Indo-German Energy Forum

Techno-Economic Review on Flexibility Potential of PSH In India

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Abbreviations:

Abbreviation	Description
BESCOM	Bangalore Electricity Supply Company Ltd
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
CERC	Central Electricity Regulatory Commission
DAM	Day Ahead Market
DPR	Detail Project Report
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GoI	Government of India
GSDP	Gross State Domestic Product
GSVA	Gross State Value Added
IGEF	Indo German Energy Forum
IEGC	Indian Electricity Grid Code
IEX	Indian Energy Exchange
INR	Indian Rupee
kV	Kilo Volt
kWh	kilo Watt hour
Mn	Million
MW	Mega Watt
MSEDCL	Maharashtra State Electricity Distribution Company Limited
PFR	Pre-Feasibility Report
PLF	Plant Load Factor
PPA	Power Purchase Agreement
PSH	Pumped Storage Hydro/(hydropower)
RE	Renewable Energy
REC	Renewable Energy Certificate
R&R	Resettlement and Rehabilitation
SRTPV	Solar Rooftop Photovoltaic
TANGEDCO	Tamil Nadu Generation and Distribution Corporation Limited
TNERC	Tamil Nadu Electricity Regulatory Commission
USD	US Dollar
WAPCOS	Water and Power Consultancy Services Limited

1. Introduction

1.1. Background

The Government of India (GoI) has set an ambitious plan of achieving 175 GW Renewable Energy (RE) by 2022 and a further target of 450 GW by 2030 and policies are being developed and implemented for achieving the same. This is expected to induce instability in the grid discipline, as the VRE sources are inherently accompanied by variability and intermittency. This necessitates the development of storage solutions which can provide the requisite flexibility option to meet the grid requirements. In energy storage ecosystem (ESS), hydro plants (in general) and Pumped Storage hydropower (PSH) (in specific) are expected to play a pivotal role in grid balancing requirements.

Under this context, IGEF commissioned the captioned study to understand the techno-commercial feasibility of PSH to meet India's future demand and maintain grid stability with increasing RE penetration. This study is aimed at reviewing the current scenario of PSH in India, retrofitting requirements of existing hydro plants and assessing the economic viability of PSH plants, the broad objective of the assignment is exhibited in a graphical below:

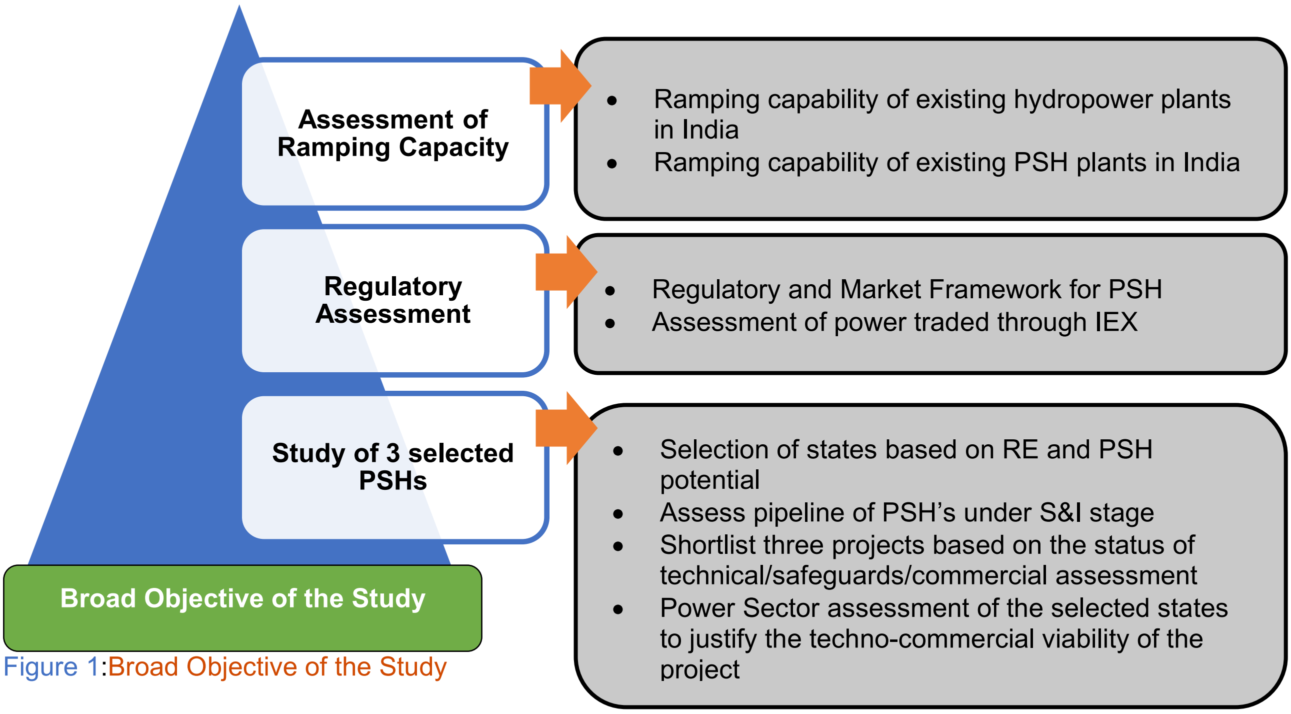


Figure 1:Broad Objective of the Study

1.2. Implementation of the project

The project was kicked off in 18 August 2020 after the award of the contract to the consultant team in the first week of August. During the execution of the project, the consultant team and the IGEF team had a series of interim meetings to discuss on the progress of the project. Further the consultant team has also projected the key findings of the study in the meeting of the IGEF Subgroup-4. As a part of the engagement, the consultants' team are required to organize stakeholder consultations with the project sponsors of the three selected PSH's out of which 1- stakeholder consultation has already been conducted. The remaining stakeholder consultations are planned to be organized soon.

A list of key meetings/discussion held with stakeholders are provided in the table below

Table 1: List of key meetings and discussions

Sl No	Particulars	Stakeholders	Date	Details
1	Kick-off meeting and preliminary discussions to understand stakeholder requirements and finalize approach	IGEF, kfW PwC	18 Aug 2020	
2	Discussion on preliminary technical and commercial assessment of Silhalla, and Malsej PSH	IGEF, PwC,	2 Nov 2020	
3	Interim Report Presentation: • Assessment of ramping capacity of PSHs and hydro, • Regulatory Assessment of PSH • Study on 3 PSHs-Justification of PSH based on a rigorous power market assessment of Karnataka, Tamil Nadu and Maharashtra	IGEF, kfW, PwC	11 January 2021	
4	Meeting of the IGEF Subgroup 4 " Green Energy Corridors: Presentation on the study outcomes	IGEF, kfW, SG4, DEA, PwC	12 March 2021	
5	Meeting with KPCL team to discuss on the status of Saravathy PSH and explore potential areas of cooperation between KPCL and KfW	KPCL, IGEF, PwC	19 March 2021	Discussion summary attached in annexure 9.5
6	Meeting with THDC team to discuss on the status of Malshej Ghat PSH and explore possible cooperation between THDC and KfW	THDC, IGEF, KfW, PwC	26 May 2021	Discussion Summary attached in annexure 9.6

2. Need for PSH

2.1. Power Sector in India

Indian power system – with more than 200 million customer base and 370 GW installed capacity – is one the largest and complex power systems in the world. In recent years, substantial growth in installed generation capacity and augmentation of transmission and distribution infrastructure, have led to a reduction in peak shortages (0.8% peak deficit in 2018–19 as against 9.0 % deficit in 2012-13) and surplus generation capacity.

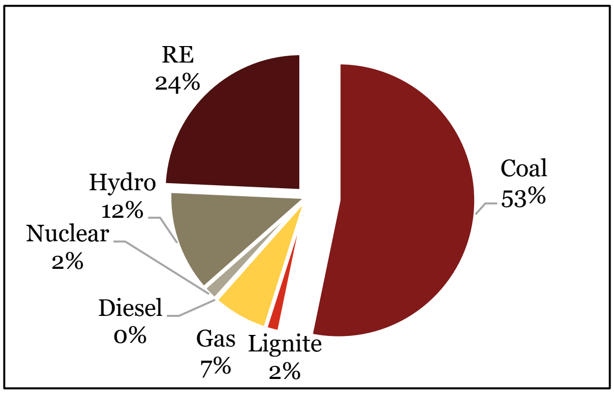
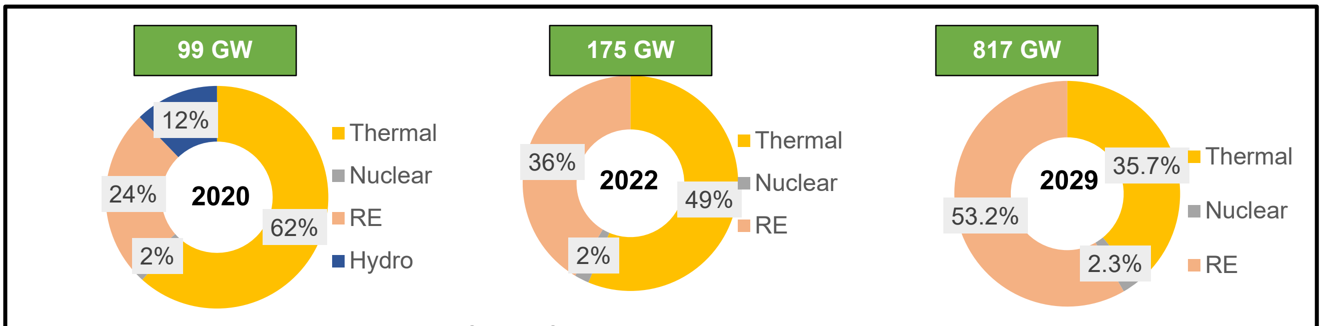


Figure 2 : Installed Capacity of India, Dec 2020

Going forward, India intends to reduce the emissions intensity of its GDP by 33 to 35 % by 2030 from 2005 level, in concordance with the NDC targets. In order to achieve this target, GoI has set a target to achieve a cumulative installed electric power capacity of 40%, from the non-fossil fuel-based energy resources by 2030, with the help of transfer of technology and low-cost international finance.

2.2. Renewable Energy (RE) Scenario in India

GoI is taking progressive steps to ensure an equitable and sustainable socio-economic development and has launched programmes like ‘Power for All’ to guarantee 24x7 power supply. This programme, coupled with the other factors like rapid growth of the manufacturing sector, rising urbanization, development of industrial corridors emerging ecosystem of e-mobility and metro rails are expected to be the driving factors that will contribute in rising power demand in the country. In order to cater to this expected increase in power demand while fulfilling its climate change commitments as part of the 21st Conference of Parties (COP 21), and reduce GHG intensity of the country, the GoI has set a RE capacity addition target of **175 GW by 2022** and **450 GW** by 2030



Source: CEA

Figure 3: Renewable Energy Penetration

Over the last decade, capacity addition by Renewable Energy (RE) sources has experienced significant growth (CAGR of 19% since FY 2006-07). The contribution of RE sources in the installed capacity has increased from 6% in FY 2006-07 to 19.2% in FY 2020-21 with a cumulative installed capacity of 91.2 GW as in December 2020.

The National Electricity Plan (NEP) by the Central Electricity Authority (CEA) targets 275 GW of RE capacity by 2027, without requiring any additional thermal plants viz. coal, gas, lignite, diesel (beyond the ones already under construction)

2.3. RE and Grid Discipline

With huge RE penetration in grid, one of the major issues that every system operator is faced with is maintaining system security and reliability. Renewable sources such as solar and wind exhibit variability and intermittency in generation due to seasonality and changes in weather conditions, (e.g. cloud formation, which would lead to sudden reduction in solar output, while strong winds may cause a spike in wind energy generation).

This section attempts to demonstrate the impact of RE integration on net load and underlines conclusively the importance of flexibility on the grid discipline. The graphical representation below demonstrates the load and the net load for the southern and western regions of India during a period of high RE penetration. In comparison with load, net load (= Load – RE power) in both regions is seen to exhibit steeper ramps and lower minimum generation levels.

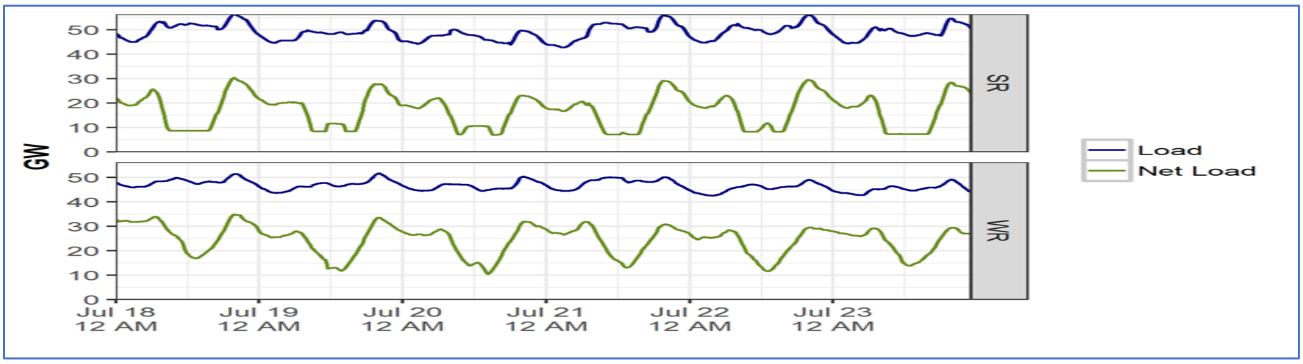


Figure 4: Load Curve -Impact of RE

SOURCE: Greening the grid, MoP, 2017

Hence, the **generation that serves net load, in aggregate, needs to be more flexible** in order to meet the demand and balance the variability in the system due to high RE integration.

Apart from the steep ramping capacity, another challenge that the grid is faced with high RE penetration is curtailment. Curtailment may occur due to excess generation or system constraints such as transmission unavailability. The graphics below highlights some of the curtailments due to excess generation when monsoon coincides with high wind season. The figure below highlights the expected curtailment in a particular day during monsoon season by 2030.

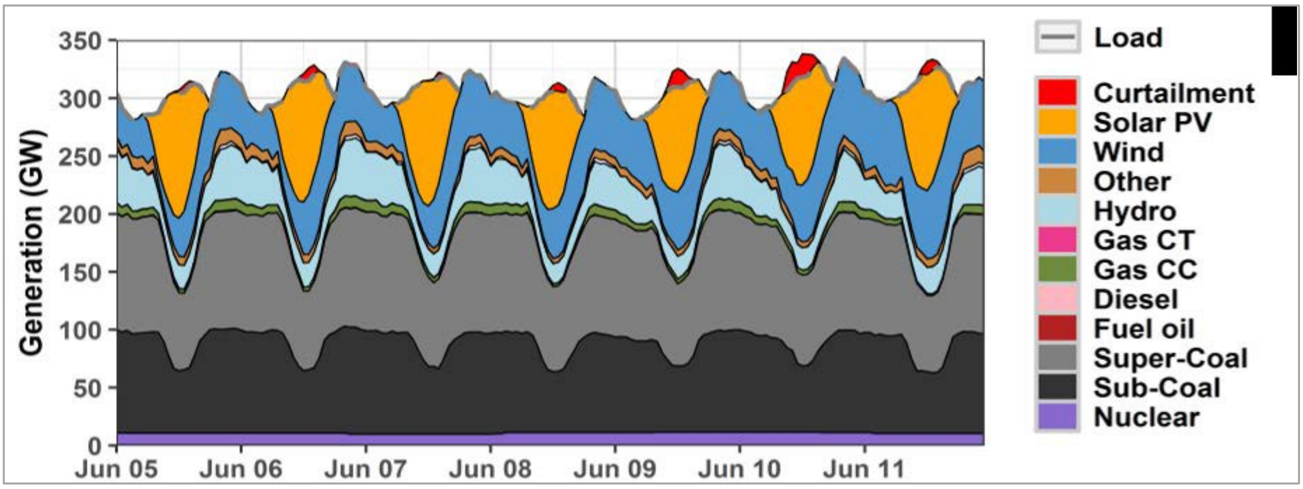


Figure 5 :Forecasted Curtailment in 2030

Source: NREL Report on “India 2030 Wind and Solar Integration Study”

It is to be noted that the curtailment occurs during the middle of the day when both wind and solar are generating. As shown in the graphic alongside, Andhra Pradesh, Karnataka, Odisha and Rajasthan are going to be largely affected by RE curtailments.

The Government has focused on several measures to increase grid flexibility to prepare for increased RE penetration, such as increasing flexibility of coal-based power plants, enlarging geographic and electrical balancing areas, expanding transmission in strategic locations, and installing grid-scale storage systems like battery and pumped hydro systems.

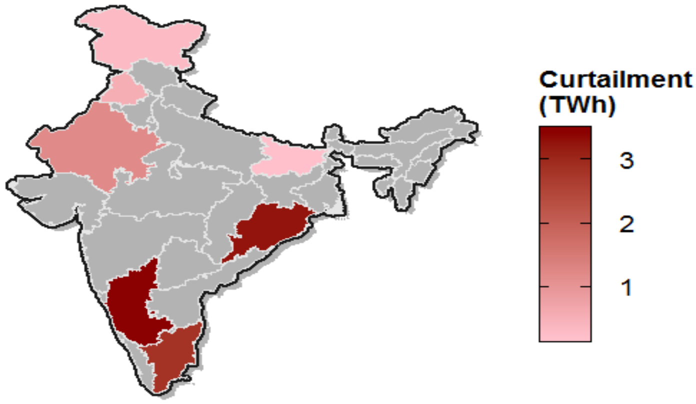


Figure 6: Curtailment Scenario in India

PSH is the largest contributor towards the electricity storage development by time shifting the energy during off peaks times and effectively utilizing during peak hours. As per IRENA report on Storage technology, 85% of the electric energy time shift is catered by PSH, which can further be, used either for providing ancillary services or selling in the open market

.

2.4. Grid Balancing and Importance of Hydro

The high pace of addition of renewable energy to meet the target of 175 GW by 2022 explains the recent measures taken by the government to promote grid balancing assets. This provides a tremendous opportunity for energy storage systems which will play a pivotal role in efficacious implementation and integration of upcoming renewable power plans in order to meet India's targets of achieving 175 GW renewable capacity by 2022. The storage solutions would further aid in providing stable services to the mini grids, improving power quality, mitigating power curtailment and furthermore supplementing decarbonisation in the key segments of energy market. There are various types of storage technologies to balance grid viz. Battery storage, Hydro (storage and pumped hydro), Compressed Air Energy Storage (CAES) etc. Amongst the above, hydro is the commercially mature and economically feasible technology and a result, and as a result it is the front-runner for grid balancing options.

Hydropower primarily has the capability to play a crucial role in the sustainable development and energy security, considering that it meets the criteria of sustainability, availability, reliability and affordability by virtue of high ramp rate and flexible operation profile. Moreover, hydropower can be operated complementary to the generation by RE resources (particularly with solar generation) by ramping up generation during evening and early morning when solar generation is low.

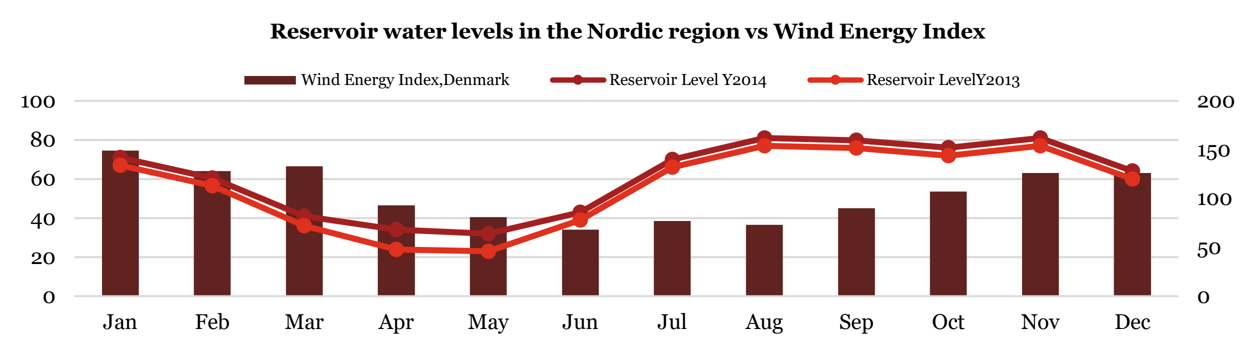
Currently the increased demand for ramping is primarily being met by the thermal sources, which was mostly operating as base load around a decade back. While the contributing to other generation sources towards ramping is yet to increase commensurately, it is can be concluded that hydro plants, in general and PSH, specifically, has emerged as a suitable candidate to cater to the to the specific demands of the Indian power system and bridge the supply-demand gap. The government aims to balance the intermittent power generation from renewable sources by utilizing the ramping rate of all generating stations. The list of the services provided by hydro power plants (including PSH) are presented as below:

- **Overload capability** – Hydropower plants are capable of being operated at much higher heads than their rated head which enables them to produce more mechanical output.
- **Peaking support** – Hydropower plants can be used for both base load and peaking power applications. With rising percentage of renewable having variable intermittent nature of generation hydropower plants will provide stability in power supply.
- **Fast ramping rate** – Hydropower plants have a higher ramping rate than other generation sources and hence are suitable for flexible power generation.

- **Frequency and voltage control** – Hydropower plants are used for the deliberate frequency and voltage control because of their fast ramp rates.
- **Black Start Capability** – Ability of hydropower plants to restart without any support of external sources of power makes them valuable as assets for black start capability.

Hydropower in Norway supporting large scale integration of wind in Denmark

Denmark with wind capacity of 5227MW, contributing more than 40percent of the energy generation, observes a shortfall in wind generation in the summer months due to seasonal variations. In order to balancing the variable wind generation in the summer months, Denmark imports power from the hydro reservoirs of Norway.



The Polish Zarnowiec hydropower plant's contribution to system stability

The flexible units of Zarnowiec, Poland's largest hydropower plant with 716 MW capacity, play an important role in ensuring stability in the national electricity system, where coal-fired thermal power plants dominate electricity generation. The plant is located in a very sensitive area, with huge amounts of wind energy coming from Germany, but also soon from Polish sites. Thus, there is a need for balancing. The Zarnowiec hydropower plant fulfils several essential functions for the Polish national electricity system:

- Flexibility to cope with the fast activation and disconnection of units, and covering a sudden power drop or increase in the system
- Control of reactive power flow in the system (voltage regulation and reactive power control)
- Establishment of rotating reserve by means of second power controlling (primary control) and minute power controlling (secondary control)

Zarnowiec therefore played an important role in managing the European blackout of 4 November 2006. Activating pumps helped to stabilize the frequency and voltage and restore the system after power failure.

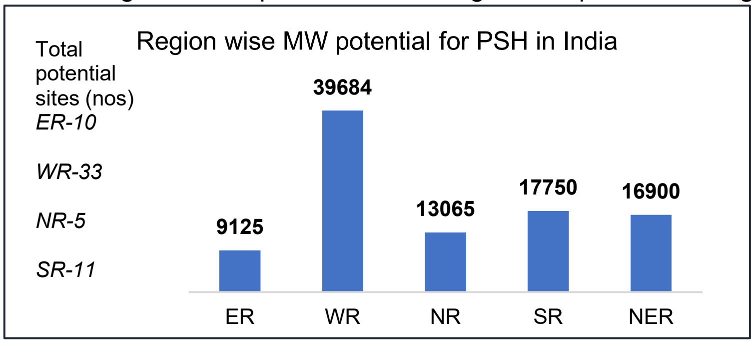
The benefits of hydropower in providing flexibility is further enhanced in the case of PSH as these also allow storage of surplus energy when the demand is low, which can then be utilized when demand increases. It allows other sources such as thermal or nuclear to continue to operate at high efficiency levels and thus allows optimization of base load generation. PSH can provide energy-balancing, stability, storage capacity, and ancillary grid services such as network frequency control and reserves. The turbine can respond swiftly to frequency changes just like storage hydro plants in the generating mode, aiding in the overall balancing of grid. In both turbine and pump-modes, it can contribute to reactive power load and voltage stabilization through variation in generator-motor excitation. While neither generating nor pumping, PSHf plants can provide spinning reserve and the ability to balance surplus generation when operated in synchronous condenser mode. Large plants with digitally controlled turbine governors and larger storage reservoirs can provide balancing services ranging from seconds to hours.

Thus, the focus of GoI has turned towards the responsible and accelerated hydropower growth, which will address the collective concerns of hydropower developers while ensuring sustainability and addressing socio-economic concerns around developing projects[1]

2.5. Pumped Storage Hydro Ecosystem in India

India has immense potential for the development of PSH. CEA has identified 63 sites for PSH exploration, with total potential of about 96,500 MW. The region wise PSH development potential is provided in the table and map below. As evident, the western region in India has the highest PSH potential with a significant potential being clustered in the state of Maharashtra.

The sites for off-river closed loop system are yet to be identified in India. Similarly, the sites that use sea as the lower or upper reservoir and gravity based hydro power plants are yet to be identified and implemented. India has 5745 large dams and provides an excellent opportunity for developing PSH by placing it in between two large dams in cascade or using one dam and second reservoir on the hilltop with very low impact on biodiversity and resettlement and rehabilitation (R&R) issues. The PSH plants under various stages are discussed as follows:



Source: Central Electricity Authority

Figure 7:Region wise MW potential for PSH in India

I. Operational PSH installed capacity in India

In India, out of the eleven (11) PSH, six (6) plants are working operating in the pumping mode and contribute 3.3 GW. The table below represents PSH's that are operating in pumping mode

Table 2:Operational PSH capacity in India

Sl. no	Project	State	Capacity (MW)		Owner	Project Cost (INR Crore)	Year of commissioning
			No of units	Total (MW)			
1	Srisailam LB	Telangana	6 * 150	900	APGENCO / TSGENCO	2530	2003
2	Nagarjuna Sagar	Telangana	7 * 100	705.6	APGENCO	-	1985
3	Purulia PSS	West Bengal	4 * 225	900	WBSEDCL Govt. of WB	2500	2008
4	Kadamparai	Tamil Nadu	4 * 100	400	TANGENCO Govt. of TN	1078	1989
5	Ghatghar	Maharashtra	2 * 125	250	MAHAGENCO Govt. of Maharashtra	1540	2008
6	Bhira	Maharashtra	1 * 150	150	Tata Power	-	1995
Total			**3305.6**				

SOURCE: CEA, Pumped Storage Development in India, 2021

Besides the operational PSH plants, there are three (3) plants are that are not operating in pumping mode due to various issues (as mentioned in the table below). Such PSH plants, adding to the capacity of 1.48 GW are presented in the table below:

Table 3:Operational Plants not working in pumping mode

Sl. no	Project	State	Installed Capacity (MW)		Owner	Year of commissioning	Status
			No of units	Total (MW)			
1	Sardar Sarovar*	Gujarat	6 * 200	1200	**SSHEP** Govt. of Gujarat	2006	Operation of project in pumping mode is under discussions with Narmada Control Authority(NCA) and concerned State govts.
3	Kadana St. I&II*	Gujarat	2 * 60 +2 * 60	240	**GSECL** Govt. of Gujarat	1998	Vibration problem
4	Panchet Hill*	DVC	1 * 40	40	DVC	1991	Tail pool dam not constructed
	Total (MW)		**1480**				

SOURCE: CEA, Pumped Storage Development in India, 2019

II. Pumped Hydro Storage projects under construction and pre-development stage

Along with an installed capacity of ~4.8 GW, following are the PSH projects which are currently in construction or survey & investigation (S&I) stage – **cumulative capacity of ~ 9.5 GW:**

Table 4: PSH under construction and pre-development stage

Sl No.	Project	State	MW	Owner	Status
		Projects under construction			
1	Tehri PSH	Uttarakhand	1000	**THDCIL** JV of GoI and Govt. of UP	Under construction
2	Kundah Stage -I,II,III and IV	Tamil Nadu	500	**TANGEDCO** Govt. of TN	Under construction
3	Koyna LB	Maharashtra	80	**GoMWRD** Govt. of Maharashtra	Under construction
	A. Total: Under construction (MW)		**1580**		
		Projects at pre-development stage/			
1	Turga PSH	West Bengal	1000	**WBSEDCL** Govt. of WB	DPR Concurred by CEA
2	Upper indravati	Odisha	600	**OHPC** Govt. of Odisha	Under S&I
3	Balimela	Odisha	500	**OHPC** Govt. of Odisha	Under S&I
4	Upper Kolab	Odisha	320	**OHPC** Govt. of Odisha	Under S&I

Sl No.	Project	State	MW	Owner	Status
5	Sharavathy	Karnataka	2000	**KPCL** Govt. of Karnataka	Under S&I
6	Kodayar	Tamil Nadu	500	**TANGEDCO** Govt. of TN	Under S&I
7	Silahalla St-I	Tamil Nadu	1000	**TANGEDCO** Govt. of TN	Under S&I
8	Upper Sileru	Andhra Pradesh	1350	**APGENCO** Govt of AP	Under S&I
9	Pinnapuram	Andhra Pradesh	1200	**Greenko**	Under S&I
10	Saundatti	Karnataka	1260	**Greenko**	Under S&I
B. Total: Pre-development (MW)			**9730**		
C. Total (A+B) (MW)			**11310**		

SOURCE: CEA, Pumped Storage Development in India, 2019

A total of 11310 MW (including under construction and pre-development) of PSH are in the pipeline in India. Out of this, 7810 MW is planned to come up in the southern states in Karnataka, Tamil Nadu and Andhra Pradesh.

2.6. Cost Estimation of PSH Schemes

The cost estimation of PSH under different o schemes have been broadly classified under two categories mentioned below:

- **Developing PSH Projects with Existing Hydro Plant Reservoir (Conversion of existing storage project to PSH)**
- **Developing New PSH Project**

The cost estimation of a PSH under both the categories viz. new PSH development and conversion of existing hydro plants, must consider some design elements to estimate the cost of the project. The constituents of the cost estimation need to consider the following aspects:

- **Input Site Characteristics** – In this category, the technical requirements for conversion of scheme is to be defined.
- **Develop Reference Design** – The reference design would evolve using design equations and engineering judgement.
- **Estimate Project Category Cost** – Based on the reference design, a cost estimate for each of the major cost categories is developed, including contingencies for undefined, uncertain, and risk items;
- **Output Project Initial Capital Cost** – The sum of all project categories is determined and output as project additional capital cost;

The aspects of the costing of the PSH Plants under both the categories has been discussed in the following section.

2.6.1. Developing PSH through conversion of existing hydro

Conversion of existing hydropower stations to PSH could be undertaken by means of adding new pump(s) at or adjacent to the existing power station, matching the current installed capacity of the units (or thereabout due to additional head loss whilst pumping) or at a lower capacity. Power stations which can be categorized in the PSH with Existing Hydro category should have the following characteristics:

- An existing lower reservoir just downstream of the station or close enough for connection;

- Fully pressurized existing water conveyances (tunnel/pipe/penstock);
- Reasonable head that could justify the upgrade – preferably more than 100 m head to produce acceptable cyclic efficiency and be cost effective; and
- Enough storage capacity in the upper reservoir so that water could be pumped up to the upper reservoir during off-peak hours and then be used for generation during peak hours.
- Possibility of replacing conventional turbine generator by fixed/variable speed reversible pump turbines
- Alternatively, possibility of creating and accommodating additional fixed/variable speed reversible pump turbines in the powerhouse by refurbishment of the system
- Current utilizations of the existing power stations are a major consideration. Additionally, the positioning of a station in a cascade scheme could have an impact on the attractiveness of the conversion.

The detailed illustration of the capacity and per unit cost of the PSH plants with existing hydro projects are provided in **Table 4** below:

Table 5:Cost of PSH Projects with Existing Hydro

S.No.	Project	State	MW	Project Cost (INR Cr)	Cost/MW (INR Cr)
1	Tehri PSH	Uttarakhand	1000	4826	4.83
2	Upper Indravati	Odisha	600	2978	4.96
3	Balimela	Odisha	500	2413	4.83
4	Upper Kolab	Odisha	320	1600	5.00
5	Koyna LB	Maharashtra	400	838.9	2.10
6	Kundah Stage -I, II, III and IV	Tamil Nadu	500	1831	3.66
7	Sharavathy	Karnataka	2000	5017	2.51

SOURCE: Plant DPRs, PwC Analysis

As per current PSH scenario in India, 7 plants have been identified with under this category with collective capacity of ~5320 MW. These plants are under different phases of design, planning and development, and the development of PSH is conducted by modification of the existing reservoir of the hydro power plants.

In this category of PSH with existing hydro reservoir, the range of cost/MW varies from INR 2.1 Cr per MW offered by Koyna PSH in Maharashtra to as high as INR 4.96 Cr per MW in Upper Indravati in Odisha. It may be worth-while to mention that these costs pertain to DPR costs/pre-feasibility costs where the base years considered for cost estimations for the projects are different and hence the costs may not be strictly comparable

2.6.2. Developing New PSH

The second category, as per our delineation is development of new PSH, in the regions devoid of any existing hydro power reservoirs. The detailed illustration of the capacity and per unit cost of the PSH plants is exhibited in **Table 5** below:

Table 6: Cost of New PSH Projects

S.No.	Project	State	MW	Project Cost (INR Cr)	Cost/MW (INR Cr)
1	Turga PSH	West Bengal	1000	6921	6.92
2	Silahalla St-I	Tamil Nadu	1000	4900	4.90
3	Pinnapuram	Andhra Pradesh	1200	5468	4.56
4	Malsej*	Maharashtra	700	2825	4.04
5	Saundatti	Karnataka	1260	4985	3.96

SOURCE: Plant DPR, PwC Analysis; *2010 price level

In India, we have identified 5 plants in pipeline, with nearly 5160 MW capacity, which are under various development phases (pre-development, construction and planning). The project cost of the upcoming plants ranges from INR 3.96 Cr/MW to as high as INR 6.92 Cr/MW.

In the category of PSH with new hydro, the range of cost/MW varies from INR 3.9 Cr per MW for Saundatti PSH in Karnataka to as high as INR 6.92 Cr per MW in Turga PSH in West Bengal.

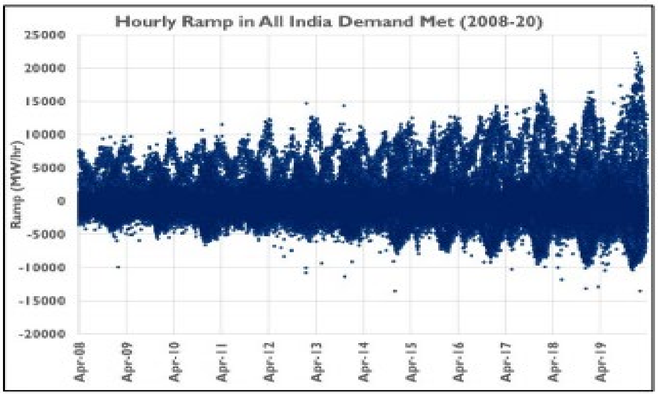
2.6.3. Cost Comparison

It is pertinent to mention that, it is relatively challenging to assess precisely assess the actual cost involved in case of development, refurbishment and retrofitting of a hydro plant because hydropower is a highly site-specific technology where each project is a tailor-made outcome for a particular location within a given river basin to meet specific needs for energy. And, nearly three-quarters of the total investment costs of hydropower projects are driven by site-specific elements that impact the civil engineering design and costs.

Broadly, it has emerged from the evaluation that the cost of development of projects with existing reservoirs which involves converting existing storage hydro projects to PSH, is relatively lower – with worked out weighted average cost i.e. INR 4.04 Cr/MW (calculated on the basis of identified plants) being INR 1.05 Cr/MW lower than the new developments.

2.7. Assessment of ramping in existing plants

Ramping is an important flexibility attribute for managing power systems with high penetration of RE. Some systems have established specific market products to procure essential ramping services, and some are providing incentives to the generators to enhance ramping performance as discussed in the subsequent sections. Further, with the application of national-level security constrained economic dispatch (SCED), the national power system operator of India, POSOCO, has started to detect constraints in ramping capability obtained from generators under SCED, which could get further aggravated with more VRE (POSOCO, 2020).[1]



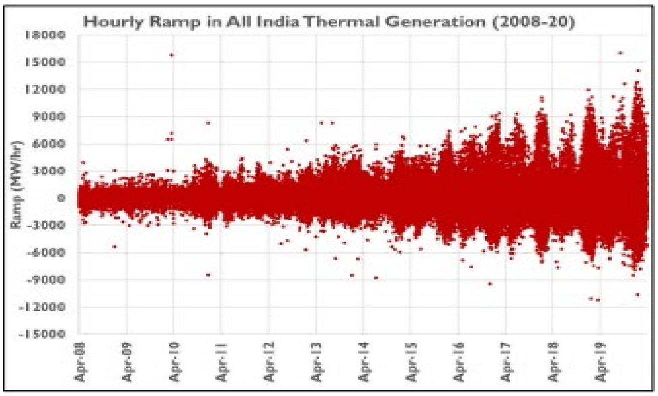


Figure 8: Hourly ramp rates of demand and thermal generation in India from 2008–2020

Source: NREL

With the outset of ambitious RE targets of 175 GW in short-term (2022), 275 GW in medium-term (2027) and prospective 450 GW in long-term (2030), the importance of the ramping requirements have grown over the years, and with these targets, the ramping requirements for India are also expected to rise and so is the risk of net load.

The GOI's RE targets have led to several technical planning studies that have identified power system ramping to be a potential issue for further research and planning efforts. For example, the National Electricity Plan (Generation) has given importance of a fast ramping capability for large-scale RE in the grid (NEP 2018). The study estimated that the ramping requirements to balance the net load for 2021-2022 would be higher than those required for only balancing load. Specifically, that there are more periods of time where the ramping demands of the system are above 6,000 MW/hour than if the system was without VRE. It has also determined that the additional capacity required for 2022–2027 should be from flexible sources of generation to balance the peaking, and ramping requirements of the grid.

[1] Ramping Up the Ramping Capability-India's Power System Transition

2.7.1. Ramping Capacity of Hydro Plants

While peaking capability is important, fast ramping hydro stations are equally necessary for quickly attaining the peak MW especially in periods when net load ramp becomes quite high. The ramping-up capacity of the hydro power plants in India is exhibited as follows:

Table 7: Ramping-Up Capability of Existing Hydro Power Plants in India

Installed Capacity Range (MW)	Installed Capacity for Ramp UP (MW)	%MW/min	Ramp UP capacity (MW/min)
0-150	2,631	4--20	310
150-300	3,651	4--21	384
300-600	7,042	4--17.4	669
600-900	5,141	4--9	348
900-1200	7,825	4--11	580
1200-1500	4,045	4--6	215
		Total	2,506

SOURCE: Operational Analysis for Optimization of Hydro Resources & Facilitating RE Integration India, 2017

India currently possess a hydro centric ramp-up capacity of 2500 MW spread across all its regions in India. This hydro fleet along with thermal based plant is presently catering to all the ramping support needed to match the variation in power demand like onset of day/evening peak, fast reduction of solar generation at dawn, sudden loss of wind generation etc. As relevant to our study, ramping capacities of western and southern regions are discussed as below:

Table 8: Ramping Capability of Hydro Power Plants in Western Region

Plant Name	Installed Capacity (IC)	Ramp-UP rate/IC (%) (in 5 min.)	Ramp up rate (MW/min)	Ramp-down rate/IC (%) (in 5 min.)	Ramp down rate (MW/ min)	State
Indirasagar	1,000	37	74	37	74	Madhya Pradesh
Koyna - IV	1,000	37	74	48	96	Maharashtra
Sardar Sarovar RBPH	1,200	30	72	29	69.6	Gujarat
Ukai	300	75	45	75	45	Gujarat
Koyna III	320	63	40.3	63	40.3	Maharashtra
Tons	315	51	32.1	52	32.8	Madhya Pradesh
Pench	160	>100	32	>100	32	Madhya Pradesh
Bhira PSS	150	>100	30	>100	30	Maharashtra
Kadana	240	50	24	64	30.7	Gujarat
Omkareshwar	520	23	23.9	22	22.9	Madhya Pradesh

SOURCE: Operational Analysis for Optimization of Hydro Resources & Facilitating RE Integration India, 2017

Western Region has a total ramp up hydro capacity of ~555 MW/min and ramp down capacity of ~581 MW/min. Hydro plants with high ramping capability are mostly concentrated in the state of Madhya Pradesh, Maharashtra and Gujarat in the Western Region. Hydro stations like Bhira PSS and Pench have ramping capacity greater than

100%. Hydro stations where ramping capacity is less may need modification in design and planning. It was observed that the hydro stations with single part tariff are providing lower peaking/have demonstrated lower ramping up capability.

Table 9: Ramping Capability of Hydro Power Plants in Southern Region

Plant Name	Installed Capacity (IC)	Ramp-UP rate/IC (%) (in 5 min.)	Ramp up rate (MW/min)	Ramp-down rate/IC (%) (in 5 min.)	Ramp down rate (MW/ min)	State
Sharavathi	1,035	58	120.1	46	95.2	Karnataka
Varahi	460	88	81.0	88	81.0	Karnataka
Srisailam LB	900	42	75.6	34	61.2	Andhra Pradesh
Idukki	780	46	71.8	54	84.2	Kerala
Srisailam RB	770	44	67.8	51	78.5	Andhra Pradesh
Lower Sileru	460	56	51.5	53	48.8	Andhra Pradesh
Kadamparai	400	49	39.2	49	39.2	Tamil Nadu
Sabargiri	280	63	35.3	78	43.7	Kerala
Nagarjunasagar	815.6	21	34.3	28	45.7	Andhra Pradesh
Upper Sileru	240	66	31.7	69	33.1	Andhra Pradesh

SOURCE: Operational Analysis for Optimization of Hydro Resources & Facilitating RE Integration India, 2017

Southern Region has total ramp up capacity of ~852 MW/min and ramp down capability of ~844 MW/min. Hydro power plants with high ramping capability are concentrated in Andhra Pradesh, Tamil Nadu and Kerala in Southern Region. Most of the hydropower plants are multipurpose in nature and the energy dispatch gets constrained on account of hydrological, environmental, water-supply obligation, power system and tariff related factors.

2.7.2. Ramping Capacity of PSH

Currently, out of the 44.6 GW installed hydro generation capacity, 4,785 MW is designed & capable of operation as PSH units. However, due to numerous reasons only 2,450 MW of PSH capacity is presently under operation in SR, WR & ER. The ramping capacity of PSHs is as follows

Table 10: Ramping Rate of PSH Plants

Sl. no	**Project**	**State**	**Capacity (MW)**		**Ramp Up Rate /IC (%) (in 5 min)**	**Ramp up rate (MW/min)**	**Ramp Down Rate /IC (%) (in 5 min)**	**Ramp down rate (MW/min)**
			No of units	Total (MW)				
1	Srisailam LB	Telangana	6 * 150	900	42	75.6	34	61.2
2	Purulia PSH	West Bengal	4 * 225	900	33	59.4	28	50.4
3	Kadamparai	Tamil Nadu	4 * 100	400	49	39.2	49	39.2
4	Ghatghar	Maharashtra	2 * 125	250	>100	-	>100	-
5	Bhira	Maharashtra	1 * 150	150	>100	30	>100	30

Sl. no	Project	State	Capacity (MW)		Ramp Up Rate /IC (%) (in 5 min)	Ramp up rate (MW/min)	Ramp Down Rate /IC (%) (in 5 min)	Ramp down rate (MW/min)
			No of units	Total (MW)				
6	Nagarjuna Sagar	Telangana	7*100.80	705.6	21	34.3	28	45.7
7	Kadana St. I&II	Gujarat	2*60+2*60	240	50	24	64	30.7
8	Panchet Hill DVC	Jharkhand	1*40	40	-	-	-	-
9	Sardar Sarovar	Gujarat	6*200	1200	30	72	29	69.6

Source: Operational Analysis for Optimization of Hydro Resources & Facilitating RE Integration India, 2017

2.8. Benefits of Hydro/PSH – A Use Case

On 3rd April 2020, the Hon'ble Prime Minister of India appealed to the citizens at 09:10 Hrs to switch off their lights and light lamps/candles on 5th April 2020 at 21:00 Hrs for a duration of 9 minutes. After analyzing various suggestions floating on social media for example the need to switch off all household appliances for the safety of equipment or switching on additional devices, the Hon'ble Minister of State for Power (I/C) issued a press release dated 4th April 2020 clarifying the need for switching off the lights only. The forecasted drop in all India demand during this period of 9 minutes was around 12,000–14,000 MW considering that only lights would be switched off. The total drop in all India demand recorded during the event was 31,089 MW. All India demand started reducing from 20:45 Hrs and minimum demand of 85,799 MW was recorded at 21:10 Hrs. Afterward, from 21:10 Hrs, the demand started picking up and settled around 1,14,400 MW at 22:10 Hrs.

Grid Frequency during the event was in the range of 50.26 Hz to 49.70 Hz with maximum and minimum frequency of 50.259 Hz and 49.707 Hz recorded at 21:08 Hrs and 20:49 Hrs respectively.

Hydro generation across the country was exploited by 20:45 Hrs and generation reduction of 17,543 MW (from 25,559 MW to 8,016 MW) between 20:45 Hrs to 21:10 Hrs (matching with demand reduction of 31,089 MW during the same period) was achieved with these resources. This hydro generation was again ramped up from 8,016 MW to 19,012 MW from 21:10 Hrs to 21:27 Hrs to meet the increase in demand after the event[2].

Hydropower plant were used with the following objectives during the lights off event:

a) Generation balance and frequency control

b) Voltage control

c) Power system stability and transmission network loading

In addition to hydropower in India, generation flexibility of around 400 MW was achieved during the event with change in generation at Tala, Chukha and Mangdechhu HEP of Bhutan.

[2] https://posoco.in/wp-content/uploads/2020/04/Preliminary-Report-on-Pan-India-Light-Switch-Off-Event-on-5th-April-2020-2-5.pdf

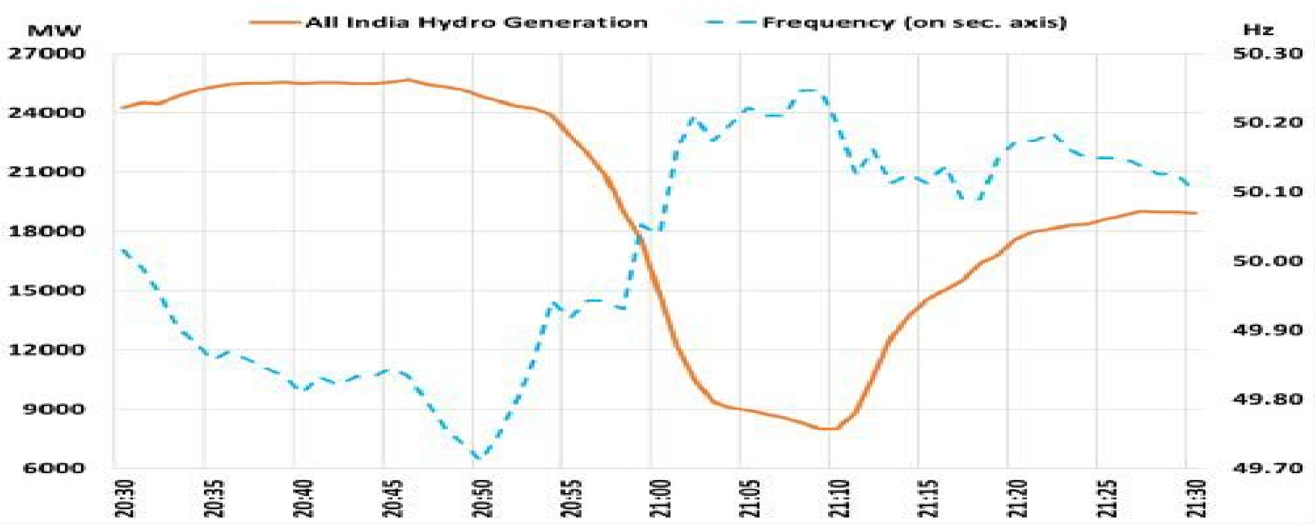
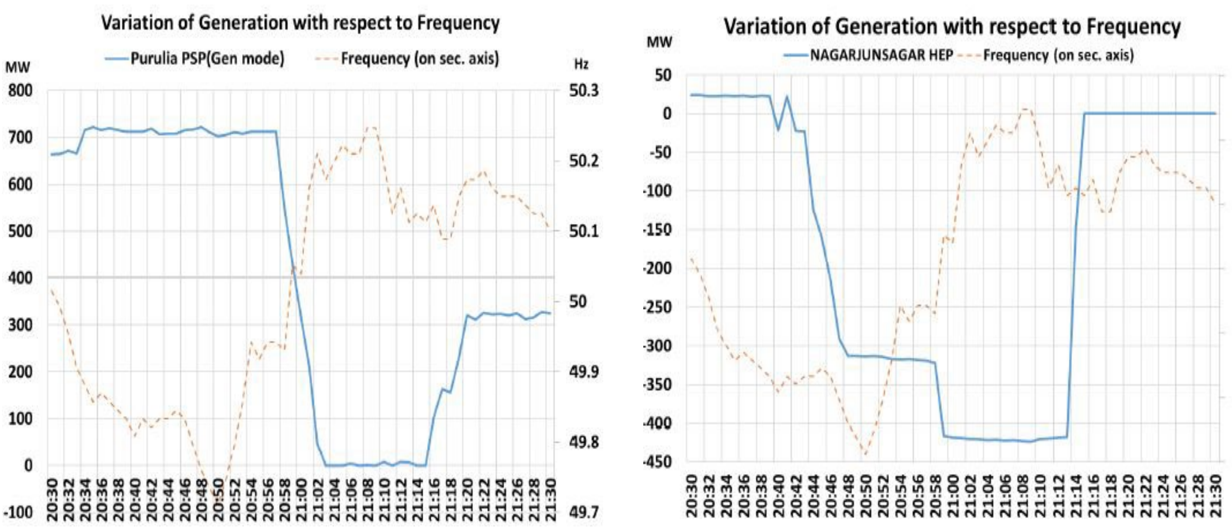


Figure 9: All India hydro generation during lights off event

SOURCE: Pan India Lights Off Event, POSOCO, 2020

Table 11: Generation/demand during the lights off event

Description	Generation / Demand (MW)			Reduction from A to B (MW)	Increase from B to C (MW)	Max. Ramp MW/ min A to B (-)	Max. Ramp MW/min B to C
	20:45 hrs (A)	21:10 hrs (B)	21:30 hrs (C)				
Hydro	25,559	8,016	18,923	17,543	10,907	2,728	1,977
Thermal	75,277	68,037	75,661	7,240	7,624	1,109	637
Gas	7,305	5,355	7,175	1,950	1,820	339	226



SOURCE: Pan India Lights Off Event, POSOCO, 2020

Figure 10: Operation of Purulia PSH and Nagarjuna PSH during lights off event of 5th April 2020

- All four units of Purulia PSH (4X225 MW) were kept in generation mode prior to the start of the event and the generation in the units was modulated with the change in frequency during the event.

- During the event, 04 units of Nagarjuna Sagar PSH (4x110 MW) and 02 units (2x110 MW) of Kadamparai PSH were taken in pump mode.f

2.9. Regulatory and Market Framework for PSH

The diagram below represents the key policy initiatives (notified and under consideration to promote development of hydro power project including pumped hydro storage projects.

• Wind-Solar Hybrid Policy, 14th May,2018 (Notified) • Amendment to National Wind-Solar Hybrid Policy,13th August,2018 (Notified)	Hydro Power Policy (Notified)	Ancillary Market Regulation (Notified)

Wind Solar Hybrid Policy

MNRE notified the National Wind-Solar Hybrid Policy on 14th May,2018 as a step towards promotion of large grid-connected wind-solar with storage. On August,2018, the policy was further amended to include PSH in the definition of storage.

Key features of the policy:

Objective	Provide a framework for promotion of large grid connected wind - solar PV hybrid system
Sizing	A wind-solar plant will be recognized as hybrid plant if the rated power capacity of one resource is at least 25% of the rated power capacity of other resource.
Storage	Early definition of storage included battery. It was amended and further broadened to include pumped hydro storage, compressed air and fly wheel. Power from hybrid may include firm power or power on hourly basis
Conditions when storage can be added to solar wind hybrid	Storage may be added to solar wind hybrid project (i) to reduce the variability of output power from wind solar hybrid plant; (ii) providing higher energy output for a given capacity (bid/ sanctioned capacity) at delivery point, by installing additional capacity of wind and solar power in a wind solar hybrid plant; and (iii) ensuring availability of firm power for a particular period
Power Offtake	• Sale to Discom at tariff determined by the respective SERC or at tariff discovered through transparent bidding process • Captive purpose • Sale to third party through open access • Sale to the distribution company (ies) at APPC under REC mechanism and avail RECs • Power from hybrid may be used to fulfil RPO requirement
Incentives	The Government will encourage development wind-solar hybrid systems through different schemes and programmes. All fiscal and financial incentives available to wind and solar power projects will also be made available to hybrid projects.

Hydropower Policy in India

The Government of India has approved various measures to promote Hydro Power Sector via office memorandum on March 08, 2019. The measures are listed below:

Large Hydropower Projects as Renewable Energy source

- Presently, only hydropower projects less than 25MW are categorized as Renewable Energy. Henceforth, the projects more than 25 MW will be categorized as renewable energy . However social and environmental clearance will still be applicable to LHP.

Hydropower Purchase Obligation (HPO)

- HPO will cover LHPs commissioned after notification of these measures as well as the untied capacity.
- HPO will be within the existing non- solar RPO after increasing the percentage assigned for it so that the existing non-solar RPO remains unaffected
- Annual HPO targets will be notified by Ministry of Powerbased on projected capapcity additions plans in hydropower sector

Tariff rationalization

- Flexibility to developers to determine tariff by back loading of tariff after increasing project life to 40 years, increasing debt repayment period to 18 years and introducing escalating tariff of 2%

Budgetary support

- For funding flood moderation component of hydropower projects on case to case basis.
- For funding cost of enabling infrastructure i.e. roads and bridges on case to case basis as per actual, limited to Rs. 1.5 crore per MW for upto 200 MW projects and Rs. 1.0 crore per MW for above 200 MW projects.

The share of hydropower in the total capacity has declined from 50.36% in the 1960s to around 13% in 2018-19. These measures are likely to boast the amount of hydroelectricity in the grid. Some of the likely positive influences due to the policy changes mentioned above are as follows:

- Considering 160 GW capacity addition by 2022 from infirm sources of power like solar and wind, hydropower (including PSH) would provide a stable grid by enhancing flexibility in the overall system.
- Discoms are reluctant sign Power Purchase Agreements (PPAs) hydro and PSH plants due to higher tariff, particularly, in the initial years. One of the reasons for high tariff of hydro and PSH is the loading of cost of flood moderation and enabling infrastructure in the project cost. In this backdrop, the decision has been taken to adopt measures to promote hydropower sector (including PSH) by providing budgetary support for flood moderation, enabling infrastructure. This would help in tariff rationalization and finding off-taker
- The increased tenure for loan repayment from 12 years to 18 years and increasing project life from 35 years to 40 years will reduce the higher interest on loan and higher depreciation in the initial years. This would reduce tariff and will encourage Discoms in signing the PPA

Hydropower Obligations

With an objective to firm up the hydropower capacity in India and add 30 GW of hydro capacity by FY30, MoP has announced a revised trajectory of Renewable Purchase Obligation (RPO) in January 2021. Under the new RPO trajectory, Hydro Power Purchase Obligation (HPO) has been included under the ambit the of overall RPO trajectory by considering the Large Hydro power projects (LHPs) commissioned after 8th March 2019.

Table 12 :Hydropower Obligations

Year	Solar RPO	Non-Solar RPO			Total RPO
		HPO	Other Non-Solar RPO	Total Non-Solar RPO	
FY21	**8.75%**	**-**	**10.25%**	**10.25%**	**19%**
FY22	**10.50%**	**0.18%**	**10.50%**	**10.68%**	**21.18%**
FY23	To be Specified Later	**0.35%**	To be Specified Later		
FY24		**0.66%**			
FY25		**1.08%**			

SOURCE: GoI, MoP Order No. 23/03/2016-R&R dated 29/01/2021

The point to be underscored here is that Solar RPO is separate from Other RE sources. Solar RPO can be met by procuring power from Solar PV or Solar Thermal Plants. On the other hand, Other non-solar RPO may be met from any RE source (other than solar and LHPs).

HPO liability of the state could be met out of the free power being provided to State from LHPs (commissioned after 08/03/2019). Free power (not that contributes for Local Area Development) only to the extent of HPO liability of the State, shall be eligible for HPO benefit. However, in case, the free power is insufficient to meet the HPO obligation, then State would have to buy additional hydro power to meet the HPO obligation. The alternate option can be buying the corresponding amount of Hydro Energy Certificates to meet the Hydro Purchase Obligation.

To ensure HPO compliance under this mechanism, CERC is going to develop the Hydro energy certificate mechanism with the capping price of INR 5.50/unit of electrical energy w.e.f. 8th March 2019 to 31st March 2021 with 5% of annual escalation

Ancillary Market Regulation:

The Central Electricity Regulatory Commission (CERC) has issued notification for ancillary services operation on 13th August 2015. Subsequently the Power System Operation Corporation Limited (POSOCO) has published the detailed procedure of ancillary services operation on March 2016.

The existing regulatory framework limits ancillary services only to providing frequency support. The frequency support or the 'reserves regulation ancillary services' /RRAS market is governed by the CERC 'Ancillary Services Operations' Regulations, 2015 and the RRAS market has been in operation since April 2016. The box below represents the salient features of the Ancillary Services Market in India.

Ancillary Services Market in India: Salient features

- All Regional Generators, whose tariff for full capacity is determined by CERC are mandated to provide the Ancillary Services as RRAS Providers.
- NLDC, through the RLDCs has been designated as the Nodal Agency for Ancillary Services Operations and it prepares the Merit Order Stack based on the variable cost of generation.
- The energy dispatched under RRAS is deemed delivered ex-bus and any variation from the scheduled values beyond revised schedule is settled as per CERC Deviation Settlement Mechanism (DSM) Regulation.
- RRAS Energy Accounting is conducted along with the DSM account on weekly basis by the respective Regional Power Committee.
- Any post-facto revision in the rates/charges by RRAS providers is not permitted.
- In Regulation Up, fixed and variable charges along with pre-specified mark-up are payable to RRAS providers from the pool. CERC specified mark-up for providing Ancillary Services is INR 0.50/kWh.
- In Regulation Down, 75% of variable charges are payable by RRAs providers to the pool
- No commitment charges are payable to the RRAS providers.

In September 2018, CERC has notified a discussion paper titled "Re-Designing Ancillary Services Mechanism in India". The paper attempts to assess the performance of the current framework of frequency support and balancing ancillary services mechanism in India and to suggest next-generation reforms by way of introduction of auction-based procurement of ancillary services. The table below presents a comparison of the existing Ancillary Services Market and the proposed changes by CERC.

Table 13: Comparison of the existing Ancillary Services Market and the proposed changes by CERC

Particulars	Existing Regulation	Proposed Regulation
Eligibility of RRAS	Only Regional Entities whose tariff for full capacity is determined	All Inter-State / Intra-State generation (Public or Private) resources
Schedule of RRAS	SLDC schedules MW from RRAS as per merit order stack	• Traded in Day Ahead bidding in power exchanges. Final settlement through an real time market • Generators will bid simultaneously in Day Ahead Energy and Day Ahead AS Market
Clearing mechanism	Continuous Trading	Auction based market mechanism
Pricing methods	Fixed, variable, mark up price determined by CERC	Pricing of AS with respect to the opportunity lost by the RRAS in foregoing the energy market or other AS market
RE reserves as tertiary	Not allowed to participate	The participation of RE resources will be notified at a later date

Source: Re-Designing Ancillary Services Mechanism in India, CERC, 2018

In addition to the above policy initiatives, the government and Regulators need to explore the requirements for extending the ancillary services market to include **spinning reserves, voltage regulation, black start,** etc. which is currently limited to frequency support only. Additionally, the ancillary services market mechanism should be suitably modified to compensate PSH for both the **'generation' and 'pumping'** modes of operation. Further some of the below mentioned initiatives could aid in development of PSH

- **Regulatory Asset**

  Existing policy can be revised to bring PSHs under the category of a regulatory asset. As a result, PSH will be operated as per the requirement of national grid operator, mainly towards load leveling on the lines of Reserves Regulation Ancillary Services (RRAS). This will also ensure the tariffs for the input power for pumping and output power to be decided by the regulator.

- **Common Asset under Ancillary Regime**

  Second development can be acknowledging the PSH as a common asset under ancillary services regime by the regulator. This would further require development of market mechanisms and innovative economic models that evaluate energy storage technologies based on their abilities to provide key support services to the overall electric grid, particularly when taking into consideration project lifecycle costs, performance, and energy storage system degradation

- **National Storage Policy**

  National Storage Policy should allow energy storage as an eligible transmission component and thus, direct/advise CEA/Central Transmission Utilities (CTU) to include energy storage in future transmission planning. Further, the PSH projects can also be delinked from the per unit energy cost basis for expeditious development.

- **Enhancing economic viability**

  PSH has many more functionalities other than just providing balancing power for a few hours to support VRE and can be exempted from transmission charges. Moreover, as the time shifting shall be performed by PSHs to offset the wind and solar energy, thus the time of day differential pricing can be provided to the PSH plants

PSH plants have various grid benefits besides peaking and balancing support. Hence, in addition to capital cost and energy supplied, PSH developers and policy makers may consider the magnitude of other factors while prioritizing projects:

- **Location** - The location of the project under protected area or within 10 km of projected area boundary or otherwise
- **Capacity** - Capacity of the project as projects of 200 MW and above all are considered more economical presently
- **Hydrology** – PSH is an off-river or on-river plant
- **Technical Aspects** - Cycle efficiency and duration of storage
- **Detailed Due-Diligence** - Availability of the pre-feasibility report, detailed surveys, and investigations, detailed project report, etc.
- **Expected Project Completion** - PSH projects that could be implemented within next 10 years with bankable feasibility reports
- **Enabling Infrastructure** - PSH projects with some existing structures/hydro projects and grid connectivity at interstate and super grid level.

2.10. Hydro Power Trade in Energy Exchanges

Historically, bulk electric power supply in India has been mainly tied with long-term PPAs with the state Discoms, governed by the CERC/SERC regulations. The long-term PPAs regime lacks the capacity to induce market competition, attract liquidity and support demand flexibility. The enactment of the Electricity Act 2003 laid down the provision for promoting of competition in the Indian power market. This laid the foundation for the development of short-term power markets which subsumes the contracts of less than one-year period for electricity transacted under bilateral transactions through Inter-State Trading Licensees and directly by the DISCOMs, Power Exchanges (IEX, PXIL) and Deviation Settlement Mechanism (DSM).

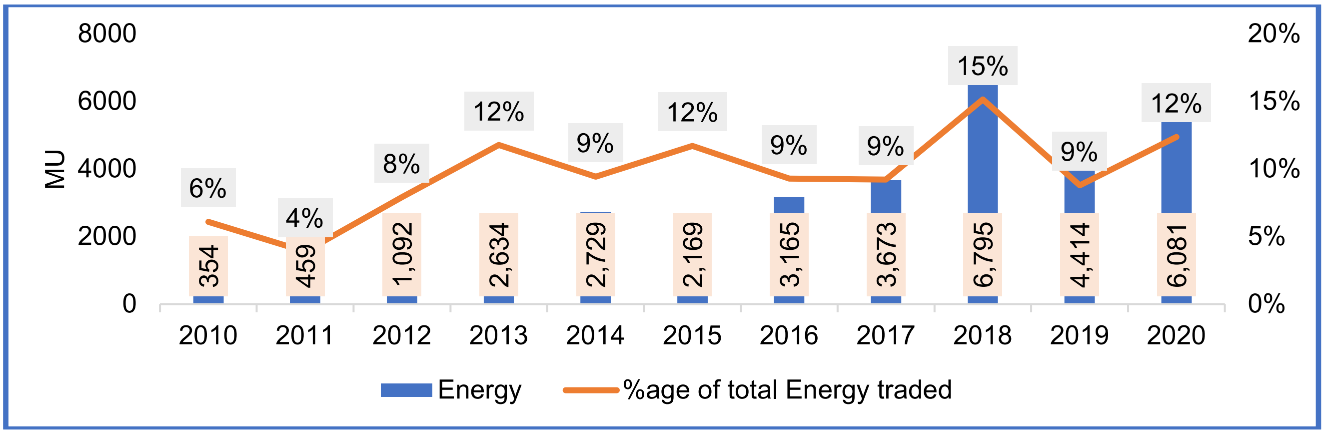
Hydropower procurement by the Discoms in India is still majorly driven by the legacy long-term PPAs under the cost-plus route. One of the mandates of the study is to assess the potential of the hydropower trade through other routes such as Electricity Exchanges. The following subsection presents the current scenario of short-term power market and the contribution of hydro power to this market.

2.10.1. Power Trade

Over one decade, the volume of electricity transacted through traders and power exchanges increased from 24.69BU (FY09) to 86.40BU (FY20). As in FY 2020, short-term power markets contributed to nearly 10% of the total power procured by Discoms which corresponds to the volume of 137.1 BUs, out of which ~86.40 BUs is contributed by the culmination of power markets and short-term bilateral trades. The volume traded through short-term market has registered a higher CAGR viz. 8% as compared with total generation CAGR of 6%.

During December 2020, total electricity generation excluding generation from RE and captive power plants in India was 1,03,656 MUs. Of the total electricity generation, 14% was transacted through short-term, comprising of 6.5% through Day Ahead Market (DAM) and Real Time Market (RTM) of power exchanges, followed by 5.2% through bilateral (through traders and term-ahead contracts on power exchanges and directly between distribution companies) and 1.79% through DSM. Out of total 86.40 BUs, hydropower contributes only 7% to the total traded volume (as in 2020). The trajectory of hydropower traded in past one decade is exhibited as follows:

Figure 11: Hydro Power Traded in IEX (Million Units)



Source: MoP Data, Report on Short-term Power Market in India, 2019-20

- Hydro trade in DAM has increased at a CAGR of 33% from 2010 to 2020.
- Majority of the hydro traded is in the Northern Region mainly from Himachal Pradesh and Sikkim.
- Major traders in DAM market include GoHP,Teesta Urja Limited and Karcham Wangtoo HEP.

The prices of the major hydropower plants, transacting power over IEX range from as INR 2.32/unit (2014) by Karcham Wangtoo HEP and tapped a high price of INR 4.38/unit (2015) by HPSEB. The detailed representation of the major hydropower plants partaking in IEX are annexed as **Annexure-1.** Broadly, the average price of the hydro power traded in DAM has decreased at a CAGR of 2.5% from 2012 to 2020. The average price of the power in the DAM stood at INR 3.24/kWh (as in 2020), which has observed a YoY downtick of -0.24%.

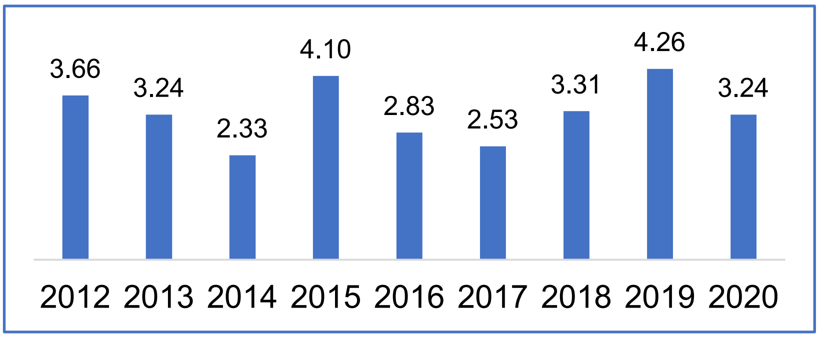


Figure 12: Hydro power average tariff in DAM

SOURCE: *MoP Data, Report on Short-term Power Market in India, 2019-20*

With an overall trend-shift of the power market towards short-term markets, hydropower is expected to soon follow the suit and the trade from hydropower in short term markets are expected to increase

3. Assessment of PSH in three states in India

3.1. Methodology

We have followed a robust approach to shortlist the states and RE based projects for the study. The approach is a three-layered filtration approach. Our approach considers a basket of PSH's spread across different states in India. The sequential steps of the approach are exhibited in the tabular representation as below:

Step-I: Shortlisting Regions with high RE Penetration

- Selection of Region with high RE penetration
- SR and WR were selected
- Three states were selected in the regions with high RE and PSH potential
- States of Tamil Nadu, Karnataka and Maharashtra were finally shortlisted based on discussions with IGEF team

Step - II: Projects status and Ownerships

- Projects in advanced stage of technical feasibility (DPR preparation/pre feasibility stage) were selected
- Projects proposed to be implemented by State Genco/Central PSUs are selected

Step - III: Environment & Social Assessment

- Projects with limited safeguard issues were given priority

Final Shortlist

State	Name of the Project	Capacity (MW)	Status
Karnataka	Saravathy PSH	2000	Pre-Feasibility report prepared by WAPCOS (1000 MW) in 2017. Draft DPR is expected to be available in May 2021 Environmental Clearance in Process
Tamil Nadu	Sillahalla Stage I PSH	1000	Pre-Feasibility report prepared by WAPCOS (1000 MW) in 2019 Environmental Clearance in Process
Maharashtra	Malsej PSH	700	DPR of the project prepared (needs to be updated) and awaiting agreement

4. Karnataka State Assessment

4.1. Karnataka - State Overview

Karnataka, a state located in the southern region of India, has a geographic spread of 192,000 sq. km and is surrounded by the Arabian Sea in the west, Goa in the northwest, Maharashtra in the north, Andhra Pradesh in the east, Tamil Nadu in the southeast, and Kerala in the southwest. Karnataka has a total population of 61.1 Mn (FY20) with the population density of 319 persons/sq. km. The capital city of Karnataka viz. Bengaluru is termed as Silicon Valley of India. Favorable policies designed by Karnataka have encouraged industries to set up their research and development (R&D) centres in the state.

The current Gross State Domestic Product (GSDP) of Karnataka stands at USD 227.25 Bn (as in FY20), which has steadily grown with a CAGR of 12.8% since FY12. As per 2019 statistics, the economy of Karnataka was majorly driven by the tertiary sector which contributed 67.87 per cent to the state's GSVA, followed by the secondary sector (21.27%) and the primary sector (10.85%).

4.1.1. Power Sector Overview

As of 31 March 2020, Karnataka has ~29,825 MW of total installed capacity. Renewables account for 51% to the total installed capacity which is followed by thermal installations (coal +lignite) contributing 35% to the generation mix. Hydro segment –currently contributes ~ 12% to the installed capacity with remaining 2% by nuclear plants

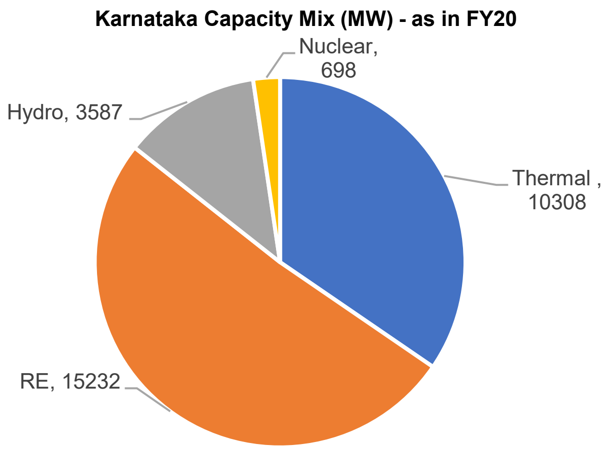


Figure 13: Karnataka Installed Capacity mix

4.1.2. Demand-Supply Assessment of Karnataka

Karnataka power supply and demand position are stable. In the last six years, both peak demand and supply grew at a CAGR of ~5.8% and ~6.7%. The state has reduced its deficit at a CAGR of ~38% from 4.5% in 2015 to 0.6% in 2021. The total peak power requirement in 2021 was 14,040 MW, which was almost met with the peak power supply of 14,125 MW, as shown in figure.

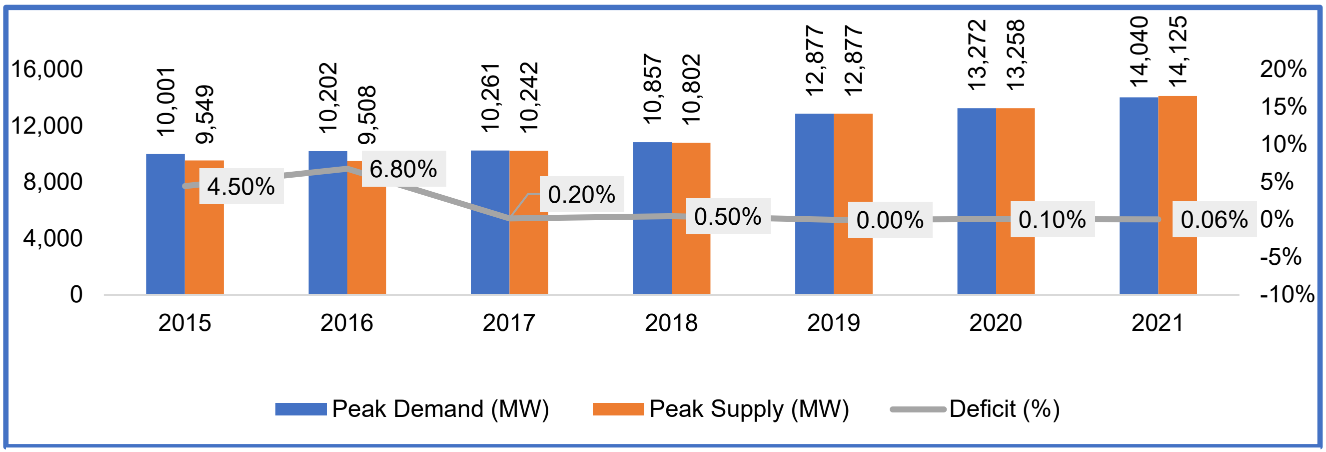


Figure 14: Energy demand and supply position on Karnataka

Source: CEA, LGBR

4.1.3. Renewable Penetration in Karnataka

As in FY20, the state solar installed capacity observed ~7310 MW capacity which is followed by wind installed capacity tapping ~4855 MW. The overall RE installed capacity in the state is 15.2 GW. The state has a solar energy potential of 10,000 MW. The graphical below exhibits the planned capacity addition by the state government.

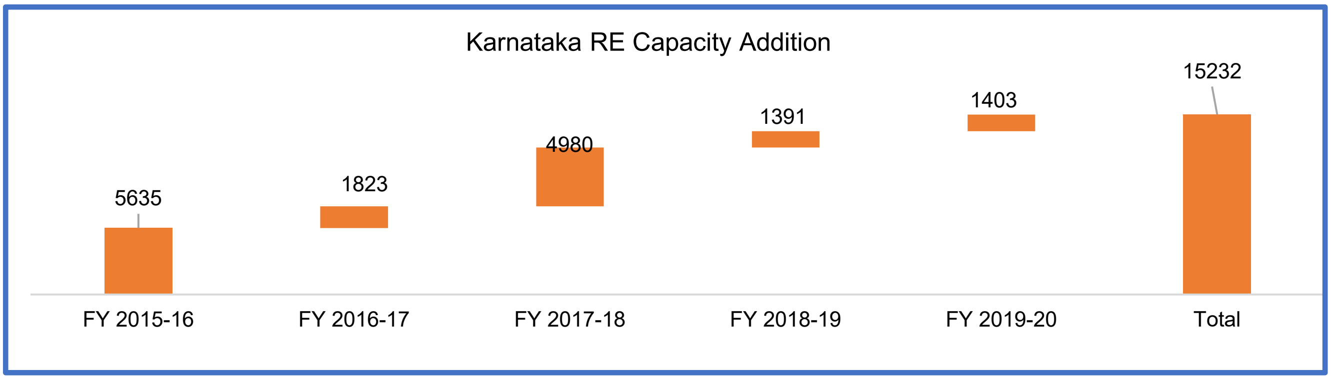


Figure 15: Renewable Penetration in Karnataka

Source: KREDL, CERC, Karnataka Renewable Energy Policy

Some of the recent State and Central initiatives to promote RE in Karnataka are highlighted below:

- Karnataka's Draft Renewable policy 2021 aims at developing 20 GW of renewable energy projects with and without energy storage
- BESCOM has announced in March 2021 offer of 20%-40% of the project cost as subsidy to individual houses, group housing communities and resident welfare associations to install solar rooftop photovoltaic (SRTPV) units recently.

- Govt has granted ISTS waiver extension for solar, wind projects until June 2023 as a step to promote renewable.

Incentives: Incentives aimed to aid developers with the sale of energy, land acquisition, obtaining grid connectivity, project allotment, clearances, energy storage, and metering and connectivity shall be provided by the Government of Karnataka

Other Policy Measures:

- Karnataka will promote renewable energy parks under the PPP model or through private development by investing up to 50% of the equity as required.
- KREDL also prescribed the procedure for applying for projects and land allotment for all renewable energy-based projects.

A snapshot of Karnataka's Draft Renewable Policy 2021-2026

Objectives: The major objectives are as follows:

- To facilitate development of 20 GW of RE projects with or without energy storage systems in the State, including 2 GW of Rooftop solar PV projects;
- To attract investment in the RE sector and development of State economy;
- To tap RE potential in the State and use of available resources for development of RE projects for the purpose of meeting the RE demand within the State and exporting energy outside Karnataka;
- To achieve the RPO target(s) as specified by KERC from time to time

Focus Areas

Green Energy Corridor	Renewable Energy Market	Solar Energy Project	Wind Energy Project	Solar-Wind Hybrid Energy Project
Energy Storage	Biomass	Waste to Energy	Mini and Small Hydro P	R&D

High RE penetration can draw curtailment of RE during peak hours of generation or in case of lack of transmission availability. As in FY20, the Karnataka load dispatch center has observed RE curtailment during day peak hours of load. The details of the RE curtailment in Karnataka state is exhibited in the tabular representation below:

Table 14: Curtailment in 2019

Date	Curtailment in FY 2019	Time duration
7.09.2019	10% of RE generation	12:15 hrs to 17:30 hrs
08.10.2019	20% of RE generation	13:00 hrs to 16:30
08.09.2019	10% of RE generation	12:15 hrs to 17:30 hrs
26.09.2019	10% of RE generation	12:15 hrs to 16:00 hrs
27.10.2019	20% of RE generation	10:30 hrs to 16:00 hrs

Date	Curtailment in FY 2019	Time duration
28.10.2019	10% of RE generation	11:30 hrs to 16:00 hrs

Source: KPTCL RE curtailment sheets

The curtailment is expected to grow worse with the increasing share of renewables in Karnataka's energy mix. The following figure depicts the fluctuations in the net load versus demand in FY 2031-32

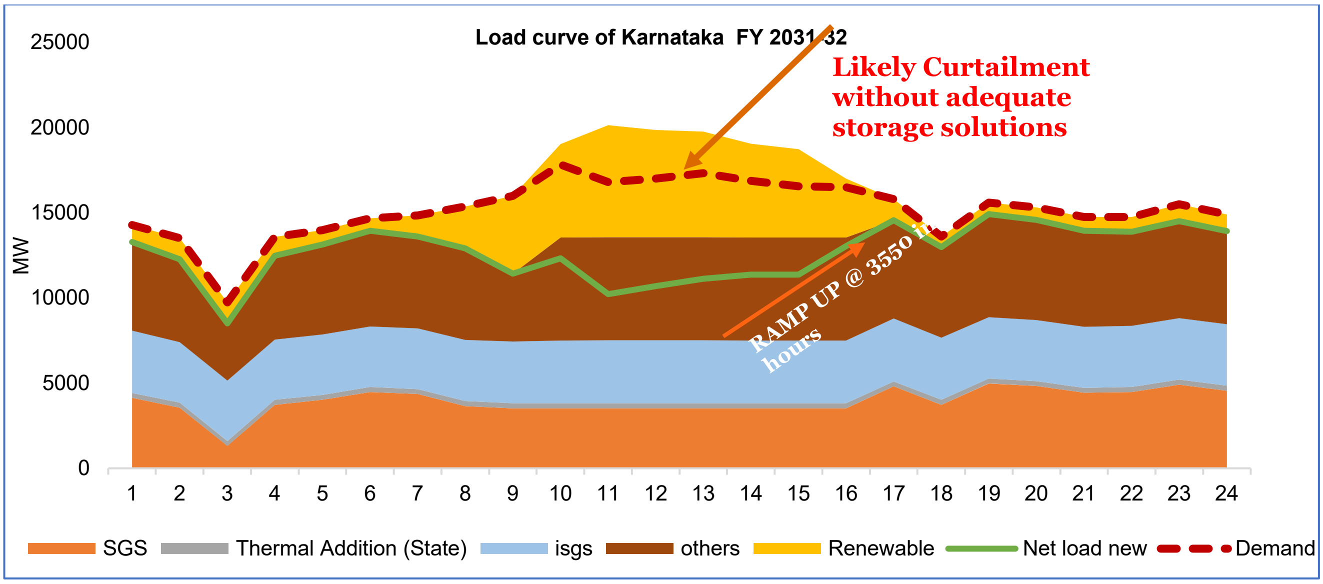


Figure 16: Forecasted Load curve of Karnataka

Source: *PwC Analysis*

Two points are noteworthy in the graphic (i) the high ramp up requirements and (ii) the likely curtailment. Currently, ramp up is being met by RRAS providers as recognised by CERC. They are all thermal –(mostly gas/coal based) and they cater to the whole Southern Grid. The tariff ranges from 2.5-5 INR /kWh with additional 0.5 INR/kWh as charge for provisioning.

High ramp up rate requirements and reduction of projected RE curtailment would requires introduction of flexible generation and storage solutions like PSH which are also commercially viable and environmentally sustainable. The additional energy likely to be curtailed can be used to schedule and pump up water at (preferably only variable costs to lower cost of pumping) to pumped hydro during daytime and energy generated from PSH can be used as peaking load during evening hours.

4.1.4. Need for flexible resources like PSH in Karnataka

Apart from solving the RE curtailment, PSH can play a vital role in maintaining the thermal-hydro mix, reducing short term purchases and providing support in grid stability.

Hydro-Thermal mix:

In regional grids, the seasonal demand pattern matches with the generation from hydro power generation. During monsoons when the generation at hydro power plants is high, the load factor of the system is high due to heavy agricultural load. During winter, the thermal stations operating at base load and hydro stations working as peak load stations will take care of weather beating loads. Thus, the operational needs of hydro & thermal stations are complimentary, and the balanced mix helps in optimal utilization of the capacity

However, both in SR and in Karnataka, the hydro-thermal ratio has been decreasing every year.

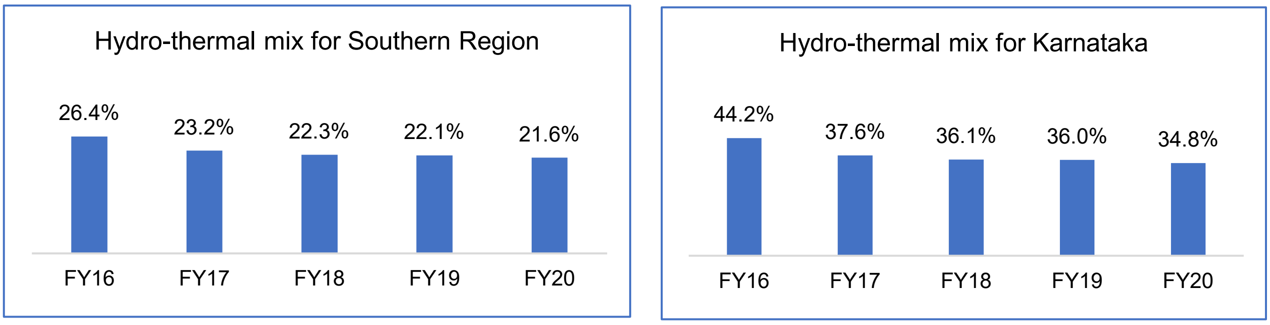
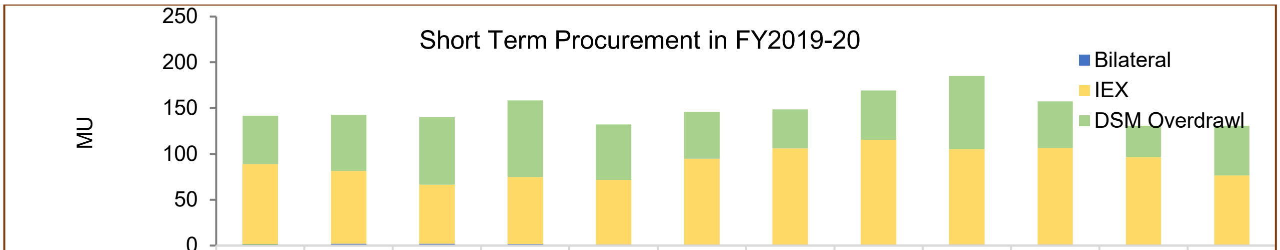


Figure 17: Hydro thermal Mix

Source: CEA Report

The ratio for Southern Region is much lower than the optimum ratio of 40%. This necessitates addition of additional hydro resources (hydro plants or PSH) which would help in maintaining the optimum capacity utilization of hydro and thermal.

Short Term Purchase:



	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
DSM Overdrawl	53	61.12	73.58	83.54	60.79	51.14	42.73	54.12	79.72	51.07	34.26	54.37
IEX	86.88	79.45	64.5	73.45	70.32	93.82	106.09	115.26	103.95	105.03	96.05	76.57
Bilateral	1.94	2.17	2.05	1.49	1.21	1.04	0	0.07	1.37	1.28	0.44	0.05
Total	142	143	140	158	132	146	149	169	185	157	131	131

Figure 18 Short Term Purchase in FY 2019-20

Source: CERC Market Monitoring Report

Karnataka purchases about 1800 MU annually to meet the demand supply gap from short term purchases, out of which 60% is brought from exchanges~1071 MU at a higher rate of 4-5 INR/kWh. Karnataka is also paying deviation charges to the tune of 39% for continuously violating DSM norms by overdrawing MU more than 12% of scheduled energy at a rate of 3-4 INR/kWh. Karnataka paid INR 55 crores for over-drawal as DSM charge for FY 20. This continuous noncompliance is also a threat to system security and stability for the entire Southern Grid. Below is a snippet of prices in the bilateral and IEX market.

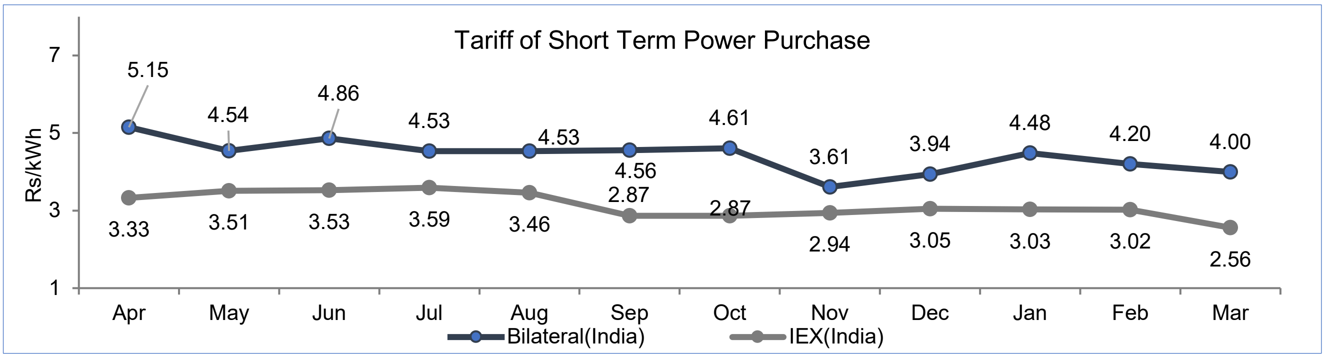


Figure 19:Short term power purchase of Karnataka

Source: CERC Monthly Report

Karnataka may look for firm power through PSH instead of relying on exchange which is susceptible to price volatility and uncertainty.

Grid Flexibility Support:

1. **Frequency:** Frequency has always been a cause of concern in the Southern Grid where the renewable penetration is about 40% of the total installed capacity. Frequency falling below the IEGC band (< 49.9 Hz) has decreased by 14.81% from FY17 to FY20 and frequency rising above the IEGC band (> 50.05 Hz) has increased by 7.77% from FY17 to FY20.

- Overdrawal- 162 MU
- Underdrawl: 192 MU
- DSM Charges Paid for Overdrawal: INR 55 crores
- Additional DSM Charges paid to DSM Pool: INR 15 crores
- DSM rate: INR 3.4/kWh
- Highest Overdrawal: December
- Highest Under drawal: January

Table 15: Grid Discipline of SR

Grid discipline in 2016-17 vis-à-vis 2019-20			
Particulars	**2016-17**	**2019-20**	**Grid Discipline in 3 FYs**
% time frequency < 49.9 Hz	**8.1%**	**6.9%**	
% time frequency between 49.9-50.05 Hz	**72.6%**	**72.3%**	
% time frequency > 50.05 Hz	**19.3%**	**20.8%**	

Source: Monthly Report, POSOCO

Karnataka may look for additional firm power from flexible resources to bring down the DSM charges paid to the Pool.

2. **Peaking Power:** Peaking support from existing hydro plants are not able to meet the peak demand because of seasonal imbalances. The system observes high peak demand during the months of February-April & September-December. This is the period when hydro generation is low due to low water flows on account of dry season.

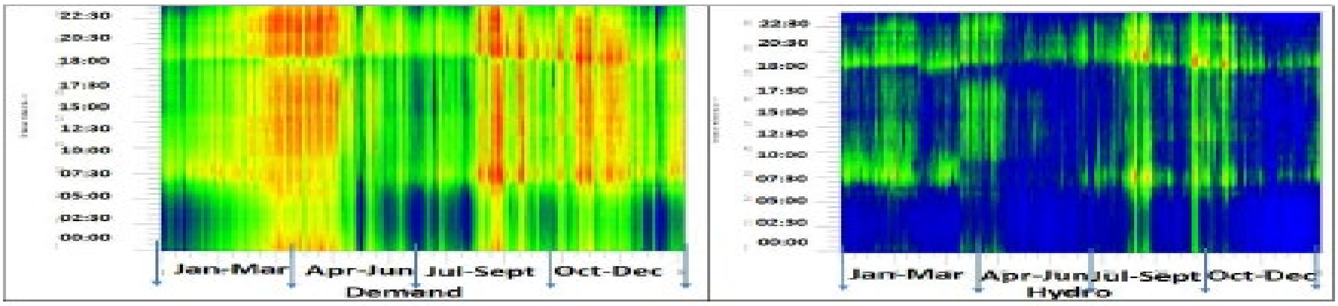


Figure 20: Hydro generation curve

3. **Dynamic VAr Support:**

Imbalances in the supply and demand of the reactive power in the system can lead to fluctuation of the voltage across the power system. This requires injection of the reactive power in the system to balance the system. PSH can emerge as an ideal solution for this as it can be operated in lead or lag modes to meet the requirement of reactive power of the grid. Moreover, PSH can also be operated in synchronous condenser mode to improve the system power factor, ensure power quality and voltage stability.

4. Black Start Support:

Black start is the capability of a generating plant to start on its own without complete interruption of external power to the station. About 90 black start drills took place in SR since last five years. Hydro units especially PSH is most preferred for black start because of their high ramp up capacity, faster response time, economic viability and low auxiliary consumption. Also, the high inertia and reactive capacity of hydro turbines provide transient stability and helps in grid restoration.

Table 16 :Number of Black Start Drills (past 5 yrs) in SR

Location of Plants	No. of Black Start Drills
Kerala	19
Tamil Nadu	29
Andhra Pradesh	10
Karnataka	**17**
Telangana	16
Total	91

Source: Report on Operational Analysis for Optimization of Hydro Resources & facilitating Renewable Integration in India

Overall, Saravathy PSH is emerging as a suitable fit for meeting the emerging energy requirements of the Karnataka State vis-à-vis Southern Region. Few of the salient points which underpin the case of development of PSH are:

- Currently hydro-thermal mix is skewed towards thermal resources with only 12% contribution to generation mix by hydro (with hydro to thermal ratio is 0.35). Development of the additional 2000 MW PSH capacity, under the umbrella of hydro will help to balance the hydro-thermal mix. This will lead to optimal utilization of resource mix.
- The power procurement cost from some of the Central Stations can be as high as INR 8-10/kWh. Saravathy PSH can replace such high cost plants and can help in surrendering capacity from such high cost plants
- Saravathy PSH can provide frequency balancing support to the grid and help managing the grid discipline.
- PSH can meet high peak demand in short span of time due to high ramp rate. Hnece, Saravathy PSH will play a vital role in peak shaving needs of Karnataka
- PSH plants have been recognized as the assets for purpose of peak shifting and load leveling. Saravathy PSH can also play an important role in Karnataka power system to store the power during off peak hours and utilize the same as peak hours.
- SR region is reeling with the issue of RE curtailment. PSH can assist in bring this element of RE curtailment lower by absorbing the additional power.

4.2. Commercial Assessment – Sharavathy PSH

The aim of this section is to gauge the commercial viability of the Sharavathy PSH in the Karnataka power system by benchmarking it against other generation plants in the state. This is followed by a comparison with other peer PSH plants and lastly the comparison with some upcoming plants. Saravathy PSH has been planned by the Government of Karnataka to meet peaking capacity need, promote integration of renewables and increasing share of hydro in overall mix.The salient features of Saravathy PSH plant are exhibited below:

Table 17: Salient features of Saravathy PSH

Parameter	Details
Location	Located in The Shimoga and Uttara Kannada in Karnataka
Technical Parameters	• Capacity: **2,000 MW** • Gross Generation:**4,380 MU** • Daily hours of generation:**6 hrs**
Project Cost	Project Cost is estimated at ~ **INR 5,017 crores**

Parameter	Details
Tariff	Levelised tariff of **- INR 5.33-INR 6.67/kWh**

SOURCE: WAPCOS Prefeasibility Report, 2017

The projected levelised tariff of the plant is expected to be in the range of INR 5.33/kWh to INR 6.67/kWh on the basis of scenarios considering pumping power at INR 2/kWh and INR 3/kWh. As per the KERC, the source-wise availability in Karnataka was 102,614 MUs and addition of capacity from the Saravathy PSH to the system will supplement, this baseline FY20 generation mark by **4.2%.** The Distribution of Electricity, including retail supply, in the State is being undertaken by the five Distribution Companies. Power Procurement Cost (PPC) by BESCOM (Discom with more than 51% of the state capacity allocation) is presented as below.

Table 18: Power Procurement Cost

Source	MU	FC (INR)	EC (INR)	TC(EC+FC) (INR)
NTPC Bundled power solar (Old)	120.5	0.0	10.5	10.5
Bellary Thermal Power Stations_BTPS-3 (1x700)	1400.0	4.4	3.4	7.8
YTPS	1571.6	4.7	3.1	7.8
Bellary Thermal Power Stations_Btps-2 (1x500)	1300.0	3.5	3.7	7.3
PRIYADARSHINI HYDRO (6x39)	90.7	0.0	6.5	6.5
Udupi Power Corporation Limited UPCL (2x600)	4352.3	2.6	3.5	6.2
Bellary Thermal Power Stations_Btps-1 (1x500)	1430.0	2.0	3.9	5.9
Kudgi	3014.0	2.6	3.0	5.6
NTPC Tamilnadu Energy Company Ltd (NTECL) -Vallur TPS Stage I &2 &3 (3X500MW)	738.0	2.2	3.1	5.3
Bhadra Hydro Electric Powerhouse - BHEP ((1x2+2x12) + (1x7.2+1x6))	48.0	0.0	5.3	5.3
Raichur Thermal Power Station - Rtps 8 (1x250)	1427.0	1.6	3.6	5.2
Solar	3453.7	0.0	5.5	5.5
Biomass	88.0	0.0	5.3	5.3
Cogen	461.7	0.0	5.2	5.2

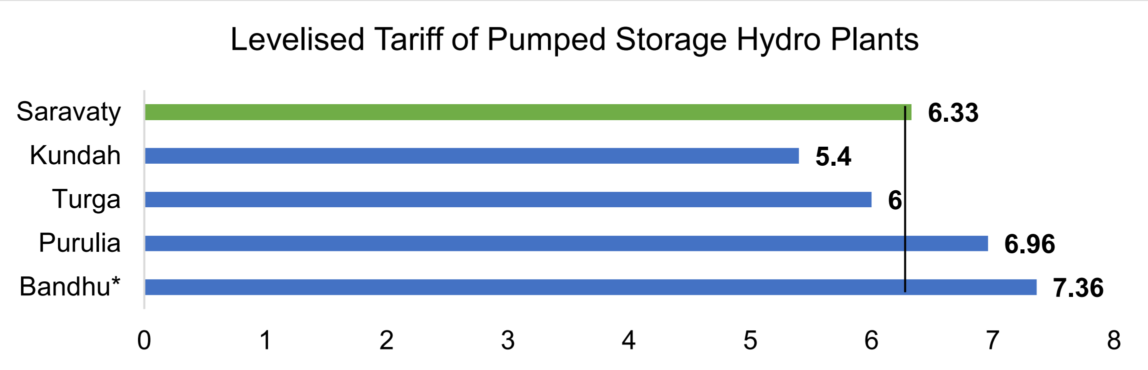
The synopsis of the observations from the power procurement by BESCOM for the period of FY19-20, is presented as below:

- The overall APPC for FY20 for BESCOM was ~INR 5.9/kWh which is
- The power procured from KPCL (State Genco) contributes 24% to the total quantum and the average rate of procurement is ~INR 5.78/kWh.
- The power procurement from the other non-conventional sources contributes nearly 25% and the average PPC is ~INR 6/kWh.
- The average cost of procurement from solar plants is INR 5.5/kWh and from biomass is INR 5.3/kWh.
- The power procurement cost from central stations is ~INR 7.07/kWh

As per the FY20 Tariff, the actual Average power purchase cost incurred by BESCOM is INR 5.91/kWh. The projected (lower) levelized tariff of Saravathy PSH viz. INR 5.33/kWh is ~9.6% lower than the Average Power Purchase Cost of the BESCOM

The above-mentioned analysis reveals that cost of generation from the Saravathy PSH is competitive in the Karnataka power system which can contribute in meeting peak demand and provision flexibility the grid. The comparison of Saravathy PSH levelised tariff against other PSH plants in India is as follows:

Figure 21: Levelised Tariff of Pumped Storage Hydro Plants



**Low tariff scenario for Bandhu (with 2 fixed + 2 variable unit)* , SOURCE: WAPCOS feasibility Reports, JICA Reports, PwC Analysis

From the levelised tariff comparison of Saravathy with other 4 selected PSH plants, the average levelised tariff has been worked out to be INR 6.41/kWh. From this analysis, it has emerged that the levelised cost of Saravathy PSH is lower than worked out average levelised tariff.

The commercial assessment of Saravathy PSH demonstrates that the levelised cost of Saravathy PSH is competitive in comparison with the per unit procurement cost by Karnataka. As compared to peers PSH plants, Saravathy PSH also has a comparable tariff. Overall, this strengthens the case of Saravathy PSH as a candidate for the Karanatake to facilitate supply during peak hours, provision grid flexibility and increase share of hydro in state generation capacity mix

4.3. Technical Assessment

WAPCOS Limited (a Govt. of India Undertaking) has prepared the prefeasibility report of the project in April 2017 for Karnataka Power Corporation Limited (Govt. of Karnataka), who is the developer of the project. This technical due diligence report is based on the prefeasibility report prepared by WAPCOS. The detailed technical assessment of the project is presented in the following sub-sections:

4.3.1. Location and Accessibility of the Project

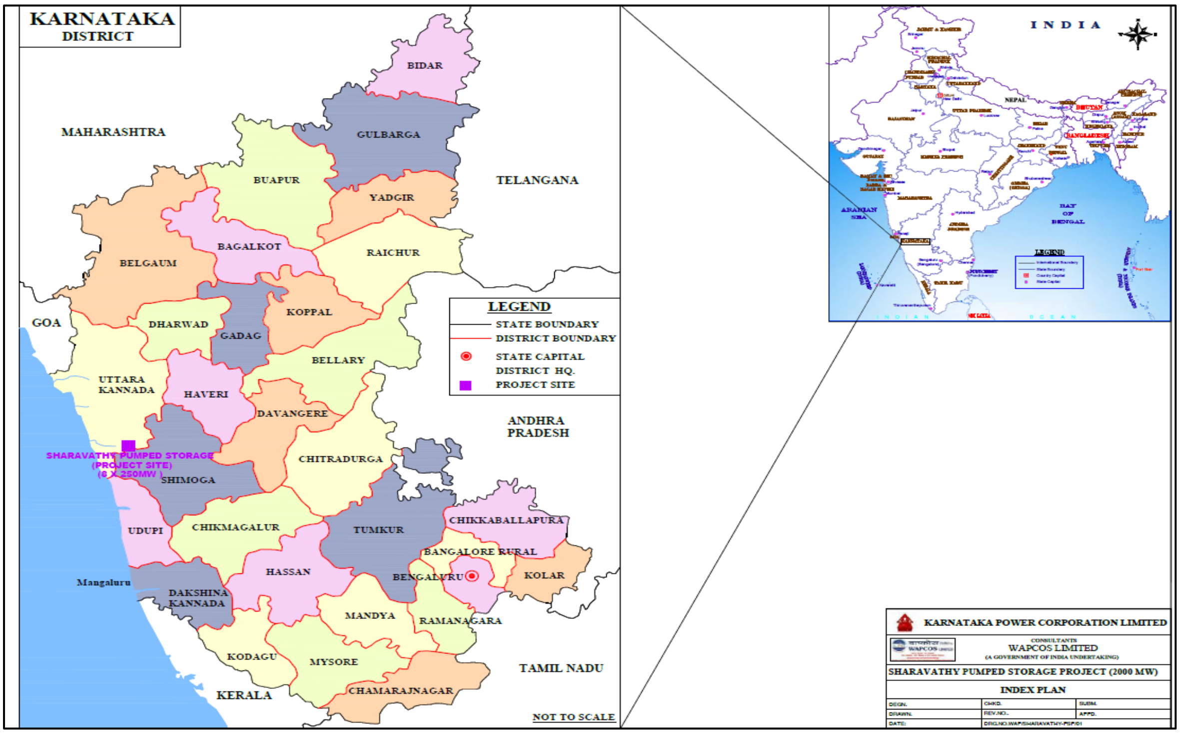
Locational

The project is planned to be developed in the Sharavathy river system with Talakalale dam as upper reservoir and Gerusoppa dam as lower reservoir. The project is planned to be developed in the Sharavathy river system with Talakalale dam as upper reservoir and Gerusoppa dam as lower reservoir. Both the reservoirs exist, which is the big advantage for the project.

Technical and Locational details of the Plant

- 2 (two) nos. intake with trash racks having mechanical raking arrangement
- 2 (two) nos. 2.726 km long, 9 m diameter circular concrete lined headrace tunnels including cut & cover
- 2 (two) nos. 0.828 km long, 5.25m diameter inclined circular steel lined (including horizontal) pressure shafts
- 2 (two) nos. 16m dia. circular Surge Shafts 52m high
- An underground powerhouse having ana installation of 8 nos. Francis type reversible pump-turbine driven generating units of 250MW capacity each
- 2 (two) nos. 3.780 km & 3.830 km long concrete lined tail race tunnels to carry the powerhouse releases to lower reservoir.
- Geographic co-ordinates - The upper reservoir is bounded by N- 14° 11’ 43.90”, E- 74˚ 46’ 43.14” and N - 14˚ 11’ 38.98”, E- 74˚ 47’ 1.60”. The lower reservoir is bounded by N- 14 ˚ 14’ 56.03”, E- 74 ˚ 40’ 34.76”and N- 14 ˚ 15’ 14.58”, E- 74 ˚ 40’ 29.43”

The nearest railhead for the upper reservoir is Mangalore and for lower reservoir, it is Bhaktal. The nearest airport is located in Panaji, Goa. From the Mangalore railway station, the project is accessed by road via Jog Fall and the road distance is about 240 Km. From Bhaktal rail head the project is only 44 km by road. Similarly, the road distance from Panaji airport is about 248 km.



4.3.2. Review of Hydrology

The proposed Sharavathy PSH envisages utilization of the hydro potential from two existing reservoirs at Talakalale dam on Talakalale stream and Gerusoppa dam on Sharavathy River. Talakalale reservoir is fed mainly by the daily discharge release through tailrace of dam toe powerhouse at Liganamakhi dam. The reservoir at Gerusoppa dam is fed by the combined tail water releases through Mahatma Gandhi hydroelectric station and Sharavathy powerhouse alongwith the river inflows from the catchment in between the Talakalale and Gerusoppa dam site. The brief description on hydrological aspects of the project is presented below.

4.3.2.1. Catchment area details

The catchment area details corresponding to existing dam sites and gauge and discharge site on rivers in adjoining river basin are reproduced herein as under:

- Catchment area corresponding to Liganamakhi dam site = 1991.56 km^2
- Catchment area corresponding to Talakalale dam site = 46.62 km^2
- Catchment area corresponding to Gerusoppa dam site = 151.52 km^2
- Catchment area corresponding to Shimoga gauge and discharge site = 2831 km^2
- Catchment area corresponding to Aghanashini gauge and discharge site = 1090 km^2

As per the pre-feasibility report, the discharge released through dam toe powerhouse at Liganamakhi dam is available from 1st July 1995 to 16th May 2015. In addition to this, the mean daily flows available at Shimoga gauge and discharge site on Tunga River and Santeguli gauge and discharge site on Aghanashini River in the adjoining basin was used. The mean daily flows at both the gauge and discharge sites are available from January 1990 to May 2003.

The used discharge data of the two gauge and discharge sites and discharge release data from Liganamakhi dam toe powerhouse are not available in the pre-feasibility report.

4.3.2.2. Water availability assessment (as per pre-feasibility report)

Existing reservoir at Talakalale dam will act as upper reservoir and reservoir at Gerusoppa dam will act as lower reservoir for the proposed pumped storage hydro scheme. As the discharge availability at Liganamakhi dam site will have impact on the availability of discharge at upper reservoir at Talakalale dam and lower reservoir at Gerusoppa dam, estimation of annual runoff at Liganamakhi dam was carried out. Due to unavailability of gauge and discharge data on Sharavathy River, the discharge data at two gauge and discharge sites on the river in adjoining basin was transposed in catchment area proportion to Liganamakhi dam site. The assumption was made that both the catchments fall within the same hydro-meteorological region. Transposed discharge series indicated a mean daily runoff of 121.28 $m^3/s/day$ at Liganamakhi dam site transposed from Shimoga gauge and discharge site while it was estimated as 234.03 $m^3/s/day$ from Santeguli gauge and discharge site.

For the proposed pumped storage hydro scheme, the diurnal inflow requirement is in the range of 130-140 $m^3/s/day$. Hence, it was concluded that the water availability at Liganamakhi dam site is adequate to meet the flow requirement for diurnal operation of existing and proposed pump storage scheme. The design flood for spillway of Talakalale dam and Gerusoppa dam is 849.52 m^3/s and 5378 m^3/s respectively.

The approach adopted for water availability assessment at Liganamakhi dam site is found in order. It is to mention here that estimated discharge at Liganamakhi dam site could not be examined due to unavailability of discharge data in the pre-feasibility report.

Design flood for the spillway of Talakalale dam and Gerusoppa dam is acceptable at this planning stage keeping the fact in view that the spillways are in successful operation.

There is no mention regarding the sedimentation aspects of the existing reservoirs. It needs review during detailed project stage to rule out any possibility of encroachment of live storage, especially of Talakalale reservoir

4.3.3. Review of Power Potential

The study has been carried out for optimization of installed capacity and daily energy generation /energy requirement of the proposed PSH project. The brief description on various parameters such as operating levels, live storage, heads, installed capacity optimization and daily energy generation/energy requirement for pumping is presented below.

4.3.3.1. Installed capacity and energy generation (as per prefeasibility report)

The project envisages the utilization of two existing reservoirs for recycling the water and exploiting head available between upper reservoir and lower reservoir. As the two existing reservoirs are used for the conventional power generation, the proposed Sharavathy PSH plant has been planned by maintaining the same full reservoir level (FRL), minimum drawdown level (MDDL) and keeping the storage capacity of the two reservoirs in view. For assessment of useful live storage available for the PSH project, the area elevation capacity curve for the two reservoirs has been used. The elevation area capacity curve indicates the live storage capacity of 13.6 Mm^3 and 58.21 Mm^3 at the upper Talakalale reservoir and lower Gerusoppa reservoir. For the uninterrupted operation of the existing hydropower project, there is requirement of 3.25 Mm^3 for one block operation of Sharavathy power station. Keeping aside, the remaining live storage capacity of 10.37 Mm^3 would be utilized for PSH development. The requirement of storage capacity for 6 hours of peaking operation is worked out to be 10.37 Mm^3 for maximum discharge of 491 m^3/s. Due to limitation of storage capacity at upper Talakalale reservoir (13.6 Mm^3), the peak generation of Sharavathy PSH project was restricted to 2000 MW for 6 hours of peaking operation. However, the lower reservoir at Gerusoppa dam as such does not impose any constraint in terms of live storage capacity requirement on the installed capacity of PSH. Various operating levels and storage capacity of both the reservoirs are provided below

Table 19: Various operating levels and storage capacity at Talakalale and Gerusoppa reservoir

S.No	Levels/Storage capacity	Upper reservoir at Talakalale dam site	Lower reservoir at dam site
1	Full reservoir level (m)	El. 522.12	**El. 55**
2	Minimum drawdown level (m)	El. 520.59	**El. 43.5**
3	Storage capacity at FRL	El. 129.86	**El. 130.59**

S.No	Levels/Storage capacity	Upper reservoir at Talakalale dam site	Lower reservoir at dam site
4	Storage capacity at MDDL	El. 116.22	**El. 72.38**
5	Live storage (Mm^3)	El. 13.6	**El. 58.21**

Simulation study was carried out for daily energy generation and energy required during pumping for precise calculation. It was aimed to capture the head variation due to rise/drop in reservoir water levels with shorter time interval of 9 minutes. An average efficiency of reversible units considered is 92% in generating mode and is 90% in the pumping mode. The cycle efficiency is 80.9%. The head loss of 7m has been considered during generation mode and 6 m during pumping mode. Based on the above-mentioned parameters, maximum daily energy generation is estimated as 12000 MWh for installed capacity of 2000 MW. The proposed number of generating units is eight with unit capacity of 250 MW. Based on the simulation study during pumping mode, daily pumping energy requirement is estimated as 14833.33 MWh for daily operation of 7.42 hours.

The available live storage capacity of 10.37 Mm^3 at Talakalale dam is found adequate to meet the discharge requirement of 491.04 m^3/s for the proposed PSH project. The lower reservoir as such does not pose any constraint in fixation of installed capacity.

There is no mention regarding the requirement of environmental flow release in the simulation of daily operation. It needs to be included during detailed project report stage as per the prevailing guideline requirement.

As per simulation study, net head varies from 459.12 m to 463.52 m during generation mode considering the head loss of 7 m, while it varies from 471.6m to 475.2m during pumping mode considering the head loss of 6 m in pumping mode. However, as per main technical parameters of turbine, maximum head loss is 9m during generation mode and 6 m in pumping mode. The difference in head loss of 2 m is observed during generation mode.

The cycle efficiency of turbine/generator can be increased upto to 84% to 85%. The impact of increased cycle efficiency can be studied at detailed project stage.

The proposed installed capacity of 2000 MW is acceptable. The daily energy generation is estimated as 12000 MWh for daily operation of 6 hours and pumping energy requirement of 14833 MWh for daily operation of 7.42 hours. There may be variation in pumping energy requirement depending the efficiency during pumping mode, refinement in head loss calculation and pumping hours.

4.3.4. Review of Project Geology

The proposed project envisages diversion of water from the existing Talakalale balancing reservoir through two intake channels and thereafter through two headrace tunnels (HRT) –pressure shafts to an underground powerhouse to generate 2000MW (8 x 250 MW) of power. The tail water will be diverted through tunnels (TRT) to existing Gerosoppa Reservoir of Sharavati River. At this pre-feasibility stage, the geological studies have been undertaken based on the literature survey and limited site visit. The brief geological discussion is presented below:

4.3.4.1. Regional Geomorphology and Geology

Geomorphologically, the area of Southern Karnataka is represented by highly rugged terrain comprising steep hills and subsequent valleys, mainly covered by thick forest. A number of tributaries meet the Sharavati River on both the banks. Dendritic and sub-parallel drainage pattern is characteristic of the terrain. Sub-parallel drainage pattern of first order streams are generally joint controlled and occasionally flowing along faults.

The terrain represents by rocks of Peninsular Gneissic Complex (PGC), Bababudan Group, Chitradurga Group of Dharwar Super group, Ultramafic Complex (Sargur Group) of Archaean age. The rock mass has been intruded by mainly basic and acid intrusives of Palaeo-proterozoic age. The stratigraphic succession is presented below:

Table 20: Stratigraphic Succession

Lithology	Group	Super Group	Age
Laterite			
Quartz Vein, Dolerite	Younger Intrusives		Palaeoproterozoic

Lithology	Group	Super Group	Age
Quartzite, Chlorite schist, Homblende-actinolite –chlorite schist, Amphibolite	Western Ghat (Bababudan)	Dharwar	Archaean
		Unconformity	
Granite gneiss	Peninsular Gneiss	Peninsular Gnieissic Complex	Archaean
Ultramafite	Sargur		Archaean

Mainly granite gneiss belonging to Peninsular Gneissic Complex (PGC) and amphibolite represent the major part of project site. However, schistose (Hornblende- actinolite-chlorite schist) rock of Bababudan Group are present at lower part of TRT and TRT outfall area. At the project site, surface is mainly covered by thick laterite and/or slope wash material with occasional outcrops of granite gneiss/augen gneiss and amphibolites. Bababudan Group is unconformable over PGC. The schistose rock (Hornblende- actinolite-chlorite schist) appears to be occurred as outlier at the project site. Gneissocity / foliation are well developed in the rock mass. The general strike of foliation is N – S (N 05° E) and dip 60° towards S 85° E. Besides foliation rock mass is traversed by four more joints.

The terrain represents by rocks of Peninsular Gneissic Complex (PGC), Bababudan Group, Chitradurga Group of Dharwar Super group, Ultramafic Complex (Sargur Group) of Archaean age. The PGC is represented by various gneisses and Babbudan group consists of quartzite, chlorite schist, hornblende-actinolite-chlorite schist, amphibolite etc.

4.3.4.2. Seismicity

The project area is located in Kanada and Shimoga district of Karnataka. As per seismotectonic map of India, the project area falls in seismic zone III. Further to mention, that the upper and lower dams are in existence and hence seismic coefficient has already been applied for the dams, which might be used for the other component of the project.

Assessment of Project Components in view of Geology

- **Intake:** The area of intake is apparently occupied by lateritic soil and slope wash material surrounding the reservoir tip. The thickness of deposits is anticipated to be substantial. From the topography, it is apprehended that the tunnel portal would be away from the intake location near to the foothill. Therefore, a cut and cover section between intake and tunnel portal is anticipated. The area should be investigated through drilling to establish the intake foundation condition, which will also provide some idea about the foundation of cut and cover section. As such, the area can accommodate both the structures.
- **Head Race Tunnel (HRT):** Two concrete lined circular HRT of 9 m diameter and 2.762 km long are proposed for the project. HRT portals will be established at the foothill and slope wash deposits apparently cover the area. From the surface exposures, it is anticipated that the HRTs will pass through granitic gneiss and amphibolite although dolerite may be encountered in between. The rock type would be mostly of class III and class II. But, Class IV and V rock type will also encounter wherever shear zone or any other weak geological features intercept.
- **Surge Shaft**: Two surge shafts – one at the end of HRT and the other one at TRT are envisaged to accommodate the water hammer in case of sudden shut down of machine. Both the Surge shafts would be underground and will be excavated in granite gneiss and amphibolite rock mass. Rock type are expected to be of class II and II. The size of the surge shafts would be 16 m diameter and 52 m high.
- **Pressure Shaft**: Two numbers of pressure shafts of 5.25 m diameter and about 800 m long are envisaged. Pressure shaft would be excavated through granitic gneiss rock mass, but the structure would be steel lined.
- **Underground Powerhouse:** An underground powerhouse (323.8m long x 22m width x 53m high) has been contemplated within granite gneiss rock mass, where patches of amphibolite may intercept. The long axis of powerhouse has been kept in N 35° E – S 35° W orientation by considering foliation and other joints. At this pre-feasibility study stage, the concept of powerhouse is in line.
- **Tail Race Tunnel (TRT)**: Two TRTs each of about 3.75 km long are envisaged through the granite gneiss rock mass initially but it is expected to be excavated through hornblende schist towards the outlet.

In case of Sharavathy PSH the biggest advantage is the presence of existing reservoirs. The balance project components are to be constructed. The geology of the project area has now been evaluated based on the surface geology and literature survey. Geotechnical investigation for some of the project components need to be undertaken at DPR stage. However, as the dominating rock type is granite gneiss and amphibolite that generally provides the fair to good foundation and also tunneling condition, no major issue is anticipated. Further, both the lower and upper dam are existing and seismic parameters used for the designing of those can be used for other project components

4.3.5. Review of Civil Works

4.3.5.1. Project Layout

The Sharavathy PSH is planned to develop by utilizing the existing reservoirs – upper Talakalale and Lower Gerusoppa. As the existing reservoirs are functional for conventional hydropower generation, the operating levels as defined for their respective projects would remain same. The intake and tail water outlet for the PSH will function as an intake as well as an outlet since directions in generating and pumping modes are exact reverse as hydraulic feature is quite different between water intake and discharge.

4.3.5.2. Intake

Intake structure for this PSH is proposed away from the existing intake at Talakalale. The intake is planned with an inlet trash rack and anti-vortex louver and a vertical intake gate away from the inlet after the cut and cover conduit. Water depth from sill of an inlet to the minimum water level would be kept 1.5 to 2.0 times as high as internal diameter of the connecting pressure conduit in order to prevent air from flowing into the pressure conduit. The inlet and outlet are designed in accordance with the guideline proposed by Central Research Institute of Electric Power Industry in Japan.

Conceptually it is in order; however, during DPR stage the hydraulic and structural analysis will provide more insight for the structure

4.3.5.3. Head Race Tunnel

Two numbers of 9 m diameter tunnel are envisaged based on velocity consideration. Final sizing would be undertaken in DPR stage. The invert elevation is set out at El 503 m.

Initial concept of 9 m diameter tunnel appears to be in order; however, actual sizing of tunnel is to be carried out at DPR stage

4.3.5.4. Surge Shaft

Two surge shafts at the end of each HRT has been envisaged to accommodate the water hammer and sudden rise of water pressure during sudden shut off machine. Surge shafts would be 16 m dia. and 52 m high.

This is conceptually in order, but the final sizing of surge shaft would be carried out through transient analysis

4.3.5.5. Pressure Shaft

Two pressure shafts of 5.25 m diameter steel lined are proposed to emerge from each surge shaft, which horizontally connect butterfly valve chamber and then inclined pressure shafts down to El 489.37 m with an inclined length of 668 m. Then the lower horizontal limbs would be of 100 m long upto bifurcation point. Design criteria for steel liner thickness are as below:

- Steel liner has been designed to take the entire internal pressure independently without any rock participation.
- Steel liner has been capable to withstand maximum external pressure under empty condition.
- Penstock has been designed for loading condition at mid span and at the supports where additional stresses are developed.
- Sickle plate for penstock manifold should take care of all unbalanced forces at the point of bifurcation.

The concept of pressure shafts and design criteria for steel liner are in order

4.3.5.6. Powerhouse and Transformer Cavern

The size of machine hall would be 323.8m in length, 22m in width and 53 m in height to accommodate 8 units of 250 MW each. Spacing of generating units would be 26 m centre to centre. The transformer cavern would be 282.17 m long, 20 m in width and 29 m in height to accommodate 4-unit transformers.

The size of powerhouse and transformer hall are conceptually in order

4.3.5.7. Tail Race Tunnel and Transient Analysis

Two numbers tail race tunnel of 10 m diameter each are envisaged. Length of each tunnel is 3780 m. To accommodate water, hammer a surge gallery of size 60 m (L) X 15 m (W) X 81 m (H) is proposed.

Transient Analysis: Hydraulic transient analysis has been carried out in considering of shut-off for both power generation and pumping up mode. Therefore, based on the analysis conceptual model of the whole water conductor system has been adopted. No negative pressure has been arisen that indicates there is no water column separation.

The tail race tunnel and the complete water conductor system concept based on transient analysis is in order

4.3.6. Review of Electromechanical Works

4.3.6.1. Turbine

The project has been proposed with an installed capacity of 8x250 MW i.e. 2000 MW as per PFR prepared by WAPCOS in 2017. The main Technical Particulars of turbine are provided below

Table 21: Main Technical Particulars of Turbine

Sl. No	Descriptions	Parameters
1	Type	Vertical Francis turbine
2	Upper reservoir levels	
	Full reservoir level (FRL)	El. 522.12 m
	Minimum draw down level (MDDL)	El. 520.59 m
3	Lower reservoir levels	
	Full reservoir level (FRL)	El. 55.00 m
	Minimum draw down level (MDDL)	El. 43.50 m
4	Head losses	
	Turbine mode	9 m
	Pumping mode	6 m
5	Number of turbines	Eight
6	Rated capacity to generate at generator terminal	250 MW
7	Capacity in pumping mode	225 MW
8	Capacity in turbine mode	253 MW
9	Operating head range as turbine	
	Maximum net head	461.12m
	Rated net head	458.61m
	Minimum net head	456.59m
10	Operating head range as pump	
	Maximum net head	476.12m
	Rated net head	473.61m
	Minimum net head	471.59m
11	Rated speed	375 rpm
12	Rated turbine discharge	61.38 m^3/s
13	Rated pump discharge	42.22 m^3/s
14	Cycle efficiency	80.9%

- The type, rated capacity, rotational speed for 8 units of 253MW turbines are generally in order. However, detailed justification for selection of eight numbers of unit is not available in the PFR, the same may be reviewed in the DPR level engineering works.
- Detailed transport survey for feasibility of transportation of over dimensional consignment such as turbine, generator, and generator transformers is required to be conducted in appropriate time.
- The selection of vertical Francis type turbine with a head range of 456m to 461m is considered to be technically in order. However, the various operating heads in turbine and pumping modes are required to be reviewed and updated in DPR stage based on CEA approved practices.
- The selection of vertical Francis type turbine with a head range of 456m to 461m is considered to be technically in order.
- It is observed that the pumping capacity is proposed as 225 MW and turbine capacity as 253MW. In clause no. 7.16 (Power evacuation system), it is mentioned as "The estimated pumping load (MW), presuming all the hydro units to be operated simultaneously as motors, will be around 2200 MW". In that case, the pump capacity should have been higher. Pump capacity needs to be reviewed during further engineering stage.
- The cycle efficiency is proposed as 80.9% in the PFR. It is expected that the cycle efficiency could be increased to the range of 84%-85% with improvised technology to be adopted for turbine/generator design. With variable speed system, the efficiency can be increased.

4.3.6.2. Generator-Motor

The main features of the generator are provided in the table below:

Table 22: Main Technical Particulars of Generator-Motor

Sl. No	Description	Parameters
1	Rated capacity	250 MW
2	Generation voltage	18kV
3	Synchronous speed	375 rpm
4	Power factor	0.90 lagging (generator operation) 0.95 leading (motor operation)
5	Rated frequency and variation	50 Hz with + 3% to -5%
6	Bearing arrangement	Suspended type
7	Excitation system	Static excitation system
8	Static frequency converter	Two static frequency converters (SFCs) one each for starting of two groups of units in pumping mode.
9	Type speed regulation of generating unit	Fixed speed pump/turbine units
10	Overload capacity	110% of rated capacity

The type, rated capacity, synchronous speed etc. for 8 units of 250MW generators is generally in order subject to optimisation possibilities which may be studied during detailed project report stage.

The generation voltage as proposed as 18kV is in order. However, the same can be optimised within the range of 15kV-18kV. The voltage variation shall be mentioned as +/- 10%.

In the PFR, fixed type pump/turbine generating units are proposed. Feasibility of variable speed pump/turbine unit in order to have better performance and to enhance grid stability may be explored in consultation with CEA, grid operators etc.

110% overload capacity is proposed in the generator whereas there is no such overloading provision is mentioned in the turbine mode. The provision of 110% overloading requirement for turbine and in generator may be reviewed as per the requirement of Indian Electricity Grid Code (IEGC)/ CEA also.

4.3.6.3. Generator-Motor Transformer

There are 26 nos. (including two spares) generator-motor transformers proposed for the project as per PFR. Each transformer comprises of 102 MVA, 18/400/√3 kV, 1-phase transformers with OLTC +10% to -5% and is provided with oil directed air forced (ODWF) cooling. The transformers are proposed to be installed in a transformer cavern. The HV side of the terminal of the transformers are proposed to be connected to 400kV indoor type Gas Insulated Substation (GIS) through Gas Insulated Busduct (GIB).

- Considering unit configuration for reliability and flexibility of operation, a bank of three nos. 102 MVA single-phase transformers for each unit with 10% overloading as proposed in the PFR is considered adequate.
- The proposed cooling of ODWF is considered technically suitable.

4.3.6.4. Main Inlet Valve

As per the PFR, a main inlet valve of spherical type for shutting-off pressure water supply from the penstock to the pump-turbine shall be provided in each unit complete with necessary piping, control cabinet, upstream and downstream connecting pipes with companion flanges, dismantling joint, bypass, operating mechanism etc. The valve shall have two oil pressure operated working seals (one service seal and the other maintenance seal). The seals shall be of material having high resistance to silt erosion.

The selection of spherical type main inlet valve for each unit with double seal (maintenance and service seal) is technically in order. The seals shall be of metallic type of stainless-steel materials.

4.3.6.5. 400 kV Gas Insulated Substation (GIS) & 400 kV XLPE Cables

As per the PFR, the proposed 400 kV GIS shall have double bus arrangement with thirteen (13) bays: - 8 nos. incoming bays for generator-motors, 4 nos. outgoing bays for connection to transmission lines through 400 kV XLPE cables and one bus coupler bay. Power from 400 kV GIS would be transmitted to/from Ynd11 connected with on load tap changer (Adjustable range of the secondary voltage (-5% to +10% i.e. 3kV/tap) two nos. double circuit 400 kV lines through 400 kV XLPE cables. 13 nos. (Including one spare), single-phase XLPE cables shall be laid snake shape on the cable racks in the cable tunnel from main transformer cavern to outdoor pothead yard.

The proposed 400kV gas insulated substation (GIS) having double bus arrangement and bus-coupler is considered technically suitable

4.3.6.7. EOT Crane

Two electric overhead travelling (EOT) cranes each of 200/40/10 tonnes main and auxiliary hooks are proposed to be provided for handling the assembled rotor along the full length of the powerhouse. Both the EOT cranes shall be used in tandem to handle the rotor. A lifting beam of adequate size /capacity for this purpose shall be provided. One monorail crane of 10T capacity supported beneath the outside girders of both the cranes. In addition, the following cranes are proposed:

i) One EOT crane of 10 Tonnes capacity shall be installed in GIS hall.
ii) One EOT Crane of 40 Tonnes capacity shall be installed downstream of transformer for handling bonneted valve for draft tube control.

- Two numbers of 200/40/10 tonnes EOT crane proposed for the powerhouse is considered in order. However, capacity of the cranes shall be verified during detailed engineering stage based on design input from the turbine-generator manufacturers.
- One EOT crane in butterfly valve house is also required to be provided for handling the valves.

4.3.6.8. Control, Automation and Protection System

The control, automation system and relay and protection system is generally described in the PFR.

- Provision described in the PFR is generally in order. However, more details and scope are required to be included in the detailed project report/ tender documents.
- Reservoir water levels, various gate monitoring and control, discharge measurement etc. shall be included in the automation system.
- Dam instrumentation and monitoring, automatic reservoir monitoring and control (ARMAC) system shall be provided in each dam.

4.3.6.9. Communication System

In the PFR, PLCC (power line carrier communication) system is proposed for efficient sources and reliable information links to meet the communication need of protection, voice and data including for SCADA system. It shall provide for distance protection and direct tripping for remote end breaker, signal transmission & speech communication between the powerhouse/substation and data communication to remote places through various frequency channels etc.

For protection tripping and voice communication, the PLCC system is OK but as per latest grid operator's/CEA recommendations, the PLCC system is being phased out and communication system through optical fibre is being introduced which is considered most advance and efficient mode of communication for data, voice and protection signalling. For the same, optical link terminal equipment (OLTE) at the PSH end and OPGW cable in the transmission line would be required. Also, communication system already provided or being provided at the remote end substation is also required to be studied.

4.3.6.10. Penstock Protection Valve

Penstock protection valves are shown in the project layout drawings just after surge shafts. There are four pressure tunnels and one valve house is shown in the layout drawings. No details of the penstock protection valves (PPV) are mentioned in the electro-mechanical chapter of the PFR. Penstock protection valve is suggested in each pressure shaft emanating from the two surge shafts in order to protect the powerhouse from inundation due to penstock rupturing. Also, during major maintenance of the main inlet valve or penstock, the same can be attended by closing respective PPV. This would allow the other generating units to continue generation uninterruptedly and this is the big advantage of providing PPV in each pressure shaft/ penstock.

- The PPV shall be suitable for remote monitoring and emergency operation by closing the same from powerhouse control room in case of rupturing of penstock.
- In view of the above, total four (4) numbers of PPV would be required alongwith all associated equipment.

4.3.6.11. Power Evacuation System

In the PFR, two alternatives are proposed for power evacuation.

<u>Alternative-I</u>

- 400kV Sharavathy PSS – Talaguppa 2xD/C lines with twin HTLS conductor (about 60km 2xD/C lines)
- LILO of one circuit of the existing 765kV Narendra- Madhugiri D/C line at Talaguppa (65 km LILO portion)
- Upgradation of the existing 220/400kV Talaguppa S/S to 220kV/400kV/765 kV level with a provision of 2x1500 MVA 400/765kV ICTs
- Creation of GIS system at the PSS and Talaguppa S/S

<u>Alternative-II</u>

- Generation step-up voltage at 765 kV

- LILO of one circuit of the existing 765kV Narendra- Madhugiri D/C line at Sharavathy PSS ---about 90 km (LILO portion)
- Provision of 2x330 MVAr shunt and 2x330 MVAr line reactors (switchable) at the PSS station
- Provision of 765 kV GIS line bays (2 nos.) and reactor bays (4 nos.) at the PSS project

- As per the 2nd southern region standing committee meeting convened by Central Electricity Authority on power system planning dtd. 10th June 2019, it was recorded that the following transmission scheme was proposed by Karnataka Power Transmission Co. Ltd (KPTCL) for Sharavathy PSS.
  - ✓ Construction of 400 kV Multi Circuit lines with Quad Moose conductor from proposed Sharavathy PSH to 400/220 kV Talaguppa sub-station by utilizing the existing 220 kV S 1, S2 or S3, S4 corridor with 4 Nos of 400 kV TBs at Talaguppa.
  - ✓ Strengthening of 400 kV Talaguppa- proposed C.N.Halli D/C Twin Moose line by higher ampacity conductor (Twin Moose equivalent HTLS).
  - ✓ Augmentation of existing 1x315 MVA (out of 3X315) transformers by 1x500 MVA, 400/220 kV transformers at Talaguppa.
  - ✓ Strengthening of 220 kV Talaguppa- Sharavathy D/C line by higher ampacity conductor (Drake equivalent HTLS).
  - ✓ By utilizing the existing corridor of S1-S2 or S3-S4, replacing the S1-S2 & S3-S4 D/C lines with Drake conductor by 220 kV MC line between Sharavathy-Shimoga (S1, S2, S3, S4) with AAAC Moose conductor.
- KPTCL has informed CEA that the commissioning timeline for the Sharavathy PPS would be in the year 2025. CTU has advised to provide proper reactive power compensation in the PSS by providing 2x125 MVAR reactor.
- In the meeting, it was decided that the transmission scheme proposed above, would be discussed and finalized at a later stage, based on the status of commissioning of Sharavathy PSH.
- Cost of transmission line, substation upgradation is not considered in the PFR. It is to be ensured that cost of transmission/substation would be borne by central/state transmission utilities.
- As per CERC connectivity regulation 2009, it is mentioned that *"However, a thermal generating station of 500 MW and above and a hydro generating station of 250 MW and above, other than a captive generating plant, shall not be required to construct a dedicated line to the point of connection and such stations shall be taken into account for coordinated transmission planning by the CTU and CEA*". In view of the same, the construction of the transmission line and substation is not in the project developer's responsibility. However, latest status/amendment of CERC on this regard is required to be referred.

4.3.7. Review of Project Cost Estimate

At this prefeasibility stage, the project cost has been estimated based on the Indian Standard guidelines such as:

- Guidelines for preparation of project estimates for River Valley Projects dated 1997 by Central Water Commission, Govt. of India
- Guidelines for preparation of Detailed Project Report of Irrigation and Multipurpose projects 2010 by Central Water Commission, Govt. of India.

The overall cost of the project is estimated as INR 5017Crs, which includes civil cost of INR 2740 Crs and electromechanical cost of INR 2278 Crs.

4.3.7.9. Civil Works Cost

The civil cost works out as INR 273980.38 Lacs in the PFR stage. The cost is based on Schedule of Rates of Water Resource Department, Govt. of Karnataka at price level of 2014-15 with price escalation upto February 2017 level. The cost does not include VAT and IDC escalation during construction period. The cost has been built up based on unit rate and estimated quantities and wherever unit rate was not available a lump sum provision has been considered based on experience of similar projects.

- The cost estimation approach is in order.
- As the estimated cost is at price level of 2017, it has to be escalated to the present price level of 2021 for the project
- As VAT and IDC has not accounted for the actual cost of the project would be higher as projected in the report.
- The project cost after escalated to the present price level has been taken with variation of ±30 %.

4.3.7.10. Electromechanical and Transmission Cost

As per the PFR, the electromechanical cost has been proposed as INR 227764.29 Lacs. The total cost of electromechanical works at April, 2017 level has been worked out to be INR 227764.24 lacs, which includes, the cost of main electromechanical equipment (excluding the transmission system) such as turbines, generators, transformers etc. based on the prevailing market prices in India and abroad. Suitable provision for transportation, erection and commissioning charges, freight and insurance etc. have been made as per general guidelines issued by CEA. Provision for establishment and Audit and Account charges for the electromechanical works have been made under this cost separately.

- In order to justify the cost, comprehensive budgetary offers from leading EPC contractors may be obtained during DPR stage.
- Price escalation from year 2017 to 2021 and USD rate from INR 64 per USD at 2017 and INR 73 per USD at present is required to be considered.
- Excise duty, customer duty, central sale taxes have been considered in the present cost estimate. However, upon implementation of goods and service tax (GST), the excise duty, sales tax etc. are required to be replaced by GST.
- Cost of transmission and augmentation of grid substation is not considered in the PFR. As per CERC grid connectivity regulation 2009, hydro project above 250MW is not required to include transmission cost, which is in the scope of transmission utilities. However, the same is required to be reaffirmed as per latest amendment to CERC regulation.

4.11. Risk Associated and Mitigation Measures

4.11.1. Risk Category

A risk matrix along with mitigation measures has been prepared based on the comprehensive technical due diligence carried out. The categorization of the risk is as follows:

Risk Category: High

Matters that should be addressed prior to closure of investment deal as they may have impact on Project suitability or cost or both.

Risk Category: Medium

Matters that may constitute a risk and should be dealt with further during construction and operation/ maintenance of the project but should not necessarily have any significant impact on Project suitability or cost.

Risk Category: Low

Matters with no/limited material impact on project suitability and cost.

Table 23: Risk Matrix

Risk	Risk Level
Existing dams will be utilized for the proposed pumped storage hydro scheme. The design flood for both the dam spillway has been considered same keeping the fact in view that the both the dam spillways are in successful operation.	**Low**
There is no mention regarding sedimentation aspect of reservoirs in the pre-feasibility report.	**Medium**
Geology	
Both Upper and Lower reservoir and dams are existing	**Low**
Investigations	**Medium**
Most of the structures are underground	**Medium**
Seismicity	**Low**
Civil Works	

All the civil structures appear conceptually in line based on limited analysis and applying project experience from various other projects. However, the detail analysis and actual sizing of the structures may affect the overall project.	**Medium**
There is no availability of transport survey report in the PFR	**Medium**
It is observed that the pump capacity is proposed as 225 MW and turbine capacity as 253MW. In clause no. 7.16 (Power evacuation system), it is mentioned as “The estimated pumping load (MW), presuming all the hydro units to be operated simultaneously as motors, will be around 2200 MW”. In that case, the pump capacity should have been higher. Pump capacity needs to be reviewed during further engineering stage.	**Medium**
The cycle efficiency is proposed as 80.9% in the PFR which is considered less	**Medium**
In the PFR, fixed type pump/turbine generating unit are proposed.	**Low**
110% overload capacity is proposed in the generator whereas there is no such overloading provision mentioned in the turbine.	**Medium**
In the PFR, power line carrier communication (PLCC) system is proposed for voice, data and protection communication.	**Medium**
No details of the penstock protection valve (PPV) are mentioned in the electro-mechanical chapter of the PFR except showing the same in project general layout drawings.	**Medium**
Total construction including pre-construction work has been considered as 63 months. Main project construction will be in 53 months and looks adequate. However, if any geological surprise occurs the project may be delayed.	**Medium**
As per PFR, the civil cost has been projected as INR 273980.38 Lacs at 2017 price level. The civil cost has been estimated following Indian Standard guidelines for preparation of cost estimate for river valley projects.	**Medium**
As per the PFR, the electromechanical cost has been proposed as INR 227764.29 Lacs.	**Medium**
Cost of transmission line, substation upgradation is not considered in the PFR. It is to be ensured that cost of transmission/ substation would be borne by central/state transmission utilities.	**Medium**

The detailed risk association matrix along with the mitigation measures to address the risks, is attached as an **Annexure 9.2**

5. Maharashtra State Assessment

5.1. Maharashtra – State Overview

Maharashtra is a state situated in the western region of India, sharing land borders with Gujarat, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Goa, Karnataka, Dadra and Nagar Haveli, and on the western side, Maharashtra is surrounded by Arabian Sea. Maharashtra is the 3rd largest state in India with the geographical area of 3.08 lakh sq. km. Maharashtra has ranked 3rd in terms of population with the population base of ~112.4 million (FY17) and population density of 365 persons/sq. km. Maharashtra is the most industrialized state in India and has maintained the leading position in the industrial sector in India. The state is a pioneer in small scale industries and boasts of the largest number of special export promotion zones.

The current Gross State Domestic Product (GSDP) of Maharashtra stands at USD 405.35 Bn (as in FY19), which has steadily grown with a CAGR of 11.83% since FY12 till FY19. As per 2019 statistics, the economy of Maharashtra was majorly driven by the tertiary sector which contributed 54.5% to the state's GSDP, followed by the secondary sector (30.88%) and the primary sector (18.05%).

5.1.1. Market assessment of Maharashtra

Maharashtra has ~43,496 MW of total installed capacity as of FY20, out of which renewable (excluding large hydro) contributes ~22%. Total thermal installation in the state is ~68% which totals to ~29737 MW (in FY20). The total hydro generation in the state was ~8% in the total generation mix. Overall hydro to thermal mix of the state is only 11.3% (i.e. 11.3 MW hydro for every 100 MW thermal capacity).

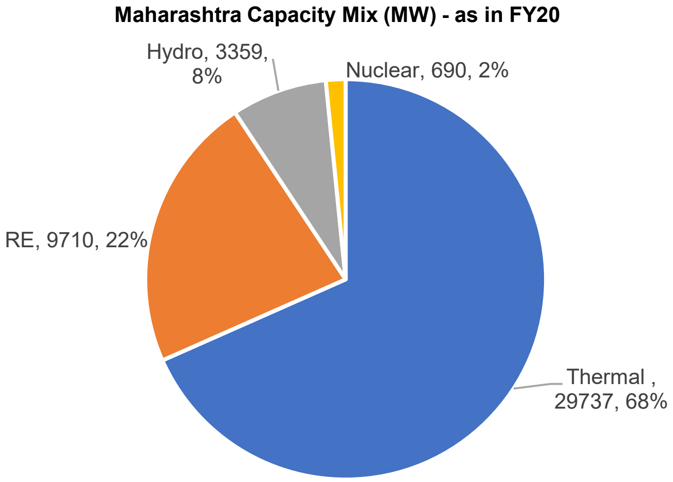


Figure 22: Maharashtra Capacity Mix

5.1.2. Demand-Supply Assessment of Maharashtra

Maharashtra's power supply and demand position are improving. In the last six years, both peak demand and supply grew at a CAGR of ~3.1% and ~4% during 2015 to 2021. The state's deficit was -1.7% in 2015 while in 2021 the state has a surplus of ~3.5%. The total peak power requirement in 2021 was 24,160 MW, which was almost met with the peak power supply of 25,000 MW, as shown in figure.

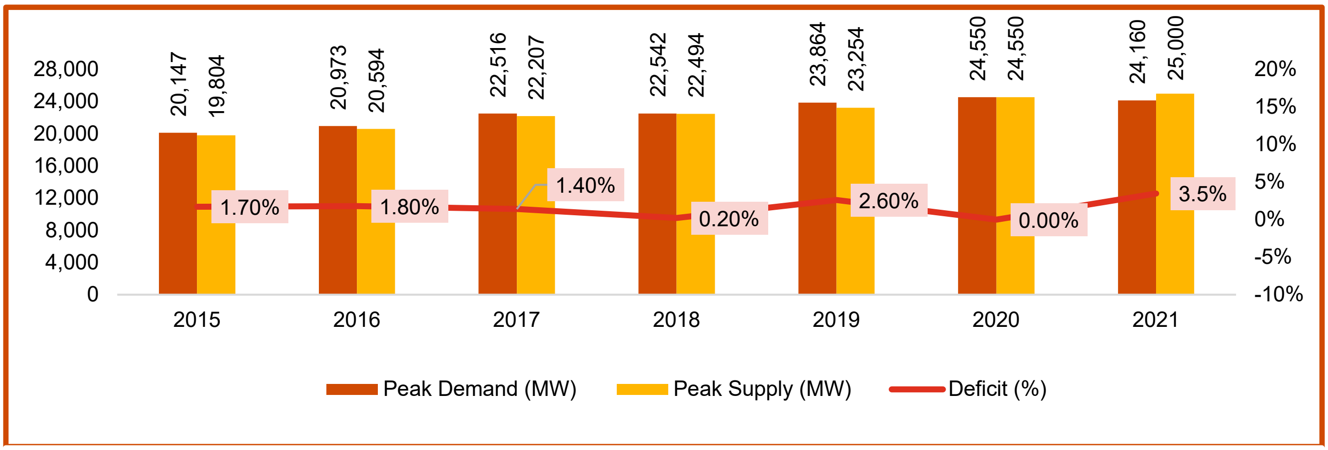


Figure 23: Energy demand and supply position for Maharashtra

Source: CEA, LGBR

5.1.3. Renewable Penetration in Maharashtra

As in FY20, the state RE installed capacity observed an uptick of ~395 MW which culminates to a total installed RE capacity of 9.7 GW. The state has overall RE potential of 75 GW which is ~8.3% of the total national RE potential. The graphic below exhibits the capacity addition by the state government.

Source: CERC Installed Capacity Report, 2016-2020

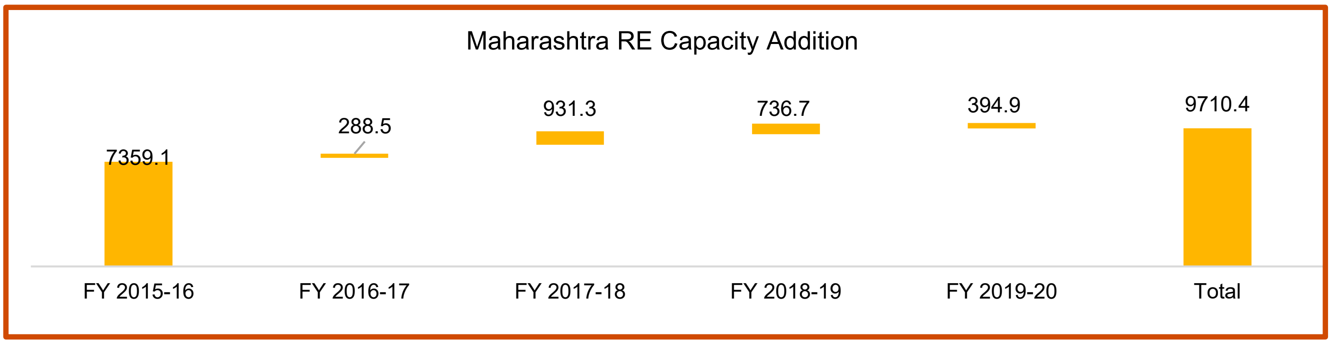


Figure 24:Maharashtra RE Capacity Addition

Maharashtra state government has set an ambitious target of achieving 22 GW by FY22, as per the State's National Electricity Plan, 2018. Maharashtra is undertaking multiple initiatives in the form of RE Policies, RPO declarations to boost the overall RE contribution in the state's installed capacity.

Some of the recent State and Central initiatives to promote RE in Maharashtra are highlighted below:

- The Maharashtra state government has issued a two-part policy viz. "Non-conventional Energy Generation Policy" in 2020 to promote the state's RE target and adequately meet the demand of Industrialization and Urbanisation.
- Maharashtra State Electricity Distribution Company Limited (MSEDCL) has taken initiatives to meet the RPO targets and plug in 1.5% of the gap in RPO target by purchasing RECs (worth INR 150 crore) in FY19.

- The state electricity regulator viz. Maharashtra Electricity Regulatory Commission, issued the Grid-Interactive Rooftop Renewable Energy Generating Systems Regulations in 2019 to develop a net metering framework for the state.
- The state government has target to promote the RE in agricultural segment as well and garner inclusive growth of the sectors by deploying 1 lakh off-grid solar powered agricultural pumps, deployed in three phases spread across 2019 to 2022, under Mukhyamantri Saur Krushi Pump Yojana scheme.
- The state announced an integrated Renewable Energy Policy in 2015, with a focus on developing renewable energy capacity in the state. The policy also emphasized on the development of hybrid and distributed solar projects.

A snapshot of the Non -conventional Energy Generation Policy, 2020

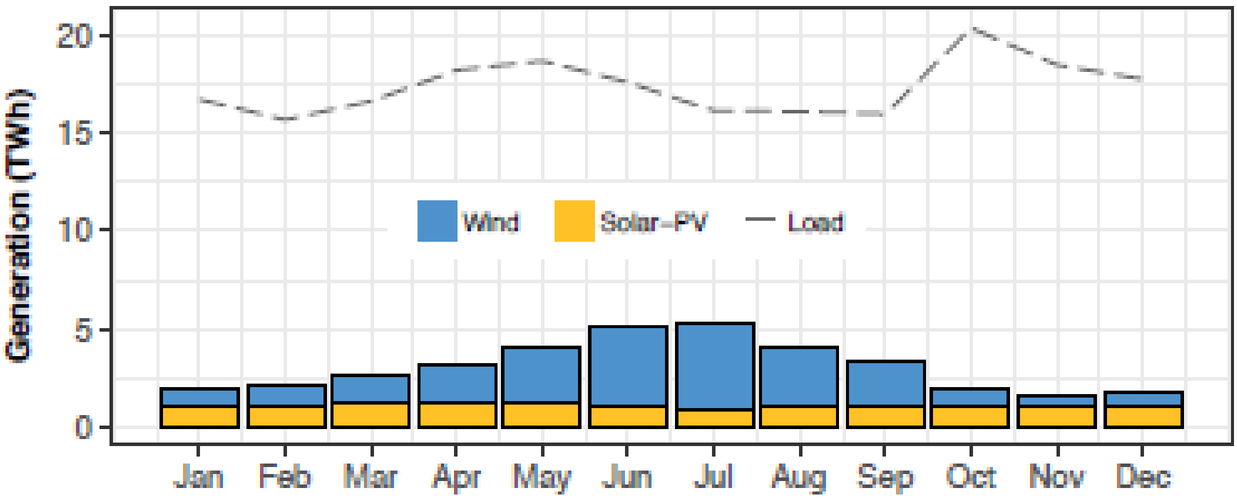
- The two-pronged state policy aims to promote non-conventional source-based energy generation
- **Part One of the Strategy:**
  - This part of the strategy aims to achieve the implement of 17,360 MW of transmission system-connected renewable power projects by 2025. This installation is further segregated into contribution by different sources exhibited as below:

Total 17360 MW = **Solar** 12930 MW + **Wind** 2500 MW + **Co-Gen** 1350 MW + **Small Hydro** 380 MW + **Urban Waste** 200 MW

  - The 12,930 MW of solar projects include 10 GW of standalone solar power projects, 2 GW of grid-connected rooftop solar projects, 500 MW of solar-based water supply projects, 250 MW of solar generation projects for farmers.
- **Part Two of the Strategy:**
  - The second part of the project deals with implementation of the off grid RE projects.
  - Planned investment of USD 10.5 Mn/annum on transmission free projects (power projects that are not connected to the grid).
  - Further this shall include 100,000 agricultural solar pumps, 52,000 kV of rooftop solar systems, 2,000 solar water supply stations, the electrification of 10,000 rural homes, microgrid projects for 20 homes, 55,000 square feet of solar water/solar cooking systems, and 800 solar cold-storage projects.

Going forward, Maharashtra power generation mix can witness a cumulative RE installation of nearly 27 GW by 2025. Such a steep growth in the RE penetration can draw curtailment of RE during peak hours of generation or in case of lack of transmission availability. The forecast of the RE generation by FY22, as projected by a study conducted by MoP in collaboration with USAID is exhibited below:

Fig. Forecasted RE generation in FY 2022



Source: Greening the Grid, USAID, 2017

It has been estimated that by 2022, the state of Maharashtra will witness an annual curtailment of 2,000 to 2,500 MW, with almost 1,000 MW daily curtailment in the month of July. Such curtailment of the RE creates an opportunity for energy arbitrage necessitating the development of grid level storage assets which can economically absorb additional energy during off-peak hours and supply during peak hours. Considering the need of increasingly flexible generation sources in the power mix, capable of fast ramp-up or ramp-down, a PSH is ideally suited to meet the requirements of the grid and comes across as a matured and commercial proven technology.

5.1.4. Need for flexible resources like PSH in Maharashtra

Apart from addressing the problem of RE curtailment, PSH plants have many other value propositions which can be leveraged in the case of Maharashtra power system. Some of such benefits can be:

Hydro-Thermal mix:

In the western region grids, overall hydro generation to overall generation mix is low with 7622 MW out of total installed capacity of 1,20,618 MW. The overall hydro-thermal mix of the state is highly skewed towards the thermal assets with hydro-thermal mix standing at 8.9% (against every 1000 MW of thermal installation, the system has only 89 MW of hydro asset). The generation complementarity between thermal and hydro resource is prevalent in the western region as well with higher generation of hydro in monsoons and lower generation in
Source: *PwC Analysis*

Considering the case of Maharashtra in Western Region, the overall hydro-thermal mix of the state viz. 11.3% is relatively higher than the regional hydro-thermal mix viz. 8.9%, as exhibited in the graphical representations below:

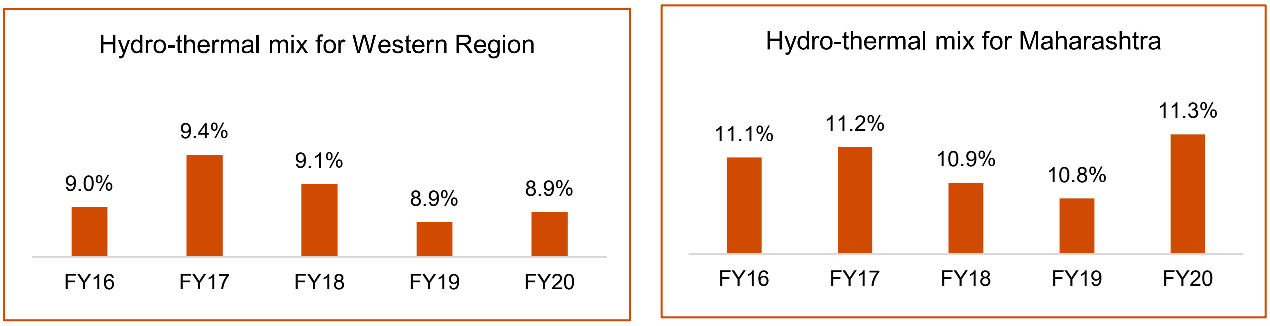
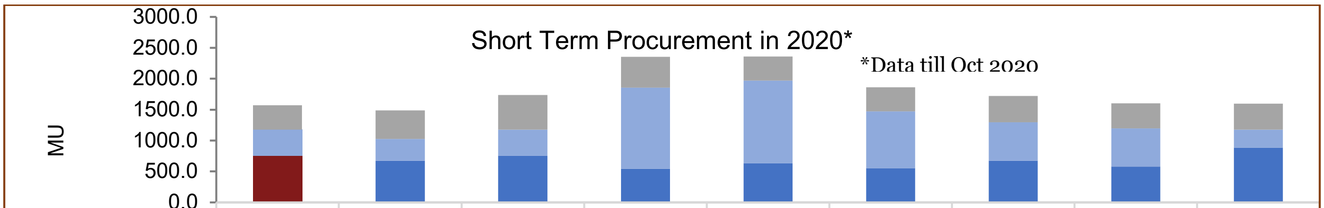


Figure 25 Hydro-thermal mix for Maharashtra

Source: CEA Report

> The hydro-thermal mix of the region as well as the state of Maharashtra is way below the optimal hydro-thermal mix of 40%. This necessitates addition of additional hydro resources i.e. Hydro Plants (large and small) and/or PSH plants which would help in maintaining the optimum capacity utilization of hydro and thermal.

Short Term Purchase:



	Jan	Feb	Mar	Apr	May	Jun	Aug	Sep	Oct
DSM Overdrawl	391.8	460.2	564.6	499.0	389.3	392.4	424.3	408.6	417.1
PX	425.7	355.1	418.4	1311.3	1337.9	915.0	621.3	614.3	290.1
Intra-State OA	752.0	672.3	755.9	544.0	630.6	555.4	675.9	581.0	888.3
Total	1569	1488	1739	2354	2358	1863	1722	1604	1596

Figure 26: Short Term Purchase for Maharashtra

Source: Maharashtra State Load Dispatch Centre

Maharashtra (MSEDCL+ Mumbai region) has a collective total short-term power procurement of ~1490Million Units. In FY19, the total short-term procurement by Maharashtra was in the range of 5879 Million Units with nearly 59% of the power sourced from energy exchanges at a high purchase procurement cost of ~5.27 INR/kWh. The remaining 41% of the procurement is sourced from bilateral ties at the procurement cost of 4.32 INR/unit, and as a result the overall average short-term tariff works out to be 4.89 INR/kWh. The short-term power procurement cost of the Maharashtra is exhibited as below:

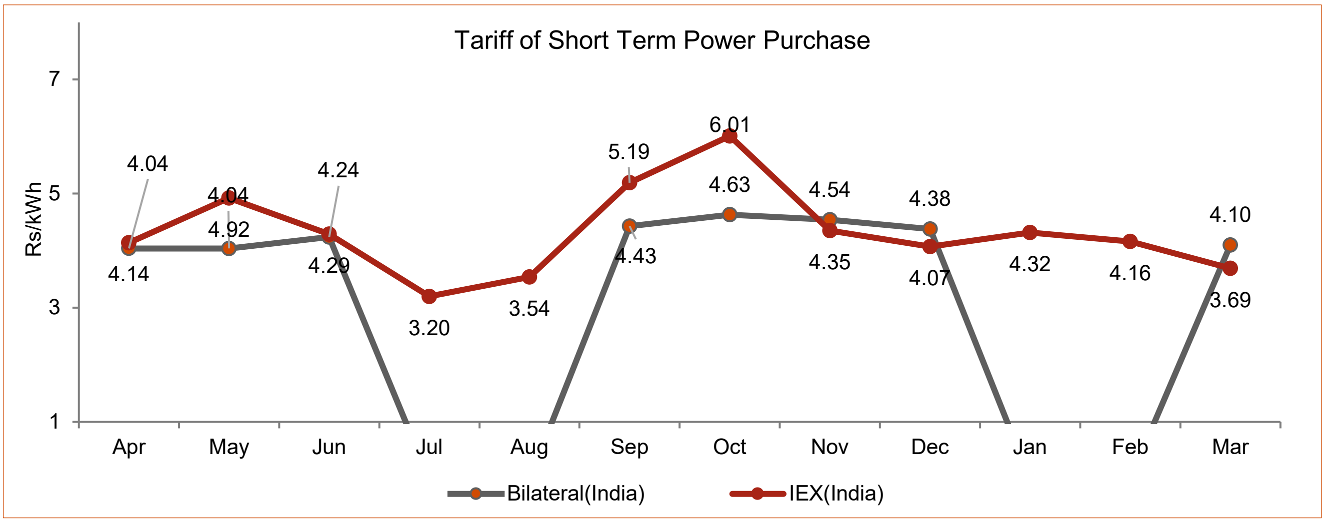


Figure 27: Tariff of Short-Term Power Purchase

Source: CERC Monthly Report

Moreover, as per the FY20 DSM pool settlements, it has emerged that Maharashtra (MSLDC UI Settlement) has paid 53.26 Crore to the DSM pool for overdrawal of power. In this regard, Maharashtra can leverage a PSH for sourcing additional power rather than going for over-drawls which can be threat to the grid security and stability. Moreover, power sourcing from exchange/short term is also susceptible to price volatility and uncertainty, in which case PSH can emerge as viable solution

Grid Flexibility Support:

1. **Frequency:** India has already attained a status of “one nation and one grid” and as a result the maintenance of the frequency discipline between the IEGC band (49.95 Hz – 50.05 Hz) is mandatory for all the five regions in India. The grid discipline of the western region is exhibited as below:

Particulars	2016-17	2018-19	Grid Discipline in 3 FYs
% time frequency < 49.9 Hz	13.48%	12.1%	⬆
% time frequency between 49.9-50.05 Hz	67.2%	76%	⬆
% time frequency > 50.05 Hz	19.3%	11.8%	⬆

SOURCE: WRLDC, Quarterly Report

Overall, the grid discipline of the Western grid has improved over years and the deviation of the frequency below the IEGC band has decreased by 1.38% vis-à-vis the deviation above the IEGC band has decreased by 7.5%, from FY17 to FY19.

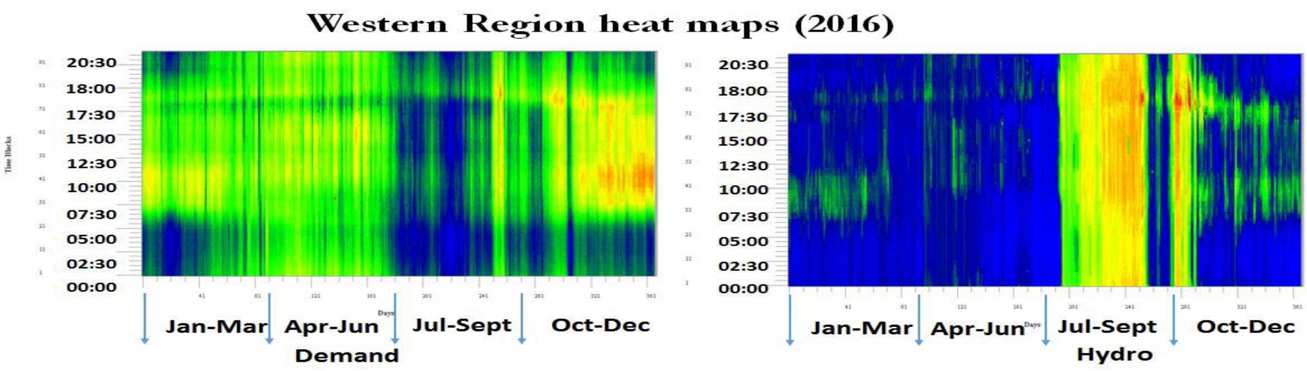
Going forward, the high RE penetration in the WR (~17.3 GW by 2025) will lead to increase in the deviations from the IEGC band and as a result there would be requirement of flexible generation assets to balance the grid frequency. In this regard, PSH can emerge as an ideal candidate

2. **Dynamic VAr Support:** Imbalances in the supply and demand of the reactive power in the system can lead to fluctuation of the voltage across the power system. This requires injection of the reactive power in the system to balance the system. PSH can emerge as an ideal solution for this as it can be operated in lead or lag modes to meet the requirement of reactive power of the grid. Moreover, PSH can also be

operated in synchronous condenser mode to improve the system power factor, ensure power quality and voltage stability.

3. **Peaking Power:** Peaking is an important parameter of the grid, as it deals with meeting the peak demand of the power system. Hydro generating units, especially at the storage type and PSH, are capable of providing this peaking service. Hydro power plants are dependent on the water flow pertinent to seasonality. The seasonality of the hydrology (which forms the basis of water flow for hydro plants) is exhibited through a heat map, as below:

Figure 28:: Hydro Generation in WR



SOURCE: Operational Analysis for Optimization of Hydro Resources & facilitating Renewable Integration in India, 2017

The assessment of the displayed graphical suggest that the July-September months are high hydro season in WR, and as a result hydro generation becomes must run during monsoon (July to mid-October). This is followed by October to December season when hydro generations dips and contributes towards providing peaking support during morning & evening peaks. The peaking capacity further slips due to dry season and as a result peaking support is available only during morning, in Jan to March season.

Western Region observes very high demand from April to Jun months, which are accompanied by limited hydro generation as well. As a result, the development of PSH plant in the region can enhance the capacity vis-à-vis flexibility of the power system in provisioning peaking support.

4. Black Start Support:

Black start capacity of the system has emerged as an important element of the grid stability, especially in the light of black out in Mumbai power outage in October 2020. As per CERC data, Western Region has nearly 18% of the total black start stations in India (16 out of total 87 stations). Hydro units especially PSH is most preferred for black start because of their high ramp up capacity, faster response time, economic viability and low auxiliary consumption. Also, the high inertia and reactive capacity of hydro turbines provide transient stability and helps in grid restoration.

Overall, Malshej Ghat PSH can be as suitable grid asset for meeting the emerging energy requirements of the Maharashtra State vis-à-vis Western Region. Few of the salient points are:

- Currently hydro-thermal mix is skewed towards thermal resources with only 7.7% contribution to generation mix by hydro, and hydro-thermal mix of 11.3%. Development of the additional 700 MW PSH capacity and addition of 1680 Million Units, under the umbrella of hydro will help to balance the hydro-thermal mix. This will lead to optimal utilization of resource mix.
- As discussed, in FY20, Maharashtra has incurred additional charges of INR 53.26 Cr in the form of DSM UI Settlement on account of over-drawl from the grid due to high unanticipated demand. This deviation and over-drawl charges to the regional pool can be avoided by development of flexible storage solutions like Malshej PSH which can provide peaking support.
- The power procurement cost from some of the stations that can be as high as 10 INR/kWh viz. PPC from Mauda II is ~ 7.85 INR/kWh, for FY20. Malsej PSH can replace such high cost plants and can help in surrendering capacity from such high cost plants
- PSH can meet high peak demand in short span of time due to high ramp rate. With the upcoming high RE penetration in the Maharashtra Power System, plants like Malshej PSH will play a vital role in peak shaving needs of Maharashtra.
- PSH plants have been recognized as the assets for purpose of peak shifting and load leveling. Malsej PSH can also play an important role in Maharashtra power system to store the power during off peak hours and utilize the same as peak hours.
- In light of the planned RE development in the Western Region, the issue to RE curtailment will happen – 2000-2500 MW annual curtailment, as per Greening the Grid Report, 2017. PSH can assist in bring this element of RE curtailment lower by absorbing the additional power.

5.2. Commercial Assessment – Malsej PSH Project

The aim of this section is to gauge the commercial viability of the Malsej PSH in the Maharashtra power system by benchmarking it against other generation plants in the state. This is followed by a comparison with other peer PSH plants and lastly the comparison with some upcoming plants. Malsej PSH has been planned by the Government of Maharashtra to meet peaking capacity need, promote integration of renewables and increasing share of hydro in overall mix. The salient features of Malsej PSH project are exhibited below:

Table 24: Salient features of Malsej PSH

Parameter	Details
Location	Located in Thane and Pune District of Maharashtra
Technical Parameters	• Capacity:**700 MW** • Gross Generation:**1,680 MU** • Daily hours of generation:**8 hrs**
Project Cost	Project Cost is estimated at ~ **INR 2,825** crores (includes transmission infrastructure)
Purpose	Project is required to meet peaking capacity need.
Tariff	Levelised tariff (including pumping) is expected to be – **INR 6.09 (first year) – INR 7.84/KWh**

The projected levelised tariff of the plant, as per the new CERC guidelines, is expected to be in the range of INR 3.89/kWh to INR 4.78/kWh, without the pumping cost. With addition of the pumping cost (INR 2.0/kWh), the final levelized tariff works out to 7.48 INR/kWh and first year tariff of INR 6.09/kWh . The total project cost of the plant is expected to be ~INR 2,825 crore. The addition of the Malsej PSH will add additional capacity of 1680 MUs and will increase the contribution of hydro to be 9.2% to total capacity mix, as compared to 7.7% in FY20. Power Procurement Cost (PPC) of select plants by MSEDCL is presented as below.

Table 25: Power Procurement Cost FY19-20

Source	Quantum (MUs)	FC (Crore INR)	EC (INR/kWh)	TC(EC+FC) (INR/kWh)
SIPAT TPS I	4223	572	1.21	2.62
KSTPS III	967	135	1.22	2.71
Adani Power	9042	1030	1.88	3.02
EMCO Power	1370	164	1.83	3.62
Chandrapur 8	3500	665	2.12	4.02
GANDHAR	807	153	2.15	4.12
KORADI - 7	789	142	2.56	4.36
Mauda II	317	158	2.6	7.85

The synopsis of the observations from the power procurement by MSEDCL for the period of FY18-19, is presented as below:

- The overall APPC for FY19 for MSEDCL was ~INR 4.12/kWh
- The power procured from MSPGCL (State Genco) contributes 36% to the total quantum and 24% power is procured from IPPs
- Nearly 26.5% of the power is purchased at a higher cost of INR 5/kWh.
- The power procurement cost from central stations is ~INR 7.07/kWh

As per the FY19 Tariff, the average power purchase cost incurred by MSEDCL was INR 4.12/kWh. Certain state plants like Mauda II have high cost of INR 7.85/kWh, which is comparable to the Malshej Ghat Project.

The above-mentioned analysis reveals that cost of generation from the Malsej PSH is not only competitive but even critical in the Maharashtra power system as it can contribute in meeting peak demand and provision flexibility to the grid. The comparison of Malshej PSH levelised tariff against other PSH plants in India is as follows:

Figure 29: Levelised Tariff of Pumped Storage Hydro Plants

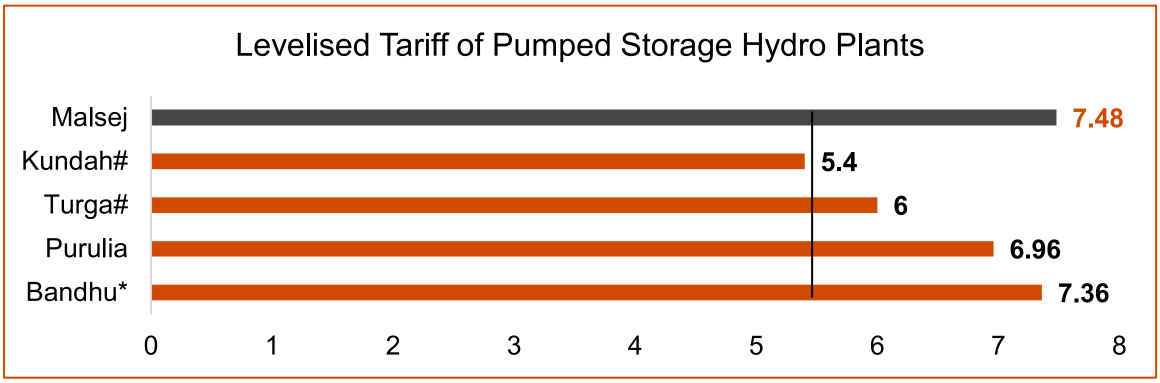


Figure 30: Levelised Tariff of Pumped Storage Hydro Plants

**Low tariff scenario for Bandhu (with 2 fixed + 2 variable unit)*
 # Data for Turga and Kundah are based on DPR cost estimates

From the levelised tariff comparison of Malshej with other 4 selected PSH plants, the average levelised tariff has been worked out to be INR 6.64/kWh. From this analysis, it has emerged that the levelised cost of Malshej PSH is ~12.6% i.e. INR 0.84 higher than worked out average levelised tariff and ~1.6% i.e. INR 0.12 higher than the high cost peer like Bandhu.

The commercial assessment of Malsej PSH demonstrates that the levelised cost of Malsej PSH is higher in comparison with the per unit procurement cost by Maharashtra. However, GoMH has proposed a tariff of INR 5/kWh to implement the project. In this regard, the discussions and deliberation on the acceptable and economically viable tariff range is under process with THDCIL

5.3. Technical Assessment

The Malsej Ghats PSH is situated on the river Kalu on the border of Pune & Thane Districts in Western Maharashtra. The Malsej Ghats PSH is currently in the post DPR stage, and the DPR was been prepared by THDC in 2010. Currently, the project is awaiting the agreement signing with the State Government. The project is proposed to be developed by THDC. The detailed technical assessment of the project is presented in the following sub-sections:

5.3.1. Location and Accessibility of the Project

The project is planned to be developed to be developed on the Kalu River system. The project is having nearness to Mumbai and Pune. For the Upper dam site, the nearest airport is Pune (145 Km) and nearest railhead is Kalyan (105 Km). For the Lower dam site, which falls in Thane District, the nearest airport is Mumbai (165 Km), nearest railhead is Kalyan (85 Km).

The existing dams of the project are located at the following geographic co-ordinates:

- Upper Dam: Lat: 19° 21' 39" N and Long: 73° 47' 46" E
- Lower Dam: Lat: 19° 21' 39" N and Long: 73° 47' 46" E

5.3.2. Review of Hydrology

As per the available report, Malsej Ghat PSH project envisages utilization of the hydropotential by construction of two dams i.e. upper dam and lower dam on Kalu River. The main storage for the proposed scheme shall be in upper reservoir. The water thus stored in upper reservoir would be re-cycled to generate peaking power. The brief description on hydrological aspects of the project is presented below.

5.3.2.1. Catchment Area

The catchment area corresponding to proposed upper dam and lower dam site is 10.53 km2 and 26.03 km2 respectively.

5.3.2.2. Water Availability

Estimated 90% dependable yield at upper and lower dam site are 14.78 Mm3 and 27.36 Mm3 respectively.

5.3.2.3. Design Flood

Design flood of upper dam spillway is 106 m3/s and for lower dam spillway is 460 m3/s.

- The height of upper dam is 37m above riverbed level and height of lower dam is 62 m. Hence, both the dams fall into the category of large dams. Probable Maximum Flood (PMF) has been adopted as the design flood for these large category dams, which is in line with the requirement of BIS: 11223 (1985), guidelines for fixing the spillway capacity.
- 90% dependable yield at upper and lower dam indicates the availability of 210 m3/s discharge. Further assessment with updated discharge data would be required as the detailed project report is prepared during 2010.
- Currently, no clarity on the return period of flood peak adopted as design flood, which needs to be reviewed before project implementation.

5.3.3. Review of Power Potential

The brief description on various parameters such as operating levels, live storage, heads, installed capacity optimization and annual energy generation/energy requirement for pumping is presented below.

5.3.3.1. Installed Capacity

The project envisages the utilization of two reservoirs for recycling the water and exploiting head available between upper reservoir and lower reservoir. For the proposed Malshej Ghat PSH, the live storage is 23.75 Mm3 at the upper reservoir and 15.56 Mm3 at the lower reservoir. The requirement of live storage for 8 hours of peaking operation is estimated as 6.05 Mm3 for maximum discharge of 210 m3/s.

Installed capacity of Malsej Ghat PSH is proposed as 700 MW. Various operating levels and live storage of both the reservoirs are exhibited as below:

S.No	Levels/Live storage	Upper dam	Lower dam
1	Full reservoir level (m)	686.8	**286**
2	Minimum drawdown level (m)	679	**263**
3	Live storage (Mm^3)	23.75	**15.56**

The live storage of 6.05 Mm3 is found adequate for fulfilling the requirement of maximum discharge of 210 m^3/s during 8 hours of peaking operation

The proposed installed capacity of 700 MW is found in order. Estimated annual energy generation is 1680 GWh and annual energy for pumping is 2237 GWh. There may be variation in pumping energy requirement depending on reservoir simulation study on daily basis

5.3.4. Review of Project Geology

5.3.4.1. Topography

The relief of the region is an extremely undulated and some interesting features like lofty peaks, clear-cut ridges, steep slopes and deep ravines with interfluves and round top hill in the form of residue of erosion are characterising the landscape. Terrain is dissected by flat summits, steep slopes, serrated ridges and entrenched valleys. Project is conceived in Kalu River. Area is drained by a number of seasonal streams from high hills around Khubi and surroundings at steep gradient.

The earthquake events in all of peninsula India are intraplate events. Several faults have been identified in the Western Ghat region out of which many show evidences of movement during the Holocene epoch. The north-south trending West Coast and Chiplin Faults run along the coast and the Sahyadri range. The West Coast fault runs along the eastern shore of the Thane Creek in the Mumbai area, along the flanks of the Parsik Hills (Belapur-Vashi region). The project area falls under seismic zone III as per Seismic Zonation Map of India.

Terrain is dissected by flat summits, steep slopes, serrated ridges and entrenched valleys; Project is conceived in Kalu river; Area is drained by a number of seasonal streams from high hills around Khubi and sorroundings at steep gradient.

5.3.4.2. Geology of the Project Area

From Geological point of view, almost all-geographical area surrounding project area are stratified trap called 'Deccan trap' with inter- trappean beds. It is the youngest mega- geomorphic unit of the Indian peninsula (Kale 2000). Deccan trap means step like topography of the volcanic terrain of the Deccan region. This is mainly formed from basaltic rocks.

The structure of such rock observed mainly in two categories. The non- vesicular type is hard, tough, compact and medium to fine grained with conchoidal structure. The second one is amygdaloidal type, which is comparatively soft and breaks more easily. The basaltic layers have been disturbed by diastrophic movement and has undergone to sub-aerial process, which have led to produce a multitude of microforms. The most striking feature is the 1000 m fault escarpment that forms the western margin of the district

The project area belongs to Western Ghat of Maharashtra with Deccan basalt, which is a fine-grained volcanic rock. The main rock type would be basalt and their variants. Basaltic flows are generally disposed horizontally

5.3.4.3. General geological assessment of project Components

The project consists of upper and lower dam. The upper dam axis is aligned nearly NS or NNW-SSE direction and the lower dam axis would be oriented NNE-SSW direction. Both the dams are proposed to be roller compacted concrete structures. Power intake is proposed on the left bank of Kalu river. The head race tunnel, surge shaft, powerhouse and transformer cavern are all underground structure and located on the left bank of river.

In general, basalt as such provides good foundation strata as well as good tunneling medium. However, between two lava flows occasional presence of red bole / green bole may occur. These rock types are generally weak and if encounter for any structures, these would be treated accordingly.

5.3.5. Review of Civil Works

5.3.5.1. Project Layout

A roller compacted concrete for both dam locations having length 2450 m & height 37 m for upper dam and length 690 m & height 62 m for lower dam are proposed for the project. The FRL & MDDL of upper reservoir is at El 686.8 m & El 679 m respectively, and FRL & MDDL of Lower reservoir is at El 286 m & El 263 m respectively. The water conductor system comprises of 8.0 m diameter circular HRT of length 350 m followed by inclined pressure shaft of 6.5m bifurcating to 4.5 m near powerhouse. The tailrace tunnel to discharge water from powerhouse to lower reservoir is of diameter 9m of length 1110 m. The total cost of the project is 2695.26 crores.

Further to mention that a rated head of 396 m is available for the project, which is suitable to consider the project as PSH.

Project layout at the DPR stage has been evolved by studying the alternative locations and found in line with prevailing design practices.

- **Upper Dam**: A 37 m roller compacted concrete dam with deepest foundation at El 656 m shall be used for upper reservoir. Top of dam would be El 690 m. There is an ungated ogee spillway with crest level at El 286 with design flood of 106 m^3/s.
- **Lower Dam:** A 62 m roller compacted concrete dam with deepest foundation El 229 m is envisaged. The top level of the dam is at El 291 m. There is ogee shaped spillway with width of 78 m and sluice bay of diameter 3.3 m, to pass 460 m^3/s flood.

5.3.5.2. Intake

Intake is proposed by considering topography, geology and independent construction viewpoint. It is located on the left bank of dam. The hydraulics of the intake for PSH scheme is different from the conventional hydropower schemes in view of its reversible mode of operation. In the pumped storage project, the intake and tailrace outlet are to function as an intake as well as an outlet since directions in generating and pumping modes are exact reverse as hydraulic feature is quite different between water intake and discharge. There is no specific criteria on hydraulic design for intake of a PSH in Indian Standard code.

The preliminary concept of designing intake and tailrace following CRIEPI guideline is in line

5.3.5.3. Head Race Tunnel

A 8 m diameter circular head race tunnel of 350m length is contemplated between Intake and surge shaft.

The preliminary concept of designing intake and tailrace following CRIEPI guideline is in line

5.3.5.4. Surge Shaft

At the end of HRT, a circular underground surge shaft of diameter 15m and 138 m height has been proposed to adjust and accommodate water hammer effect in the water conductor system by shutting off/sudden starting of Pump Turbines in different modes.

The arrangement of underground surge shaft is in line following the transient analysis

5.3.5.5. Pressure Shaft

The main pressure shaft of 6.5m diameter will emerge from the surge shaft and bifurcates into 4.5 m near powerhouse.

The arrangement is in line; however, economic sizing could not be revalidated in absence of complete DPR.

5.3.5.6. Powerhouse

An underground powerhouse (120 m length x 25 m width X52 m height) has been proposed with 2 units of 350 MW capacity, each with reversible Francis Pump Turbine. The powerhouse complex consists of machine hall, transformer cavern, bus duct, draft tube tunnels, TRT tunnels, Main access tunnel, cable tunnel etc.

The layout arrangement for the structures are in line; however, due to non-availability of DPR, the recheck and revalidation could not be undertaken

5.3.5.7. Tail Race Tunnel

A tailrace tunnel of 9 m diameter 1100 m long is proposed. A surge shaft has been provided to accommodate the water hammer as per the calculation of transient analysis.

It is conceptually in line and further check vis-à-vis optimization may be done during detail engineering stage

5.3.6. Review of the EM Works

5.3.6.1. Turbine

The project has been proposed with an installed capacity of 2x350 MW i.e. 700 MW as per draft DPR available. The main Technical Particulars of turbine are provided below:

Table 26: Technical Particulars of Turbine

Sl. No	Descriptions	Parameters
1	Type	Vertical reversible Francis turbine
2	Number of turbines	Two
3	Rated capacity to generate at generator terminal	350 MW
4	Capacity in turbine mode	359 MW
5	Upper Reservoir Levels	
	Full Reservoir Level (FRL)	686.8 m
	Minimum Drawdown Level (MDDL)	679.0 m
6	Lower Reservoir Levels	
	Full Reservoir Level (FRL)	286 m
	Minimum Drawdown Level (MDDL)	263 m
7	Operating head range as turbine	
	Maximum net head	396 m
	Rated net head	396 m
	Minimum net head	370.0 m
8	Operating head range as pump	
	Maximum net head	431 m
	Rated net head	413 m
	Minimum net head	400 m
9	Rated speed	333 rpm
10	Rated turbine discharge	105 m^3/s
11	Rated pump discharge at maximum head	92 m^3/s
12	Cycle efficiency	80 %
13	Turbine centre line proposed	**El. 221 m**

- The type, rated capacity, rotational speed for 2 units of 359 MW turbines are generally in order.
- Detailed transport survey for feasibility of transportation of over dimensional consignments such as turbine, generator, and generator transformers is required to be conducted in appropriate time.
- The selection of vertical Francis type turbine with a head range of 391 m to 431m is considered technically in order.

5.3.6.2. Generator Motor

The main features of the generator is as provided below:

Table 27:Technical Parameters of generator-Motor

Sl. No	Description	Parameters
1	Rated capacity	350 MW
2	Generation Voltage	18kV
3	Synchronous Speed	333 rpm
4	Power factor	0.90 lagging (generator operation) 1.0 leading (motor operation)
5	Rated frequency	50 Hz with
6	Bearing arrangement	Suspended type
7	Head Variation on Pump	400 – 431m i.e. 31m
8	Type speed regulation of generating unit	Reversible Francis pump turbine units
9	Motor capacity	430 MW
10	Configuration of the main units	2 reversible Francis pump turbine Units of 350 MW each

- The type, rated capacity, synchronous speed etc. for 2 units of 350 MW generators is generally in order.
- The generation voltage as proposed as 18kV is in order. However, the same can be optimised within the range of 15kV-18kV.
- Necessary overloading provision (10%) as per grid code/CEA shall be provided in the generating units.

5.3.6.3. Generator-Motor Transformer

There are 6 nos. (1 as spare) single phase generator-motor transformers proposed for the project as per DPR. Each transformer comprises of 18/ 400/√3 kV, 160 MVA type. The transformers are proposed to be installed in a transformer cavern. The HV side of the terminal of the transformers are proposed to be connected to 400kV indoor type Air Insulated Substation (AIS).

Considering unit configuration for reliability and flexibility of operation, a bank of three nos. 160 MVA single-phase transformers for each unit with 10% overloading as proposed in the DPR is considered adequate.

5.3.6.4. Main Inlet Valve

As per the DPR, a main inlet valve of spherical type for shutting-off pressure water supply from the penstock to the pump-turbine shall be provided complete with necessary piping, OPU system, upstream and downstream connecting pipes, dismantling joint, bypass, operating mechanism etc.

The selection of spherical type main inlet valve for each unit with double seal (maintenance and service seal) is technically in order. The seals shall be of metallic type of stainless-steel materials.

5.3.6.5. 400 kV Air Insulated Substation (AIS)

As per the DPR, the proposed 400 kV AIS (or outdoor AIS) shall have one and half breaker scheme. The details are not available for review.

The proposed 400kV air insulated substation (AIS) having one and half breaker scheme is considered technically suitable.

5.3.6.6. Power Evacuation System

In the DPR of Malshej Ghat PSH the following power evacuation is proposed. 400 kV double circuit transmission line from Malshej Ghat PSH to Kudui 400 kV Substation which is about 85km (approx.) is proposed.

- The proposed power evacuation scheme is tentative and needs to be finalised in consultation with all the stakeholders such as Central Electricity Authority, central and state transmission utilities.
- A comprehensive load flow study is necessary during implementation stage under peak demand load scenario and pumping power requirement during lean hours encompassing the substations for Malshej Ghat PSH and thereby setting up Substation & Transmission system effectively for finalization of power evacuation scheme.

5.3.7. Review of Project Cost Estimation

Considering the prefeasibility stage, the project cost has been estimated based on the Indian Standard guidelines such as:

- Guidelines for preparation of project estimates for River Valley Projects dated 1997 by Central Water Commission, Govt. of India
- Guidelines for preparation of Detailed Project Report of Irrigation and Multipurpose projects 2010 by Central Water Commission, Govt. of India

The overall cost of the project is estimated as below including IDC and FC:

- Total cost excluding transmission = Rs. 2695 crores
- Total cost including transmission = Rs. 2825 crores

5.3.7.1. Civil Works Cost

The civil cost works out as INR 1151.26 crores in the DPR stage. The cost of preliminary land, buildings, miscellaneous has considered as INR 383.92 crores. The cost is based on Schedule of Rates of Water Resource Department Govt. of Maharashtra at price level of 2010 and the cost might undergo substantial revision on updation of DPR. This cost does not include VAT and IDC escalation during construction period. The cost has been built up based on unit rate and estimated quantities and wherever unit rate was not available a lump sum provision has been considered based on experience of similar projects.

- At this DPR study, the cost estimation approach is in order
- As the estimated cost is at price level of 2010, it has to be escalated to the present price level of 2021 for the project
- The project cost after escalated to the present price level has been taken with variation of ±30%

The electromechanical cost in the DPR has taken as INR 861.22 crores and the transmission cost INR 130.65 crores.

5.3.7.3. Electromechanical Cost for the powerhouse generating units

The above costs of INR 861.22 crores include the cost of main electromechanical equipment (excluding the transmission system) such as turbines, generators, transformers etc. based on the prevailing market prices in India and abroad. Suitable provision for transportation, erection and commissioning charges, freight and insurance etc. are expected to keep as per general guidelines issued by CEA.

- The cost break-up is not available. However, it should be as per CEA guideline; establishment cost of 4%-6% on electro-mechanical cost should be considered. 1% as contingency and 0.5% as audit and account charges should be considered.
- A comprehensive budgetary offer from leading EPC contractors may be obtained to justify the costs.

5.4. Risk Association and Mitigation Measures

5.4.1. Risk Category

A risk matrix along with mitigation measures has been prepared based on the comprehensive technical due diligence carried out. The categorization of the risk is as follows:

Risk Category: High

Matters that should be addressed prior to closure of investment deal as they may have impact on Project suitability or cost or both.

Risk Category: Medium

Matters that may constitute a risk and should be dealt with further during construction and operation/ maintenance of the project but should not necessarily have any significant impact on Project suitability or cost.

Risk Category: Low

Matters with no/limited material impact on project suitability and cost.

Table 28:Risk Matrix for Malsej PSH

Risk	Risk Level
Hydrology	
General	**Medium**
Geology	
Regional geological aspects	**Low**
Dam and underground structures	**Medium**
Seismicity	**Low**
Civil Works	
Structural aspects	**Medium**
Electro-Mechanical and Transmission Works	
There is no availability of transport survey report in the DPR.	**Medium**
Project Cost	
As per the DPR, the cost evaluation is in order.	**Medium**

The detailed risk association matrix along with the mitigation measures to address the risks, is attached as an **Annexure 9.3**

6. Tamil Nadu State Assessment

6.1. Tamil Nadu-State Overview

Tamil Nadu is situated in the southern region of India. It has a geographic spread of 192,000 sq. kms surrounded on the north by Andhra Pradesh and Karnataka, on the west by Kerala, to the east the Bay of Bengal (and the Indian Ocean to the south. Tamil Nadu has the highest rate of urbanization in India.

Tamil Nadu is a also the industrial powerhouse of India with about 57 approved Special Economic Zones (SEZ) and four industrial corridor based development namely Chennai-Bengaluru Industrial Corridor (CBIC) , Chennai–Kanyakumari Industrial Corridor (CKIC) , Tamil Nadu Defense Industrial Corridor (TNDIC) and Vizag Chennai Industrial Corridor (VCIC).Tamil Nadu is the 2nd largest state economy in the country contributing to 8.4% of India's GDP.

Tamil Nadu has tremendous investment potential. It is one of Asia's most preferred investor destinations with 9% of Foreign Direct Investment in India since 2000. The State is presently home to more than 70 Fortune 500 companies.

The current Gross State Domestic Product (GSDP) of Tamil Nadu stands at USD 264 Bn (as in FY20), which has steadily grown with a CAGR of 12.2% since FY15. In 2019-20, tertiary sector contributed 53.67% to state's Gross State Value Added (GSVA) at current prices, followed by secondary sector at 33.44%

6.1.1. Power Sector Overview

As of 31 March 2021, Tamil Nadu has ~33,695 MW of total installed capacity. Renewables account for 45% of the total installed capacity which is followed by thermal installations (coal +lignite) contributing 44% to the generation mix. Hydro segment –currently contributes ~ 7% to the installed capacity with remaining 4 % by nuclear plants.

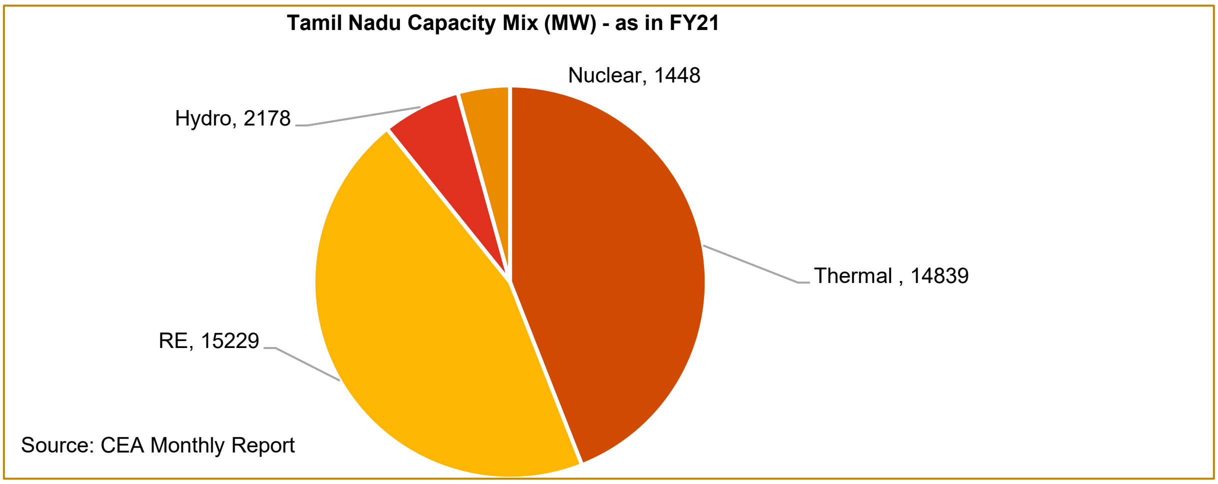


Figure 31:Tamil Nadu Energy Mix

6.1.2. Demand-Supply Assessment of Tamil Nadu

Tamil Nadu power supply deficit has reduced constantly and FY17 was the first time, when no power deficit was registered. Peak demand grew at a CAGR of 3% since 2015. The total peak power requirement in FY 2021 was 16263 MW, which could be completely met with the supply

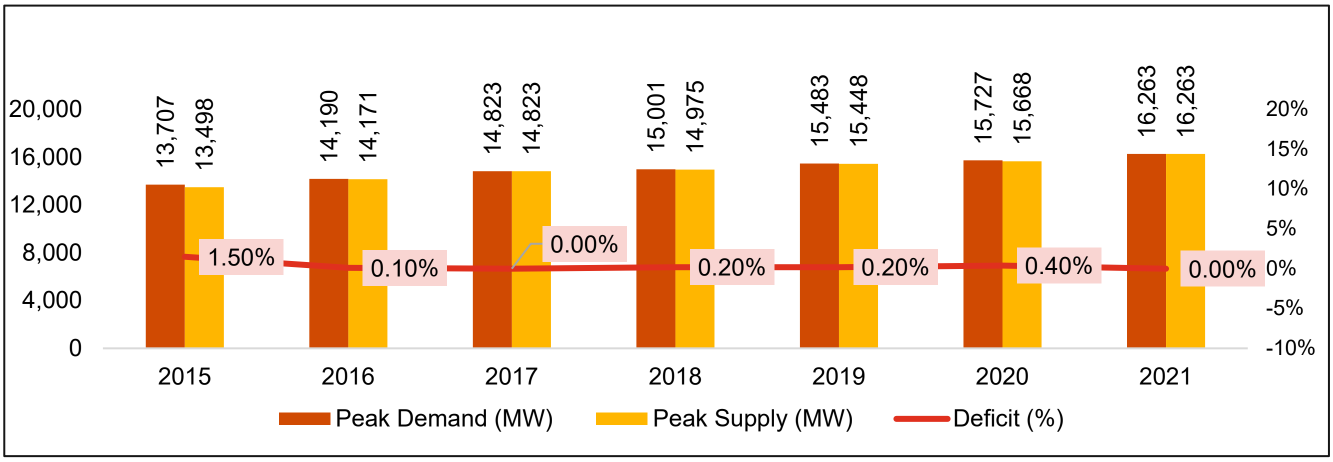


Figure 32: Energy Demand and Supply Position in Tamil Nadu

Source: CEA, LGBR

High Renewable Penetration in Tamil Nadu

As in FY 21, the state RE installed capacity observed was ~15 GW with installed solar power of 3 GW, small hydro ~2 GW and wind power~ 9GW. The graphical below exhibits the planned capacity addition

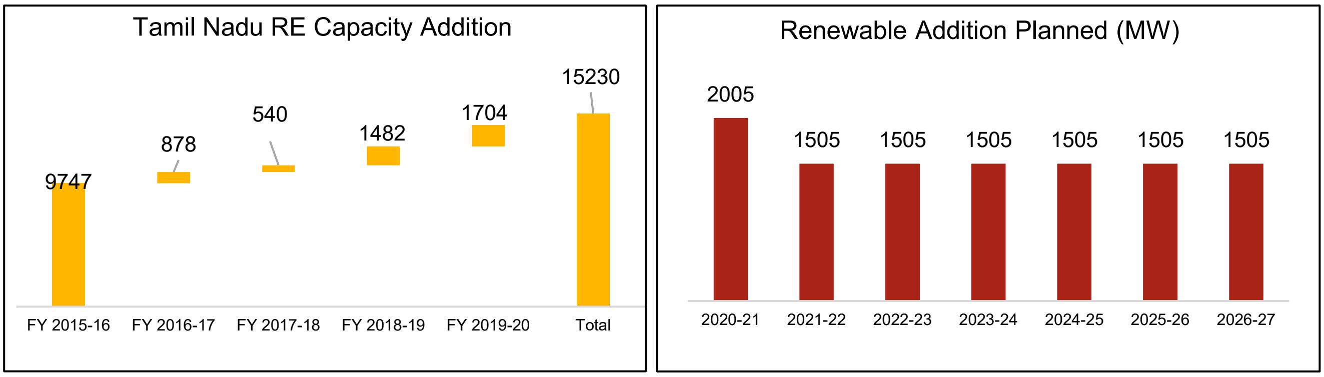


Figure 33: RE Capacity Addition in Tamil Nadu

Source: CEA Monthly report ,www.teda.in

Some of the recent State and Central initiatives to promote RE in Tamil Nadu are highlighted below:

- Vision Tamil Nadu 2023, a strategic Plan for Infrastructure Development in Tamil Nadu, includes a solar energy target of 5,000 MW.
- TN Solar Policy 2019 aims to increase the solar power generation capacity of the state to 9,000 MW by 2023.The policy also provides incentives in the form of waiver from electricity tax to consumers, special incentives to farmers and land for development of solar system component manufacturing
- TNERC has issued new regulations for wind power procurement in Oct 2020 with guidelines for procurement with details on mode of power procurement, energy banking, transmission, wheeling, scheduling, and system operation charges.

  The new guidelines also state that procurement of wind power by DISCOMs for the compliance of RPO targets would be done through competitive bidding. If the bidding is not successful, the DISCOM may go for bidding without prescribing a cap after obtaining the Commission’s approval
- Central Govt has granted ISTS waiver extension for solar, wind projects until June 2023 as a step to promote renewables

High RE penetration can draw curtailment of RE during peak hours of generation or in case of lack of transmission availability.

- In July 2017 TNERC rejected petitions from three Adani subsidiaries regarding implementation of must-run status of solar projects in Tamil Nadu. It has been observed that curtailment from cheaper projects remained near zero, the other three subsidiaries faced curtailment of over 50% on a number of days.
- Since the lockdown in March 2020, Tamil Nadu has curtailed 50% of solar power while its average curtailment of wind power in 2019 went up to 3.52 hrs/ day from 1.87 hrs/day in 2018.

The curtailment is expected to grow worse with the increasing share of renewables in Tamil Nadu's energy mix. The following figure depicts the fluctuations in the net load versus demand in FY 2031-32

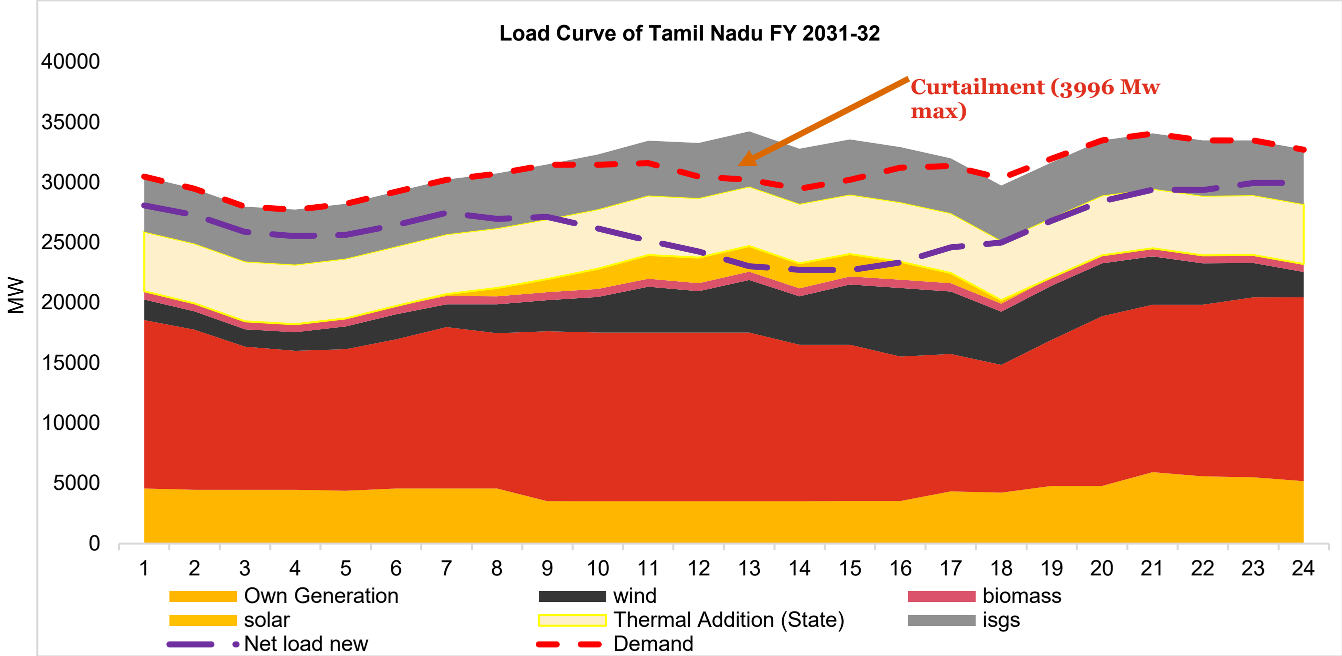


Figure 34: Load Curve of Tamil Nadu

Source: *PwC Analysis*

Two points are noteworthy in the graph- (i) the high ramp up requirements and (ii) the likely curtailment. Currently, ramp up is being met by RRAS providers as recognised by CERC. They are all thermal –(mostly gas/coal based) and they cater to the whole Southern Grid. The tariff ranges from 2.5-5 INR /kWh with additional 0.5 INR/kWh as charge for provisioning.

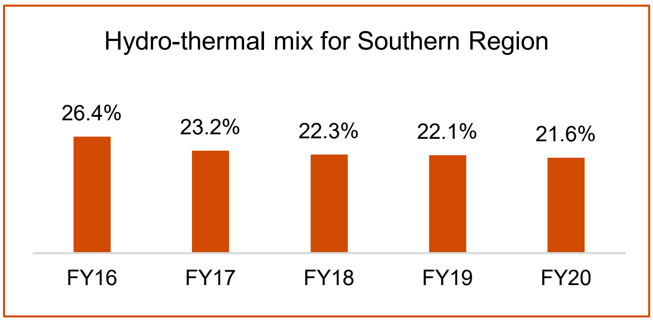
High ramp up rate requirements and reduction of projected RE curtailment would requires introduction of flexible generation and storage solutions like PSH which are also commercially viable and environmentally sustainable. The additional energy likely to be curtailed can be used to schedule and pump up water at (preferably only variable costs to lower cost of pumping) to pumped hydro during daytime and energy generated from PSH can be used as peaking load during evening hours.

6.1.3. Need for flexible resources like PSH in Tamil Nadu

Apart from solving the RE curtailment, PSH can play a vital role in meeting peak demand, maintaining the thermal-hydro mix, meeting HPO Obligations, reducing short term purchases and providing support in grid stability.

Hydro-Thermal mix:

In regional grids, the seasonal demand pattern matches with the generation from hydro power generation. During monsoons when the generation at hydro power plants is high, the load factor of the system is high due to heavy agricultural load. During winter, the thermal stations operating at base load and hydro stations working as peak load stations will take care of weather beating loads. Thus, the operational needs of hydro & thermal stations are complimentary, and the balanced mix helps in optimal utilization of the capacity. However, both in SR and in Tamil Nadu, the hydro-thermal ratio has been decreasing every year



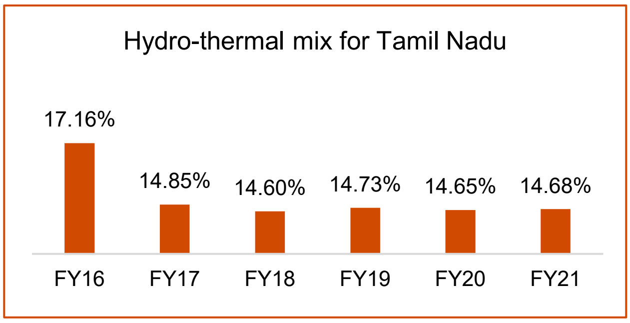


Figure 35: Hydro-thermal mix
Source: CEA Report

The ratio for Southern Region is much lower than the optimum ratio of 40%. This necessitates addition of additional hydro resources (hydro plants or PSH) which would help in maintaining the optimum capacity utilization of hydro and thermal.

Short Term Purchase:

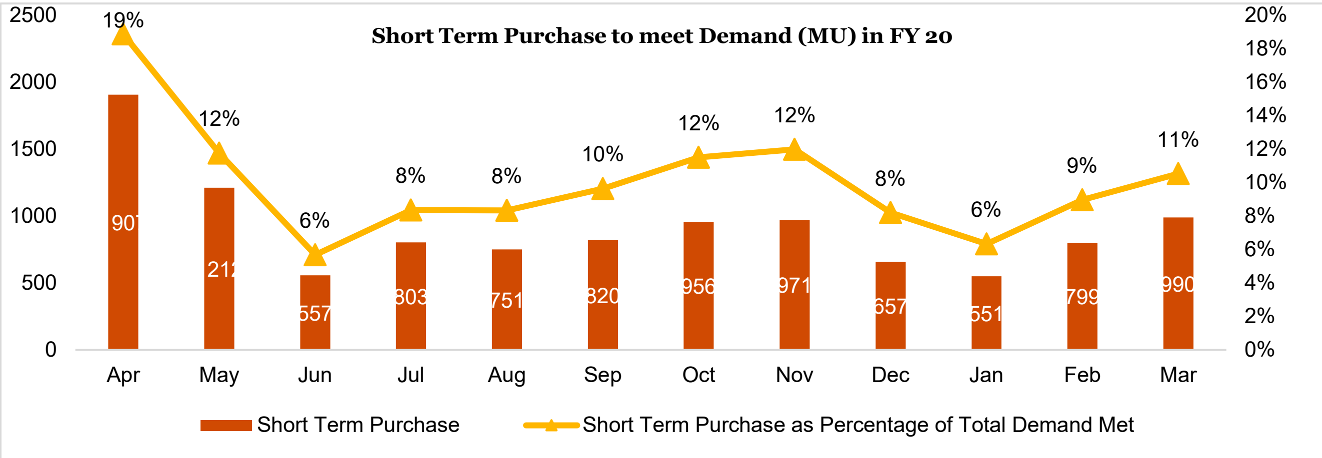


Figure 36 Short term purchase to meet Demand in FY20
Source: CERC Market Monitoring Report

Tamil Nadu purchased 10,972 MU from short term purchase in FY 20 to meet the demand supply gap. It has been observed that Tamil Nadu has bought around 10% of its short-term power (through IPPs) at a rate of INR 6.85/kWh which is much higher than its APPC.

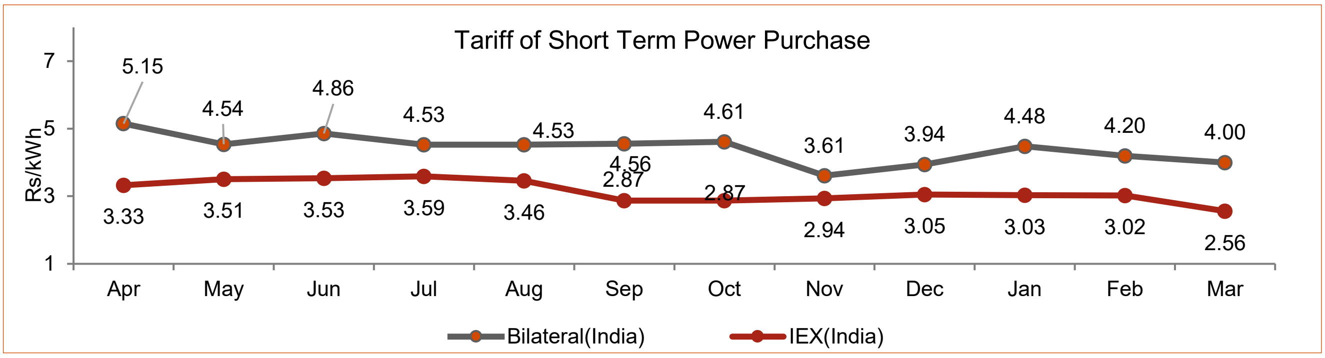


Figure 37 Tariff of Short-Term Power Purchase

Source: CERC Monthly Report

Tamil Nadu may look for firm power through PSH instead of relying on short term market which is susceptible to price volatility and uncertainty.

Grid Flexibility Support:

1. **Frequency:** Frequency has always been a cause of concern in the Southern Grid where the renewable penetration is about 40% of the total installed capacity. Frequency falling below the IEGC band (< 49.9 Hz) has decreased by 14.81% from FY17 to FY20 and frequency rising above the IEGC band (> 50.05 Hz) has increased by 7.77% from FY17 to FY20.

Table 29: Grid Discipline for Southern Grid

Grid discipline in 2016-17 vis-à-vis 2019-20			
Particulars	**2016-17**	**2019-20**	**Grid Discipline in 3 FYs**
% time frequency < 49.9 Hz	**8.1%**	**6.9%**	↑
% time frequency between 49.9-50.05 Hz	**72.6%**	**72.3%**	↓
% time frequency > 50.05 Hz	**19.3%**	**20.8%**	↓

Source: Monthly Report, POSOCO

Payment paid by Tamil Nadu to the DSM Pool for frequency deviation was INR 212 crores for FY 19-20. Tamil Nadu may look for additional firm power from flexible resources to bring down the DSM charges paid to the Pool

2. Peaking Power:

Although Tamil Nadu does not have a peak deficit, for meeting the peak demand especially during the summer season Tamil Nadu has to depend on short term purchases. Tamil Nadu met about 8-19% of its peak demand through short term purchases in FY20. The dependence on short term power is usually high in Mar-May and in Sep-Nov.

Hydro generating units, especially at the storage type and PSH, can provide this peaking service. Hydro power plants are dependent on the water flow pertinent to seasonality. In Tamil Nadu, hydropower which is only 7% of the total installed capacity and is susceptible to seasonal variations is not sufficient to meet the peak load.

In order to meet short/medium term deficits, TANGEDCO has recently signed PPA to procure 500 MW power for a period of three years from **PTC** at a rate of 3.26 INR/kWh.

PSH can be an ideal source to meet peaking power because of characteristics like high ramp up MW and fast response time

3. Dynamic VAr Support:

Imbalances in the supply and demand of the reactive power in the system can lead to fluctuation of the voltage across the power system. This requires injection of the reactive power in the system to balance the system. PSH can emerge as an ideal solution for this as it can be operated in lead or lag modes to meet the requirement of reactive power of the grid. Moreover, PSH can also be operated in synchronous condenser mode to improve the system power factor, ensure power quality and voltage stability.

4. Black Start Support:

Black start is the capability of a generating plant to start on its own without complete interruption of external power to the station. About 90 black start drills took place in SR since last five years. Hydro units especially PSH is most preferred for black start because of their high ramp up capacity, faster response time, economic viability and low auxiliary consumption. Also, the high inertia and reactive capacity of hydro turbines provide transient stability and helps in grid restoration.

Table 30: Number of Black starts drills in SR

Location of Plants	No. of Black Start Drills
Kerala	19
Tamil Nadu	**29**
Andhra Pradesh	10
Karnataka	17
Telangana	16
Total	91

Overall, Sillahalla Ghat PSH can be as suitable grid asset for meeting the emerging energy requirements of the Tamil Nadu State and Southern Region. Few of the salient points in justification for the Sillahalla project in Tamil Nadu are as following

- Currently hydro-thermal mix is skewed towards thermal resources with only **6.46%** contribution to generation mix by hydro, and hydro-thermal mix of **14.68 %.** Development of the additional 1000 MW PSH capacity and addition of 2190 Million Units, under the umbrella of hydro will help to balance the hydro-thermal mix. This will lead to optimal utilization of resource mix.
- As discussed, in FY20, Tamil Nadu paid INR 212 Cr to the DSM Pool for frequency deviation. Tamil Nadu would require a balancing asset to avoid the DSM charges paid to the pool by development of Sillahalla PSH
- The power procurement cost from some of the IPP stations was INR 6.85/kWh in FY20. Sillahalla PSH can provide a relatively low-cost alternative with additional benefits of peaking support, ramping capacity and flexibility to the grid, and conclusively help in surrendering power from high cost plants.
- PSH can meet high peak demand in short span of time due to high ramp rate. With the upcoming high RE penetration in the Tamil Nadu Power System viz. additional 9000 MW by 2023. Plants like Sillahalla PSH will play a vital role in peak shaving needs of Tamil Nadu.
- PSH plants have been recognized as the assets for purpose of peak shifting and load leveling. Sillahalla PSH can also play an important role in Tamil Nadu power system to store the power during off peak hours and utilize the same as peak hours.

In light of the planned RE development in the Southern Region, the issue to RE curtailment will widen further. PSH can assist in bring this element of RE curtailment lower by absorbing the additional power.

6.2. Commercial Assessment – Sillahalla PSH

The aim of this section is to gauge the commercial viability of the Sillahalla PSH in the Tamil Nadu power system by benchmarking it against other generation plants in the state. This is followed by a comparison with other peer PSH plants and lastly the comparison with some upcoming plants.

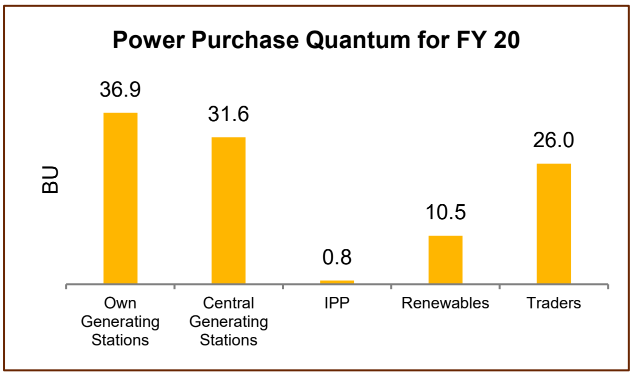
Sillahalla PSH has been planned by the Government of Tamil Nadu to meet peaking capacity need, promote integration of renewables and increasing share of hydro in overall mix. The salient features of Sillahalla PSH plant are exhibited below:

Table 31: Salient features of Sillahalla PSH

Parameter	Details
Location	Located in Nilgiri district in Tamil Nadu
Technical Parameters	• Capacity: 1**,000 MW** • Gross Generation:2190 **MU** • Daily hours of generation:**6 hrs**
Project Cost	Project Cost is estimated at ~ **INR 4,900 crores**
Tariff	Levelised tariff of **- INR 6.72-INR 7.99 /kWh**

The projected levelised tariff of the plant is expected to be in the range of INR 6.72/kWh to INR 7.99/kWh on the basis of scenarios considering pumping power at INR 2/kWh and INR 3/kWh.

Power Procurement Cost (PPC) by Tamil Nadu is presented as below. As per the TNERC, the source-wise availability in Tamil Nadu was~106 BUs and addition of capacity from the Sillahalla PSH to the system will supplement, this baseline FY20 generation mark by ~ 2**%.**



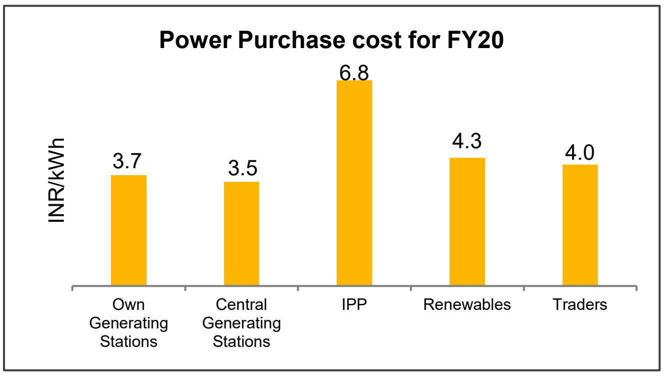


Figure 38: Power Procurement Cost in Tangedco

Source: Tariff Order Tamil Nadu

The synopsis of the observations from the power procurement by Tamil Nadu for the period of FY19-20, is presented as below:

- The overall APPC for FY20 was ~INR 4.13 /kWh
- The power procured from Central & State Genco) contributes 65% to the total quantum and the average rate of procurement is ~INR 3.6/kWh.
- The average cost of procurement from renewable plants is INR 4.3/kWh
- TN purchases ~26 BU from power traders and 0.8 BU from IPPs where tariff is considerably higher than central and state generating stations. **IL&FS Tamil Nadu Power Company (5.47), Coastal Energen (4.68), OPG Power Gen (4.67)**

As per the FY20 Tariff, Tamil Nadu has bought around 10% of its total quantum from IPP at a rate of INR 6.85/kWh which is~ 2% higher than the projected (lower) levelized tariff of Sillahalla PSH viz. INR 6.72/kWh. Also, PSH can act as flexible resource and maintain grid flexibility which is the immediate need of the hour with high RE penetration.

The above-mentioned analysis reveals that cost of generation from the Sillahalla PSH will be competitive and can contribute in meeting peak demand and provisioning flexibility the grid. The comparison of Sillahalla PSH Levelised tariff against other PSH plants in India is as follows:

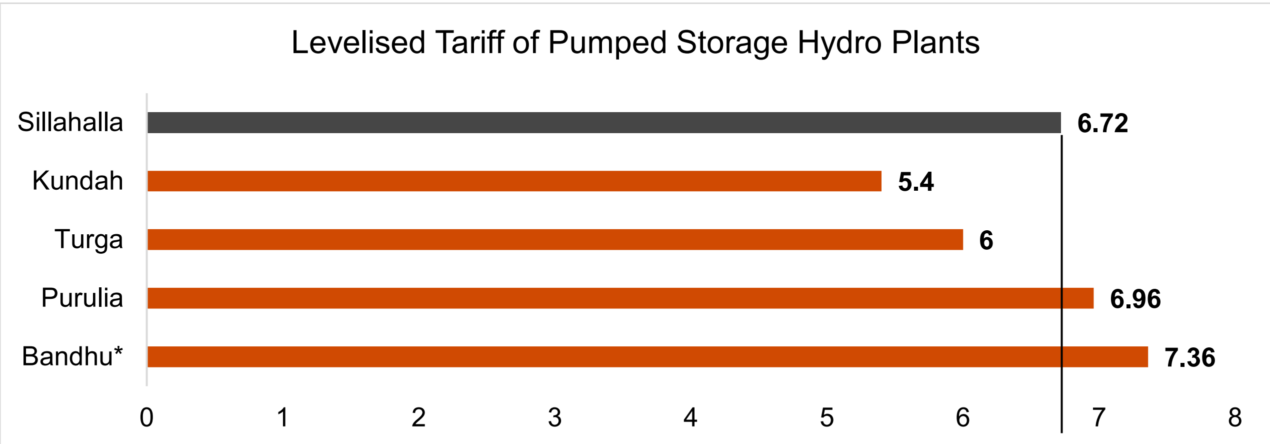


Figure 39: Levelised Tariff of Pumped Storage Hydro Plants

**Low tariff scenario for Bandhu (with 2 fixed + 2 variable unit)*
SOURCE: WAPCOS feasibility Reports, JICA Reports, PwC Analysis

The commercial assessment of Silllahalla PSH demonstrates that the levelised cost of Sillahalla PSH is a little higher than the per unit procurement cost by Tamil Nadu. However,considering the benefits that Sillahalla can bring in terms of response time,high ramp up and availability, this will be an ideal candidate for Tamil Nadu to facilitate supply during peak hours,maintaining grid flexibility and reducing dependence on Exchange and short term market which are subject to uncertainity and price volatility

6.3. Technical Assessment

WAPCOS Limited (a Govt. of India Undertaking) has prepared the feasibility study report (FSR) of the project in June 2019 for Tamil Nadu Generation and Distribution Corporation Ltd (Govt. of Tamil Nadu), who is the developer of the project. This report is based on the FSR prepared by WAPCOS. The detailed technical assessment of the project is presented in the following sub-sections:

6.3.1. Location and Accessibility of the Project

Locational: The proposed Sillahalla PSH is located in the Nilgiris district of the southern Indian state of Tamil Nadu. This project would utilize the unutilized water of Sillahalla River, a perennial tributary stream to River Kundah and in turn to River Bhavani

Technical and Locational details of the Plant

- Construction of concrete gravity upper dam of 82 m height and 327 m length across Sillahalla River.
- 1 no. power intake with trash rack having mechanical raking arrangement and gate shaft.
- 1 no. 2862 m long, 9 m diameter circular concrete lined head race tunnel.
- 1 no. 70 m high, 20 m diameter circular concrete lined HRT surge shaft.
- 2 nos. 533 m long, 6.5 m diameter Inclined circular steel lined pressure shaft.
- 4 nos. 55 m long, 4.75 m diameter circular steel lined penstocks.
- An underground powerhouse cavern of size of 160m X 24m X 55m to house 4 no. Francis reversible pump turbine generating units of 250 MW capacity each.
- 1 no. transformer cavern of size 130m X 18m X 22.5m to house 4 banks of generator transformers.
- 1 no. main access tunnel (MAT) D- shaped of 1240 m long 8m width & 8m height.
- 3 nos. construction adits –adit 1 for HRT, adit 2 for HRT surge shaft, adit 3 for butterfly valve
- Geographical coordinates: Upper Dam: Latitude: 11°18’53.72” and Longitude: 76°38’56.34”
  Lower Dam: Latitude: 11°16’25.81” and Longitude: 76°40’13.00”

Accessibility

The proposed site is accessible by road, rail and airways from Coimbatore, Tamil Nadu. The nearest airport is Coimbatore. The nearest railhead is Mettupalayam/Coimbatore. From Coimbatore, the project is located about 100km by road (Coimbatore - Mettupalayam -Udhagamandalam – Sillahalla Dam site) distance. Nearest seaport is Tuticorin

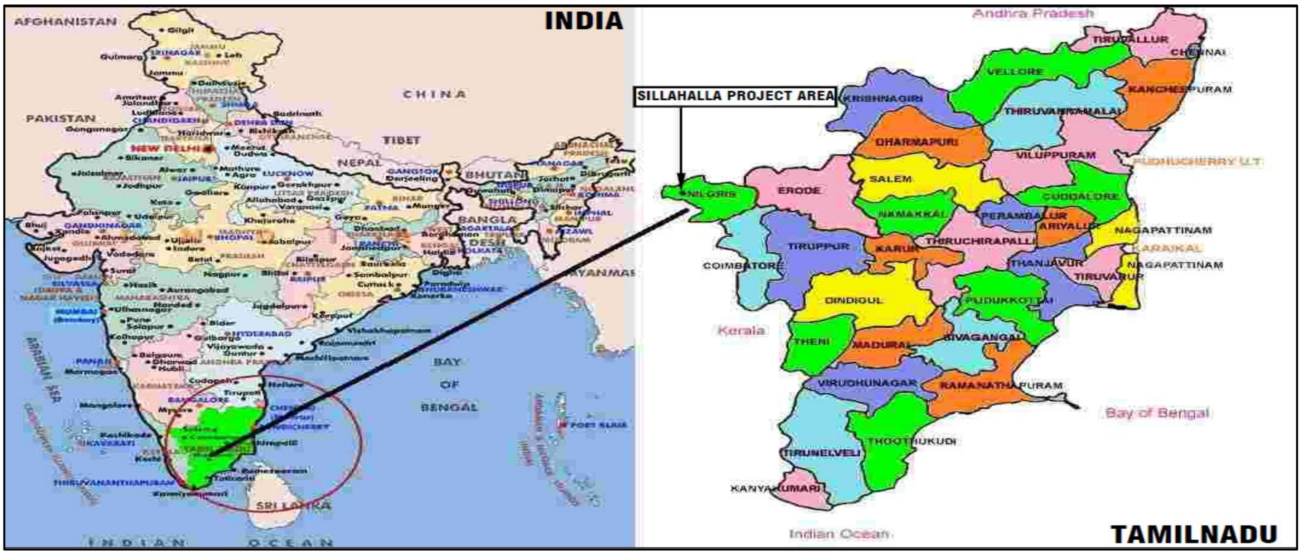


Figure 40: Accessibility of the project

6.3.2. Review of Hydrology

Sillahalla PSH envisages utilization of the hydro potential by construction of two dams - upper dam on Sillahalla River and lower dam on Kundah River. Upper reservoir will be the main storage for proposed scheme. The water from upper reservoir would be re-cycled to generate peaking power. The brief description on hydrological aspects of the project is as below.

6.3.2.1. Catchment area details

The catchment area corresponding to proposed upper Sillahalla and lower Sillahalla dam site is 65 km^2 and 183.48 km^2 respectively.

6.3.2.2. Water availability assessment (as per pre-feasibility report)

Assessment of water availability was focused mainly to derive the discharge series at upper Sillahalla dam site. Consistency check was performed on the available data before its use. For the purpose to derive long term discharge series at upper dam site, monthly rainfall-runoff correlation was carried out using data of concurrent period (1986-87 to 2000-01) for monsoon months to obtain the best fit relationship. Using this relationship, the discharge series was further extended from 2001-02 to 2016-17 for monsoon months. However, the non-monsoon monthly flows for this period was extended based on percentage of average monthly flow to average monsoon flow for the observed period of 1986-87 to 2000-01. Developed flow series at upper Sillahalla dam site indicated flow volume of 30.19 Mm^3, 21.12 Mm^3 and 13.01 Mm^3 corresponding to 50%, 75% and 90% dependable year respectively.

6.3.2.3. Flood peak estimation (as per feasibility study report)

Flood peak estimation at the proposed upper dam on Sillahalla River was carried out by hydro-meteorological approach. The approach utilized empirical relations for deriving synthetic unit hydrograph (as per CWC sub-zone 3(i) report) by considering physiographic characteristics of the catchment. Basin lag (t_p) was estimated as 3.55 hours and peak discharge of unit hydrograph as 44 m^3/sec. For selection of design storm for the project, 1- day probable maximum precipitation (PMP), 100-year, 50 year and 25 year was considered as 55.2 cm, 33 cm, 30 cm and 24 cm respectively. It was obtained from the published report from Indian Meteorological Department (IMD) and Central Water Commission (CWC) for Cauvery and east flowing River basins. Other parameters such as design loss rate as 0.5 cm/hr and base flow as 3.25 m^3/s (0.05 m^3/s/km^2) was considered. Convolution of effective rainfall (cm) with unit hydrograph at dam site after critical sequencing resulted in probable maximum flood (PMF) /other return period flood peaks taking into account the base flow. The flood peaks at lower Sillahalla site was estimated using Dicken's formula. Resulting probable maximum flood /other return period flood peaks at upper Sillahalla and lower Sillahalla dam site are reproduced here as presented in the table below.

Table 32: Flood peak discharge of various return period at upper and lower Sillahalla dam site

S.No	Return period	Flood peak discharge at upper Sillahalla dam (m^3/s)	Flood peak discharge at lower Sillahalla dam (m^3/s)
1	25 year	486.5	1059.47
2	50 year	622.8	1356.3
3	100 year	691	1504.82
4	PMF	1384	3018.08

The height of upper Sillahalla dam is 82m above riverbed level and height of lower Sillahalla dam is 112 m. Hence, it falls into the category of large dams. For large category dams, adoption of probable maximum flood (PMF) as design flood is found in line with the requirement of BIS: 11223 (1985) on guidelines for fixing spillway capacity.

Design flood of 1384 m^3/s for upper Sillahalla dam spillway and 3018 m^3/s for lower Sillahalla dam spillway is acceptable at this stage

6.3.2.4. Sedimentation Study

As per feasibility study report, the main storage dam viz. upper dam on Sillahalla River entails a gross storage of 27.84 Mm^3. No silt data is available for Sillahalla River. The earlier report considered a silt rate of 4.43 ha-m/100 km^2/year tentatively. Using the same rate, the elevation of deposited sediments was estimated as El. 1910 m for upper reservoir and El. 1509 m for lower reservoir after 70 years of reservoir operation.

Considered average annual silt rate of 4.43 ha-m/100 km^2/year is found within reasonable limit. Estimated deposition levels of sediments in upper and lower reservoir of Sillahalla dam is acceptable at this preliminary stage. As recommended in the feasibility study report, detailed sedimentation study would be required for estimation of New Zero Elevation and revised elevation area capacity curve after 70 years of operation as per applicable sediment rates for the rivers in that region

- Approach adopted for water availability assessment at the proposed upper Sillahalla dam site is found in order. However, further assessment with updated discharge data would be required at the detailed project report stage.
- Design flood of 1384 m^3/s for upper Sillahalla dam spillway and 3018 m^3/s for lower Sillahalla dam spillway is acceptable. However, the flood study needs to be reviewed based on site-specific probable maximum precipitation (PMP) and its temporal distribution after obtaining data from Indian Meteorological Department (IMD) during detailed project report stage.

6.3.3. Review of Power Potential

The study has been carried out for optimization of installed capacity and daily energy generation /energy requirement of the proposed PSH project. The brief description on various parameters such as operating levels, live storage, heads, installed capacity optimization and daily energy generation/energy requirement for pumping is presented below.

6.3.4. Installed capacity and energy generation (as per prefeasibility report)

The project envisages the utilization of two reservoirs for recycling the water and exploiting head available between upper reservoir and lower reservoir. In order to fix full reservoir level (FRL), minimum drawdown level (MDDL) and storage capacity of the proposed upper Sillahala and lower Sillahalla reservoir, the topographical features of proposed lower Sillahalla dam site and free stretch requirement of existing Kundah Palam reservoir was studied. The study suggested to restrict the maximum allowable full reservoir level at around El. 1560 masl based on area-elevation-capacity curve. However, the minimum drawdown level (MDDL) has been proposed to be kept based on tentative sedimentation deposition level and details of waterway optimization. The requirement of live storage for 6 hours of peaking operation is estimated as 6.36 Mm^3 for maximum discharge of 294.51 m^3/s.

Due to limitation of live storage at lower Sillahalla reservoir (6.49 Mm^3), the installed capacity of Sillahalla PSH is restricted to 1000 MW for 6 hours of peaking operation. Moreover, the upper reservoir has been proposed to be kept with live storage of 10.62 Mm^3 with additional reserve of about 4.13 Mm^3. Various operating levels and storage capacity of both the reservoirs are reproduced here.

Table 33: Various operating levels and storage capacity at upper and lower Sillahalla reservoir

S.No	Levels/Storage capacity	Sillahalla upper reservoir	Sillahalla upper reservoir
1	Full reservoir level (m)	El. 1950	**El.1560**
2	Minimum drawdown level (m)	El.1940	**El.1530**
3	Minimum drawdown level with additional reserve in upper reservoir (m)	El.1944.68	**El.1530**
4	Live storage (Mm^3) (without additional reserve)	6.49	**6.49**
5	**Live storage (Mm^3)(with additional reserve)**	**10.62**	**6.49**

Simulation study was carried out for estimation of daily energy generation during generation mode and energy required during pumping mode for precise calculation. It was aimed to capture the head variation due to rise/drop in reservoir water level with shorter time interval of 10 minutes. Summary of simulation study carried out for three scenarios is presented in the following table:

Table 34: Simulation study for estimation of daily energy generation

S. No	Cases	Generation mode levels (masl)		Pumping mode levels (masl)		Operation (hours)	
		FRL (upper)	MDDL (lower)	MDDL (upper)	FRL (lower)	Generation	Pumping
(i)	Normal operation - Additional storage available and not utilized	1950	1530	1944.7	1558.7	6	7.16
(ii)	Operation- Additional storage is already utilized	1946.2	1530	1940	1558.9	6	7.16
(iii)	Operation – Generating from additional storage in upper reservoir	1944.7	1530	No pumping possible. Water will be released downstream of lower reservoir.		4.5	

- The live storage capacity of 6.49 Mm^3 is found adequate for fulfilling the requirement of maximum discharge of 294.51 m^3/s during 6 hours of peaking operation.
- There is no mention regarding the requirement of environmental flow release in the simulation of daily operation. It would be required to be included during detailed project report stage
- There is no clarity on the considered efficiencies during generation and pumping mode. The same needs to be suitably considered in the simulation study during detailed project report stage although the cycle efficiency of 85.7% has been mentioned in the feasibility study report.
- As per simulation study, head loss is in the range of 4.4m to 5m during generation mode and 3.2m to 3.75m during pumping mode as evident from the table for simulation of daily operation. However, as per brief particular of pump-turbine, maximum head loss is 10 m during generation mode and 11 m during pumping mode respectively. This inconsistency needs to be addressed during detailed project report stage.

The proposed installed capacity of 1000 MW is acceptable. Daily energy generation is estimated as 6000 MWh for daily operation of 6 hours and 7000 MWh for daily operation of 7 hours in pumping mode. There may be minor variation in pumping energy requirement depending on the actual efficiency during pumping mode, refinement in head loss calculation and pumping hours.

6.3.5. Review of Project Geology

During feasibility study, Geological Survey of India carried out the thorough geological studies for the project. The regional geomorphology, regional geology and seismicity has been adequately discussed in the feasibility report.

A brief regional geomorphology and geology is discussed below:

6.3.5.1. Regional Geomorphology and Geology

The proposed Sillahalla PSH is located in Nilgiri hills, Kundah Taluk, Nilgiri District, Tamil Nadu, India falls under SOI toposheet no. 58A/11/SE on 1:25000 scale. The project area is characterised by Plateau with steep slopes. Nilgiri hills abruptly rise to an El. 1370 m from the surrounding plains. In the southeast, there is Coimbator plains and Bhanani plains is located on northeast. The prominent hills are Ooty hills, Dodabetta, Kodaibetta, Bhavni Betta and Devabetta. The principal rivers that drain the area are Bhavani, Kundah in the south, Pykara towards north and Coonoor to further east of the project area. One of the major tributaries of Kundah River is Sillahalla stream – a perennial stream across which construction of the dam is contemplated.

6.3.5.2. Regional Geology

The Nilgiri district exposes charnockite group of rocks with associated migmatites and Bhavani

Group along with the enclaves of Satyamangalam Schist Complex. The Regional Stratigraphic Succession is as follows.

Table 35: Regional Stratigraphic Succession

Lithology	Group	Age
Laterite		Cainozoic
Felsite	Younger Intrusive	Proterozoic
Dolerite/Gabbro	Basic intrusives	
Fissile hornblende biotite gneiss	Bhavani Group (Penninsular Gneissic Complex)	Archean
Ultramafic complex	Satyamangalam Schist Complex	
Quartz-sericite or mica schist Banded magnetite quartzite		
Hornblende biotite gneiss	Migmatite complex	
Pyroxene granulite	Charnockite Group	
Charnockite/Magetite quartzite		

The Charnockitic Group is represented by charnockite and pyroxen granulite and covers a major part of the district in the southern part, which is popularly known as “Nilgiri Massif”. Several dolerite dykes have been intruded in this group of rocks. The Bhavani Group (Peninsular Gneissic complex) comprise fissile hornblende biotite gneiss and occur in the northern part of the district. The Satyamangalam Schist complex is represented by quartz-sericite/mica schist, ultamafics and banded magnetite quartzite. The Nilgiri Massif is capped by aluminous laterite at several places indicating the deep zone of weathering.

6.3.5.3. Seismicity

The project area falls under seismic zone II as per Seismic Zonation Map of India. Structurally, A number of escarpments (lineaments) represented mainly by master joints trending NNE-SSW, NNW-SSE and E-W are reported. Zones of brecciations along ENE-WSW direction are noted in the charnockite terrain on either side of the Bhavani Reservoir. NW-SE to NNW-SSE trending faults are noted west of Gudalur in the Bhavani gneissic terrain.

6.3.5.4. Geology of the Project Area

Charnockite Group of rocks of Archaen age spreads all over the project area. The HRT-surge shaft-pressure shaft-underground powerhouse-TRT will mainly encounter charnockite, pyroxene granulite intruded by dolerite dykes. The area is predominantly covered with top soil, lateritic soil (latosol), duricrust, lithomarge, sapprolite etc. The charnockite is hard, competent and suitable for dam foundation, tunnels and underground caverns.

6.3.5.5. Geological Assessment of project Components

Sillahalla upper dam: Geological Survey of India has carried out geological investigations and M/s Arvee Associates has prepared the Detailed Project Report (DPR). Detailed geological mapping (1:1000 scale) of dam site and subsurface exploration through 11nos. drill holes along two alternative axis located at 50m separation. In addition, standard penetration tests (SPT) and determination of c and Ø of undisturbed soil samples have also been carried out. The Charnokite rock mass is traversed by four sets of joints besides foliation. The core logs of 11nos. of drills holes indicate that the depth of fresh rock varies from 20.65m to 45.30m.

The alignment of the proposed dam is N69°E-S69°W. Because of jointing nature of rockmass, seepage/leakage may be possible which could be mitigated through consolidation and curtain grouting.

In the reservoir area, owing to presence of paleo slide and thick overburden, there are chances of reactivation of slides between FRL and MDDL due to rapid draw down condition. Therefore, adequate mitigation measures are to be adopted as part of reservoir rim stability.

Sillahalla lower dam: It is located downstream of existing Kundah Palam dam on the river Kundah. The dam would be 112 m high concrete gravity dam across Kundah River. Charnockite /charnockitic gneiss are available at both the abutments and it is also expected that bedrock at river gorge will be found at reasonable depth.

Intake: It is proposed on the left bank of Sillahalla River with invert level at El 1940 m. The area is characterised by hard, competent charnockite group of rocks under thick slopewash materials. It is apprehended that substantial excavation is required to establish the intake structure and portal in bedrock.

Head race tunnel (HRT): The proposed HRT is 2862 m long and 9 m diameter. The maximum cover of HRT will be 155m. As per the geological understanding of the project area hard, competent charnockite and dolerite are expected to be tunnelling media with rock class II and III in most cases. However, poor rock class may also be expected wherever shear zone or lineaments will encounter.

Pressure shaft: Two inclined pressure shafts bifurcating into four horizontal pressure tunnels /penstock are proposed for the project. The pressure shaft is expected to pass through charnockite. However, dolerite dykes may also be encountered. The pressure shafts are expected to encounter class II and III rock type, but occasionally poor rock class may be encountered wherever shear zone or any other geologically weak features encounter.

Underground powerhouse: The powerhouse of 160 m length, 24 m width and 55m high, a transformer cavern including secondary GIS (L=130 m, W=18 m and H=22.5 m) are proposed for the project. Charnokite is the main rock type in the powerhouse area. The rock mass is traversed by foliation and four other joint sets. The strike and dip of charnockite is N66°E-S66°W/70° S24°E. Powerhouse is proposed to be aligned along N80°W-S80°E direction and it will make an angle of 34° with the strike of the foliation. At this stage, the orientation is fair to favourable. Further, the orientation of powerhouse has been verified by the field test results from nearby project, UGPH of Pykara Ultimate Stage Hydroelectric Project, which is located about 20km North-West of this site. The direction of Major Principal Horizontal Stress at that site was N80°W-S80°E. Based on this the orientation of Sillahalla powerhouse is found in line.

Tail race tunnel (TRT): One number of 9.75 m dia. and 1567 m long TRT is proposed with maximum rock cover along TRT of 351m. It is apprehended that charnockite / charnockitic gneiss will encounter as the tunneling media for the TRT. In general, good to fair rockmass is anticipated along the TRT except at shear zones

A geological model was prepared based on the available data and it indicated that there is no major geological risk for the structures although for surface structure deep excavation may be required due to thick overburden. Further to mention that as such Charnockite and dolerite rocks provide good foundation strata as well as tunnelling media, however, presence of intermittent shear zones and weak geological features cannot be ruled out. Therefore, it is concluded that the geological challenges for the project may be accepted with due care. However, in the next stage of DPR investigations for the project components would be required to gain confidence for the structures.

6.3.6. Review of Civil Works

6.3.6.1. Project Layout

At the feasibility study stage, it is important to study the different alternative project layouts to arrive and decide the final scheme. Accordingly, three different layout studies had been carried out based on project location, topography, geology and hydrology. The alternative arrangements consider the height and width of dams, suitability of water conductor system and finally the cost elements.

Based on the study, the selected alternative arrangement envisages the following:

A concrete gravity dam for both dam locations having length 327 m & height 82 m for upper dam and length 470 m & height 112 m for lower dam. The FRL & MDDL of upper reservoir is at EL.1950m & EL. 1940 m respectively, and FRL & MDDL of lower reservoir is at EL.1560 m & EL. 1530 m respectively. The water conductor system comprises of 9.0 m diameter circular HRT of length 2.86 km followed by inclined pressure shaft of 6.5 m diameter and length 533 m. The tailrace tunnel to discharge water from powerhouse to lower reservoir is of diameter 9.75 m of length 1.57 Km. The cost of the project works out INR 4131 crores with cost benefit ratio of 1. Further, to mention that a significant head of 420 m is available for the project, which is suitable to consider the project as PSH.

The comparison of alternative study has been reviewed and found in line.

Upper dam: An 82 m high concrete gravity dam with deepest foundation at El 1870 m is envisaged. The top of dam would be El 1950 m. An ogee spillway with 3 bays 10 m width each to pass 1384.50 m^3/s design flood is envisaged.

Lower dam: A 112 m high concrete gravity dam with deepest foundation El 1450 m is envisaged. The top level of the dam would be El 1562 m. The spillway is ogee shaped with 6 bays; each bay is 9 m wide to pass 3015 m^3/s flood

6.3.6.2. Intake

Intake is proposed by considering topography, geology and independent construction viewpoint. It is located sufficiently away from the dam. The hydraulics of the intake for PSH scheme is absolutely different from the conventional hydropower schemes in view of its reversible mode of operation. In PSH the intake and tailrace outlet are to function as an intake as well as an outlet since directions in generating and pumping modes are exact reverse as hydraulic feature is quite different between water intake and discharge. There is no specific criteria on hydraulic design for intake of a PSH in Indian Standard code. Therefore, in designing of an intake and an outlet of a PSH, the guideline proposed by Central Research Institute of Electric Power Industry (CRIEPI) in

Japan, which was used for Purulia Pump Storage Project has been adopted in Sillahalla project. The CRIEPI guideline has been applied many other PSHs in India and no trouble or problem has so far been recorded. A vertical trash rack has been proposed at the entrance of intake. In view of that, the following parameters have been considered:

Dischage in m^3/s	= 294.51 (73.267 x 4 units)
Width in m	= 10.5
Height in m	= 9.5
Number of openings	= 3
Area of Total Openings in m^2	= 299.25
Velocity in m/s	= 0.984

The preliminary concept of designing intake and tailrace following CRIEPI guideline is in line

.

6.3.6.3. Head Race Tunnel

A 9 m diameter circular HRT is contemplated between Intake and surge shaft. The diameter has been decided based on velocity and economic diameter will be taken up during DPR stage.

Conceptually the arrangement is in line with prevailing design practices. Circular HRT is generally more stable than any other shape

6.3.6.4. Surge Shaft

At the end of HRT, a circular underground surge shaft of diameter 20m and 70 m high has been proposed to adjust and accommodate water hammer effect in the water conductor system by shutting off/sudden starting of pump -turbines in different modes.

The arrangement is in line with prevailing design practices however, detail transient analysis would be conducted during DPR stage

6.3.6.5. Pressure Shaft

From surge shaft two steel lined pressure shafts of 6.5 m diameter are proposed passing through valve chamber and then inclined till the powerhouse level. Near powerhouse each pressure shaft would bifurcates into two of 4.75m dia.

This arrangement appears in line at least from the preliminary concept however, economic sizing analysis should be undertaken in DPR

6.3.6.6. Powerhouse and Transformer Cavern

An underground powerhouse with 4 units of 250 MW capacity reversible Francis turbine has been proposed. The powerhouse complex consists of machine hall, transformer cavern, bus duct cavern, draft tube tunnels, TRT tunnels, main access tunnel, cable tunnel etc. The machine hall is planned at El 1498 m and the size would be 156 m x 23.5m x 53 m (L x W x H). The transformer hall is also planned at same elevation that of powerhouse but its size is smaller.

At this stage, the structures are planned conceptually, and the arrangement are in line with prevailing design practices. However, the final orientation and sizing may be slightly modified at DPR stage.

6.3.6.7. Tail Race Tunnel and Transient Analysis

Four TRT of 5 m diameter, 81 m long are proposed upto surge tank and thereafter a single TRT of 9.75 m diameter and 1567 m long is proposed to discharge water in to lower reservoir. The surge tank has been provided to accommodate the water hammer as per the calculation of transient analysis.

It is conceptually in line with prevailing design practices

6.3.7. Review of Electromechanical Works

6.3.7.1. Turbine

The project has been proposed with an installed capacity of 4x250 MW i.e. 1000 MW as per FSR prepared by WAPCOS in 2019. The main Technical Particulars of turbine are provided in the table below:

Table 36: Main Technical Particulars of Turbine

Sl. No	Descriptions	Parameters
1	Type	Vertical reversible Francis turbine
2	Number of turbine	Four
3	Rated capacity to generate at generator terminal	250 MW
4	Capacity in turbine mode	259 MW
5	Capacity with 10% overload of turbine/ pump	285 MW
6	Upper reservoir levels	
	Full reservoir level (FRL)	1950.00 m
	Minimum drawdown revel (MDDL)	1940.00 m
7	Lower reservoir levels	
	Full reservoir level (FRL)	1560.00 m
	Minimum drawdown revel (MDDL)	1530.00 m
8	Head losses	
	Turbine mode	10.0 m
	Pump mode	11.0 m
9	Operating head range as turbine	
	Maximum net head	410.0 m
	Rated net head	390.0 m
	Minimum net head	370.0 m
10	Operating head range as pump	
	Maximum net head	431.0 m
	Rated net head	420.0 m
	Minimum net head	391.0 m
11	Rated speed	333.33 rpm
12	Rated turbine discharge	73.627m^3/s
13	Rated pump discharge at maximum head	62.08 m^3/s
14	Rated pump discharge at minimum head	68.44 m^3/s

Sl. No	Descriptions	Parameters
15	Cycle efficiency	85.71%
16	Turbine centre line proposed	El. 1482.00 m

- The type, rated capacity, rotational speed for 4 units of 259 MW turbines are generally in order.
- The maximum/minimum head proposed for turbine/pump is based on rated discharge with 10m and 11m head losses. The maximum head for one unit operation at minimum head loss may also be specified.
- Detailed transport survey for feasibility of transportation of over dimensional consignments such as turbine, generator, and generator transformers is required to be conducted in appropriate time.
- The selection of vertical Francis type turbine with a head range of 370 m to 410m is considered technically in order.

6.3.7.2. Generator-Motor

The main features of the generator is as given in the table below:

Table 37: Main Technical Particulars of Generator-Motor

Sl. No	Description	Parameters
1	Rated capacity	250 MW
2	Generation voltage	18kV +/-10%
3	Synchronous speed	333.33 rpm
4	Power factor	0.90 lagging (generator operation) 0.95 leading (motor operation)
5	Rated frequency and variation	50 Hz with +/- 3%
6	Bearing arrangement	Suspended type
7	Excitation system	Static excitation system
8	Static frequency converter	One common static frequency converters (SFCs) for starting of each unit in pumping mode. One back-to-back starting method is also proposed.
9	Type speed regulation of generating unit	Fixed/variable speed pump/turbine units
10	Motor capacity	285 MW
11	Overload capacity	110% of rated capacity
12	Configuration of the main units	Option I: 4 Fixed Speed Units of 250 MW each Option II: 2 Fixed Speed Unit of 250 MW + 2 Variable Speed Unit of 250 MW Option III: 3 Fixed Speed Unit of 250 MW + 1 Variable Speed Unit of 250 MW

- The type, rated capacity, synchronous speed etc. for 4 units of 250MW generators is generally in order.
- The generation voltage as proposed as 18kV is in order. However, the same can be optimised within the range of 15kV-18kV.
- In the FSR, options of fixed type/ variable type pump/turbine generating units are proposed. Final selection of numbers of variable type units in order to have better performance and to enhance grid stability may be explored in consultation with CEA, grid operators etc

6.3.7.3. Generator-Motor Transformer

There are 13 nos. (1 as spare) generator-motor transformers proposed for the project as per FSR. Each transformer comprises of 110 MVA, 18/400/√3 kV, 1-phase transformers with OLTC +10% to -5% and is provided with oil forced air forced/oil directed air forced (OFWF/ODWF) cooling. The transformers are proposed to be installed in a transformer cavern. The HV side of the terminal of the transformers are proposed to be connected to 400kV indoor type gas Insulated substation (GIS) through gas insulated busduct (GIB).

- Considering unit configuration for reliability and flexibility of operation, a bank of three nos. 110 MVA single-phase transformers for each unit with 10% overloading as proposed in the FSR is considered adequate.
- The proposed cooling of OFWF/ODWF is considered technically suitable

6.3.7.4. Main Inlet Valve

As per the FSR, a main inlet valve of spherical type for shutting-off pressure water supply from the penstock to the pump-turbine shall be provided in each unit complete with necessary piping, OPU system, upstream and downstream connecting pipes, dismantling joint, bypass, operating mechanism etc. The valve shall have two oil pressure operated working seals (one service seal and the other maintenance seal). The seals shall be of material having high resistance to silt erosion

The selection of spherical type main inlet valve for each unit with double seal (maintenance and service seal) is technically in order. The seals shall be of metallic type of stainless-steel materials

6.3.7.5. 400 kV Gas Insulated Substation (GIS) or Air insulated Outdoor Station

As per the FSR, the proposed 400 kV GIS (or outdoor AIS) shall have double bus arrangement with nine (9) bays: - 4 nos. incoming bays for generator-motors, 4 nos. outgoing bays for connection to transmission lines through 400 kV XLPE cables and one bus coupler bay. Power from 400 kV GIS (or AIS) would be transmitted through 4 numbers 400kV transmission circuit.

The rated current of the GIS is proposed as 2000A and short time rating as 50kA

- The proposed 400kV gas insulated substation (GIS) having double bus arrangement and bus-coupler is considered technically suitable.
- It is also proposed to install outdoor type (AIS) substation in place of GIS. However, for the same, suitable area is required to be identified. The cost of outdoor substation is substantially less than the indoor GIS.
- In case of indoor GIS, outdoor pothead yard location with equipment shall be specified

6.3.7.6. EOT Crane

Two cranes each of 250/80/10 tonnes main and auxiliary hooks are proposed to be provided for handling the assembled rotor along the full length of the powerhouse. Both the EOT cranes shall be used in tandem to handle the rotor. A lifting beam of adequate size /capacity for this purpose shall be provided. One monorail crane of 10T capacity supported beneath the outside girders of both the cranes. In addition, the following cranes are proposed:

- One EOT crane of 10 Tonnes capacity shall be installed in GIS hall.
- One EOT Crane of 80 Tonnes capacity shall be installed downstream of transformer for handling draft tube gate

- Two numbers of 250/80/10 tonnes EOT crane proposed for the powerhouse is considered in order. However, capacity of the cranes shall be verified during detailed engineering stage based on design input from the turbine-generator manufacturers.
- One EOT crane in butterfly valve house is also required to be provided for handling the valves

6.3.7.7. Control, Automation and Protection System

Supervisory control and data acquisition (SCADA) system is proposed for an efficient and economic plant operation. The control and monitoring system will be built up of distributed control technique with independent control module in hierarchical control levels and standard open protocol for communication network. The control system of the project will be provided with distinguished operating characteristics, high reliability and responsibility.

The powerhouse will be designed to be operated with three levels of control:

- ✓ From the control room
- ✓ From the Unit control board located on the machine hall floor.
- ✓ From local control cubicles of each element located adjacent to the unit.

A main supervisory computer system supporting necessary man-machine interface will be located at

the Main Control Room and separate local plant controllers will be provided for each main unit, station service circuit and 400 kV switchyard. The computer system and controllers will be linked by high-speed data transmission system

- Provision described in the FSR is generally in order. However, more details and scope are required to be included in the detailed project report/ tender documents.
- Reservoir water levels, various gate monitoring and control, discharge measurement etc. shall be included in the automation system.

6.3.7.8. Communication System

In the FSR, PLCC (power line carrier communication) system is proposed for efficient sources and reliable information links to meet the communication need of protection, voice and data including for SCADA system. It shall provide for distance protection and direct tripping for remote end breaker, signal transmission & speech communication between the power house/substation and data communication to remote places through various frequency channels etc

For protection tripping and voice communication, the PLCC system is OK but as per latest grid operator's requirement, the PLCC system is being phased out and communication system through optical fibre is being introduced which is considered most advance and efficient mode of communication for data, voice and protection signalling. For the same, optical link terminal equipment (OLTE) at the PSH end and OPGW cable in the transmission line would be required. Also, communication system already provided or being provided at the remote end substations is also required to be studied.

6.3.7.9. Penstock Protection Valve

Penstock protection valves are shown in the project layout drawings just after surge shafts. There are two pressure tunnels and one valve house is shown in the layout drawings

- No details of the penstock protection valves (PPV) are mentioned in the electro-mechanical chapter of the FSR. Penstock protection valve is suggested in each pressure shaft emanating from the surge shaft in order to protect the powerhouse from inundation due to penstock rupturing. Also, during major maintenance of the main inlet valve or penstock, the same can be attended by closing respective PPV. This would allow the other generating units to continue generation uninterruptedly and this is a big advantage of providing PPV in each pressure shaft/ penstock.
- The PPV shall be suitable for remote monitoring and emergency operation by closing the same from powerhouse control room in case of rupturing of penstock
- In view of the above, total two (2) numbers of PPV would be required along with all associated equipment.

6.3.7.10. Electrical Balance of Plants

Electrical balance of plants such as 11kV switchgears, station auxiliary transformers, 220V station DC system, illumination system, grounding system, LT distribution system, generator circuit breakers, unit staring system, cabling system, protection system, emergency power supply system, lifts, testing equipment have been proposed in the FSR.

Electrical balance of plants as proposed in the FSR are generally in order. More details of the same may be furnished in detailed project reports, tender documents.

6.3.7.11. Mechanical balance of Plants

Mechanical balance of plants such as cooling water system, LP compressed air system, drainage and dewatering system, heating ventilation and air conditioning system, fire protection system, oil handling and storage system, workshop equipment have been proposed in the FSR.

Mechanical balance of plants as proposed in the FSR are generally in order. More details of the same may be furnished in detailed project reports, tender documents.

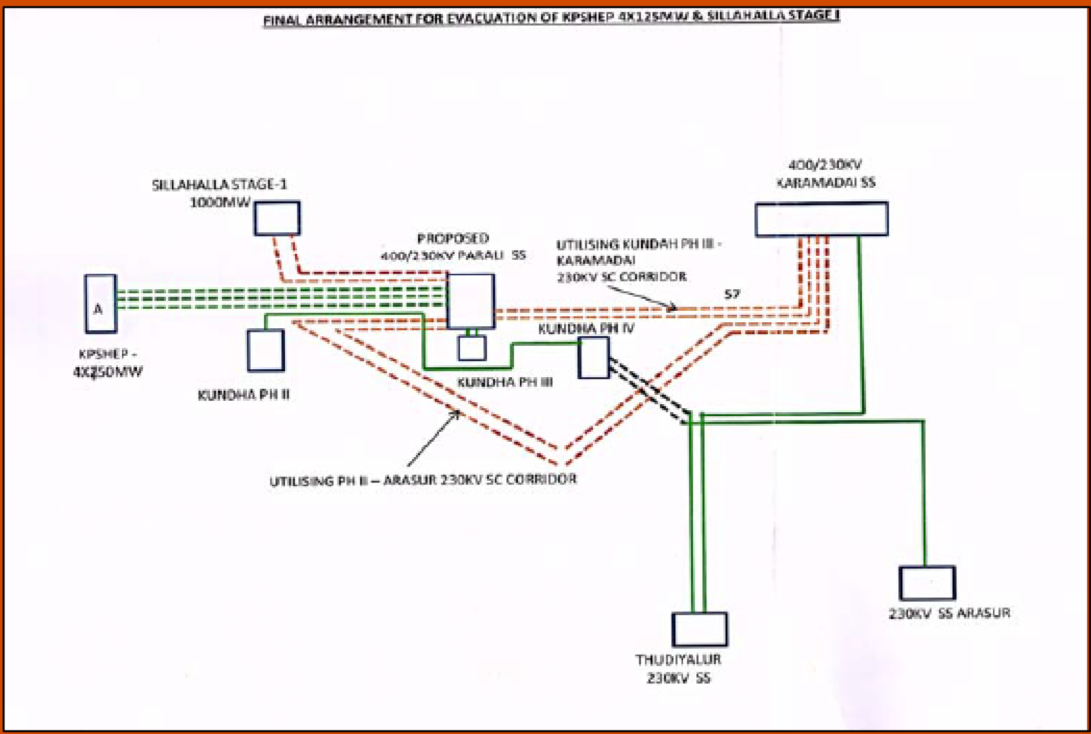
6.3.7.12. Power Evacuation System

In the FSR, following two (02) nos. of power evacuation schemes are proposed for Sillahalla PSH.

i) 400 kV double circuit transmission line with twin Moose conductor from Sillahalla PSH to Karamdai 400 kV Substation and Sillahalla PSH to Arasur 400 kV Substation. Line length from Sillahalla PSH to Karamdai SS is 32km (approx.) and Sillahalla PSH to Arasur SS is 54 km (approx.).

ii) One no. of double circuit and two nos. of single circuit Transmission lines of twin Moose conductor are proposed to be constructed from Sillahalla PSH to Arasur 400 kV Substation, Karamdai 400 kV or Rasipallam 400 kV substation for evacuation of generated power or receiving of power for pumping purpose. Line length from Sillahalla PSH to Rasipallam SS is 103km (approx.)

- As per the 42nd standing committee meeting convened by Central Electricity Authority on power system planning of southern region dtd. 27th April 2018, it was recorded that the following transmission scheme was proposed by Tamilnadu Transmission Company (TANTRANSCO).
  - 400kV double circuit (D/C) line from Sillahalla PSH to 400 kV Parali substation
  - 400kV double circuit (D/C) line from Parali substation to Karamadai 400/230kV substation. This D/C line was proposed to run on D/C towers upto the location no 57(hilly terrain) utilising Kundah PH II – Arasur 230 kV S/C line corridor. Subsequently, the line will be erected on 400 kV M/C towers (with four circuits) upto Karamadai 400/230 kV Substation. The multi circuit towers will also accommodate existing Parali-Karamadai 400 kV D/C line utilising the corridor of existing Kundah PH III- Karamadai 230 kV S/C line (as shown in the below diagram).



- CEA opined that as per the proposed transmission scheme, power from Sillahalla PSS would flow to other states via ISTS (Inter State Transmission System). It was opined that in such scenario would require comprehensive study involving all constituencies of Southern Region. In the meeting, it was agreed that transmission system for evacuation of power from Sillahalla PSS and associated system strengthening would be taken up at later stage by TANTRANSCO.

- As per CERC connectivity regulation 2009, it is mentioned that “However, a thermal generating station of 500 MW and above and a hydro generating station of 250 MW and above, other than a captive generating plant, shall not be required to construct a dedicated line to the point of connection and such stations shall be taken into account for coordinated transmission planning by the CTU and CEA”. In view of the same, the construction of the transmission line and substation is not in the project developer’s responsibility. However, latest status/amendment of CERC on this regard is required to be referred.

6.3.8. Review of Project Cost Estimate

At this feasibility stage, the project cost has been estimated based on the following Indian standard guidelines:

- Guidelines for preparation of project estimates for River Valley Projects dated 1997 by Central Water Commission, Govt. of India
- Guidelines for preparation of Detailed Project Report of Irrigation and Multipurpose projects 2010 by Central Water Commission, Govt. of India

The overall cost of the project is estimated as INR 4131 Crs for Option I, INR 4206 Crs for Option II and INR 4173 Crs for option III, which includes civil cost and electromechanical cost.

6.3.9. Civil Works Cost

The civil cost works out as INR 195550.42 Lacs, INR 196096.78 Lacs and INR 196062.18 Lacs respectively for Option I, Option II and Option III in the feasibility stage. The cost is based on the rates adopted for recently developed hydropower project in the region 2019 level. The cost does not include VAT and IDC escalation during construction period. The cost has been built up based on unit rate and estimated quantities and wherever unit rate was not available a lump sum provision has been considered based on experience of similar projects

- At this feasibility study, the cost estimation approach is in order.
- As the estimated cost is at price level of 2019, it has to be escalated to the present price level of 2021 for the project.
- As VAT and IDC has not accounted for, the actual cost of the project would be higher as projected in the report.
- The project cost after escalated to the present price level has been taken with variation of ± 20%.

6.3.10. Electromechanical and Transmission Cost

As per the FSR, the electromechanical cost has been proposed as below for three options at February 2019 price level:

Option I (with fixed speed units)	-	INR 2176 Crs
Option II (with 2 fixed 2 variable)	-	INR 2245 Crs
Option III (with 3 fixed 1 variable)	-	INR 2212 Crs

The above costs include the cost of main electromechanical equipment (excluding the transmission system) such as turbines, generators, transformers etc. based on the prevailing market prices in India and abroad. Suitable provision for transportation, erection and commissioning charges, freight and insurance etc. have been made as per general guidelines issued by CEA. Provision for establishment and Audit and Account charges for the electromechanical works have been made under this cost separately.

- Although, it is mentioned in the FSR that the cost of transmission line was not considered, however, in the cost estimate, INR 189.2 Cores is considered as transmission line cost. As per CERC grid connectivity regulation 2009, hydro project above 250MW is not required to include transmission cost, which is in the scope of transmission utilities. However, the same is required to be reaffirmed as per latest amendment to CERC regulation.
- INR 121.0 Crores is proposed as Preliminary cost against E/M head. The same is considered too high. Normally preliminary cost includes model test, consultancy charges etc.
- INR 145.06 Crores is considered as overhead. As per CEA guideline, establishment cost of 4%-6% on electro-mechanical cost should be considered. 1% as contingency and 0.5% as audit and account charges should be considered. The cost estimate should be prepared as per CEA guidelines.
- A comprehensive budgetary offer from leading EPC contractors may be obtained to justify the costs

6.4. Risk Associated and Mitigation Measures

6.4.1. Risk Category

A risk matrix along with mitigation measures has been prepared based on the comprehensive technical due diligence carried out. The categorization of the risk is as follows:

Risk Category: High

Matters that should be addressed prior to closure of investment deal as they may have impact on Project suitability or cost or both.

Risk Category: Medium

Matters that may constitute a risk and should be dealt with further during construction and operation/ maintenance of the project but should not necessarily have any significant impact on Project suitability or cost.

Risk Category: Low

Matters with no/limited material impact on project suitability and cost.

Table 38: Risk Matrix of Sillahalla PSH

Risk	Risk Level
Hydrology	
The study for water availability carried out based on old site-specific data available upto 2001 at upper Sillahallla dam site.	**Low**
Impact on the dam spillway of lower Sillahalla reservoir in case of extreme flood release from upstream Kundah Palam dam spillway.	**Low**
Geology	
Regional geological aspects	**Low**
Survey and Investigation	**Medium**
Most of the structures are underground	**Medium**
Seismicity	**Low**
Civil Works	
All the civil structures appear conceptually in order based on limited analysis and applying project experience from various other projects. However, the detail analysis and actual sizing of the structures may affect the overall project.	**Medium**
Electro-Mechanical and Transmission Works	
There is no availability of transport survey report in the FSR	**Medium**
In the FSR, power line carrier communication (PLCC) system is proposed for voice, data and protection communication.	**Medium**
Construction Schedule	
Total construction including pre-construction work has been considered as 66 months. Main project construction will be in 54 months and looks adequate. However, if any geological surprise occurs the project may be delayed.	**Medium**
Project Cost	
As per feasibility study the civil cost has been projected as INR 195550.42 Lacs, INR 196096.78 Lacs and INR 196062.18 Lacs at 2019 price level respectively for option I, II and III. The civil cost has been estimated as per Indian Standard guidelines for preparation of cost estimate for river valley projects.	**Medium**

Risk	Risk Level
As per the FSR, the electromechanical cost has been proposed as INR 217600.00 Lacs to INR 221200.00 Lacs in various options.	**Medium**
Cost of transmission line is considered as INR 189.2 Cores in the FSR.	**Medium**

The detailed risk association matrix along with the mitigation measures to address the risks, is attached as **Annexure 9.4.**

7. Additional Hybrid Opportunities – Floating Solar Projects (FSPV)

7.1. Introduction

India has done a tremendous job in terms of deployment of renewable energy-based installations, which has grown remarkably 250%, from 35 GW in FY14 to 87 GW in FY20. Majority of the capacity addition under the RE domain is coming from Wind (37.7 GW as of FY20) and Solar PV (34.6 GW as of FY20). For now, India's solar market is driven by large-scale, ground-mounted projects. As of September 2019, ~82.3% of India's installed solar capacity came from utility-scale plants[3]. The majority of this growth in solar has been triggered by the launch of Jawaharlal Nehru National Solar Mission (JNNSM) on January 11, 2010. The target set under the mission was to achieve 20 GW of grid-connected solar power by the year 2022, which was later revised in the year 2015. The new targets under the mission are to achieve 175 GW RE capacities of which 100 GW is from solar by 2022[4].

Moreover, at the United Nations' Climate Summit in New York on 23 September 2019, the Prime Minister of India announced a new target of 450 GW of renewable electricity capacity (without specifying a date). Solar PV has been on a rapid rise in recent years. However, it is an established fact that solar PV deployment is quite land intensive and scaling up the project sizes requires large chunk of contiguous land parcels, which becomes challenging in many situations. In order to keep pace of development commensurate with the national targets for solar capacity additions, alternatives are required to be explored and established. Floating solar PV (FSPV) or photovoltaics is one such alternative, which has started getting traction worldwide and is expected to grow strongly over the coming years.

7.2. Floating Solar in Hydro Power Projects

A hybrid system combining floating solar and hydropower projects may have the potential to generate a significant amount of clean energy annually. According to a research report by the National Renewable Energy Laboratory (NREL), the addition of floating solar projects on the top of water bodies, which already have hydropower stations, can annually generate around 7.6 TW of clean energy from the solar photovoltaic systems alone. For comparison, the global final electricity consumption was just over 22,300 TWh in 2018, the most recent year for which statistics are available.

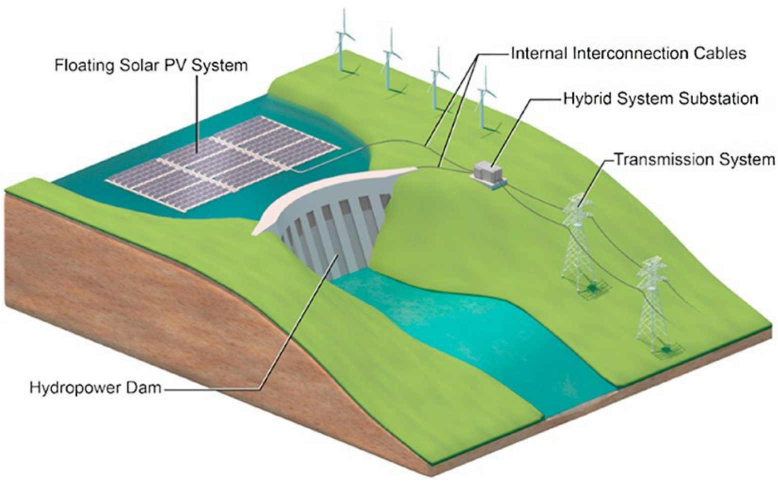


Figure 41 :Different components of a floating solar system

The report finds that the collaboration of floating solar project with hydropower project has several benefits. A hybrid system can reduce the transmission cost by connecting both systems to a common substation, and both systems can balance each other too. A hybrid system equipped with a pumped-storage hydropower project can also store surplus solar energy generated by floating solar panels. Hydropower and solar power plants were developed separately in the past. Recently, hydro and solar plants have started to merge into photovoltaic-hydropower hybrid plants, where floating solar panels are installed on the water surface of hydropower reservoirs and/or on the dam surface. This

[3] https://www.solarpowereurope.org/wp-content/uploads/2020/02/SolarPower-Europe_India-Solar-Investment-Opportunities.pdf
[4] https://www.teriin.org/sites/default/files/2020-01/floating-solar-PV-report.pdf

represents a cost-effective strategy for allocating new PV plants without occupying natural lands, protecting dams from insulation and increasing hydropower generation by reducing evaporation losses.

In photovoltaic-hydropower hybrid plants, PV panels are incorporated into the hydro plant mainly in two ways:

- installation of PV panels on the downstream face of the dam, an option only possible in certain plants where the face slope of the dam is below 40° (like in gravity and embankment dams)
- floating PV panels on the water surface of the hydropower reservoir.

Floating panels can increase the capacity factor of a hydropower plant than can be generated if the hydro plant would always work at its maximum installed power capacity. Floating panels can gain 7% to 14% more energy than a land installation due to the reduction of temperature.

> Cost of EPC is higher for floating solar farms as compared to ground mounted solar farms. However, with floating solar farms achieving additional generation due to the cooling effects of water, the levelized cost from both forms of solar farm is comparable.

7.3. As-Is situation of Solar FSPV in India

India being a tropical country is blessed with good sunshine over most parts, and the number of clear sunny days in a year also being quite high. India is located in the sunny belt of the world. In comparison with the fast-paced progress of Solar PV segment in India, Solar FSPV domain is in the incipient stage with the cumulative installed capacity of mere 2.7 MW in FY19 and nearly 1721 MW plants in various stages of implementation. The majority of these FSPV Projects are being developed through the tendering process. Some of the major FSPV project developers are SECI – which is leading the development – followed by NTPC Ltd, NHPC, State Discoms from Kerala (KSEB), Andhra Pradesh (GVSCCL).

The output of the FSPV Plant is directly proportional to the average solar energy incident in the region. As per Ministry of New and Renewable Energy (MNRE), Government of India (GoI), the country receives solar energy equivalent to more than 5,000 trillion kWh per year with a daily average solar energy incident over India, which varies from 4.0 to 7.0kWh/m^2 depending upon the location. India's equivalent solar energy potential is about 6,000 million GWh of energy per year. This reveals that there is enormous potential for the development of FSPV plants in India.

7.3.1. Factors governing the development of FSPV

The development of FSVP is dependent on two broad factors i.e. i.) Technical, ii.) Financial. As the FSPV Project development is in very nascent stage, so we have enlisted the high-level factors and values which shall be considered while evaluating the FSPV plant.

Technical Aspect

Some of the important technical aspects of floating solar projects in reservoirs of hydro and PSH are exhibited as below:

S.No.	Factor	Details
1	Effective area of the reservoir	The effective area of the reservoir where floating solar PV panels are planned to be installed is required to be worked out. The reservoir water levels play an important role i.e. the effective area shall be worked out based on the area available at water level at minimum draw down level (MDDL) of the reservoirs
2	Climate zone as per solar radiation	The daily average global radiation is around 5 .0 kWh/m2 in north eastern and hilly areas to about 7.0 kWh/m2 in western regions. That means reservoirs associated with hydro/PSH in western/ southern regions will have more solar energy generation
3	Shading effect on the reservoirs	Shading effect on the reservoirs is required to be examined. In case of reservoirs surrounded by steep hills will have more shading effect in the morning and evening due to direct

S.No.	Factor	Details
		interference of the hill peak on sun radiations and hence the lesser capacity/ generation from solar projects
4	Flood Value of the Reservoir	The flood value of the reservoir is to be examined so that even during any flash flood there would not be any damage on the solar PV panels. Large water reservoirs usually have optimal conditions for the installation of floating Solar PV like stable water inflow and outflow
5	Access to the arrays of solar PV	Access to the arrays of solar PV panels already installed in the reservoir is required to be examined so that the same is convenient during operation & maintenance stage as well

Financial

The development of the FSPV is in very nascent stage in India. Hence, unlike the ground- mounted solar PV, there are no specific standards or policy for FSPV technology as of now. Moreover, accurate data on the Capex and Opex of the FSPV plants also find limited access. The indicative capital costs of some of the plants in operations and under various stages of implementation as exhibited as below:

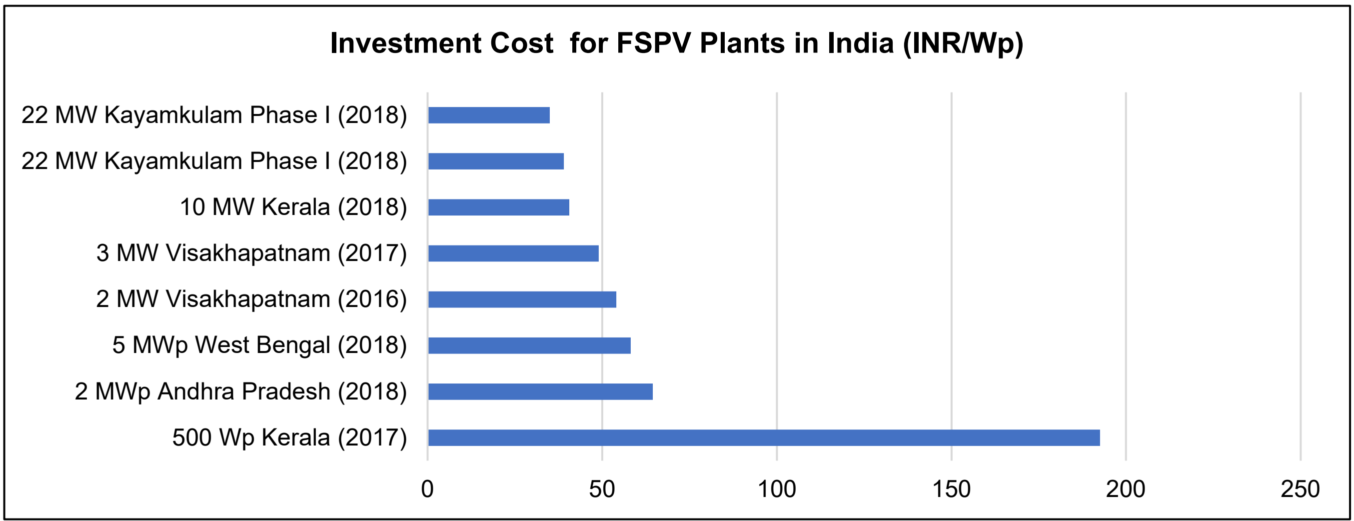


Figure 42: Investment Cost for FSPV Plants in India

SOURCE: Floating Solar Photovoltaic Report, TERI, 2019

Over the span of last 3 years, the cost of development of the FSPV plants is plummeting and has taken a dip of ~45% in the cost. Going forward, the expected cost of the development of FSPV plants is expected to decline further as the economy of scales develop and technology matures.

7.4. Floating solar projects under execution in India

In 2018, the government had set a target of 10 GW of floating solar PV installations by 2021. In this regard, some of the floating solar projects which are being executed and/or planned to be executed in India based on the available solar potential are exhibited as below:

- It is planned to construct a 600MW floating solar project at Omkareshwar dam on Narmada River in Khandwa district and planned to be completed by 2023. The Press Trust of India (PTI) reported that the project's primary feasibility study has been completed in partnership with the World Bank. The Madhya Pradesh state government said the International Finance Corporation, World Bank and Power Grid have granted in-principle consent for cooperation in project development, while Madhya Pradesh Power Management Company has agreed to purchase 400MW of power from the project.

- Another 1000MW floating solar project has been planned by state of Madhya Pradesh. The floating solar plant is planned for India's largest reservoir on the Indira Sagar Dam in Madhya Pradesh, in central India.

- The strong potential for expanding India's floating solar portfolio was revealed in a study published last year by think tank the Energy and Resources Institute, which found the country's reservoirs could be used to generate 280GW of solar power. It was reported in that Indian state-owned power company Damodar Valley Corporation had proposed 1,776MW of floating solar projects at four of its dams in the states of West Bengal and Jharkhand, while the country's largest power company, NTPC, will include floating PV as part of efforts to develop 5GW of solar capacity.

- Madhya Pradesh project will be among the world's largest floating plants when complete, the first 1.2GW stage of a facility being developed inside the Saemangeum seawall in South Korea is expected to come online next year, making it the largest facility of its kind. Featuring around 5.25 panels, that installation will have a total capacity of 2.1GW when fully operational in 2025.

- NHPC Limited (formerly the National Hydroelectric Power Corporation) has signed a memorandum of understanding (MoU) with Green Energy Development Corporation of Odisha Limited (GEDCOL). As part of the MoU, both the parties will collaborate to form a joint venture company for the development of techno-commercially feasible floating solar power projects of nearly 500 MW in the state of Odisha.

- Tata Power Solar, the wholly owned subsidiary of Tata Power, has received a Letter of Award from state-owned power generator NTPC to develop a 105 MW floating solar power project worth $49m. The project is supposed to be built on NTPC's reservoir Kayamkulam in the Allappuzha district, in the state of Kerala.

8. Conclusion

In response to the meet the rapid electricity demand growth and emerging INDC commitments, India chalked-out a target of increasing dependency on RE fleet and install 175 GW capacity by March 2022 and 450 GW of RE by 2030. In light of such a huge quantum of RE capacity addition, the grid is faced with the predicament of unpredictability, variability and intermittency induced by variable energy resources (VRE) i.e. solar and wind, which has a bearing on the overall grid discipline. Therefore, there are emerging grid requirements which are critical to address integration related issues such as spinning reserves, flexible generation, need for peaking requirements, ancillary services, transmission system augmentation, voltage control, frequency control etc.

In order to facilitate these critical needs of the grid, hydro power stations (storage) and PSH plants are emerging as the front runner which can play a vital role in fast ramping up and down, peak and off-peak balancing support because of their inherent flexibility. Therefore, with an aim to gauge the feasibility of the PSH plants as a long-term and cost-effective solution towards the renewable transition and balancing of the grid in the Southern and Western region, Techno-Commercial Assessment of the three PSH projects in the state of Karnataka, Tamil Nadu and Maharashtra was conducted. The key findings which support and underpin the case of these PSH plants are enumerated as below:

S.No.	Pumped Storage Hydro (PSH) Plant	Region	Value Propositions
1.	**2000 MW Saravathy PSH**	**Southern Region**	• High ramp up to the tune of 3550 MW will be needed due to RE addition in the coming years. Will contribute to high system ramp and renewable integration would remain a challenge. Saravathy storage will be well suited to provide ramping support as needed • RE curtailment during daytime to the tune of 3500 MW from 10 hrs to 16 hours. Curtailed RE may be utilised in pumping energy to PSH during daytime and PSH may be used to supply evening peak. • There will be additional capacity requirement to the tune of 5300-6000 MW due to increase in demand as per the 19th EPS Survey Report. Sharavathy PSH to may provide the additional supply to meet the required demand. • Apart from meeting peak demand, Saravathy PSH can offer ancillary services, black start support, Dynamic VaR support and Grid Flexibility.
2.	**700 MW Malshej PSH**	**Western Region**	• Maharashtra currently have thermal capacity dominated supply mix and use of thermal power stations to meet both base and peak load makes the power system susceptible to frequency excursions. This also impacts the efficiency and life expectancy of thermal assets. • Maharashtra has unavailability of ample generation asset which can ramp up within seconds (FRAS). Malsej PSH can be leveraged to provide grid flexibility and balancing. • Going forward the demand-supply gap will get accentuated and this is where Malsej can plug in the gap by offering maximum 700 MW capacity of peaking support. • Malsej can be utilised for the purpose of Energy Arbitrage
3.	**1000 MW Sillahalla PSH**	**Southern Region**	• RE is prone to seasonal variations. In FY20, the state observed gap between maximum and minimum demand in the tune of 8283 MW. Such a huge variation requires development of the power generation facilities like Sillahalla PSH with high ramping rate to meet large fluctuations in demand • TN is expected to have high VRE addition in future i.e. in the tune of ~9000 MW by 2023 from solar. Moreover, in 2020,

S.No.	Pumped Storage Hydro (PSH) Plant	Region	Value Propositions
			during the lockdown Tamil Nadu curtailed 50% of the total solar power. Energy storage solutions like Sillahalla PSH can help tide over the problem of energy curtailment from renewables. • A large part of current demand is being met by purchasing power from short term market with ~137.2 Billion Units purchase from Short term market. Therefore, additional capacity in the state is required to reduce dependence on the short-term market and plug the gap between demand and supply with additional of 1000 MW to the system.

Broadly it has emerged PSH plants will play a catalytic role in turning around the grid balance to normal IEGS range, black start supports during outages, energy arbitrage, peaking support, ancillary services etc. financing of hydro plants should not be ideally gauged from a singular lenses of financial benefits as the plurality of economic benefits extended by hydro power generation - ranging from clean source of energy, grid balancing asset, reducing environment impact and finally complementing the VRE sources - can offset the financial benefits by substantial margin. Hence, in light of all the value propositions and benefits proposed by the PSH plants, the development of aforementioned three plants in SR and WR can be taken in consideration.

9. Annexure

9.1. Major Hydro Plants over IEX

Seller entity	Location	Year	Sell volume	Weighted Average Sell Price (Rs/KWh)
Teesta Urja Ltd	Sikkim	2020	4622.86	3.24
GOHP	Himachal Pradesh	2020	1458.19	3.23
Teesta Urja Ltd	Sikkim	2019	3313.69	4.2
GOHP	Himachal Pradesh	2019	1100.32	4.31
Teesta Urja Ltd	Sikkim	2018	4131.76	3.39
GOHP	Himachal Pradesh	2018	1395.05	3.36
Karcham Wangtoo HEP	Himachal Pradesh	2018	1268.58	3.18
GOHP	Himachal Pradesh	2017	2168.01	2.54
Karcham Wangtoo HEP	Himachal Pradesh	2017	1504.51	2.52
GOHP	Himachal Pradesh	2016	2201.43	2.8
Karcham Wangtoo HEP	Himachal Pradesh	2016	963.36	2.86
GOHP	Himachal Pradesh	2015	1704.26	3.81
HPSEB	Himachal Pradesh	2015	464.65	4.38
Karcham Wangtoo HEP	Himachal Pradesh	2014	1783.36	2.32
GOHP(ADHPL+KWHEPS+LBHPPL)	Himachal Pradesh	2014	945.31	2.34
GOHP+ADHPL(GOHP)+KWHEPS (GOHP)+LBHPPL (GOHP)	Himachal Pradesh	2013	1876.27	3.18
KWHEP	Himachal Pradesh	2013	757.64	3.29
GOHP+GOHP (KWHEP)+GOHP (ADHPL)	Himachal Pradesh	2012	604.25	3.58
Karcham Wangtoo HEP	Himachal Pradesh	2012	487.27	3.74
Government of Himachal Pradesh	Himachal Pradesh	2011	458.7	3.36
GOHP	Himachal Pradesh	2010	214	
Himachal Pradesh State Electricity Board (HPSEB), Himachal Pradesh	Himachal Pradesh	2010	140	

9.2. Risk Association and Mitigation Matrix – Saravathy PSH

Risk	Risk Level	Mitigation
Hydrology		
Existing dams will be utilized for the proposed PSH scheme. The design flood for both the dam spillway has been considered same keeping the fact in view that the both the dam spillways are in successful operation.	Low	The flood study may need review based on updated site-specific probable maximum precipitation (PMP) and its temporal distribution and study related to any impact of extreme flood release from dam spillway of upper project, especially on Gerusoppa dam spillway.
There is no mention regarding sedimentation aspect of reservoirs in the pre-feasibility report.	Medium	Sedimentation study for revised area elevation capacity curve, especially in case of Talakalale reservoir will mitigate the risk against encroachment of live storage.
Geology		
Both Upper and Lower reservoir and dams are existing	Low	The health of the existing dams are to be reviewed in view of geological data
Investigations	Medium	No investigation have been done; Therefore geological assessment is based on the surface data and literature survey; at DPR stage investigations would be taken up and geological model will be firmed up.
Most of the structures are underground	Medium	Generally granite gneiss and amphibolite would be encountered that provide good foundation and tunnelling condition
Seismicity	Low	Project area lies in Seismic zone III; further seismic parameters used for dam could be applied for other structures
Civil Works		
All the civil structures appear conceptually in line based on limited analysis and applying project experience from various other projects. However, the detail analysis and actual sizing of the structures may affect the overall project.	Medium	In DPR stage, the detail engineering would mitigate all the risks.
Electro-Mechanical and Transmission Works		
There is no availability of transport survey report in the PFR	Medium	Detailed transport survey for feasibility of transportation of over dimensional consignments such as turbine, generator, and generator transformers, valves etc. is required to be conducted in appropriate time.
It is observed that the pump capacity is proposed as 225 MW and turbine capacity as 253MW. In clause no. 7.16	Medium	The pumping capacity and accordingly the generator-motor

Risk	Risk Level	Mitigation
(Power evacuation system), it is mentioned as “The estimated pumping load (MW), presuming all the hydro units to be operated simultaneously as motors, will be around 2200 MW”. In that case, the pump capacity should have been higher. Pump capacity needs to be reviewed during further engineering stage.		transformers ratings require review in detailed project report stage.
The cycle efficiency is proposed as 80.9% in the PFR which is considered less	Medium	It is expected that the cycle efficiency could be increased to the range of 84%-85% with improvised technology to be adopted for turbine/generator design. With variable speed system, the efficiency can be increased.
In the PFR, fixed type pump/turbine generating unit are proposed.	Low	Feasibility of variable speed pump/turbine units (atleast few generating units could be of variable speed units) in order to have better performance and to enhance grid stability may be explored in consultation with CEA, grid operators etc.
110% overload capacity is proposed in the generator whereas there is no such overloading provision mentioned in the turbine.	Medium	As per gazette notification of Central Electricity Authority, 2007, the hydro generating units shall be capable to operate 110% of the rated capacity in continuous basis. As such, necessary continuous overloading provision shall be provided in each generating units.
In the PFR, power line carrier communication (PLCC) system is proposed for voice, data and protection communication.	Medium	For protection tripping and voice communication, the PLCC system is ok but as per latest grid operator’s/ CEA recommendation, the PLCC system is being phased out and communication system through optical fibre is being introduced which is considered most advance and efficient mode of communication for data, voice and protection signalling. For the same, optical link terminal equipment (OLTE) at the PSH end and OPGW cable in the transmission line would be required. Also, communication system already provided or being provided at the remote end substation is also required to be studied.
No details of the penstock protection valves (PPV) are mentioned in the electro-mechanical chapter of the PFR except showing the same in project general layout drawings.	Medium	Penstock protection valve is suggested in each pressure shaft emanating from the two surge shafts in order to protect the powerhouse from inundation in case of penstock rupturing. Also, during major maintenance of the main inlet valve or

Risk	Risk Level	Mitigation
		penstock, the same can be attended by closing respective PPV. This would allow the other generating units to continue generation uninterruptedly and this is the big advantage of providing PPV in each pressure shaft/ penstock. The PPV shall be suitable for remote monitoring and emergency operation by closing the same from powerhouse control room in case of rupturing of penstock.
Construction Schedule		
Total construction including pre-construction work has been considered as 63 months. Main project construction will be in 53 months and looks adequate. However, if any geological surprise occurs the project may be delayed.	Medium	As the structures are mostly underground and investigation data are lacking, it would be better to keep probe drilling to anticipate the geological strata beforehand to take care of any uncertainties and advance preparedness to mitigate any unforeseen issue. This will help in reducing time over run.
Project Cost		
As per PFR, the civil cost has been projected as INR 273980.38 Lacs at 2017 price level. The civil cost has been estimated following Indian Standard guidelines for preparation of cost estimate for river valley projects.	Medium	The price escalation from 2017 to 2021 level has to be considered for revised cost of the project. Further, at this prefeasibility level, the overall cost of the project may be considered with variation of ±30%.
As per the PFR, the electromechanical cost has been proposed as INR 227764.29 Lacs.	Medium	It is recommended that comprehensive budgetary offers from leading EPC contractors may be obtained to justify the costs. Moreover, price escalation from year 2017 to 2021 and USD rate from INR 64 per USD at 2017 and INR 73 per USD at present shall be considered. In case of taxes and duties, GST shall be considered in place of excise duty, sales taxes.
Cost of transmission line, substation upgradation is not considered in the PFR. It is to be ensured that cost of transmission/ substation would be borne by central/state transmission utilities.	Medium	As per CERC grid connectivity regulation 2009, hydro project above 250MW is not required to construct its own transmission line and hence not required to include transmission cost, which is in the scope of transmission utilities. However, the same is required to be reaffirmed as per latest amendment to CERC regulation.

9.3. Risk Association and Mitigation Matrix – Malsej PSH

Risk	Risk Level	Mitigation
Hydrology		
General	Medium	The discussion on hydrology as regards flood value and discharge are in order. However, as the DPR was submitted during 2010, the hydrological study should be updated based on additional data till date.
Geology		
Regional geological aspects	Low	No major geological adverse feature is anticipated
Dam and underground structures	Medium	As such the terrain is occupied by basaltic rock mass that will provide good foundation as well as tunnelling media but underground structures have inherent unknown geology to be encountered
Seismicity	Low	The site lies in seismic zone III and accordingly seismic parameters should be adopted
Civil Works		
Structural aspects	Medium	As per DPR, the layout and sizing of the project components are in order. However, any change in hydrology and topographical survey parameters may affect the structural aspect; therefore, these may be reviewed once hydrology will be updated.
Electro-Mechanical and Transmission Works		
There is no availability of transport survey report in the DPR.	Medium	Detailed transport survey for feasibility of transportation of over dimensional consignments such as turbine, generator, and generator transformers, valves etc. is required to conduct in appropriate time.
Project Cost		
As per the DPR, the cost evaluation is in order.	Medium	The overall project cost in DPR is at 2010 price level. Therefore, the cost of the project is to be updated based on current price level by considering the present unit rates. The electromechanical cost should be on the basis of comprehensive budgetary offer from leading EPC contractors. Therefore the revised cost should be considered for project implementation.

9.4. Risk Association and Mitigation Matrix – Sillahalla PSH

Risk	Risk Level	Mitigation
Hydrology		
The study for water availability carried out based on old site-specific data available upto 2001 at upper Sillahallla dam site.	Low	Resuming the collection of discharge data at upper Sillahalla gauge and discharge site for validation of estimated discharges.
Impact on the dam spillway of lower Sillahalla reservoir in case of extreme flood release from upstream Kundah Palam dam spillway.	Low	Adopted design flood (PMF) of lower dam spillway needs to be compared with routed flood through upstream Kundah Palam dam spillway coupled with the inflow flood of the intermediate catchment between the two dams.
Geology		
Regional geological aspects captured clearly in the report	Low	No major geological adverse feature reported
Survey and Investigation	Medium	Upper dam has been investigated through 11 drill holes but lower dam needs to be investigated to evaluate geological model of the dam area
Most of the structures are underground	Medium	Although charnokite and dolerite will provide good foundation as well as tunnelling media but underground structures have inherent unknown geology to be encountered
Seismicity	Low	The site lies in seismic zone II and accordingly seismic parameters should be adopted
Civil Works		
All the civil structures appear conceptually in order based on limited analysis and applying project experience from various other projects. However, the detail analysis and actual sizing of the structures may affect the overall project.	Medium	To set out the structures, more structural analysis and design would be evolved during DPR stage. This will provide confidence for the structures.
Electro-Mechanical and Transmission Works		
There is no availability of transport survey report in the FSR	Medium	Detailed transport survey for feasibility of transportation of over dimensional consignments such as turbine, generator, and generator transformers, valves etc. is required to be conducted in appropriate time.
In the FSR, power line carrier communication (PLCC) system is proposed for voice, data and protection communication.	Medium	For protection tripping and voice communication, the PLCC system is OK but as per latest grid operator's requirement, the PLCC system is being phased out and communication system through optical fibre is being introduced which is considered most advance and efficient mode of communication for data, voice and protection signalling. For the same, optical link terminal equipment (OLTE) at the PSH end and OPGW cable in the transmission line would be required. Also, communication system already provided or being provided at the remote end substation is also required to be studied.
No details of the penstock protection valves (PPV) are mentioned in the electro-mechanical chapter of the FSR except	Medium	Penstock protection valve is suggested in each pressure shaft emanating from the surge shaft in

Risk	Risk Level	Mitigation
showing the same in project general layout drawings.		order to protect the powerhouse from inundation in case of penstock rupturing. Also, during major maintenance of the main inlet valve or penstock, the same can be attended by closing respective PPV. This would allow the other generating units to continue generation uninterruptedly and this is the big advantage of providing PPV in each pressure shaft/ penstock. The PPV shall be suitable for remote monitoring and emergency operation by closing the same from powerhouse control room in case of rupturing of penstock.
Construction Schedule		
Total construction including pre-construction work has been considered as 66 months. Main project construction will be in 54 months and looks adequate. However, if any geological surprise occurs the project may be delayed.	Medium	This project is having two large dams as well as many underground structures. For lower dam, there is no investigation; therefore, to ascertain geology investigations should be carried out at DPR stage. Further, it would be better to keep probe drilling to anticipate the geological strata beforehand to take care of any uncertainties and advance preparedness to mitigate any unforeseen issue. This will help in reducing time over run.
Project Cost		
As per feasibility study the civil cost has been projected as INR 195550.42 Lacs, INR 196096.78 Lacs and INR 196062.18 Lacs at 2019 price level respectively for option I, II and III. The civil cost has been estimated as per Indian Standard guidelines for preparation of cost estimate for river valley projects.	Medium	The price is based on 2019 price level. Escalation from 2019 to 2021 has to be considered for revised cost of the project. Further, at this feasibility level, the overall cost of the project may be considered with variation of ±20%.
As per the FSR, the electromechanical cost has been proposed as INR 217600.00 Lacs to INR 221200.00 Lacs in various options.	Medium	The costs of electromechanical equipment as proposed in the FSR seem on higher side. This may be due to consideration of transmission line cost and higher preliminary cost (INR. 121.0 Crores). Budgetary offers from EPC contractors may be obtained during preparation of detailed project report to justify the costs.
Cost of transmission line is considered as INR 189.2 Cores in the FSR.	Medium	As per CERC grid connectivity regulation 2009, hydro project above 250MW is not required to construct its own transmission line and hence not required to include transmission cost, which is in the scope of transmission utilities. However, the same is required to be reaffirmed as per latest amendment to CERC regulation.

9.5. Discussion summary of meeting with Karnataka Power Corporation Ltd (KPCL) team

As part of the ongoing IGEF study, PwC facilitated a meeting of KPCL on PSH .Key points during discussion with IGEF/KfW and MD, Karnataka Power Corporation Limited (KPCL) on 19th March 2021:

1. **Funding for Sharavathi PSH**: KPCL has already planned for development of 3 PSHs as follows
    - Sharavathy PSH (2000 MW)
    - Netravathy PSH
    - Varahi PSH (700 MW)

    Sharavathy PSH is in the most advanced stage and the Draft DPR is expected to be completed within the next few days (~ 15 days). Subsequently KPCL will move ahead with obtaining approvals/clearances for the project and explore funding for the project. KPCL looks forward to discussion with KFW for exploring funding opportunities for Sharavathy PSH

2. **Development of Green/Renewable projects:** KPCL is currently planning expanding into developing multiple green projects which includes (i)Waste-Energy Plants ,(ii) solar integrated battery storage solutions and (iii) EV charging infrastructure. KPCL has already commissioned one (1) Waste to Energy plant in Bengaluru and planning similar projects in the state. As part of this endeavor, KPCL is currently exploring funding for these upcoming projects and would like to discuss with KFW on potential funding options

3. **Future discussions on areas of mutual interest:** KPCL proposed to share a list of projects for which funding is being explored. Future discussions can be held post assessment of the list of projects as shared by KPCL.

4. **Updated cost of power generation**: Slide 12 of presentation: Updated numbers to be considered for analysis in the report.

9.6. Discussion summary of meeting with THDC India Ltd

As part of the ongoing IGEF study, PwC facilitated a meeting of THDC on PSH. Key points during discussion with IGEF/KfW and THDC team on 28th May 2021:

- The THDC team informed that THDC will be able to access funding from bilateral donors like KfW. THDC has an independent board and such decisions will be taken up the THDC Board

- The THDC team further informed that the equity split between THDC and NPCIL is yet to be decided. However, NPCIL recently has not been taking significant interest in the project and the project is getting driven by THDC. THDC is also willing to infuse GoMH's equity component of the project cost through its internal resources.

- The DPR of the project was prepared in 2010. Post that discussions have been ongoing with the Government of Maharashtra (GoMH) for signing of the implementation agreement and allot the project to THDC through a MoU. GoMH had recently invited THDC regarding allotment of Malshej Ghat PSH to the JV, if it is viable for THDCIL to implement the project at a tariff of INR 5/kWh. THDC has also submitted a revised tariff proposal of first year tariff of ~5.8 INR/kWh to GoMH (which includes the pumping cost) and indicated that this is among the lowest tariffs for PSH's in India.

- The THDC team also provided an indicative timeline for the various actions required prior to construction of the project post signing of the implementation agreement

Activities	Tentative Timeline
Updation of DPR and Submission of DPR for approval	T1=T+1.5 years
Environment Impact Assessment and approval	T + 1.5 years
Approval of DPR	T1+ 1 years
Commencement of construction of project	T+ 3 years

T= Signing of implementation agreement

- The THDC further informed that the project is technical feasible, and they do not foresee any significant environmental challenges associated with this project. As far as the social impacts of the project are concerned there are about 14-15 households close to the project site out of which 4-5 households could be directly impacted by the project

- The THDC team sought KfW's assistance in resolving the deadlock for the smooth execution of the project. The KfW/GiZ team informed that although direct advocacy is not their mandate, however they would like to work together with the THDC team on various aspects of the project such as technical, financial and commercial to help the project move forward

- The THDC team requested the details of interest rate and other terms & conditions of KfW financing facility. The KfW team informed that the interest rate of the facility can be confirmed subject to a credit risk assessment to assess the credit rating of THDC. The team further informed that it will be in the similar range to that of multilateral/bilateral donors

- The KfW/GiZ team requested various key documents such as DPR and any other available studies to help them conduct a preliminary due diligence of the project

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