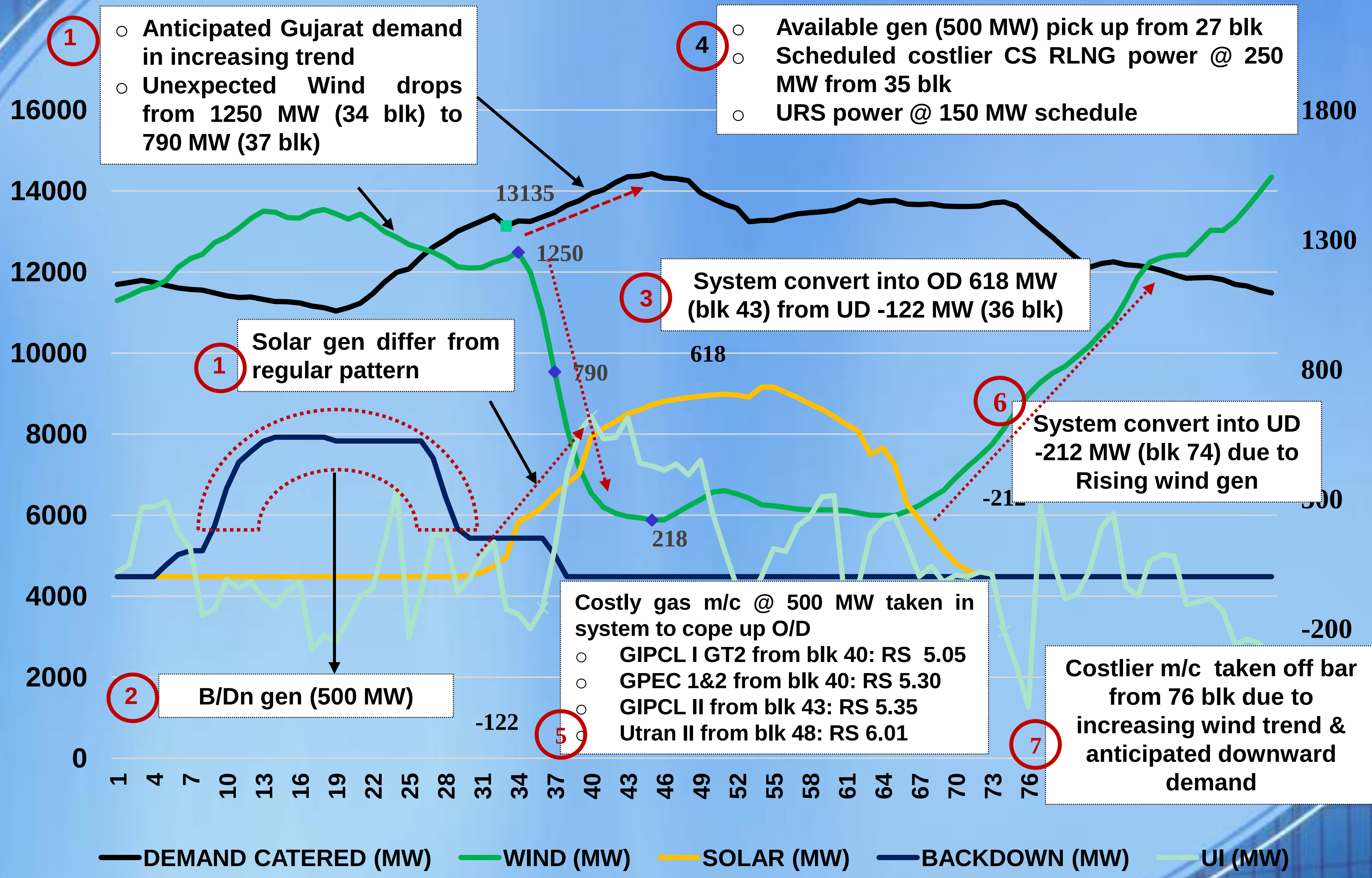


RE Generation Variation in Nos. of days

- **Solar Generation** is **highly ramp up and down at morning and evening.**
- Extremely variable during monsoon and cloud cover.



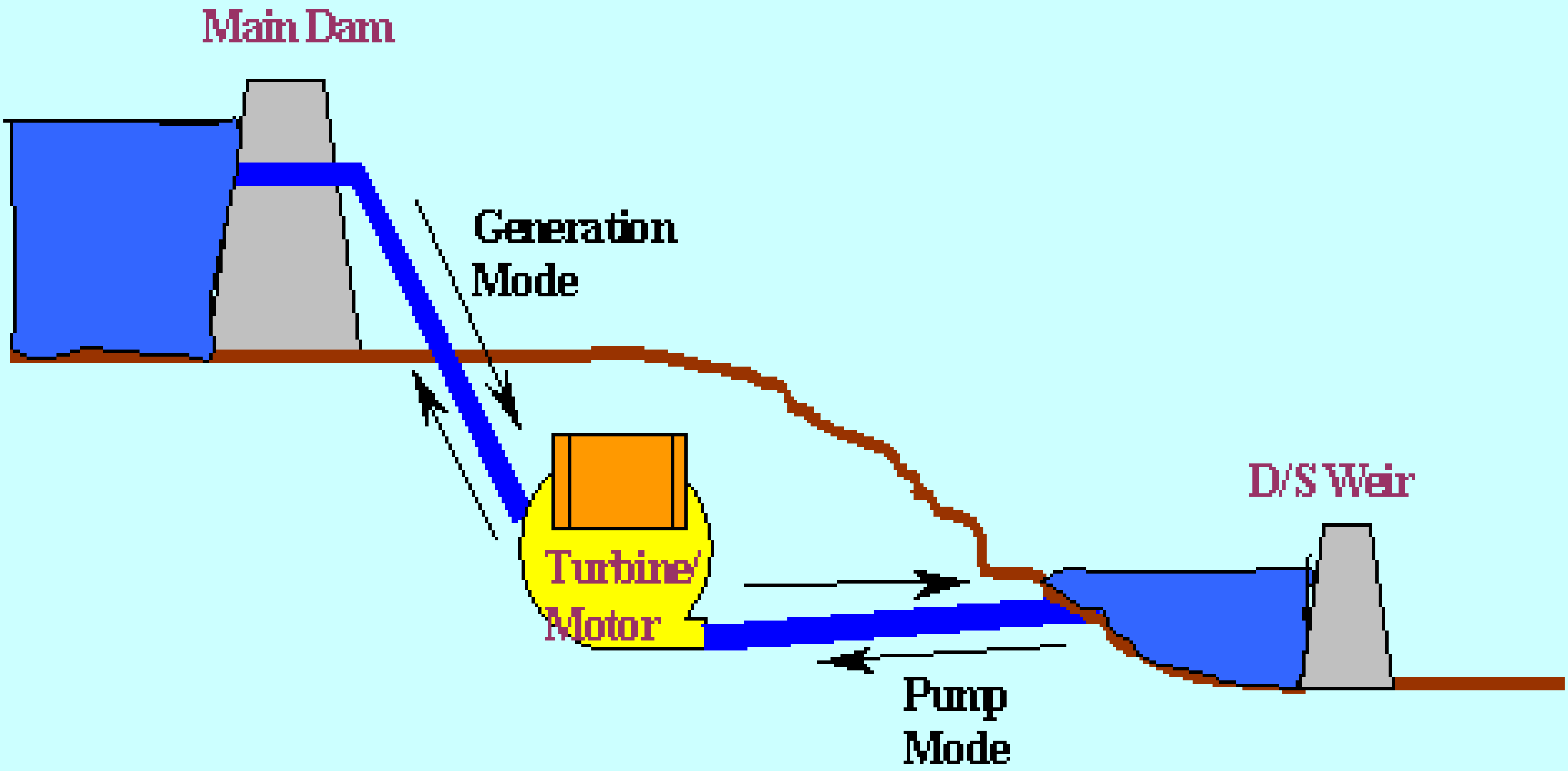
Impact of RE : 01.12.2017



Way Forward

Hydro generation with pump mode features

Typical arrangement for Pump Mode operation



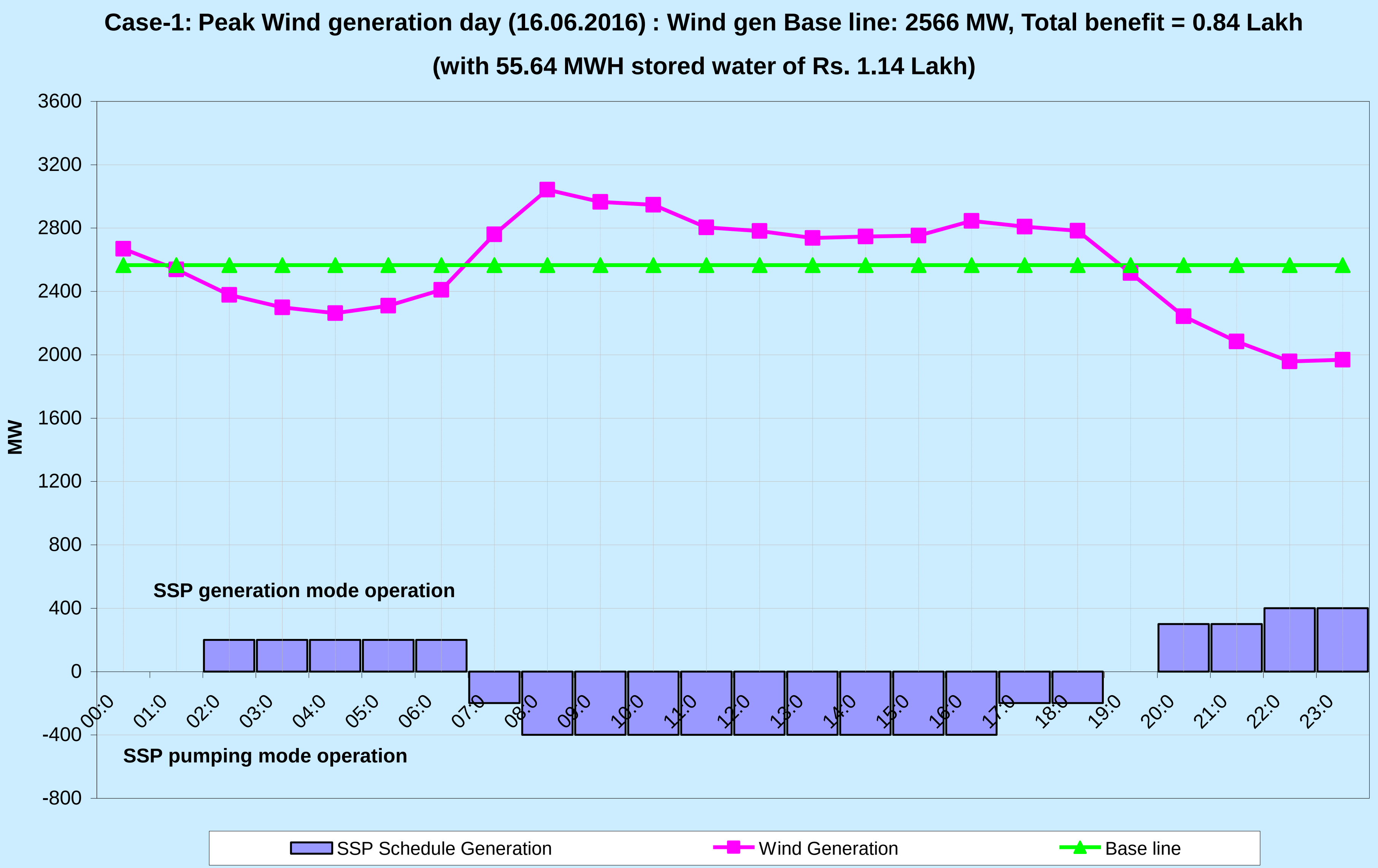
Role of Pump Storage for RE integration

- System operator needs immediate balancing measures to counter the variability of RE, load demand and grid security.
- Measures
  - Ramping Up & Down conventional generators – uneconomical and increased stresses
  - Shedding of Loads : undesirable & public inconvenience
  - To bring the required generation at a speed to match the rate of variability of RE.
  - Gas generation, Hydro generation are best balancing options
  - Gas generation is quite costly solution
  - Hydro generation is the most cheaper and viable option.
  - The hydro generation having a pump mode operation is superior balancing option compared to run of river hydro projects.

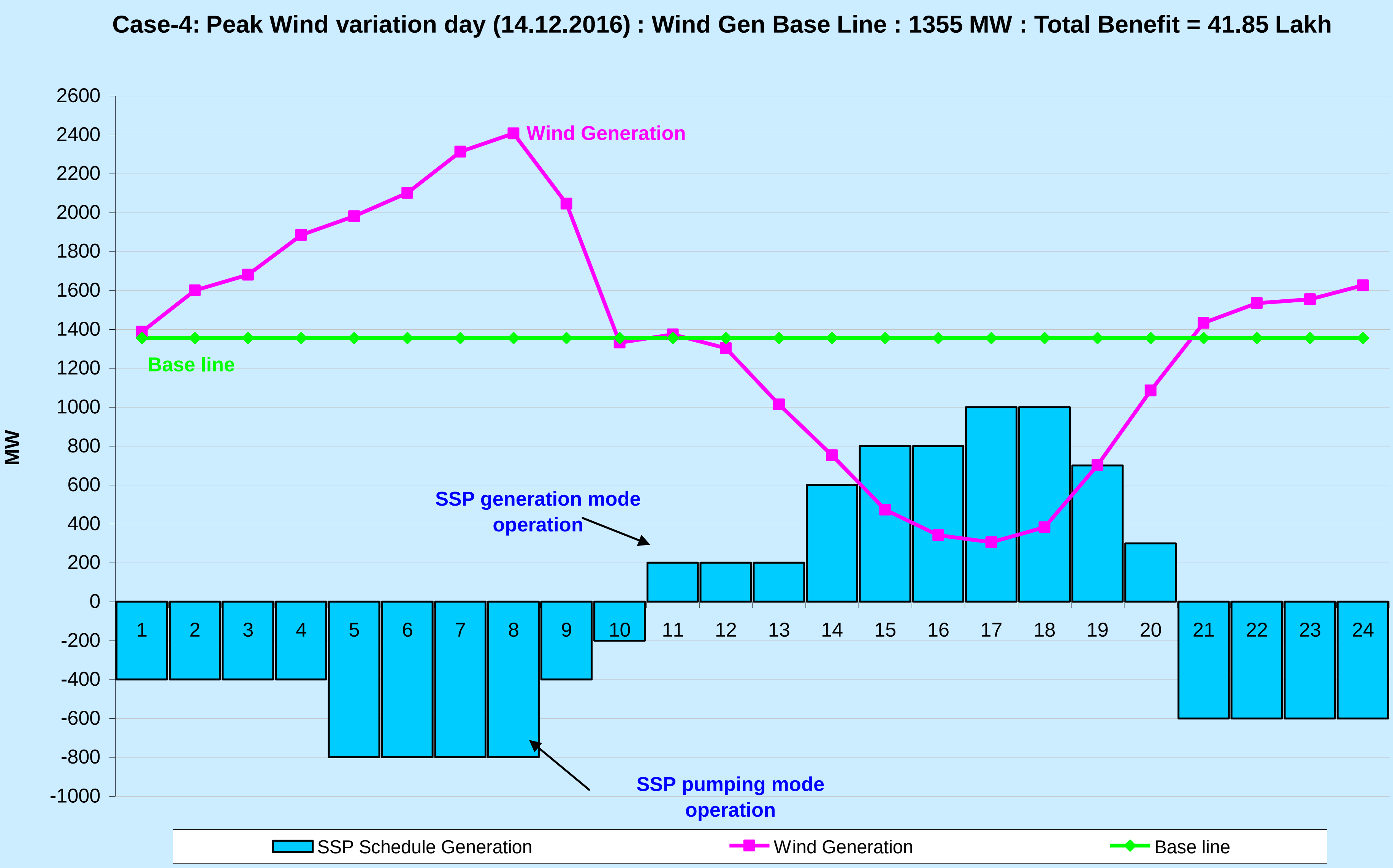
Cost Analysis for Pump Storage Plant

Operation of Hydro machines in pumping mode - Example

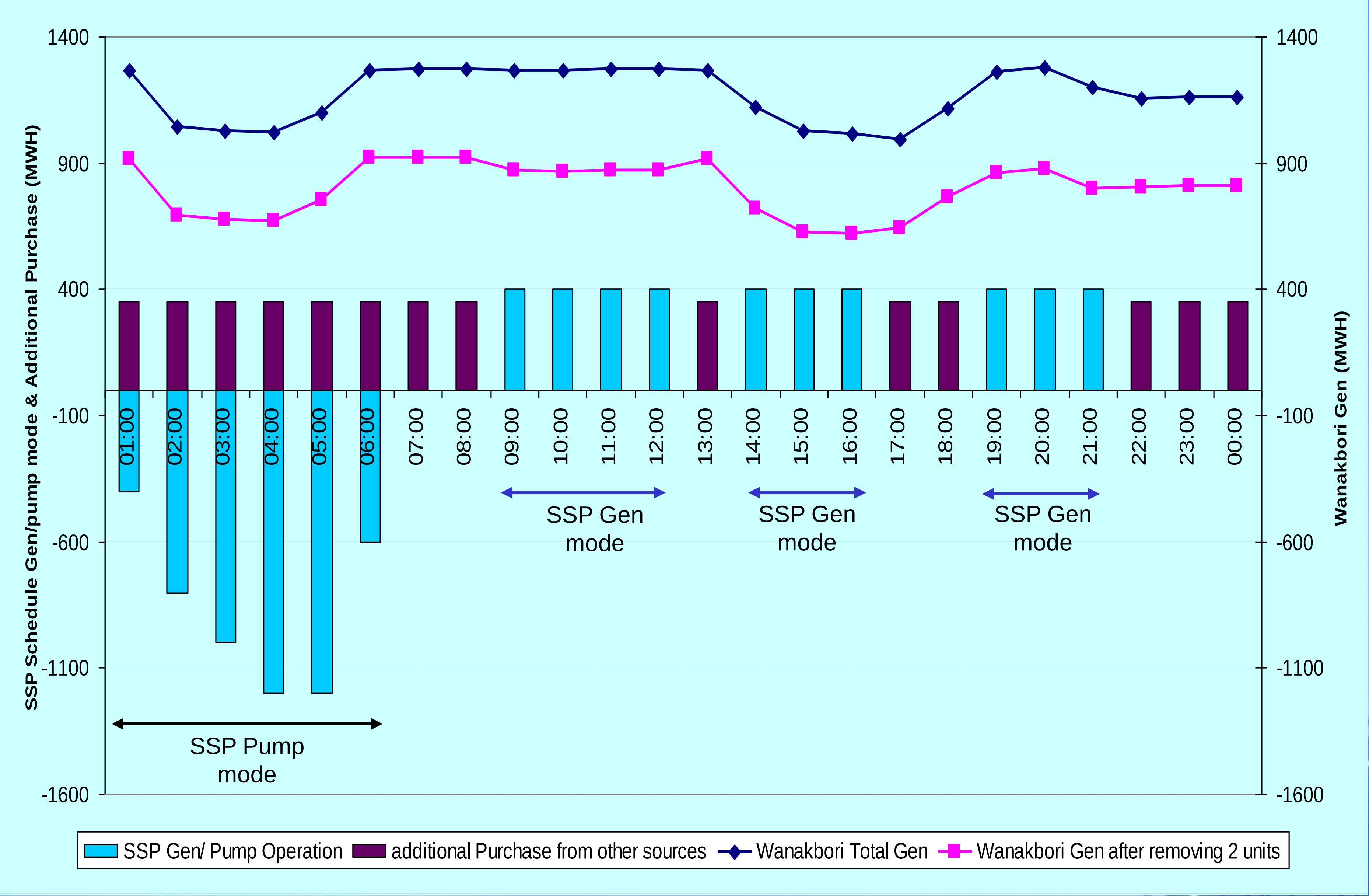
Case-1: Benefit during Peak Wind generation day (16.06.2016)



Case-2: Benefit during Peak wind variation day (14.12.2016)

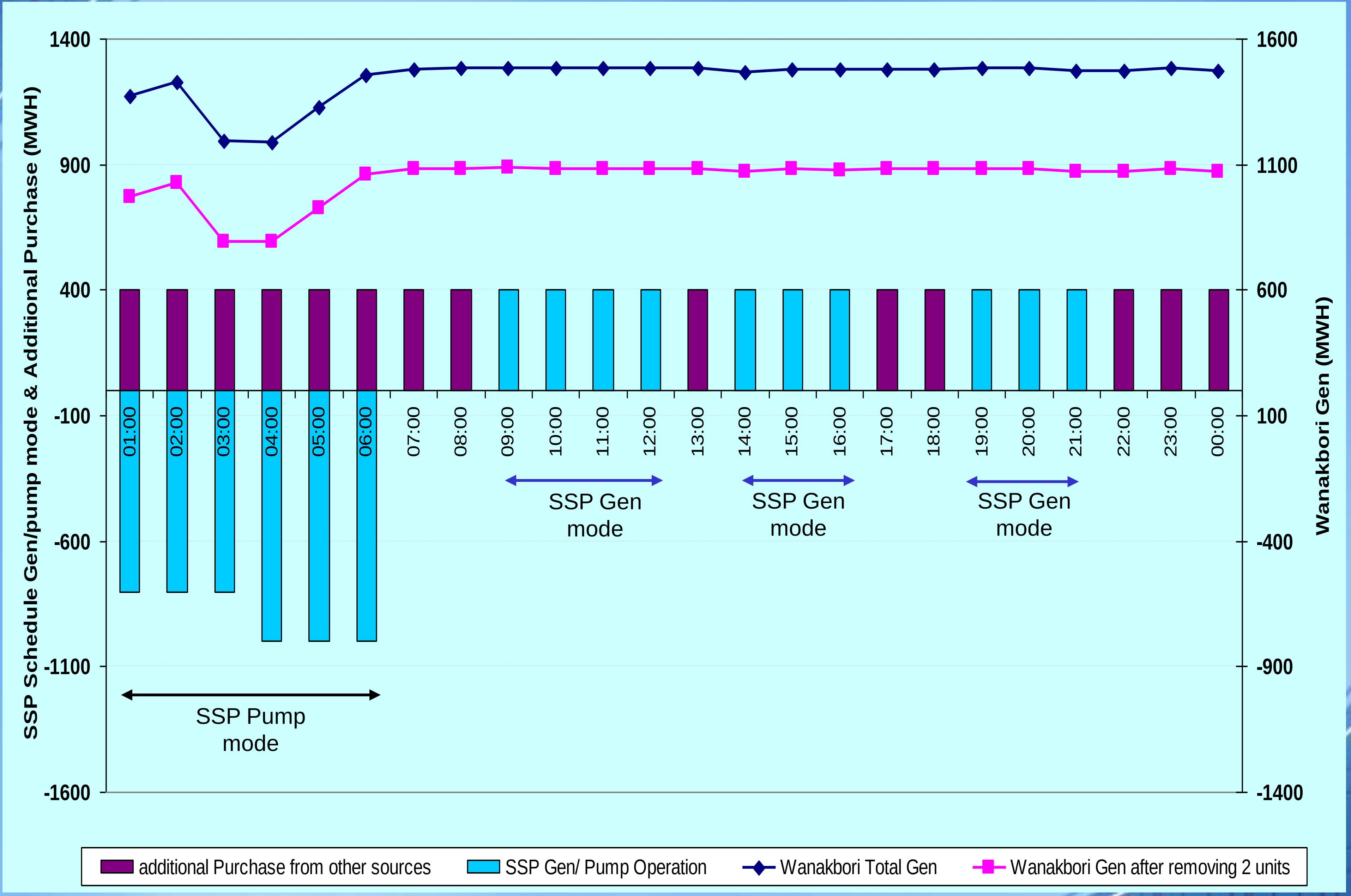


Case-3 : Replacement of 2 units of WTPS by SSP Gen on 23.01.2018
Total Benefit : 13 Lac

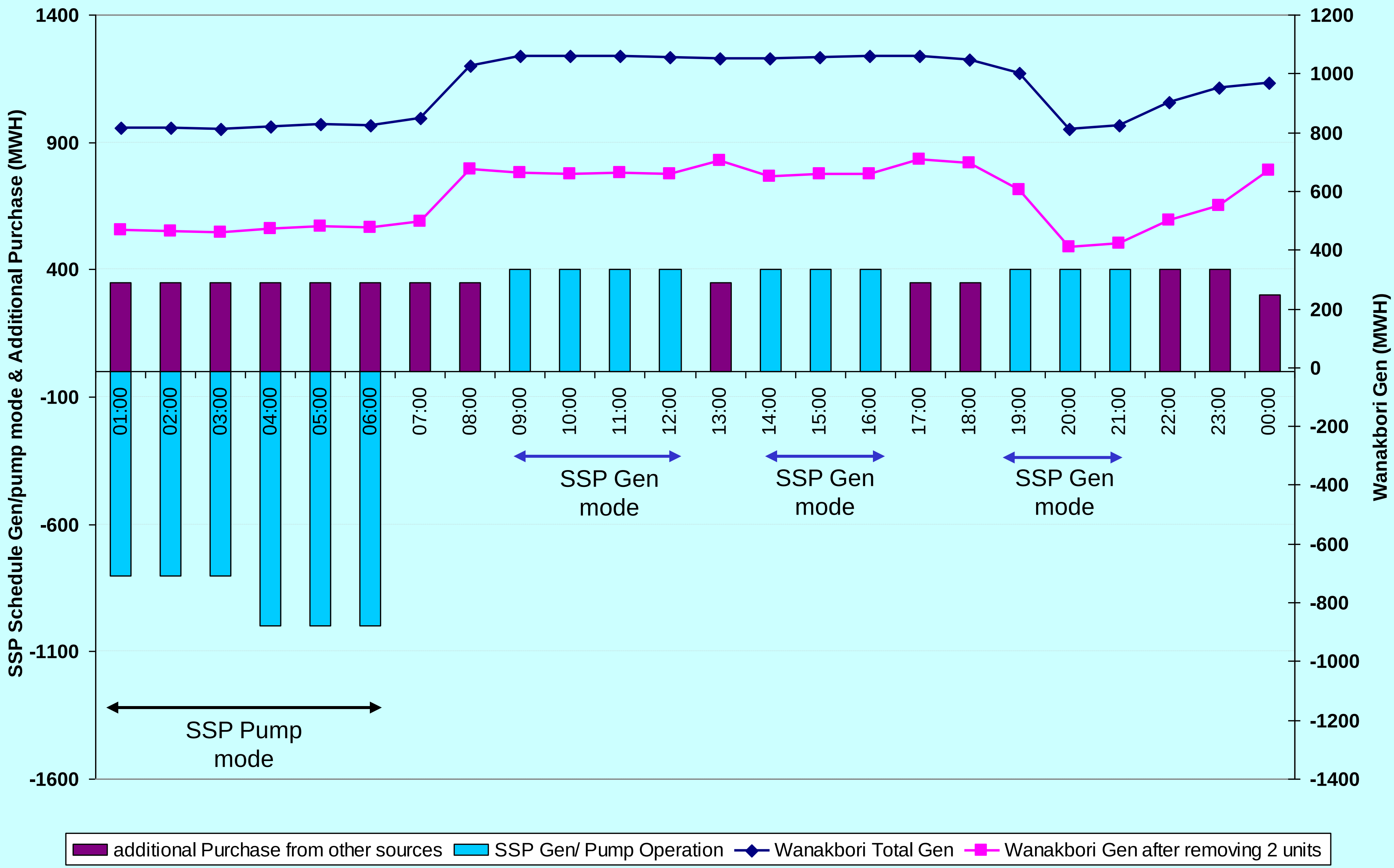


Case-4 : Replacement of 2 units of WTPS by SSP Gen on 04.01.2018

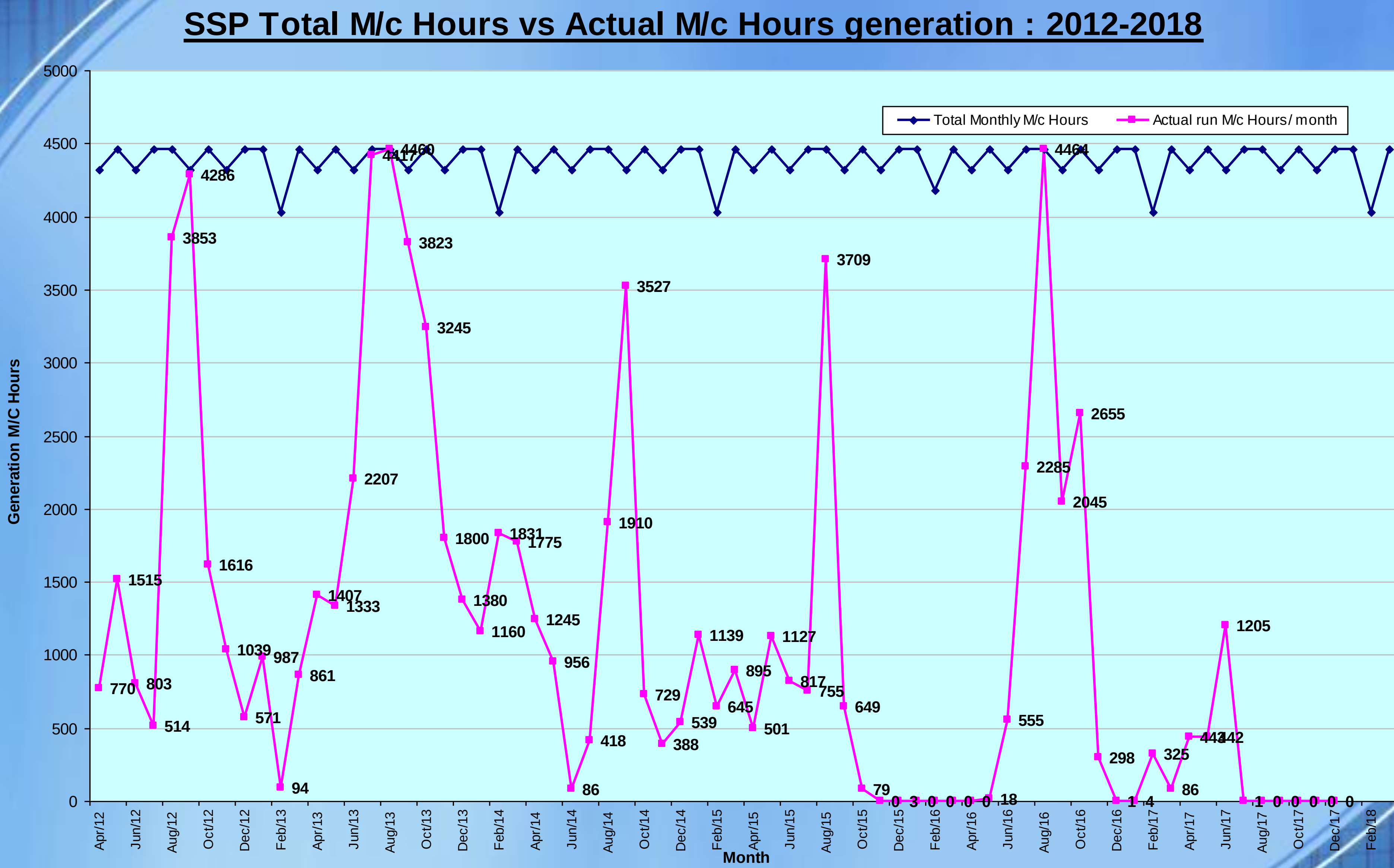
Total Benefit : 11 Lac



Case-5 : Replacement of 2 units of WTPS by SSP Gen on 15.12.2017
Total Benefit : 11 Lac



SSP Total Machine Hours Vs. Actual Machine Hours



Courtesy : SSNNL submission

Operational Status since its commissioning in Conventional Mode

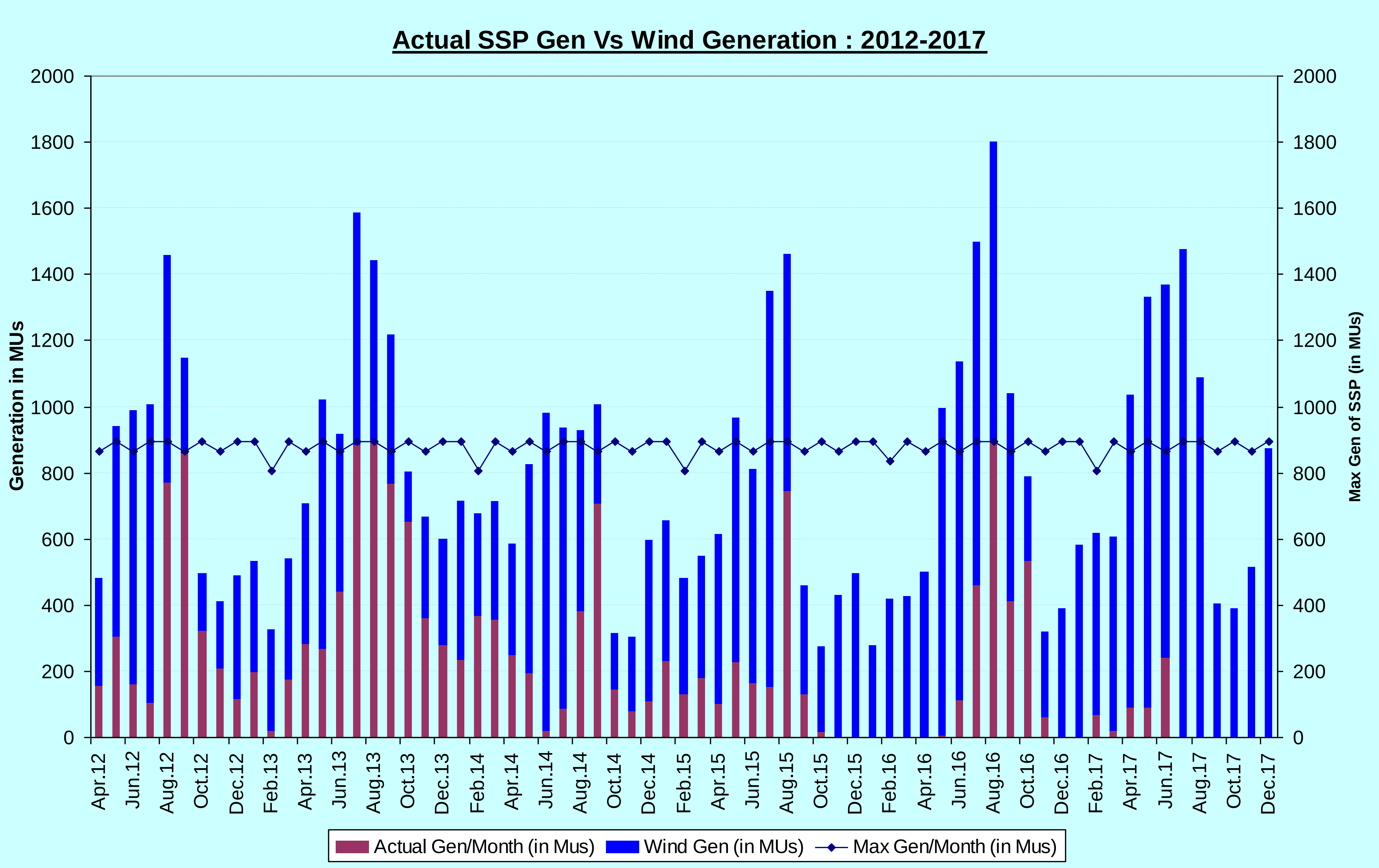
- Total Machine Hour available per year = 6 X 24 X 365 = 52560 Hours
- Machine Hour Utilized so far in last 6 years

	Year	Year-days	M/c Hours/day	Total Monthly M/c Hours/year	Actual run M/c Hours/ year	**% utilization***
1	2012-13	365	144	52560	16909	**32.1%**
2	2013-14	365	144	52560	28838	**54.9 %**
3	2014-15	365	144	52560	12477	**23.7 %**
4	2015-16	366	144	52704	7640	**14.5 %**
5	2016-17	365	144	52560	12736	**24.2 %**
6	2017-18	365	144	52560	2091	**4 %**

(*) : Balance Machine Hours can be used for following

1. To generate the electricity during peak time
2. To absorb the electricity during off-peak time through pumping operation and storage of energy in form of water head
3. Operation of the machines to maintain grid discipline against variability on account of Renewable Energy (RE)/
4. Increase in Plant Load Factor (PLF) and maximum utilization of machines.

SSP generation & wind generation : Opportunities



Pump storage hydro plant (India as whole)

State	Name of Project	Unit	Installed Capacity	Pumping mode operation
Gujarat	**Kadana St. I&II**	**4 X 60**	**240**	**Not Working**
	Sardar Sarovar	**6x200**	**1200**	**Not working**
Andhra Pradesh	**Nagarjuna Sagar**	**7 X 100.80**	**705.60**	**Not Working**
	Srisailam LBPH	6x150	900	Working
Tamil Nadu	Kadamparai	4x100	400	Working
DVC	**Panchet Hill**	**1x40**	**40**	**Not working**
Maharashtra	Bhira	1x150	150	Working
	Ghatgar	2x125	250	Working
West Bengal	Purlia PSS	4x225	900	Working

Special focus on large size balancing with multi State beneficiary either of existing / inoperative / under construction project is MUST.

Source: Large Scale Grid Integration of Renewable Energy - CEA

Pump storage hydro plant : Status

Status of Pumping mode operation	Installed Capacity	Nos. of Plant	State-wise Installed Capacity in MW
Existing	**4785.60**	**9**	GJ, MH, AP, TN, WB, DVC
Working	**2600**	**5**	TN (400), MH (400), AP (900), WB (900)
Non Working	**2185.6**	**4**	GJ (1440), AP (750), DVC(40)
Under Construction	**1080**	**2**	UTK (1000), MH (80)
Under Planning	**2600**	**4**	TN (500), MH (1100), WB (1000)

New specially built / commenced balancing project to be drafted as multi State.

Need for Pump storage hydro plant

Most reliable, feasible, accessible

- All inoperative pump mode hydro plant shall be made operative on highest priority.
- Plant wise follow up and monitoring at highest level of MoP, CEA and Utility.
- Regulatory framework for pump mode operation will be required from Hon'ble commission.
- The operation of balancing plant for other State (mutual agreement between States), policy to be finalized and RLDC should encourage without any additional charges up to allotted transmission capacity.
- A research work may be entrusted to reputed institute/agencies for converting conventional hydro in to pump mode by change in turbine, additional tail race etc. which shall be mandatory in future.

Conclusion

Ambitious target to achieve 60 GW wind & 100 GW solar generation by 2020-22.

It is suggested to……

pool pump mode sources at regional level and use them in the grid as and when required.

In a way,

RE generation to be given status of national asset and such pump storage scheme would act as a balancing mechanism of the grid.

Thanking you !!!

RE Rich State Statistic

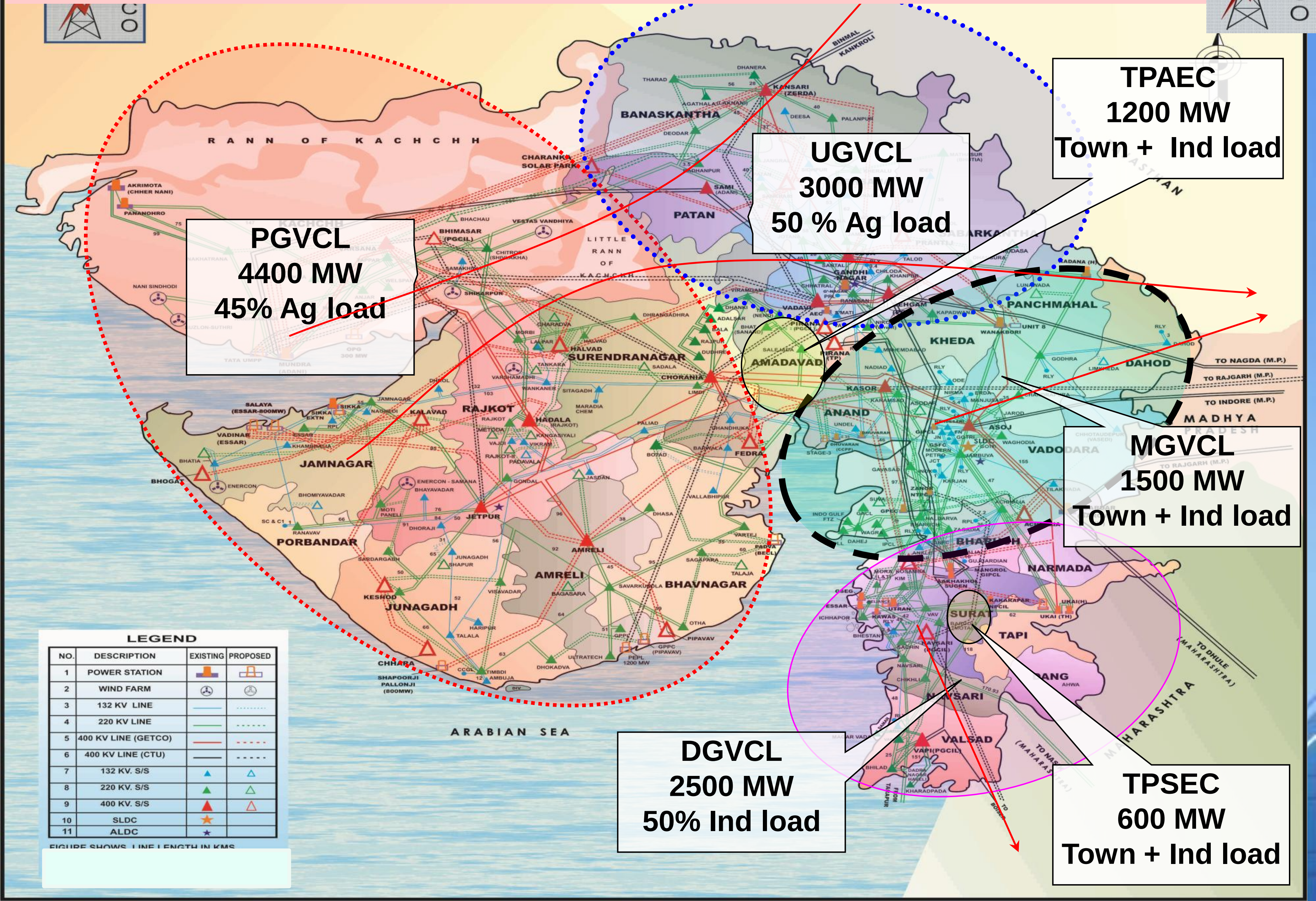
Source of power	Coal	Gas	Diesel	Nuclear	Hydro	Non RE	RE	Total
Installed Capacity (MW)	192972	25150	838	6780	44963	270995	60854	330260
Percentage (%)	**58**	**8**	**0**	**2**	**14**	**82**	**18**	**100**

Region	State**	Coal	Gas	Diesel	Nuclear	Hydro	Non RE	RE*	Total
SR	Tamil Nadu	13547	1027	412	1448	2203	**18637**	**10820**	29277
	Karnataka	9408	0	153	698	3600	**13859**	**8431**	21492
	Andhra P	9891	3930	37	127	1674	**15659**	**6598**	22069
WR	Gujarat	15528	6562	0	559	772	**19980**	**6973**	26951
	Maharashtra	26845	3753	0	690	3332	**34620**	**7977**	42269
	Madhya P	12375	357	0	273	3224	**16228**	**3891**	19766
NR	Rajasthan	10905	825	0	557	1931	**14199**	**6737**	20585
RE rich State	Total MW	96661	14825	602	4352	16742	**133182**	**49227**	182409
	Percentage (%)	52	9	0	2	9	**73**	**27**	100

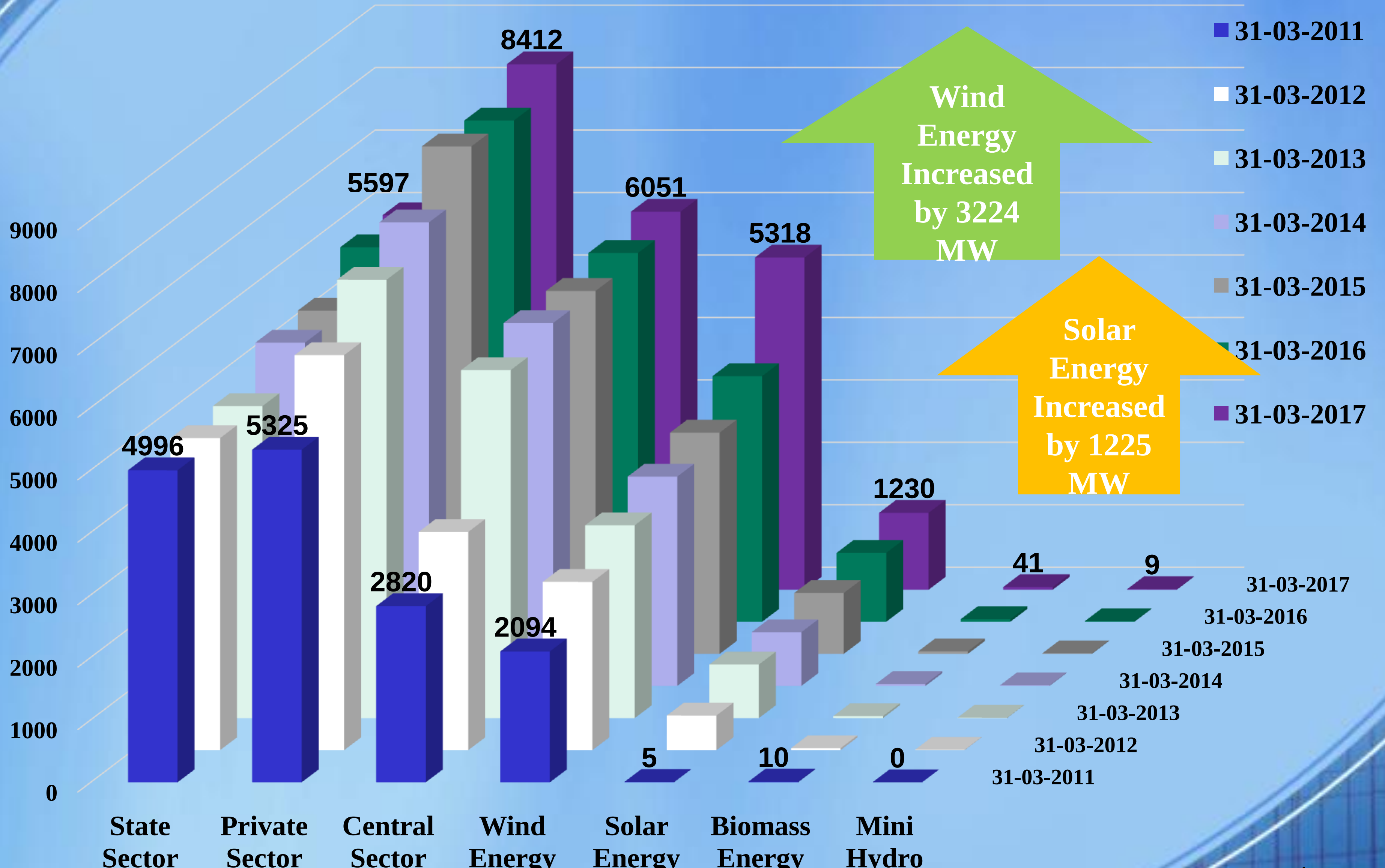
Note(*): Wind, Solar, Biomass, West to energy, etc.

** Source CEA –Dec 17

Gujarat Load Diversity Scenario



RE Development So far…

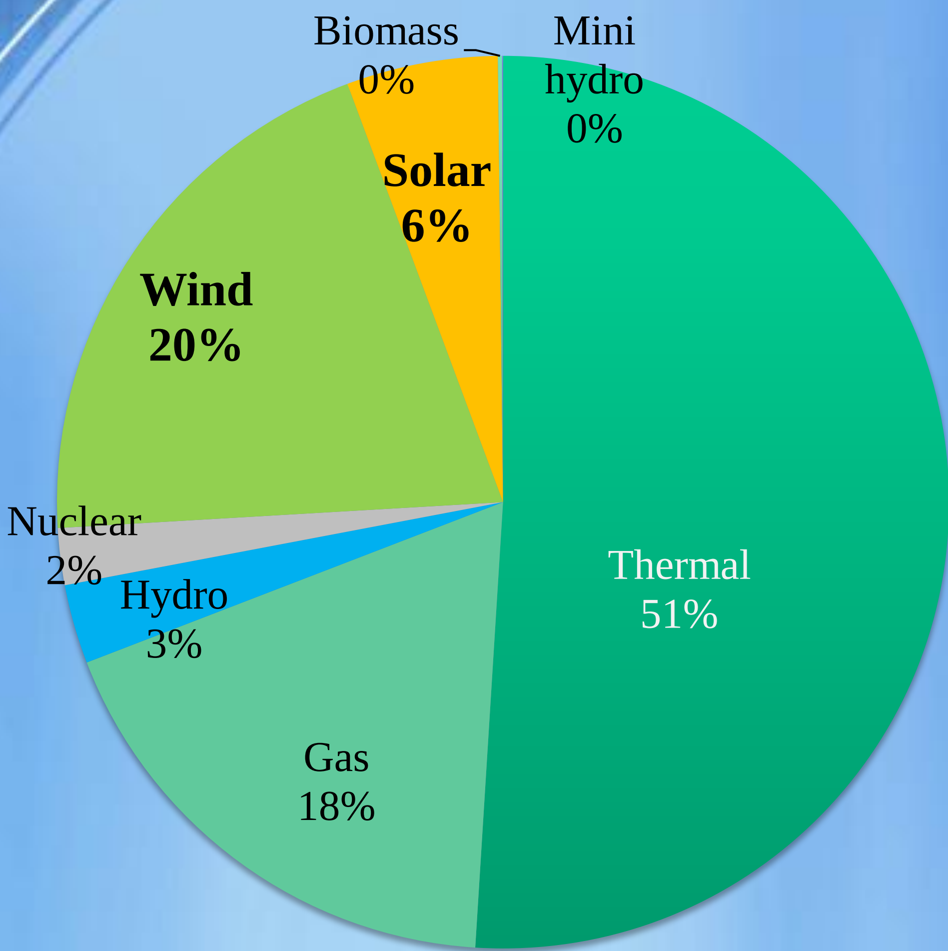


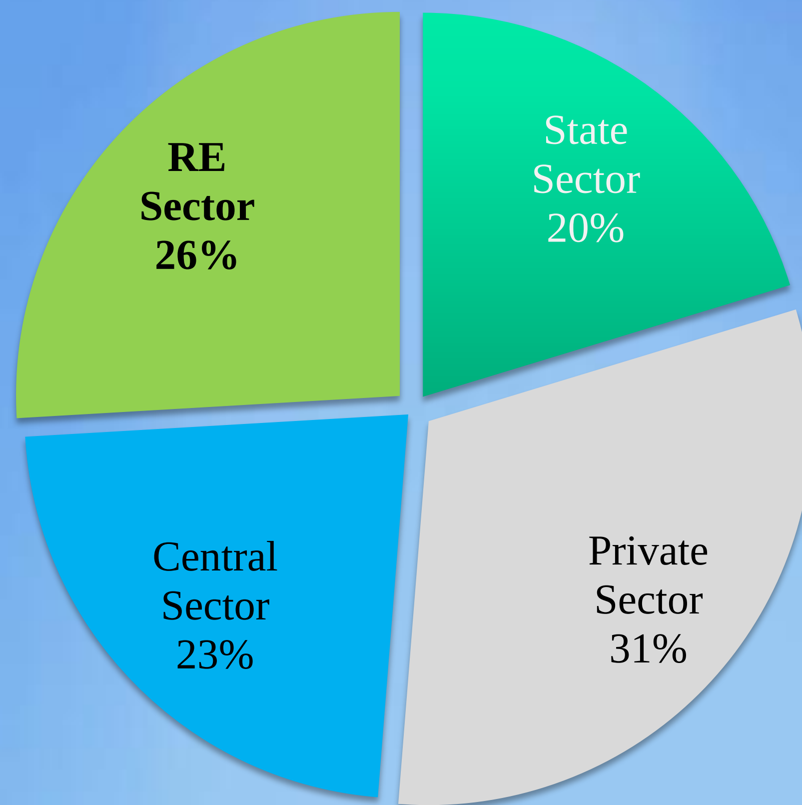
Data in MW

RE Operational Statistics in Gujarat

System scenario	Energy	Date	Remark
Max Catered in Mus	372.657	06.10.17	Max 17003 MW
Max Catered in MW	17097	09.10.17 @ 15.00 hrs	Total 366.573 Mus
Max Wind Gen in Mus	75.87	05.07.17	Max 3763 MW @ 18.00 hrs & Min 2433 MW
Max Wind Gen in MW	3763		
Max Solar Gen in Mus	7.01	18.01.18	Max 1018 MW @ 13.00 hrs & Min 0 MW
Max Solar Gen in MW	1018		

RE Installed Capacity & Actual Generation

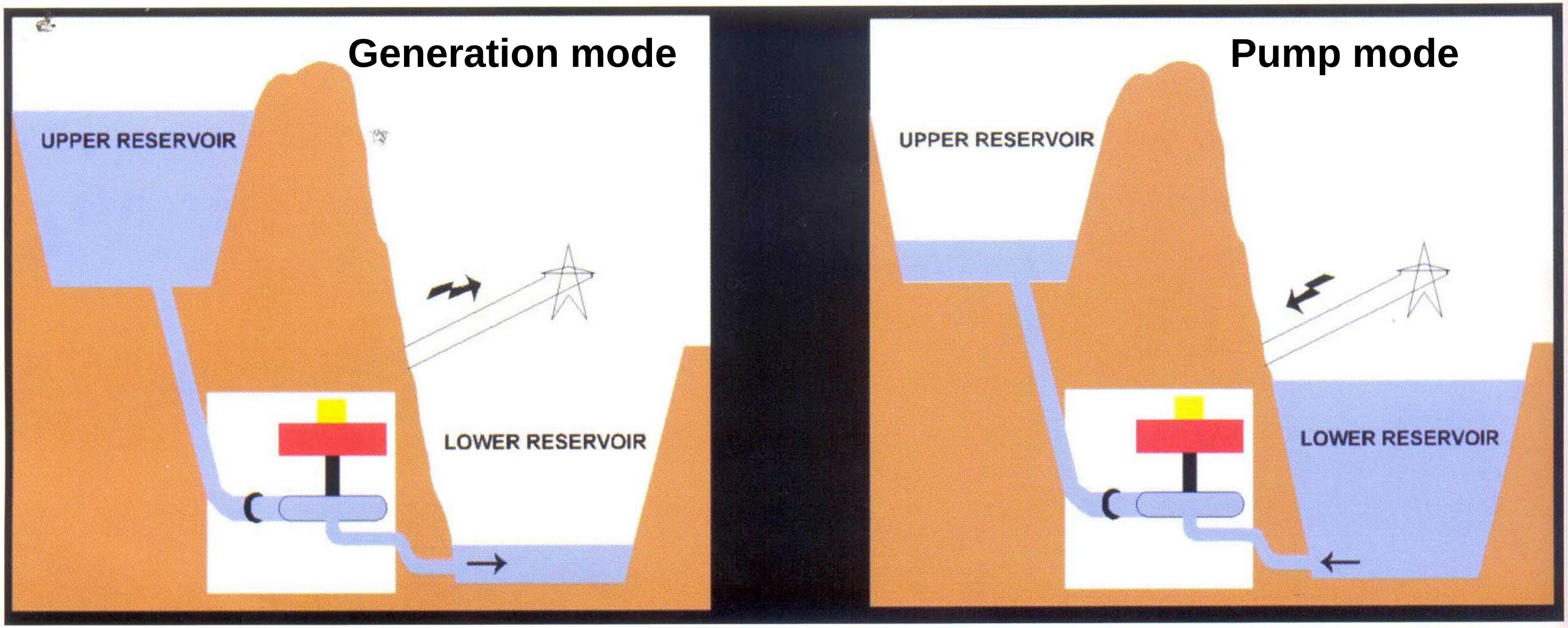




RE Source	Solar Energy of Total Inst. Cap.	Wind Energy of Total Inst. Cap.
RE Installed Capacity	6%	20%
RE Actual Injection	2%	8%

Pumped storage hydro power plant is a type of hydroelectric generation plant that stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation reservoir. It pumps water from lower reservoir to upper reservoir during off-peak period and generates electricity during peak periods. This is currently one of the most effective means of storing large amount of electrical energy. It helps in power generation load levelling.

Possible & Reliable Solution: View of Gujarat



Case-1: Benefit during Peak Wind generation day (16.06.2016)

- The peak wind generation day on 16.06.2016 is considered for the study. The wind generation baseline considered as 2566 MW for an entire day.
- In this scenario,
  - During High wind instances: scheduled costly generation is to be backed down as per merit order criteria.
  - Suddenly drop/ low wind generation instances: ramp up backed down generation / costly generation
- In view of above, the benchmark /base line of wind generation is considered for harnessing the Surplus / shortfall wind generation as
- Surplus wind generation instances using pumping operation of SSP
- Shortfall wind generation instances utilize generation operation of SSP

Case-1: Benefit during Peak Wind generation day (16.06.2016)

Sr. No.	Case-2 : Utilizing Cheaper power for pumping & generation through SSP	
	Content	
1	Wind Generation (Mus)	61.60
2	Energy Catered (Mus)	248.76
3	Power generated in Generation mode (Mus) for **11 M/c Hrs**	2.20
4	Power consume for pumping mode operation (Mus) for **20 M/c Hrrs**	3.99
Benefit		**Rs. In Lakh**
5	Total cost to pump water by utilizing cheap power available on that day of 3.99 MUs (Avg cost = 1.62/unit)	64.64
6	Saving cost due to backdown costly generators of 2.20 MUs (Avg cost = Rs. 2.99/unit)	65.78
7	Revenue using SSP as generators as 2.20 MUs (Rs. 2.05/unit)	45.10
8	Additional cost for pumping water (8) = (5)-(7))	19.54
9	Benefit due to backdown costly Generator and utilizing pumped hydro generation (9)=(6) - ((7)+(8))	**1.14**
10	Balance Stored MWH (Pump-Gen)	55.64
11	Stored water Cost (Rs. In Lakh)	**1.14**
12	**Machine Hours available /day in Gen/Pump mode**	
	Max. Machine Hours/ day for generation	63
	Max Machine Hours/ day for pumping	81
	Max Total Machine Hours/Day	144
	Actual. Machine Hours/ day for generation	11
	Actual Machine Hours/ day for pumping	20
	Total Machine Hours/ day	31
13	Total Benefit / day (9+11)	2.28
14	If such 3 cycle if operate in a day than total benefit / day (Sr. 13) X 3	6.84
15	Total Benefits / year (Rs. in Lakh) if such instance 10 times in month : (Sr. 14) X 10 instances X 12 months	**821**

Case-2: Benefit during Peak wind variation day (14.12.2016)

- The peak wind variation generation day on 14.12.2016 is considered for the study. The wind generation baseline considered as 1355 MW for an entire day.
- In this scenario,
    - During High wind instances: scheduled costly generation is to be backed down as per merit order criteria.
    - Suddenly drop/ low wind generation instances: ramp up backed down generation / costly generation
- In view of above, the benchmark /base line of wind generation is considered for harnessing the Surplus / shortfall wind generation as
    - Surplus wind generation instances using pumping operation of SSP
    - Shortfall wind generation instances utilize generation operation of SSP

Case-2: Benefit during Peak wind variation day (14.12.2016)

Sr. No.	Case-3: Peak wind variation day (14.12.16) : SSP pumping/ generation mode performed to balance variability	
	Content	
1	Wind Generation (Mus)	32.61
2	Energy Catered (Mus)	266.54
3	Power generated in Generation mode (Mus) **for 29 M/c Hours**	5.80
4	Power consume for pumping mode operation (Mus) **for 39 M/c Hours**	7.80
Benefit		**Rs. In Lakh**
5	Total cost to pump water by utilizing cheap power available on that day of 7.80 MUs (5.7 MUs @ Rs. 1.69/unit & 2.07 MUs @ Rs. 2.46/uint)	147.81
6	Saving cost due to backdown costly generators of 5.80 MUs (at Average Rs. 3.27/ unit)	189.66
7	Revenue using SSP as generators as 5.80 MUs (@ Rs. 2.05/unit)	118.90
8	Additional cost for pumping water (8) = (5)-(7))	28.91
9	Benefit due to backdown costly Generator and utilizing pumped hydro generation (9)=(6) - ((7)+(8))	**41.85**
10	**Machine Hours / Day**	
	Max. Machine Hours/ day for generation	63
	Max Machine Hours/ day for pumping	81
	Max Total Machine Hours/Day	144
	Actual. Machine Hours/ day for generation	29
	Actual Machine Hours/ day for pumping	39
	Total Machine Hours/ day	68
11	Total Benefit / day (9)	41.85
12	Total benefits / year **Rs. In Lakh** if such instance 10 times in month : (Sr. 11) X 10 instances X 12 months	**5022**

Case-3 : Replacement of 2 units of WTPS by SSP Gen on 23.01.2018

Sr. No.	Hrs.	Wanakbori Total Gen	Wanakbori Gen after removing 2 units	Wanakbori 2 unit gen pattern	SSP Operation Gen	SSP Operation Pump	additional Purchase from other sources
1	01:00	1267	917	350		-400	350
2	02:00	1044	694	350		-800	350
3	03:00	1025	675	350		-1000	350
4	04:00	1020	670	350		-1200	350
5	05:00	1101	751	350		-1200	350
6	06:00	1268	918	350		-600	350
7	07:00	1272	922	350	0		350
8	08:00	1270	920	350	0		350
9	09:00	1268	868	400	400		
10	10:00	1265	865	400	400		
11	11:00	1273	873	400	400		
12	12:00	1270	870	400	400		
13	13:00	1264	914	350	0		350
14	14:00	1119	719	400	400		
15	15:00	1027	627	400	400		
16	16:00	1017	617	400	400		
17	17:00	991	641	350	0		350
18	18:00	1114	764	350	0		350
19	19:00	1261	861	400	400		
20	20:00	1275	875	400	400		
21	21:00	1200	800	400	400		
22	22:00	1153	803	350	0		350
23	23:00	1159	809	350	0		350
24	00:00	1159	809	350	0		350
Total		**28082**	**19182**	**8900**	**4000**	**-5200**	**4900**

SR. NO.		MWH	Rs (in Lac)
1	Total Gen by Wanakbori (@Rs.3.65/-)	8900	324.85
2	From Grid (@ Rs. 3.65/-)	4900	178.85
3	Revenue from SSP (@Rs. 2.05/-)	4000	82
4	Pumping mode op of SSP @ Rs. 2.50 from Grid	5320	133
5	Addition cost for pumping (4)-(3)		51
6	Total Benefit [(1)-{(2)+(3)+(5)}]		13.00

Case-4 : Replacement of 2 units of WTPS by SSP Gen on 04.01.2018

Sr. No.	Hrs.	Wanakbori Total Gen	Wanakbori Gen after removing 2 units	Wanakbori 2 unit gen pattern	SSP Gen/ Pump Operation		additional Purchase from other sources
					Gen	Pump	
1	01:00	1371	971	400		-800	400
2	02:00	1426	1026	400		-800	400
3	03:00	1191	791	400		-800	400
4	04:00	1189	789	400		-1000	400
5	05:00	1326	926	400		-1000	400
6	06:00	1457	1057	400		-1000	400
7	07:00	1480	1080	400	0		400
8	08:00	1484	1084	400	0		400
9	09:00	1485	1085	400	400		
10	10:00	1483	1083	400	400		
11	11:00	1484	1084	400	400		
12	12:00	1483	1083	400	400		
13	13:00	1481	1081	400	0		400
14	14:00	1468	1068	400	400		
15	15:00	1479	1079	400	400		
16	16:00	1476	1076	400	400		
17	17:00	1479	1079	400	0		400
18	18:00	1480	1080	400	0		400
19	19:00	1484	1084	400	400		
20	20:00	1482	1082	400	400		
21	21:00	1473	1073	400	400		
22	22:00	1473	1073	400	0		400
23	23:00	1481	1081	400	0		400
24	00:00	1473	1073	400	0		400
Total		**34588**	**24988**	**9600**	**4000**	**-5400**	**5600**

SR. NO.		MWH	Rs (in Lac)
1	Total Gen by Wanakbori (@ Rs. 3.65/-)	9600	350.40
2	From Grid (@ Rs. 3.65/-)	5600	204.4
3	Revenue from SSP (@ Rs. 2.05/-)	4000	82
4	Pumping mode op of SSP @ Rs. 2.50 from Grid	5400	135
5	Addition cost for pumping (4)-(3)		53
6	Total Benefit [(1)-{(2)+(3)+(5)}]		11.00

Sr. No.	Hrs.	Wanakbori Total Gen	Wanakbori Gen after removing 2 units	Wanakbori 2 unit gen pattern	SSP Gen/ Pump Operation		additional Purchase from other sources
					Gen	Pump	
1	01:00	817	467	350		-800	350
2	02:00	813	463	350		-800	350
3	03:00	810	460	350		-800	350
4	04:00	821	471	350		-1000	350
5	05:00	828	478	350		-1000	350
6	06:00	824	474	350		-1000	350
7	07:00	848	498	350	0		350
8	08:00	1026	676	350	0		350
9	09:00	1060	660	400	400		
10	10:00	1059	659	400	400		
11	11:00	1061	661	400	400		
12	12:00	1056	656	400	400		
13	13:00	1052	702	350	0		350
14	14:00	1050	650	400	400		
15	15:00	1056	656	400	400		
16	16:00	1058	658	400	400		
17	17:00	1059	709	350	0		350
18	18:00	1046	696	350	0		350
19	19:00	1003	603	400	400		
20	20:00	810	410	400	400		
21	21:00	822	422	400	400		
22	22:00	901	501	400	0		400
23	23:00	950	550	400	0		400
24	00:00	969	669	300	0		300
Total		**22799**	**13849**	**8950**	**4000**	**-5400**	**4950**

Case-5 : Replacement of 2 units of WTPS by SSP Gen on 15.12.2017

SR. NO.		MWH	Rs (in Lac)
1	Total Gen by Wanakbori (@Rs. 3.65/-)	8950	326.67
2	From Grid @ Rs. 3.65	4950	180.67
3	Revenue from SSP (@ Rs. 2.05/-)	4000	102.5
4	Pumping mode op of SSP @ Rs. 2.50 from Grid	5400	135
5	Addition cost for pumping (4)-(3)		53
6	Total Benefit [(1)-{(2)+(3)+(5)}]		11.00

Cost Benefit Analysis of Kadana, Gujarat

Cost benefit analysis of KADANA pump mode operation (for 2 machines)																
Sr. No.	Content	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Total	Rate per Unit	Amount Million RS
1	Total wind generation (MUs)	500	992	1026	1041	908	631	255	259	389	578	551	591	**7720**		
2	Total back down of all conventional ONBAR generators (MUs)	478	565	514	601	808	552	800	587	717	1211	960	506	**8298**		
3	Back down having variable cost below Rs. 2.00/Unit (Mus)	36	214	197	492	903	388	594	276	233	701	456	161	**4650**		
4	Max available potential at Kadana for the month (MUs)	57	59	57	59	59	57	59	57	59	59	53	59	**955**		
7	Generation of WTPS 1-6 in Mus	596	466	276	78	0	199	142	71	362	100	73	375	**2738**	Rate per Unit	Amount Million RS
8	Available energy for pump mode operation in Mus (Minimum of 3,4 & 7)	36	59	57	59	0	57	59	57	59	59	53	59	**614**	**2**	**1228**
9	Available Generation in Mus considering 60% efficiency	22	35	34	35	0	34	35	34	35	35	32	35	**369**	**3.5**	**1290**
	Benefit															**61.43**
																Say RS. 6.14 Cr

Enough quantum of water is available for pump mode operation at Kadana

Cost benefit analysis of SSP pump mode operation (with 6 machines)

Sr. No.	Content	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Total	Rate per Unit	Amount Million RS
1	Total wind generation (MUs)	500	992	1026	1041	908	631	255	259	389	578	551	591	**7720**		
2	Total back down of all conventional ONBAR generators (MUs)	478	565	514	601	808	552	800	587	717	1211	960	506	**8298**		
3	Total Back down having variable cost below RS. 2.00/Unit (Mus)	36	214	197	492	903	388	594	276	233	701	456	161	**4650**		
4	Max available potential at SSP for the month (MUs)	494	510	494	510	510	494	510	494	510	510	461	510	**6007**		
5	Generation of WTPS 1-6 in Mus	596	466	276	78	0	199	142	71	362	100	73	375	**2738**		
6	Available energy for pump mode operation in Mus (Minimum of 3,4 & 5)	36	214	197	78	0	199	142	71	233	100	73	161	**1504**	**2.0**	**3008**
7	Available Generation in MUs considering 75% efficiency	27	161	148	59	0	149	107	53	175	75	55	121	**1128**	**3.5**	**3948**
8	Benefit	**With the utilisation of Cheaper power of Gujarat Only**												**Say 94 Cr.**		**940**
10	Cost benefit analysis with the utilisation of Cheaper power of other States up to the available potential of SSP for pump mode (as per Sr. No. 4)															
11	Max available potential at SSP for the month (MUs)	494	510	494	510	510	494	510	494	510	510	461	510	6007	2.0	12013
12	Available Generation in MUs considering 75% efficiency	370	383	370	383	383	370	383	370	383	383	346	383	4505	3.5	15767
13	Benefit	**With the utilisation of Cheaper power of all beneficiary States**												Say 375 Cr.		3754

Civil Investigation and Planning for Pumped storage Projects in Kerala

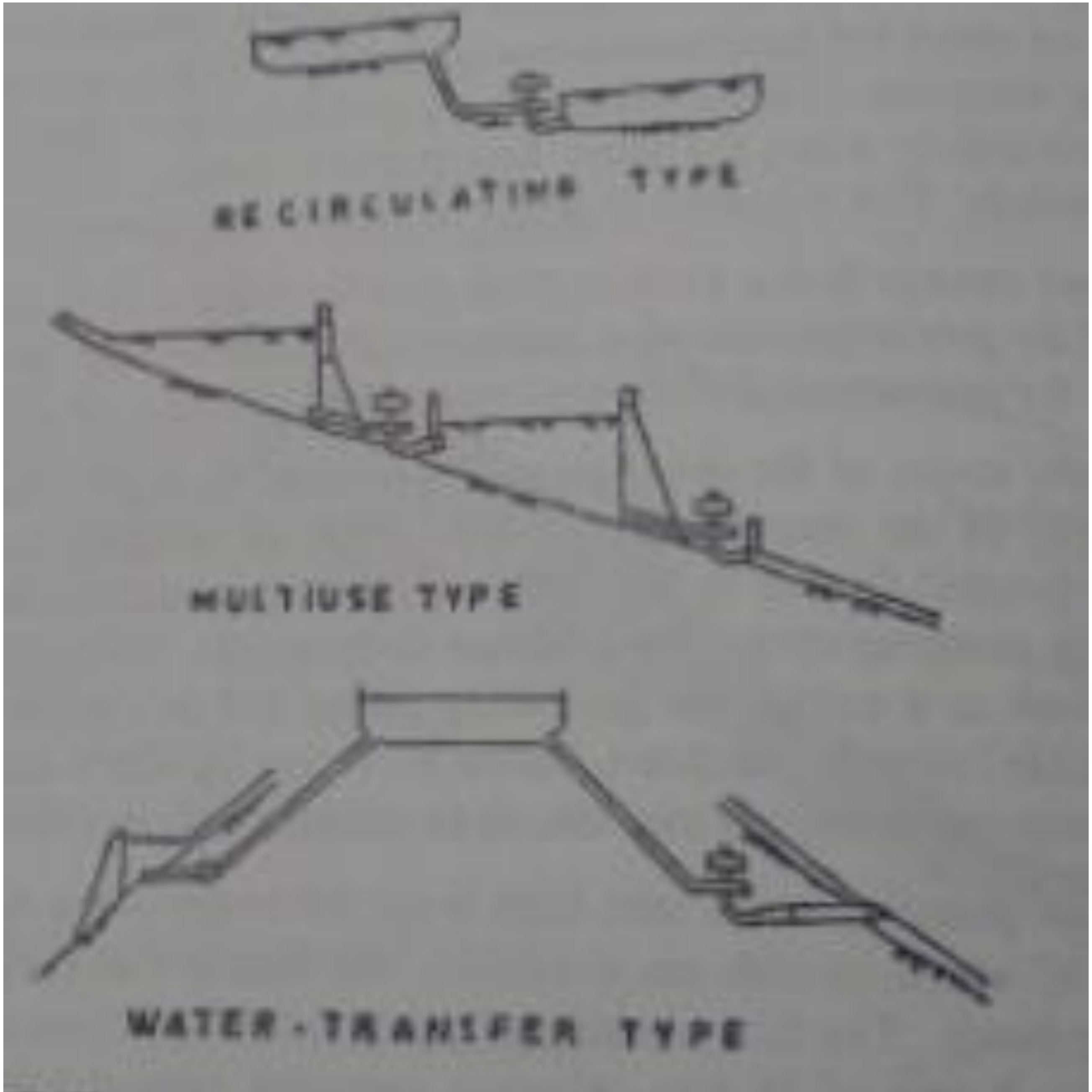
P N Biju
Executive Engineer-Civil
Head works and Tunnel Division
Pallivasal Extension Scheme
Munnar

General principle of Pumped Storage Scheme

- A Pumped storage Hydroelectric Plant may be defined as a plant in which the water that is used for power generation is pumped back into the high level reservoir using off peak power for generation of additional power during peak period

Investigation

- Types of Pumped Storage Schemes
  - Storage or Re circulating Type
  - Pond age or Multiuse Type
  - Part Head or Water user type


RECIRCULATING TYPE
MULTIUSE TYPE
WATER-TRANSFER TYPE

Investigation

- Designed for
  - For improving the daily output of a particular station
  - For improving the daily operating conditions of a large interconnected group of power stations; thermal or hydroelectric
  - For supplementing the natural flow into a storage reservoir which is insufficiently supplied by its catchment area or for increasing the firm output obtainable with the storage capacity provided

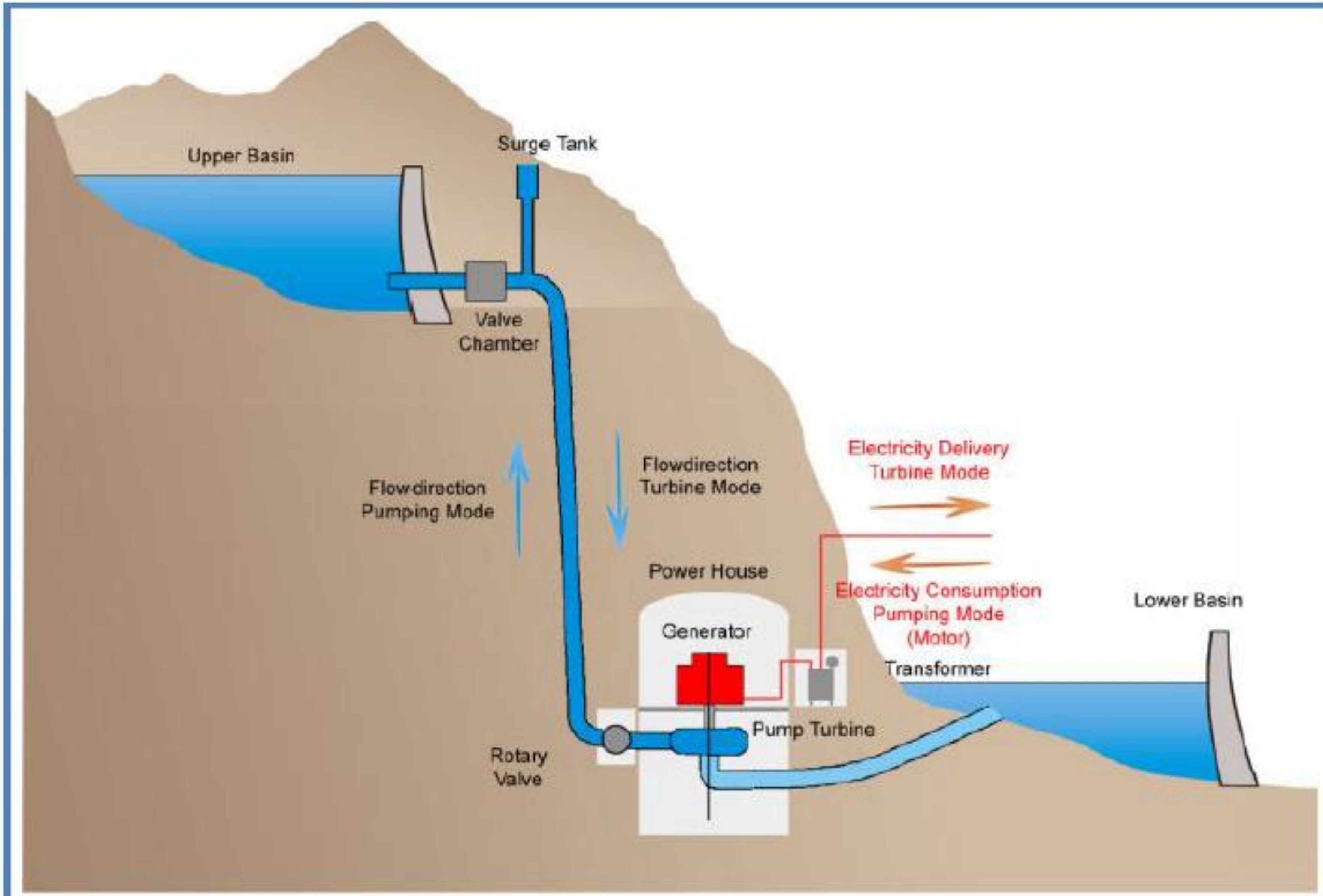
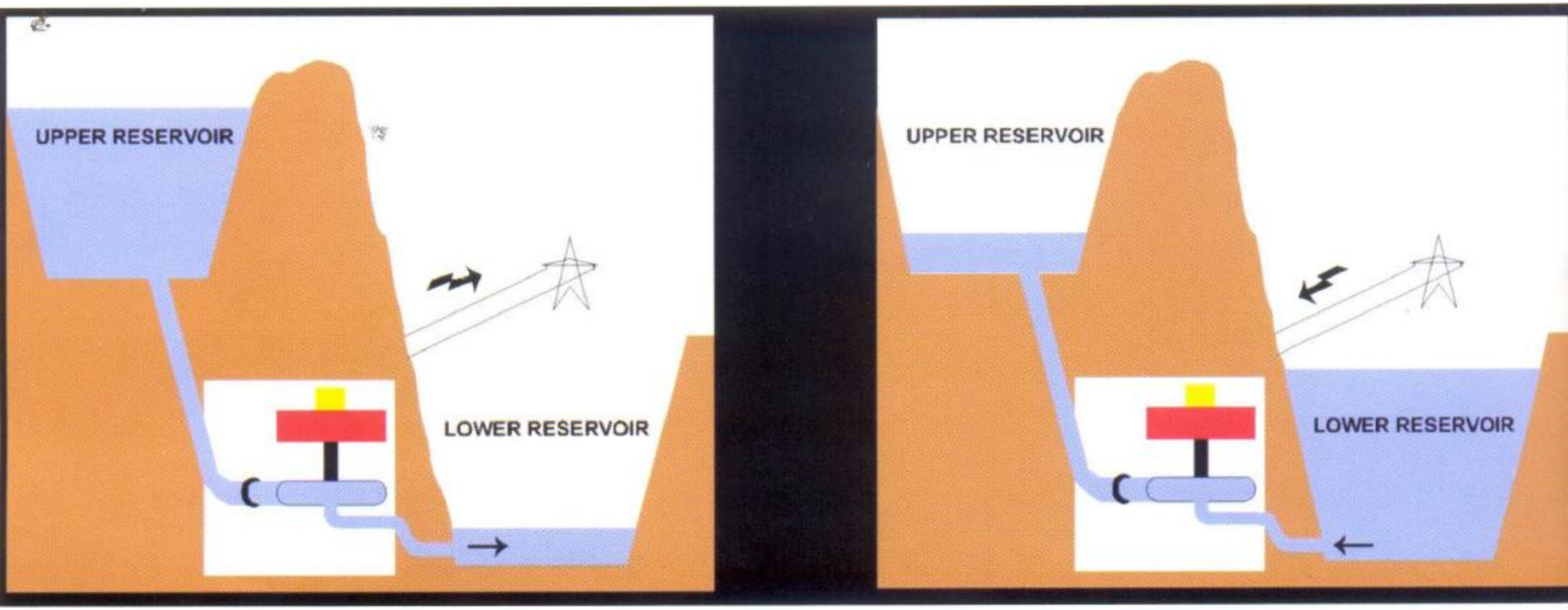


Figure 1: Typical Pumped Storage Plant Arrangement (Source: Alstom Power).

Aspects of Pumped Storage



Steps involved in Planning of a Pumped Storage Plant

- Site Identification
- Preliminary Selection of Project Layout
- Survey & Investigation
- Determination of Project Parameters & Assessment of Project benefits and Economic Evaluation
- Preparation of Detailed Project Report

Survey and Investigation

- River Survey
- Réservoir Survey
- Head works surveys (dams, barrage, weir, etc)
- Plant sites and colonies
- Canal, branch canals, and water conductor system
- Major canal structures
- Power house, switch yard, surge shaft, tail race tunnel(s), adits, penstocks etc.
- Surveys for command area including Ground Confirmation Survey
- Soil surveys
- Soil conservation
- Construction material surveys.
- Any other i.e. Archaeological, Right of way, communication etc.

Topo Sheets

Topographical Survey

- Dam site up to 500m upstream and down stream extending an elevation of top of dam + ¼ of dam height. Contour interval 1 to 5m.Scale of map 1:500 to 1:2000
- Reservoir area survey cover elevation up to 5m + MWL
- Power channel 150m on either side of channel .scale 1:2000 to 1:5000
- Survey of Tunnel – 100 to 400m wide strip along the tunnel alignment. Scale 1:2000 to 1:5000
- PH and switchyard 1:1000 to 1:2000

Survey & Investigation

1) Detailed topographical Surveys

- Detailed field surveys are to be carried out on the basis of preliminary layout.
- Surveys for the general layout should extend from about 2 km upstream of the diversion site to about 1 Km downstream of the tailrace with the stream.(These limits can be changed)
- The survey should bring out the advantages of the chosen alignment/locations of the project components

- The survey should be connected to a Permanent bench Mark
- Levels of all components are to be correlated to a salient project bench mark to ensure correctness in relation to each other
- Surveys for various locations viz. diversion weir, water conductor, cross drainage works, fore bay, penstock etc. should extend to cover an area to accommodate all possible arrangements to enable optimizing the alignment and location of the various component structures of the scheme.

Survey & Investigation

2) Hydrological Investigations : Hydrological data such as Rainfall and Snowfall measurements, Stream gauging for discharge measurement

3) Geological Investigations : A judicious and careful geological assessment with limited geological exploration is essential for selecting appropriate alignment , locating the various structures of the scheme and working out suitable strengthening measures wherever necessary.

4) Construction material survey : The availability of required quantity of construction material such as aggregate, sand earth, boulders , water etc. should be assessed and their locations identified by survey of project area and are to be tested for quality/strength

5) Infrastructure Survey: The availability of infrastructure such as Roads and bridges up to the project area and internal roads in the project area, Construction Power, Drinking water, Communication facilities, Office Building and Staff Quarters etc. should be investigated and clearly documented.

6)Survey for Power evacuation: Present Position of power supply, system loads, load factor etc..the grid after commissioning of the plant, Details of major loads to be served, energy demand etc..are to be investigated. The plan for evacuation of power shall also be investigated.

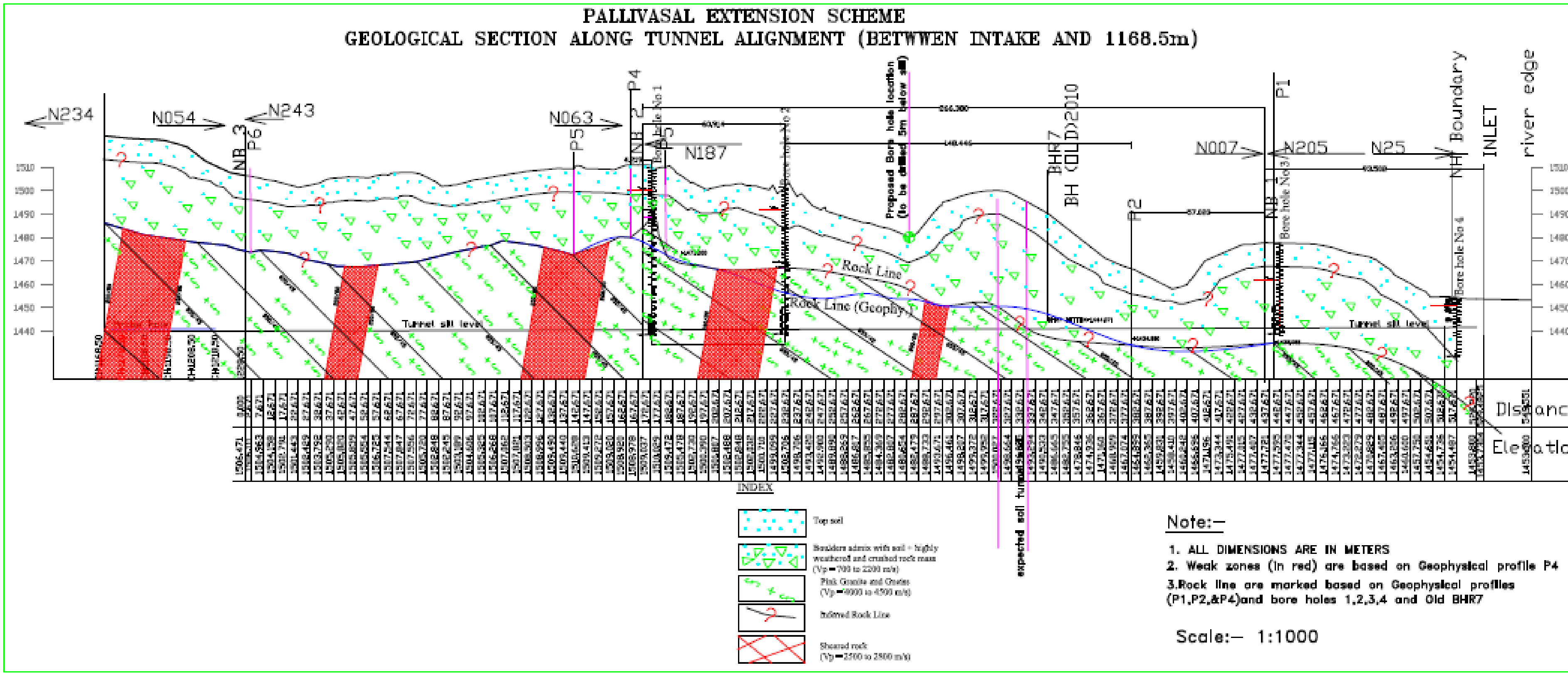
7) Environment Impact assessment : For Projects costing more than 100 Cr.

Engineering geological, geophysical, Seismological and Construction material survey

- Engineering Geological survey
  1. Surface investigation
  2. Subsurface investigation
  3. Geo technical survey
  4. Geophysical survey
  5. Seismological survey
  6. Rock and soil mechanic testing

- **Environment and Forest survey**

Geological problem



- Planning

HEAD

- Normal operating head: 90 – 630 m.
- Low head projects generally require larger conduits, less cost effective.
- High head projects (> 750 m) require more complex multistage pump/turbine units.
- High head projects more cost effective, because based on the power equation, the product of the total volume of water stored by the total head is proportional to the total energy stored.
- It require smaller reservoirs (less water required) and have smaller electrical-mechanical equipments providing an equivalent amount of energy.

FLOW RATE

- It is calculated based on desired generating capacity and available head.
- For a given head, projects with higher design flow rates require larger waterway conduits and ump/turbine units.
- it is important to perform a cost-benefit analysis to look at different flow rates/plant sizing capacity that provide the greatest overall benefit.
- Another important consideration regarding design flow rates is to minimize the head losses in the waterways.
- Smaller flow rates, and associated smaller conduit diameters, have higher head losses w.r.t larger conduits (expensive).

WATERWAY

- Pumped storage hydropower projects typically have two sections of waterways.
- The first section is the high head portion between the upper reservoir and the pump/turbine unit(s) and the second section is the low head portion between the pump/turbine unit(s) and the lower reservoir.
- A waterway that travels the shortest distance possible between the upper reservoir, powerhouse, and lower reservoir is optimal.
- A shorter waterway is preferred to minimize both construction costs and friction losses in the system.
- Waterways can either be located on the surface of the slope or buried underground

UPPER AND LOWER RESERVOIRS

- The sizing of the upper and lower reservoirs depends on the size of the installed units, the operating head, the site characteristics, and the number of hours that operation of the turbines is required.
- A typical plant is sized to operate between 4 and 20 hours depending on local energy needs.
- Storage required in the system can be estimated by the following equation

$$S = \frac{976\,(C)t_s}{He_g}$$

  S = Storage (acre-feet), C = Plant capacity (MW), ts = Storage requirement in hours of equivalent full-load generation (hours), H = Average gross head (feet), eg = generation efficiency, including head losses (%).
- The planning of the upper reservoir and depends on the following factors:
  - ❖Availability of existing reservoir
  - ❖Topography of the project site and the presence of streams and rivers
  - ❖Geologic conditions
  - ❖Seepage losses in the reservoir foundations

PUMP/TURBINE SELECTION

- The sizing of pump/turbine units depends on the project economics, site characteristics, and requirements of the power system.
- Larger scale projects are generally more economically viable.
- It requires selection of larger pump/turbine units, sufficient water available, sufficient operating head, and adequately sized upper and lower reservoirs.
- For projects with low head or limited water available, a smaller scale project is more appropriate.
- The selection of pump/unit size and type also affects the size and configuration of the powerhouse.
- Adjustable speed pumps/turbines require additional components, which result in larger overall powerhouse dimensions and higher construction costs.

Underground or Over ground ?

- Power houses - to be positioned well below the MDDL of the lower reservoir
  - to address cavitation and requirement of pumping head
- Hence underground or semi underground power houses
- Fully underground systems - Power house, Switchyard and Evacuation System require underground caverns and access tunnels
- Semi underground systems require space for power house, switchyard etc

Assessment of Project Cost, Benefits and Economic & Financial Evaluation

- An accurate assessment of the expected cost is considered as a most important activity in order to ascertain the economic feasibility and to prepare a viable financing plan.
- As the project cost estimate are made before the work is done, the estimated cost is only an indication of the order of the likely cost.
- To arrive at the total cost of the project, estimates are generally made separately for Civil works including Hydro Mechanical works and Generating Plant including E&M works.

Assessment of Project Cost, Benefits and Economic & Financial Evaluation

- The economic viability of Hydro Electric Projects is determined by comparison with the cost of alternative sources at the same place considering therein all elements such as cost of Transmission, Distribution etc.

- The Economic Evaluation could be carried out by opting for Cost of Energy Generation, Benefit-Cost Ration, Net Present value, Economic Internal Rate of return etc

Projects

Shall be

- Technically Feasible
- Practically Executable
- Economically Viable
- Environment Friendly

Assessment of Project Cost, Benefits and Economic & Financial Evaluation

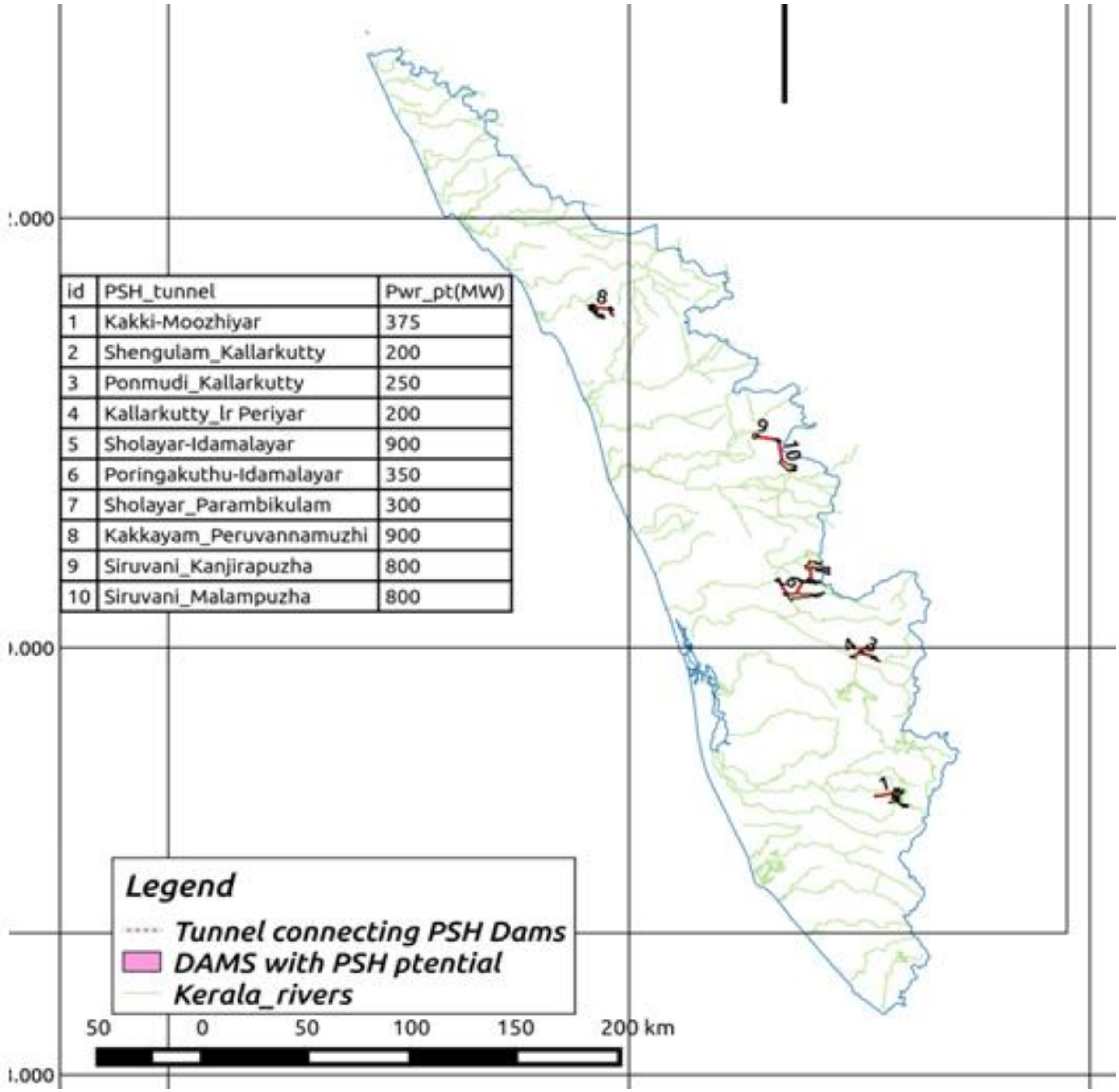
- The Financial Evaluation is undertaken to assess the financial viability /soundness of the project from the point of view of the developer and financial Institutions

- The financial Evaluation could be carried out by opting for the Pay back Period method, the Financial Internal Rate of Return method, the Net Present Value method etc.

Potential Sites Identified

Sl.No.	Existing Reservoirs	Potential (MW)
1	Kakki - Moozhiyar	375
2	Sengulam - Kallarkutty	200
3	Ponmudi - Kallarkutty	250
4	Kallarkutty - Lower Periyar	200
5	Sholayar - Idamalayar	900
6	Poringalkuthu - Idamalayar	350
7	Sholayar - Parambikulam	300
8	Kakkayam - Peruvannamoozhi	900
9	Siruvani - Kanjirapuzha	800
10	Siruvani - Malampuzha	800
	Total potential	**5075**

Identified Pumped storage schemes



id	PSH_tunnel	Pwr_pt(MW)
1	Kakki-Moozhiyar	375
2	Shengulam_Kallarkutty	200
3	Ponmudi_Kallarkutty	250
4	Kallarkutty_lr Periyar	200
5	Sholayar-Idamalayar	900
6	Poringakuthu-Idamalayar	350
7	Sholayar_Parambikulam	300
8	Kakkayam_Peruvannamuzhi	900
9	Siruvani_Kanjirapuzha	800
10	Siruvani_Malampuzha	800

THANK YOU

P N Biju. M Tech(Structural Engg),MIE,CE(I),DTA

pn.biju.pn@gmail.com

9446008403,9447523449