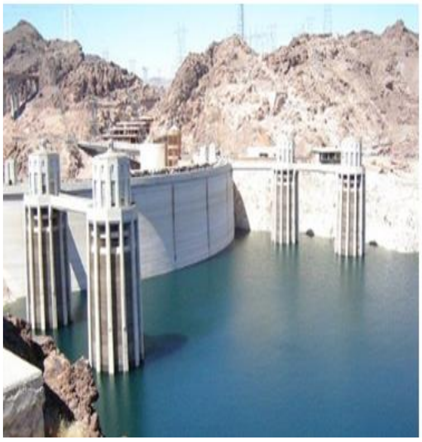
Role of Pumped Hydro Energy Storage in India's Renewable Transition

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FOREWORD

The world is moving towards higher electrification with more decentralized generation, renewable energy adoption and the gradual phase out of fossil-fuels, especially with electrification of transport. More clean power adoption means energy storage is becoming the energy security of the future. While several energy storage techniques are being developed, pumped hydro energy storage or PHES, is a reliable, time-tested technology, particularly suited for load management. It takes only seconds to bring PHES systems online—much less time than coal or gas-fired peakers.

Until recently, the greatest challenge to pumped hydro systems was the years it took to identify suitable sites for PHES. The cutting-edge work done by Australian National University (ANU) in developing the open-source atlas on global PHES sites has provided a huge technical advantage in supporting the identification and development of PHES projects. The map shows hundreds of locations in India, all reviewable from the comfort of a desktop, radically reducing the time required for site identification.

Under DFAT’s Sustainable Development Investment Program (SDIP), TAF partnered with Integrated Research and Action for Development (IRADe) and ANU to raise awareness about the suitability of PHES for India through multi-stakeholder consultations and engagement with key government agencies. The joint initiative of TAF, IRADe and ANU has played a role in informing the discourse on the efficacy and viability of PHES, as the key energy storage solution that can back up India’s green energy transition.

The Indian government has responded positively to these efforts. The renewable energy department of Andhra Pradesh, for example, brought out a tender in November 2019 for preparation of techno-commercial feasibility reports for PHES projects at 30 tentative identified locations in the state using ANU’s online atlas. Even the Central Electricity Authority, in its report called Optimal Generation Capacity Mix for 2029-2030, has raised forecast for PHES projects in India to over 10 gigawatts, from a mere fraction of the capacity operational at present. We look forward to continuing to work with all key stakeholders and development partners to enhance the development and deployment of the PHES and to support India’s green energy goals.

Nandita Baruah
Country Representative - India
The Asia Foundation

PREFACE

A significant grid transition is underway in India, as it gears up to meet its pledge of taking up the share of non-fossil fuel to 40 percent of its cumulative installed capacity in the year 2040, along with reduction of emissions intensity of GDP by 33 to 35 percent by 2030, from a 2005 baseline. While India's initial target of achieving 175 GW of renewable capacity by 2022 (100 GW of solar and 60 GW of wind) seems achievable, the future goals for renewables in the time frame of 2030 and 2050 may exceed substantially. This in turn, puts the spotlight on grid transition focusing on balancing and stability and on storage solutions.

In this context, Integrated Research and Action for Development (IRADe) in collaboration with The Asia Foundation (TAF), has endeavored to chart out actionable insights by bringing different stakeholders comprising of thought leaders in the energy space; e.g. policy makers and other experts from the Government, private sector, and power utilities etc., on a common platform. Through three events, comprising two roundtables and one regional workshop, we deliberated on various options for RE integration & grid balancing, and focused on the role of different storage technologies in general and new technologies for pumped hydro energy storage in particular, in charting a cost-effective and sustainable roadmap towards achieving high level integration.

During the deliberations, Professor Andrew Blakers of Australian National University (ANU) discussed on the Closed Loop Pumped Hydro System that allows improved sustainability outcomes. This option aims to reduce the uncertainty and costs around prospective investment in pumped hydro storage and entails low water use and less construction time, as well as low resistance by the public due to less impact on the environment. The deliberations were finally concluded with a regional workshop, attended by various stakeholders, including government officials and representatives from the neighboring South Asia Countries, viz. Bangladesh, Bhutan and Nepal, who presented the perspective of their respective countries in this respect.

Based on the discussions in the regional workshop, it clearly emerged that there is substantial hydro potential in both Nepal and Bhutan, and if such hydro potential is exploited towards grid integration at the regional level, then apart from helping the regional grid towards balancing, it shall also lead towards socio-economic benefits in terms of stimulating the local economy and generating local employment. One important outcome of this conference was to specifically find out that out of the total hydro potential, how much would be suitable for pumped hydro energy storage plants. This needs to be clearly identified by carrying out detailed assessment of PHES potential in these countries to show to the policy makers how PHES can benefit different countries in the region.

I thank all the esteemed dignitaries, speakers and participants who came together to make the Roundtables and the Regional Conference a huge success. We believe this report is very timely and shall give the insights on the subject of 'Role of PHES in India's Renewable Transition'.

Professor Jyoti Parikh
Executive Director, IRADe

Contents

1. Objective and Background of the Study

India's Nationally Determined Contribution to the 'Conference of Parties' process of the UNFCCC (United Nation Framework on Climate Change), sets the backdrop to a once-in-a-century grid transition. India has pledged 40 percent of its cumulative installed capacity to be of the non-fossil fuel variety by 2040, with a concurrent reduction in emissions intensity of GDP by 33 to 35 percent, by 2030 from a 2005 baseline. The years since the Paris Accord have seen development of a mature market for renewables investment, with generally high investor sentiment, high degrees of competition in bidding processes and involvement of large volumes of capital. The market has developed largely in response to the ambitious capacity addition targets for wind and solar set by the Government of India. India's previous target of 175 GW[1] of renewable capacity by 2022 (100 GW of solar and 60 GW of wind) will likely be met, leading to an upward revision of targets to 227 GW of renewables by 2022[2].

The scorching pace of renewable addition has prompted justifiable concerns about grid balancing and stability. An influential study commissioned by the Ministry of Power, Government of India, finds that the 175 GW renewable capacity target is achievable with 'all generating stations exploiting their inherent ramping abilities' and hydropower being repositioned to satisfy peak demand after sunset. The extension of targets, however, will almost certainly require planning for additional fast ramping infrastructure. Since India's domestic gas endowments are presently meagre, both the Government and industry have begun to explore for solutions towards balancing the grid in face of large Renewable Energy (RE) integration, including renewing their focus on reviving Indian hydropower.

This has taken the form of a proposed and contentious revision to the national hydropower policy and ambitions due to the enhanced RE target beyond 175 GW, to the effect of adding up to 10 GW of pumped storage[3] at an estimated cost of close to USD 11 billion. Overall, the Indian hydropower policy is in a state of flux, with several ongoing debates about how seemingly imminent policy interventions should be structured and the role that hydropower should play in meeting power demand and balancing a renewable-heavy grid.

TAF (The Asia Foundation) and IRADe (Integrated Research and Action for Development) have collaborated in an endeavor to study different options towards India's renewable transition in general, and the 'Role of Pumped Hydro Energy Storage (PHES)' in particular. The objective is to create a platform to proceed in a deliberate manner and to bring into focus the possibilities presented by closed-loop off-river pumped hydropower in the transition. This option has so far has not figured prominently in the relevant conversations, and projects a very favorable condition towards transition. At present, India has 4.7 GW[4] of installed pumped storage capacity, only around half of which is operational.

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[1] https://pib.gov.in/newsite/PrintRelease.aspx?relid=180728

[2] https://economictimes.indiatimes.com/industry/energy/power/ -will-add-225-gw-renewable-energy-project-capacity-by-2022-r-k-singh/articleshow/64461995.cms?from=mdr

[3] https://www.greentechmedia.com/articles/read/india-to-build-pumped-hydro-storage-for-solar

[4] Pumped Storage Hydropower in India and its Integration with Renewable Energy

The energy landscape is therefore, primed for planning and investment in storage options. In 2016, the Central Electricity Authority (India's energy planning agency) put out an expression-of-interest document for a reassessment of the country's hydropower potential; the previous round being conducted in 1978-87. Additional technical capacity on identifying pumped storage sites at this juncture could be crucial in allowing India's renewable capacity to grow unabated.

IRADe held a series of technical policy interactions on pragmatic grid-balancing options for India, in partnership with TAF and Australian National University (ANU). These interactions focus on the role that new surveying technologies for pumped storage could play in charting a cost-effective and sustainable roadmap to high renewable integration. Recent advances in surveying large geographies for pumped storage at ANU, particularly closed-loop off-river sites that allow improved sustainability outcomes, including low water usage and low construction time, were highlights of the discussions. ANU's initiative aims to reduce the uncertainty and costs facing prospective investment in pumped hydro storage. Thought leaders in the energy space, Government sector and generating utilities participated in the roundtable discussions on the topic 'Soft Landings for Renewable Energy Integration through Balancing Technologies', along with an enriching experience sharing by South Asian representatives at the regional conference. This project consisted of two roundtables and one regional conference, with stakeholders consisting of think tanks, power sector experts, government, policy makers and the private sector, followed by preparation of a comprehensive report. A brief synopsis of the two roundtables and one regional conference is given below.

Roundtable 1 was organized on 27 March 2019, with participation from energy experts across think tanks, academic institutions and industry bodies. The session deliberated on the technical aspects of the subject and different options available towards resolution, with focus on the following facets:

a) trajectories and challenges of India's renewable energy transition
b) wind and solar capacity addition; and the future of Indian coal
c) current potential of pumped hydropower
d) advances in grid-scale battery storage and the challenges plaguing India's hydropower sector

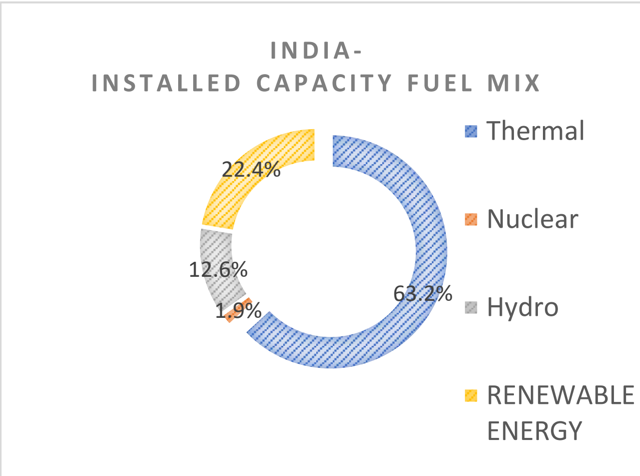
The roundtable saw presentations from IRADe on the technology options, and from Australian National University (ANU) about potential sites for setting up Pumped Hydro Energy Storage (PHES) projects in India, including a PHES atlas tool. The proceedings of the roundtable are attached as Annexure-1

Roundtable 2 built upon the takeaways of the first roundtable, witnessing participation from government agencies, regulatory authorities and power generation companies, involved in planning and implementing the power sector transition in India. Held on 16 April 2019, the meeting saw high-level attendance from the Ministry of Power, Central Electricity Authority, Power System Operation Corporation (POSOCO), besides other stakeholders from government agencies. The roundtable focused on evaluating the potential of PHES atlas tool in policymaking and working out a business model for PHES in the country. The discussions on regulatory, technical and financial aspects led to the identification of necessary steps that could help promote its adoption within India. The proceedings of the Roundtable are attached as Annexure-2

The **Regional Conference** held on 12 June 2019, aimed to disseminate the findings of the two roundtables and share the regional dimensions of the transition. The pertinence of the regional conference is evident from the fact that storage infrastructure is essential for South Asian countries to tide over their own seasonal variations in demand, as well as to address India's growing needs under renewable transition. This high-level event had participants from Bhutan, Nepal, Bangladesh and India discuss the potential for South Asian cooperation on grid balancing and the potential for power trade to improve quality of energy mixes in the region. Dr. Andrew Blakers (ANU), travelled from Australia to participate in this event and addressed the participants on the PHES Atlas tool and the potential of sustainable pumped hydro in India. The regional conference saw participation from government representatives from India, Bhutan, Nepal and Bangladesh; India's private renewable sector players; hydropower sector; key representatives from the energy policy community; multilateral agencies and other experts on renewable integration and grid transitions. The proceedings of the Regional Conference are attached as Annexure-3

2. Overview of India's Power System and Renewable Energy Scenario

Currently India has over 360 GW of total power generation installed capacity (as on July 2019).[5] India is a coal dominated power system with highest installed capacity of 195810 MW.



During the year 2018-19, peak demand registered a growth of 7.8%, with total peak demand at around 177 GW[6]. India's generation mix consists of 63.2% of thermal; 12.6% of hydro; 1.9% of nuclear and 22.4% of renewable energy (RE).[7] This clearly shows the domination of thermal in India's generation mix. In the case of RE, wind constitutes the maximum share, followed by solar. The break-up of total RE capacity in India is shown in the following figures/tables.

Figure 1 India-Power Installed Capacity Fuel Mix

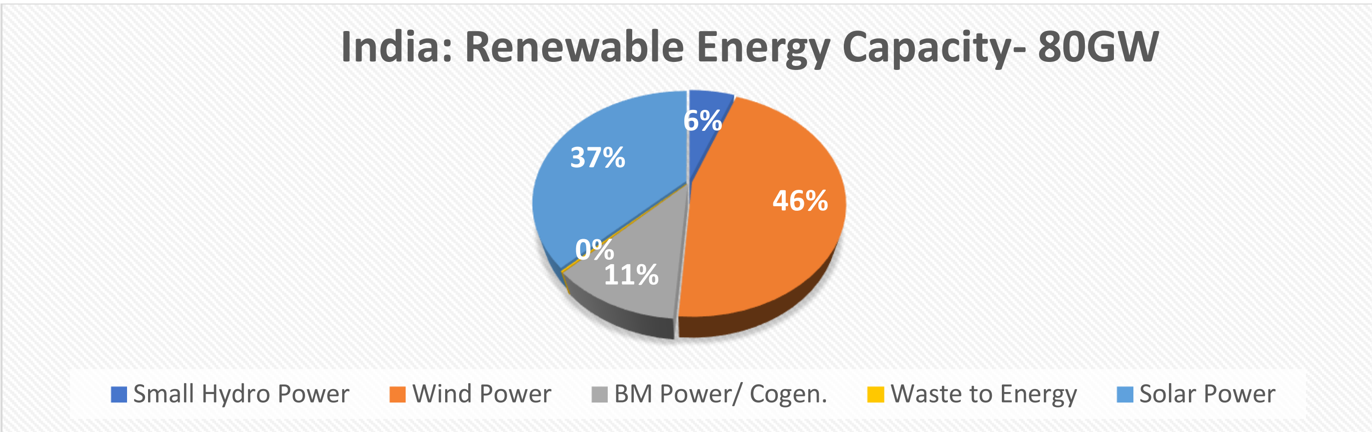


Figure 2 India- Renewable Energy Capacity- 80GW

5 http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-07.pdf
6 http://www.cea.nic.in/reports/annual/lgbr/lgbr-2018.pdf
7 https://powermin.nic.in/en/content/power-sector-glance-all-india

Small Hydro Power	Wind Power	BM Power/ Cogen.	Waste to Energy	Solar Power	Total
4604.8	36686.82	9131.5	138.3	30071.38	80632.80

Table 1: India- Renewable Energy Capacity- 80GW

Growth of Projected Demand: As per the 19th Electric Power Survey (2018)[8], the projected peak demand is expected to be 226 GW, 299 GW and 340 GW by 2021-22, 2026-27 and 2029-30 respectively. In energy terms, projected energy requirements are expected to be 1,566 BU, 2047 BU and 2325 BU by 2021-22, 2026-27 and 2026-27 respectively.

Projected Electricity Demand (As per 19th EPS)

Year	Electrical Energy Requirement (BU) Ex Bus	Peak Electricity Demand (GW)
2021-22	1566	225.751
2026-27	2047	298.774
2029-30	2325	339.973

Table 2: Projected Electricity Demand-19th EPS

As stated in the beginning of this report, India has set ambitious targets of attaining 175 GW (100 GW of solar, 60 GW of wind and 15 GW of other renewable source of energy) of renewable energy by March 2022. Further, the country has pledged that 40 percent of its cumulative installed capacity will be of the non-fossil fuel variety by 2040 with a concurrent reduction in emissions intensity of GDP by 33 to 35 percent, by 2030 from a 2005 baseline[9]. In future, the percentage of non-fossil fuel (Hydro, Nuclear and Renewable Energy Source- Renewable Energy Sources [RES]) in the installed capacity is expected to increase to 49.3% by March 2022, and 57.4% in March 2027[10]. In terms of Electrical Energy generation mix, the share of RES generation would be around 19.24% and 23.3% of the total generation expected in the year 2021-22 and 2026-27 respectively, as per the committee report on 'Optimal Energy Mix in Power Generation on Medium and Long Term Basis', published by the Ministry of Power, Government of India.

8 http://www.cea.nic.in/reports/committee/nep/nep_jan_2018.pdf
9 https://pib.gov.in/newsite/printrelease.aspx?relid=128403
10 https://powermin.nic.in/sites/default/files/webform/notices/Report_of_the_Committee_on_optimal_energy_mix_in_power_generation_on_medium_and%20long_term_basis.pdf

Growth of RE: Total Renewable Energy Sources capacity has increased significantly from 11,125 MW[11] in the year 2007-08 to 80,632 MW in July 2019, an increase of 625 % from 2007-08 level. Solar capacity has increased significantly, from just 2.1 MW in 2007-08 to 30.07GW by July 2019. Similarly, wind capacity has increased 7666.84 MW in 2007-08 to 36.62 GW as on July 2019.

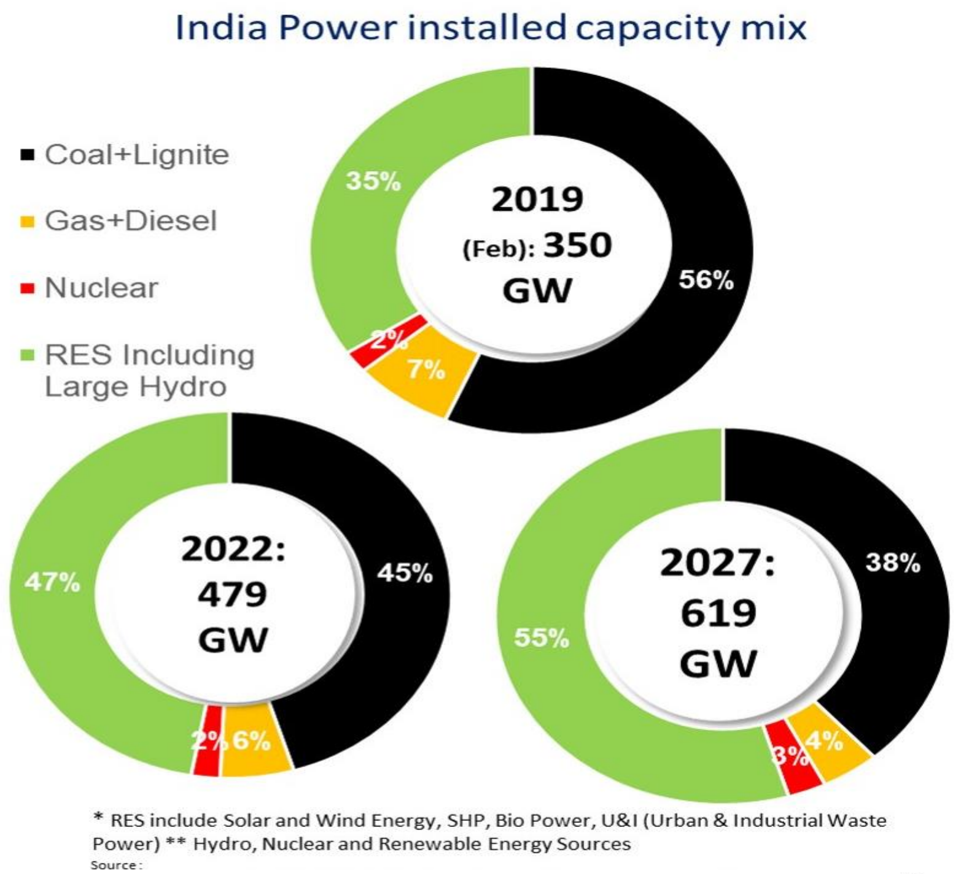
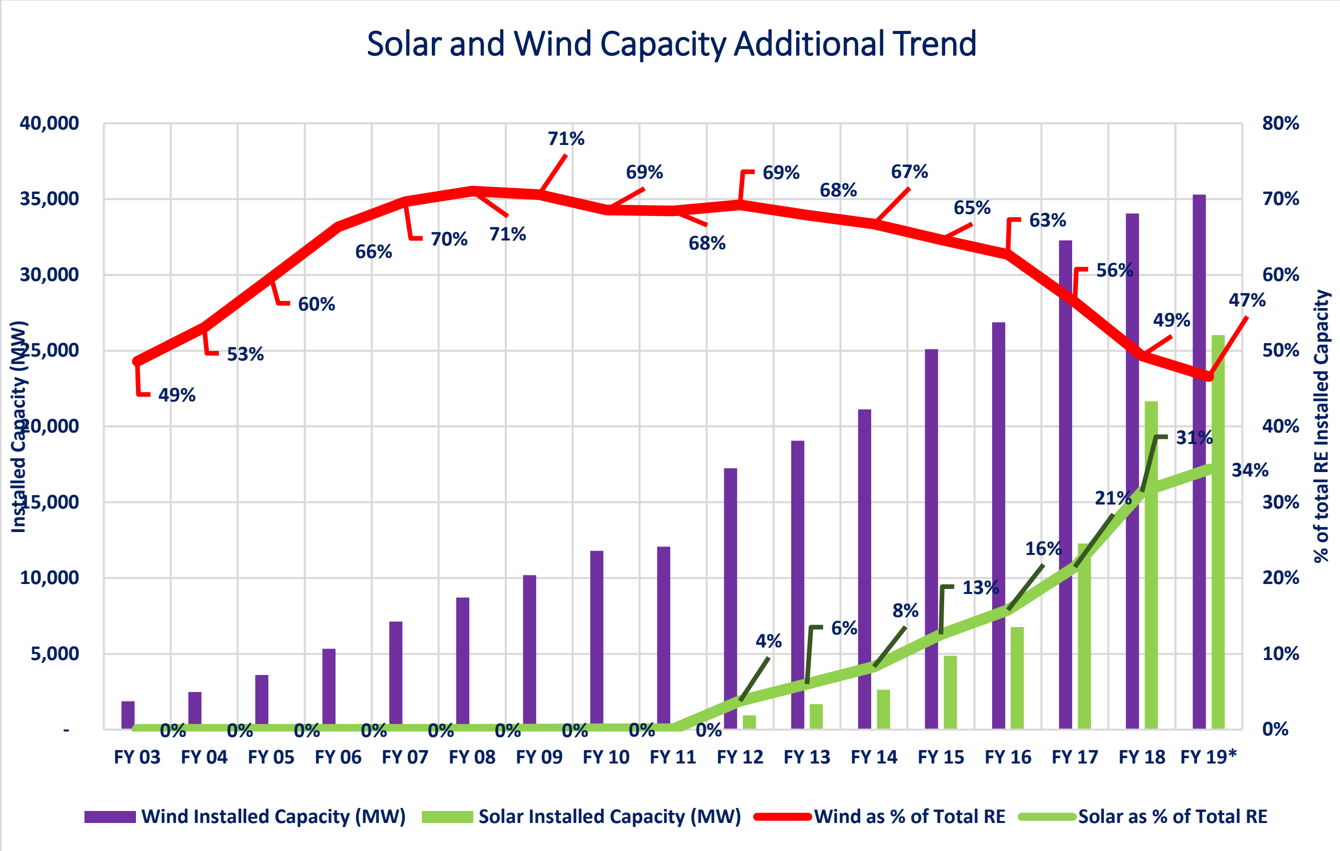


Figure 3 Indian Power Sector Projected Installed Capacity Mix

11 http://www.cea.nic.in/reports/others/planning/pdm/growth_2017.pdf



The share of solar in RE has increased from 0% in 2003-04 to almost 34 % in 2018-2019

3. Grid Integration Challenges in face of large Renewable Energy Capacity

India's integrated power grid is one of the largest synchronous power grids in the world. With the high penetration of renewable energy required in the near future, particularly from intermittent sources such as solar and wind, there is a need to manage concerns related to balancing of India's power grid and its security and stability[12]. Considering the high variability and unpredictability of generation from the renewables, efficient and economical grid operation is increasingly becoming one of the critical challenges for India's power system. The variability of renewable energy is easily accommodated when power demand and renewable supply are matched—both rising and falling together. However, they often fail to match, that is, the power demand and renewable supply move in opposite directions, giving rise to concerns of grid security and stability. For example, wind blows strongly over the night when the demand is low (as is often the case) i.e. off-peak hours; similarly, solar generation peaks during the day when power demand is moderately low. The variability of renewable resources, due to characteristic weather fluctuations, introduces uncertainty in generation output on the scale of seconds, hours and days. This challenge calls for the need to address various issues related to integration of renewable generation, such as spinning reserves, flexible generation, need for peaking hydro stations, pumped hydro energy storage, other forms of storage (electrical batteries etc.) for balancing requirements, ancillary services, transmission system augmentation & frequency control etc.

12 In the summer of 2012, India suffered the largest electrical blackout in history. Almost 700 million people—roughly equivalent to the entire population of Europe—lost power for two days.

The power grid has essentially no storage (other than small capacity of storage in the form of pumped hydro and electrical batteries), and thus, generation and transmission must be continuously managed to match fluctuating customer load. 'Making Competition Work in Electricity[13]' defines the four pillars of electrical market design: Scheduling and Dispatch, Congestion Management, Imbalance Handling and Ancillary Services. These pillars are essential to maintain security and reliability of the power system, which also helps in market development in electricity sector. In order to address this, a number of steps have been initiated, including the release of the report of technical committee for "Large Scale Integration of Renewable Energy, Need for balancing, Deviation Settlement Mechanism (DSM) and associated issues" by the Ministry of Power, Government of India,[14] and various other studies. For sustainable, safe and reliable renewable energy grid integration, some of the technical consideration/requirements projected in the above technical report are as follows.

Robust transmission services to ensure that RE generation backing down is minimal	**Adherence to Grid Standards and Regulations by RE generators**	**Load forecasting at DISCOM, SLDC, RLDC and NLDC levels**
More flexibility from conventional generation fleet comprising coal, gas and hydro	**Addition of pumped storage hydro resources**	**Need for primary, secondary and tertiary generation reserves**
Ancillary Services framework at inter state and intra state levels to operationalize the Reserves	**Establishment of REMCs at SLDC, RLDC and NLDC levels with full real time data availability from RE sources**	**Primary, secondary and tertiary frequency control, Automatic Generation Control (AGC) to implement secondary control on a regional basis**

4. Avenues towards Grid balancing in India

Power systems, especially those with a high share of RE, require access to sufficient flexible resources which may include gas turbines, flexing of generation in thermal stations, peaking hydro stations and pumped hydro energy storage, grid-scale battery storage flywheels, compressed air energy storage etc., as well as demand management measures to ensure continued stability of the grid at each moment. Since India's domestic gas endowments and supplies are presently limited, with majority of gas allocation towards non-power use, there is a renewed focus on hydropower as balancing resources with focus on PHES.

[13] S. Hunt, Making Competition Works in Electricity, New York: John Wiley & Sons, Inc., 2002.
[14] https://powermin.nic.in/sites/default/files/uploads/Final_Consolidated_Report_RE_Technical_Committee.pdf

Thermal flexing of power plants is one option for accommodating RE into the grid, however, heat rate of power plant will be important and one must be careful to avoid more coal consumption and subsequent GHG emission just to absorb RE.

A key aspect often ignored is that of demand side management, for which there are several options. For instance, agricultural load for pumping does not require firm power all the time. This load can be fed during periods of excess RE. In addition, different office timings based on availability of daylight must be planned to diversify the peak load (morning/evening). However, in case of electric energy time shift (Arbitrage) requiring storage for large periods, viz., in terms of number of hours, PHES can play an important role. PHES systems can give very fast ramping up/down & peak/off-peak balancing support because of its inherent flexibility.

5. Actions initiated - Reports by Ministry of Power, NITI Aayog, NREL

In order to maintain a continuous balance between load and generation, thermal units (both coal and lignite) are operated with higher level of flexibility. The available storage and pondage based hydro generation and gas based thermal generating units too, offer good balancing support to the grid.

However, some of the most important balancing resources are pumped hydro energy storage plants and MW scale battery storage etc., which during certain periods can absorb surplus energy from the grid and return it back to the grid at the time of deficit and/or during fast changes in the demand.

In order to meet such requirements, the technical committee report of the Ministry of Power, Government of India (GoI) and NITI Aayog's 'Report on India's Renewable Electricity Roadmap 2030' has emphasized the need for flexible generation resources. India's National Electricity Policy 2005 mandates to have 5% of total installed capacity as spinning reserves requirement at the national level[15].

NREL Grid Integration Study: U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and Lawrence Berkeley National Laboratory (LBNL) along with POSOCO, conducted a grid integration study, which confirmed the technical and economic viability of integrating 175 gigawatts (GW) of renewable energy into India's electricity grid by 2022. The report suggested the need to revise policy/regulatory-level guidelines to use the full capability of hydro and pumped hydro stations and the need to have suitable incentive mechanisms for encouraging operation of hydro and pumped hydro, depending upon system requirements[16].

Measures by the Government of India to promote Hydropower: The Government of India has recently taken some important initiatives[17] to promote hydropower. Some of the key steps are:

i) Considering large hydropower projects under the RE Category & Hydropower Purchase Obligation:

a) Large Hydropower Projects (LHPs, i.e.>25 MW projects) are declared as RE;

b) Hydropower Purchase Obligation (HPO) is notified as a separate RPO entity within non–Solar

15 https://powermin.nic.in/en/content/national-electricity-policy

16 https://www.nrel.gov/docs/fy17osti/68745.pdf

17 GoI measures to promote hydro power sector, (order 8th March 2018)- https://powermin.nic.in/sites/default/files/webform/notices/Measures_to_Promote_Hydro_Power_Sector.pdf

ii) To facilitate viability, tariff rationalization measures have been introduced to bring down hydropower tariffs, which include:

a) Back loading of tariff after increasing project life to 40 years,

b) Increasing debt repayment period to 18 years and introducing escalating tariff of 2%.

iii) Budgetary support to cost of Enabling Infrastructure, i.e., roads and Bridges: the limit of grant for such roads and bridges would be, a) Rs. 1.5 crore per MW for projects up to 200 MW; and b) Rs.1.0 crore per MW for projects above 200 MW.

iv) Budgetary support for Flood Moderation component of Hydroelectric Storage Projects

6. Grid Balancing Avenues: Technological Alternatives

Power systems, especially those with a high share of RE, require access to sufficient flexible resources to ensure continued stability of the grid at each moment. Brief details about usage of some of the measures in order to achieve grid balancing are as follows:

Flexing of Generation from Gas Based Power Plants

Gas based power plants are considered to be best suited for balancing and ramping of the grid as per requirement. There are two types of gas-based power plants:

a) Open cycle gas-based power plant

b) Closed cycle gas- based power plant

The present installed capacity of open cycle gas-based power plant is 350 MW and the capacity for close cycle gas-based plant is 24587 MW, out of the total gas-based plant capacity of 24937 MW. As evident, the major portion is that of closed cycle because of its high efficiency, while open cycle has quicker start and stop timing as compared to closed cycle. New gas- based combined cycle technology offers higher efficiency and quicker start and stop timing, which is of 30 minutes from full load to no load, and vice versa.

However, India's gas reserves are mostly utilized for non-power use, with only a miniscule share of gas allocated for power plants due to its inadequate availability in the country. As per National Electricity Plan (NEP), for 85% PLF, the normative gas requirement would be about 110 MMSCMD, significantly higher than the present availability of 29.88 MMSCMD. As per the report on 'Flexible Operation of Thermal Power Plant for Integration of Renewable Generation'[18] for integrating renewables of 175 GW by 2021-22 and to meet the peaking and ramping requirement of the system, the PLF of gas-based capacity during 2021-22 is likely to be around 37% compared to around 22% at present. The gas requirement will be of the order of about 45.27 MMSCMD.

Flexing of Generation at Coal based Thermal Plants

India has large capacity of coal generation, which can help towards grid integration by flexing the generation at the coal based thermal generation. For instance, at the NTPC coal-based power plants, the ramp rates[19] of different sub-critical and super-critical coal- based units are as follows:

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[18] http://www.cea.nic.in/reports/others/thermal/trm/flexible_operation.pdf

[19] http://www.cea.nic.in/reports/others/planning/resd/resd_comm_reports/report.pdf

For sub-critical:

a) 1% per minute in the operating load range of 55% to 80%
b) 1.5% per minute in the operating load range of 80% to 100%

For super-critical:

a) 3% per minute in the operating load range of 55% to 100%

Super-critical is ideal for providing ancillary services as tertiary reserves, considering its ramp rate - providing grid support services under Reserve Regulation Ancillary Services in India. In order to achieve higher flexibility in case of coal based thermal stations, CERC has mandated CGS (Central Generating Stations) to have a technical minimum of operation at 55% of MCR loading or installed capacity.

However, the drawback of coal-based power plant is that their efficiency reduces with time because of wear and tear of its machinery. Hence, if coal-based power plant is operated under low load continuously, its variable cost goes up drastically. As per the report[20] on 'Flexible Operation Of Thermal Plant For Integration of Renewable Generation', with 108 GW as the highest available generation from RES in the year 2021-22, thermal power plants are required to operate at average 25.73% minimum load to accommodate the RES generation into grid and to balance the system, which may not be practical. Hence, in case of reduced load operations in thermal stations, the consolidated costs may not be very economical. Further, as per CERC notification, under section 79(1) h of the Indian Electricity Act, 2003, the technical minimum load of thermal unit is 55%. Therefore, the maximum flexible power available from thermal plant on any day is equal to about 45% of grid connected thermal capacity on that day. This is not the present situation of Indian grid, as most of the state generating companies are not maintaining 55% minimum thermal load[21].

Demand Side Management:

Demand-Side Management (DSM) initiatives help end-users to optimize their energy use. With DSM, consumers can reduce their electricity costs by adjusting their time and quantity of use. Following measures are expected to contribute in improving the flexible power scenario from the demand side:

- Incentivizing self-control of load during peaks
- Using more efficient processes and equipment
- Improving quality of power supply and reliability
- Load segregation & staggering of functional timings
- Time of Day Tariff
- Open Electricity Market: Separation of carrier and content as envisaged in the Electricity (Amendment) Act
- Demand response from High Voltage industrial consumers: Energy consumption of high voltage electrical items such as arc furnace, HVAC, compressors, chillers or pumps can be managed in a more efficient manner by time varying tariff.
- Charging of Electric vehicle when solar generation is available

[20] http://www.cea.nic.in/reports/others/thermal/trm/flexible_operation.pdf
[21] http://www.cea.nic.in/reports/others/thermal/trm/flexible_operation.pdf

Battery Storage Systems

Battery Energy Storage System (BESS) has very high energy density and thus requires less space for storing, making it ideal for providing ancillary services, such as primary frequency response. High rate of charge and discharge make it highly flexible, thus providing fast response. BESS is easily portable, requires less time for setup, and can be used for a wide range of grid support activities such as energy time shift, distribution deferral, and energy arbitrage etc. Though the cost in case of battery storage is declining, it still requires high investment cost, and is therefore perceived as a high-risk venture. Further, batteries may require replacement or disposal after 5-7 years, depending upon usage (charging/discharging cycles) per year. It may also lead to future dependency on imports. The technology is still in a maturing stage for providing grid support services, and comes with the challenge of potential environmental and safety impacts.

Pumped Hydro Energy Systems

Ramping capability is a major indicator of flexibility available from any generating station. Despite the seasonal nature of hydropower, the flexibility viz. overload capability, fast ramping & peaking support etc. rendered by hydro generators, has immense value for balancing of grid and for reliable, secure and economic grid operation in India. Its ability to run as a synchronous condenser also helps significantly in managing reactive power imbalance and controlling voltage, thereby ensuring power quality & voltage stability. Hydro generators are conventionally known for providing fast ramping support to match the abrupt rise or fall of power system demand in the event of onset of day/evening peak, fast reduction of solar generation in the evening time, unexpected loss of wind generation, etc.

Comparison of various Balancing Technologies

A comparative analysis of various balancing technology options is mentioned below. Out of the many energy storage options, pumped hydro power can provide long duration storage up to 10 hours. Battery storgae is emerging, but it is yet to become commercially viable. Several challenges exist with battery storage, such as safe disposal of the waste generated, unlike the case with PHES. Batteries will be useful in some cases, such as solar rooftop and frequency regulation etc., but not elsewhere, particularly for electrical energy time shift. India is a large inter-connected grid and providing storage at each RE site would not be an optimal solution. Such individual site-wise deployment of storgae can be very expensive. Grid connected PHES is being adopted the world over for reasons such as electric energy time shift (load levelling/energy arbitrage).

Storage Technologies based on Duration, Maturity and Applications

Comparative of Energy Storage Technologies: Duration, Maturity and Applications			
Storage	Duration (hrs)	Maturity	Application
Mechanical Energy Storage System			
Pumped hydroelectric	6 –1 0	Mature	Load levelling; Peak shaving; Renewable integration
Compressed air energy storage (underground)	20	Commercial	Load levelling ; Renewable integration
Flywheels	0.25	Commercial	Frequency regulation
Electrical and Magnetic Storage System			
Superconductive magnetic energy storage		Demo	Power quality; Frequency regulation; Voltage Support
Electrochemical capacitors	~ 1 min	Demo	Power quality; Frequency regulation; Voltage Support
Electrochemical Storage System			
Advanced lead acid batteries	4	Demo	Power quality; Frequency regulation; Voltage Support; Renewable source integration
Lithium ion batteries	0.25–1	Commercial	Power quality Frequency regulation
Sodium sulfur	7.2	Commercial	Time shifting Frequency regulation Renewable source integration
Vanadium fow redox	5	Demo	Peak shaving Time shifting Frequency regulation Renewable source integration
Source: F. Valenciaga, P. Puleston, and P. Battaiotto. 2003. Power control of a solar/wind generation system without wind measurement: a passivity/sliding mode approach. IEEE Transactions on Energy Conversion.			

Figure 4: Comparative Analysis of Energy Storage Technologies

As shown in the Figure 4, Energy Storage Technologies have been compared in terms of duration, maturity and applications. The different types of storages have been been identified as follows:

1) Mechanical Energy Storage System: Three categories of storage systems have been identified which are all in mature or commercial stage. The duration varies from small to large as shown in Figure 4. These technologies are mainly used for renewable integration.

2) Electrical and Magnetic Storage System: This technology is in the demo stage and research work is in process.

3) Electrochemical Storage System: In this technology, some of the categories are in demo stage and some in commercial stage. Out of the above, a) LI-ion batteries and b) Sodium sulphur batteries are in commercial stage, and are in maximum use under the electrochemical storage system, viz. electrical battery system technology. Typically electrical batteries have low duration time and are mainly used for frequency regulation.

Storage Technologies based on Discharged Time and Rated Power:

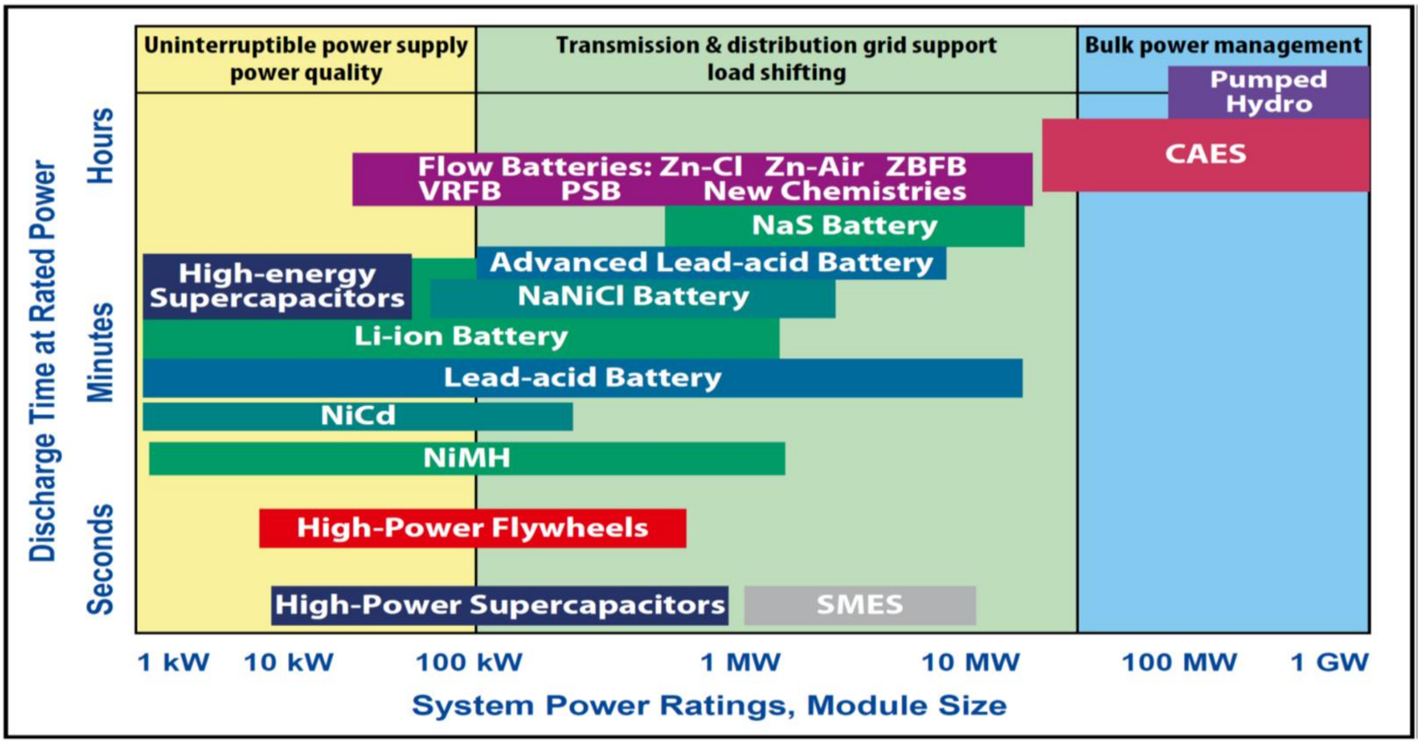


Figure 5: Comparison of diverse energy storage technologies as per power rating and discharge time

Figure 5 clarifies comparison between System Power Rating and Discharge Time. The X-axis captures System Power Rating, with module size ranging from 1 kW to 1 GW; Y-axis depicts the Discharge Time at Rated Power covering from seconds to hours. This comparison is segregated into three portions:

1. Uninterrupted power supply/power quality: In this segment, there is an uninterrupted power supply, but the storage of power is also very low. The range covers only 1 KW to 100 KW. There are different types of battery covers, as illustrated in the graph.

2. Transmission & Distribution grid support load shifting: In this segment, the power can be utilized for transmission and distribution segment, as well as for load shifting. It covers high range of batteries with capacity ranging from 100 KW to 10 MW.

3. Bulk Power Management: This is the high segment according to the range of capacity. Its range varies from around 50 MW to 1 GW. It mainly covers two categories of energy storage, viz, Compressed Air Energy Storage (CAES) and Pumped Hydro Energy Storage (PHES).

As can be seen on comparing different technologies in terms of discharge time and rated power, PHES is a mature technology that can provide the longest duration of grid balancing requirements up to 10 hours in GW scale. It also helps in load levelling, peak shaving and renewable integration.

7. Pumped Hydroelectric Energy Storage (PHES)

Among the various conventional energy sources, hydroelectricity is a source of reliable and flexible energy. Pumped Hydroelectric Energy Storage (PHES) is the world's largest energy storage system, representing 96% of the installed storage capacity worldwide (176 GW). Classifying the global operational energy storage capacity by technology, pumped hydro energy storage contains 169 GW (96%) and the rest is divided into Thermal storage (3.3 GW–1.9%), Electro-chemical storage (1.9 GW–1.1%) and Electro-Mechanical storage (1.6 GW – 0.9). This signifies that Pumped Hydro Energy storage dominates the energy storage capacity globally.

Global Operational Energy Storage Power Capacity by Technology Group – May 2017

Type	Total Capacity (GW)	Total Capacity (%)
Pumped Hydro Energy Storage	169 GW	96 %
Thermal Storage	3.3 GW	1.9%
Electro-Chemical Storage	1.9 GW	1.1%
Electro-Mechanical Storage	1.6 GW	0.9%
Total	**176 GW**	

- 10 Countries account for about 75% of Global Energy Storage
- 3 Countries account for about 48% of Global Energy Storage
  - ✓ China – 32.1 GW
  - ✓ Japan – 28.5 GW
  - ✓ USA – 24.2 GW

Source : IRENA Document Oct. - 2017

Figure 6: Global Operational Energy Storage Power Capacity

As shown in Figure 7, three countries capture about 48% of the Global Energy Storage. As per Table-3, Pumped Storage as a percentage of wind and solar capacity is high in countries like China (11%), United States (17%), Japan (55%), Spain (26%), Italy (24%) and France (27%). Pumped storage hydro plants serve the grid in wide range of applications and represent a valuable source of flexibility. Pumped storage hydro plants provide peak shaving, load balancing, frequency regulation, back-up reserve, spinning reserve, quick-start capability, black-start capability and voltage support etc. It provides very fast ramping up/down & peak/off-peak balancing support because of its inherent flexibility. Pumped storage plant's flexibility viz. fast ramp rates, fast startup and shutdown, low cycling costs, and accurate control make them ideal suppliers of

Pumped Hydro Energy Storage as percentage of Wind & Solar Country wise – Mid 2017

	Electro-mechanical	Electro-chemical	Thermal storage	Pumped hydro storage	Wind and Solar (GW) (2017)	Pumped Storage as % wind and solar (%)
China		0.1	0.1	32	294.7	11 %
United States	0.2	0.7	0.8	22.6	130.4	17 %
Germany	0.9	0.1		6.5	98.3	7 %
India *			0.2	4.85	61.3	8 %
Japan		0.3		28.3	51.8	55 %
United Kingdom				2.44	32.6	7 %
Spain			1.1	8	30.3	26 %
Italy		0.1	0	7.1	29.3	24 %
France				5.8	21.3	27 %

* For India correspondce to current figures. The above Table gives the details in respect of the top few countries accounting for Global Energy Storage Sources : IRENA Document Oct. – 2017
IRENA RE Capacity Statistics 2018 - https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Mar/IRENA_RE_Capacity_Statistics_2018.pdf

Table 3: Pumped Hydro Energy Storage as percentage of Wind & Solar Country wise

regulation and contingency reserve ancillary services and thus help in managing renewable energy grid integration.

Brief details of the various grid support services provided by PHES are as follows:

Peak shaving- PHES can meet the highest demands in a short period of time with very high ramp rate, to the tune of 200 MW/min. As per a study, the ramp rate of Pondage/Storage Hydro-based power plants is about 50% per minute[22], highest amongst the different categories of plants. In comparison to this, the ramp rate of combined cycle gas-based plants is up to 10% per minute. The lowest ramp rate is that of coal-based power plants, maximum of 3% for super-critical power plants.

Load Balancing - PHES can play a crucial role in load balancing or load leveling, that is, storing power during period of light loading (off peak hours) in the power system and utilizing the same when required during periods of high demand.

Frequency Regulation - PHES can provide excellent frequency regulation, to maintain the frequency within the given band. PHES can be operated in pumping mode when frequency is higher than 50Hz, to help the grid bring down frequency to 50 Hz. On the other hand, in case of frequency lower than 50 Hz, it can be operated in generation mode to provide necessary relief to the grid.

Spinning Reserve - PHES can also be used to provide back-up reserve, spinning reserve, with its high ramping rate and can be operated in case of sudden outage or failure of any load in the grid. It also provides quick start capability as it can be set up in just few minutes, much less than other sources. In comparison to this, gas turbines take 30 min to 1 hour, and thermal steam generation few hours, for full ramping.

Black Start Services - PHES can provide black start capability, which means if the upper reservoir of PHES is full and ready for generation, it can be used for energizing the grid in case of cascade tripping.

Voltage Control Services - PHES can also provide voltage control services by rendering reactive power balancing services. An imbalance in the supply and demand of reactive power can cause voltage to rise or drop across the power system. In both pumping and generation modes, voltage control is performed through the voltage regulator which is part of the excitation system. The machine voltage can be adjusted by changing field current via the excitation system. PHES can be operated in lead or lag mode to meet the requirement of reactive power of the grid. PHES can also be operated in synchronous condenser mode to improve the system power factor.

8. Existing Scenario of PHES in India

India has nine PHES plants with a combined capacity of 4785 MW, and two PHES Plants of 1080 MW are under construction. Currently out of the total 4785 MW capacity, only five plants with combined capacity of around 2600 MW, are being operated in pumping mode. 63 sites have been identified for Pumped Storage Plants (PSP), with total potential of about 96,500 MW. PHES can render valuable support during both deficit & surplus conditions, and can provide fast ramping up and ramping down capabilities and therefore can be a long lasting and sustainable solution.

[22] report of the technical committee on study of optimal location of various types of balancing energy sources/energy storage devices to facilitate grid integration of renewable energy sources and associated issues

9. Challenges in Harnessing Hydro and PHES capacity

The cost of project estimated at the time of concurrence is usually less than the actual expenditure incurred on development of the project. This variation in actual cost of the project may vary due to many reasons, for example, delay in commissioning of the project, price escalation, addition/deletion of components, change in design/scope, over/under provision, exchange rate variation and other avoidable or unavoidable causes during construction. Cost overruns of hydropower projects is often a recurring challenge that needs to be addressed. Reasons behind cost overruns need to be understood and clearly addressed during the planning stages itself; else, it leads to the project becoming unviable over time.

Location	State	Capacity (MW)	Year of Commissioning	Upper reservoir capacity (m^3)	Lower reservoir capacity (m^3)
Srisailam	Andhra Pradesh	6 X 150	2001-2003	6.16 X 10^9	5.44 X 10^9
Sardar Sarobar	Gujarat	6 X 200	2002-2006	5.8 X 10^9	5 X 10^9
Parulia	West Bengal	4 X 225	2007-2008	16.5 X 10^6	16 X 10^6
Ghatghar	Maharashtra	2 X 125	2008	5.87 X 10^6	3.80 X 10^6
Tehri	Uttarakhand	1000	2006	4 X 10^9	.89 X 10^9

Table 4: Major Pumped Storage Plants in India

An international comparative assessment of construction cost overrun had been carried out in 2014 for sixty-one (61) hydroelectric projects across the globe, entailing project costs worth about USD 271.50 billion, constituting 113.77GW of installed capacity. These projects experienced collective cost overruns of USD 148.60 billion, which translated to average cost escalation of 70.6%. The hydroelectric projects with cost overruns exceeding 100% are as given below:

Year	Name of the project	Installed Capacity (MW)	Country	Cost overrun (%)
2006	Sardar Sarovar dam	1450	India	513
2011	Bakun Hydroelectric Project	2400	Malaysia	417
2012	Three Gorges Dam	22,500	China	402
1978	Sayano-Shushenskaya	6400	Russia	353
1979	La Grande 2	2106	Canada	246
1976	Nurek	3015	Tajikistan	200
1950	Vinstra	1360	Norway	190
1977	Kabira Stage 2	1626	Zimbabwe	177
1981	Robert-Bourassa	5616	Canada	143
1986	Chixoy	300	Guatemala	136
2009	Longtan dam	6426	China	113
1986	Guri (Raul Leoni)	10,235	Venezuela	101

Source: An International Comparative Assessment of Construction Cost Overruns for Electricity Infrastructure.

Table 5 Major the hydroelectric projects with cost overruns exceeding 100%- Source- http://www.bea.gov.bt/wp-content/uploads/2017/11/Hydropower%20cost%20overrun%20report.pdf

Another major challenge in respect of PHES concerns its economics of operation. Since PHES is a negative energy source (input energy towards pumping the water up is higher than the output energy generated by the pump), the input power cost towards pumping operation needs to be minimized to make such plants viable. One option could be to make such plants regulatory assets for optimal utilization by Load Dispatch Centers. At the same time, while the cost of PHES as compared to normal generation is expensive, it should not be compared with a regular hydro project, given its purpose for balancing renewable energy. The significance of balancing offered by PHES needs to be considered in the context of grid stability.

10. Present Capacity and Hydro potential in India and other South Asia nations

10.1 Capacity and Potential in India

As per the study completed by CEA in 1987, the assessed hydropower potential in the country is 1,48,701 MW (1,45,320 MW from HE schemes above 25 MW capacity). Apart from this, there is a potential of 96,524 MW of Pumped Storage. It does not include the Pumped Storage schemes on small streams/*nallahs* or schemes that can be taken up on the existing reservoir schemes in operation, where pumped storage plant could be set up by constructing another reservoir upstream or downstream[23]. Thus, the total hydropower capacity including pumped storage is 2,41,844 MW. The details of the total potential of India are given below:

[23] Minutes of the meeting regarding operationalization of existing pump, storage plants held on 28th June 2017 at NRPC, New Delhi.

	Conventional		Pumped Storage		Total
	Nos.	I.C. (MW)	Nos.	I.C.(MW)	I.C. (MW)
Identified Hydro Capacity	593	145320	63	96524	**241844**
In operation	197#	40613.62	9	4785.6	45399.22
Under construction	34*	10973.50	3	1205	12178.50
Allotted for development					
(i) Cleared by CEA and yet to be taken up for construction	40	25460	1	1000	26460
(ii) Under Examination/scrutiny in CEA	6	1224	0		1224
(iii) DPRs appraised and returned for revision	29	9852	0		9852
(iv) Under S&I	35	5439	3	2920	8359
(v) S&I is held up/to be taken up	45	14332	1	660	14992
Sub-total (i-v)	**155**	**56307**	**5**	**4580**	**60857**
Total (I+II+III)	**386**	**107894.1**	**17**	**10570.60**	**118464.72**

Note- 14 nos. of Pumped Storage Schemes with aggregate capacity of 11245 MW have been identified as doable schemes for development. This includes development of PSS on existing conventional hydro projects includes utilizing

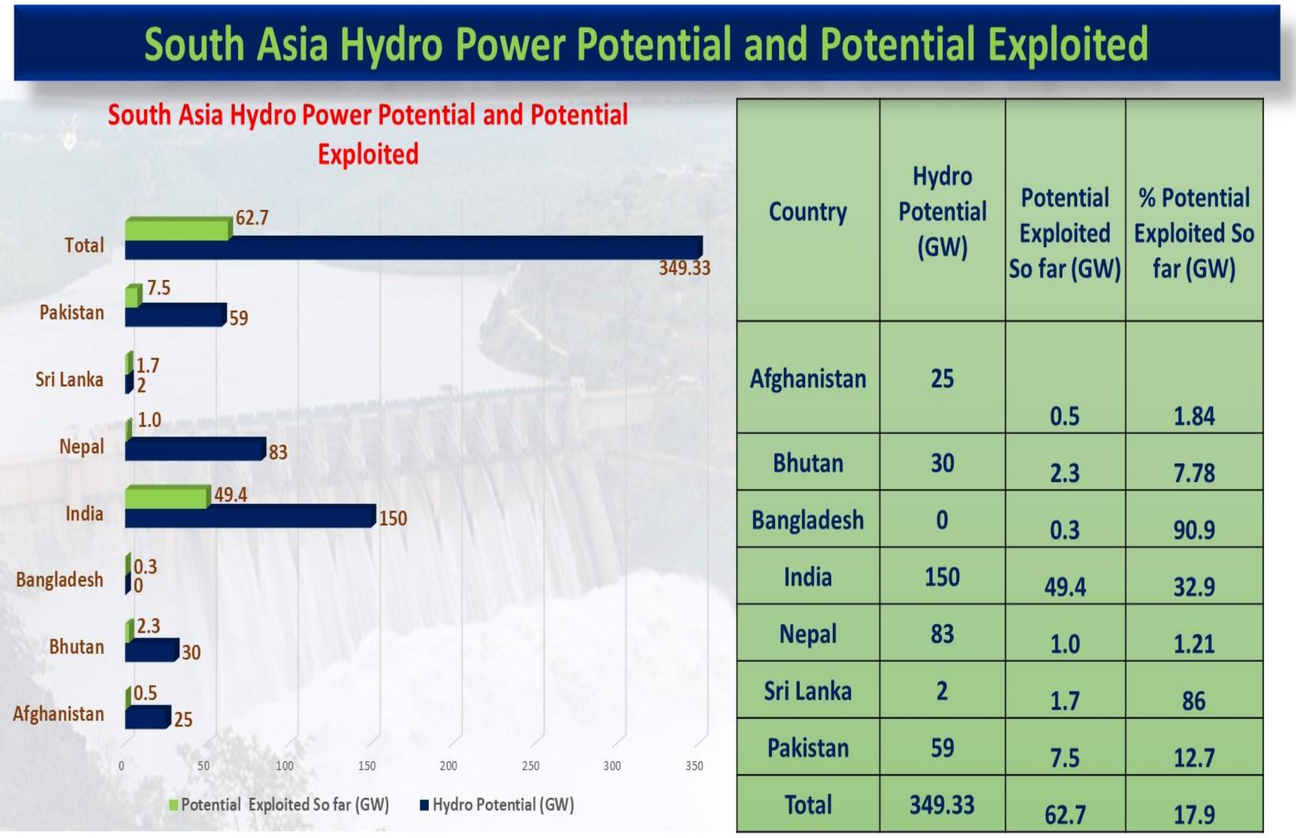
Table 6: Total hydropower potential of India

10.2 Capacity and potential in neighboring nations

Until 2017, 1242 GW[24] of hydropower capacity had been installed globally, out of which the South Asia region accounts for a meagre 5%[25] of the total installed capacity. While the region has a potential of 333 GW of hydropower, very less has been exploited. In terms of country-specific potential, India possesses the maximum potential capacity of around 150 GW. Out of the total available potential, only 7% has been exploited in the North-eastern region, though it is relatively higher in the states of Himachal Pradesh and Uttarakhand, at ranges of 60% and 30% respectively. In Pakistan, out of the 59GW of hydropower potential, only 13% has been exploited so far. Nepal possesses 83 GW of Hydro power potential, of which only 1.2% has been exploited. Afghanistan and Bhutan have 25 GW and 30 GW hydropower potential respectively. While Bhutan is continuously developing its hydropower and exporting to India, Afghanistan is still in initial stages of hydropower exploitation. Sri Lanka has exploited its maximum hydropower potential in the range of 86% and in terms of capacity, it is of the order of 2GW till date.

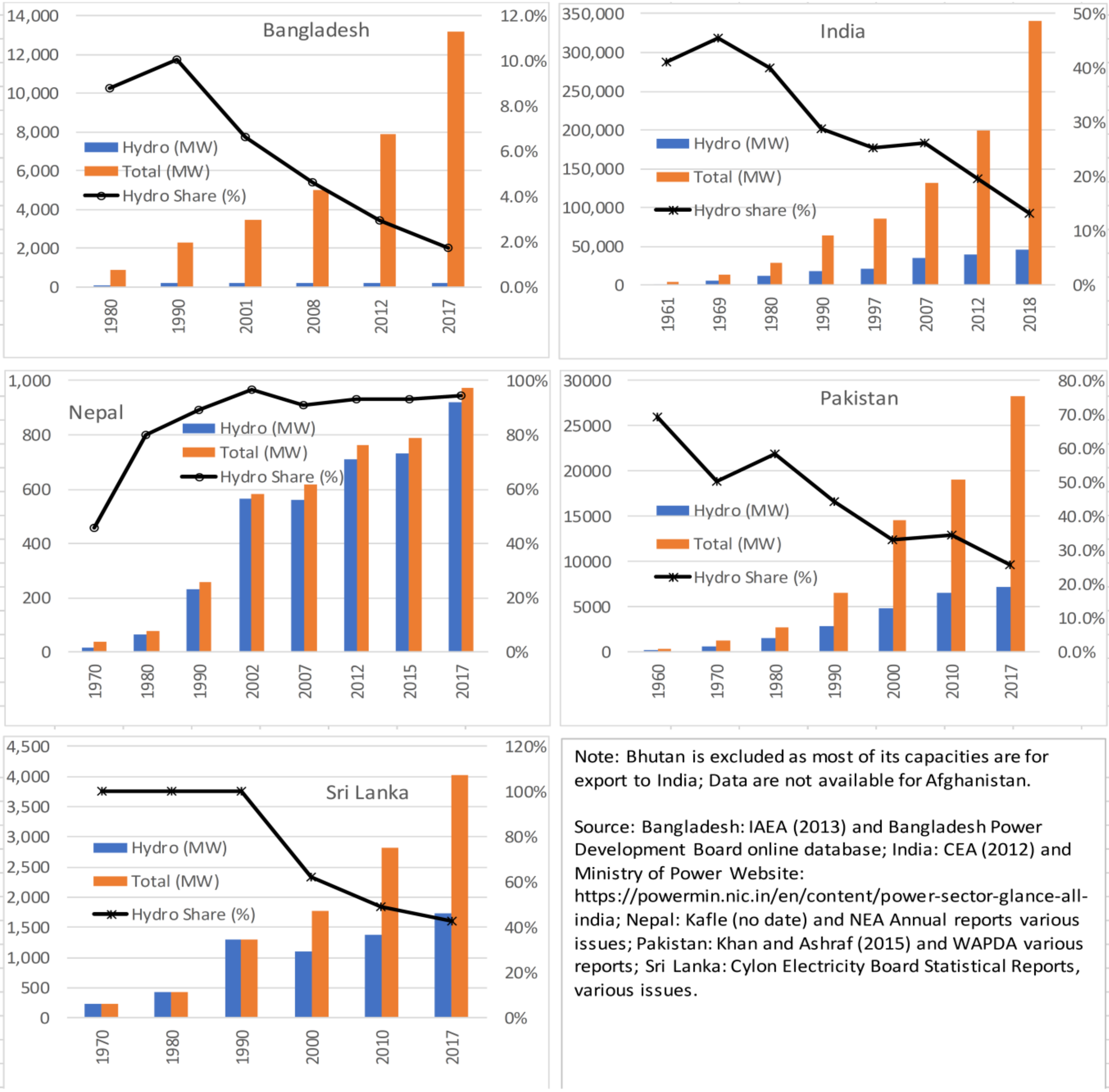
[24] Installed capacity of small hydropower plants (< 100 MW) is not included

[25] http://documents.worldbank.org/curated/en/714401531237858109/pdf/WPS8513.pdf



Country	Hydro Potential (GW)	Potential Exploited So far (GW)	% Potential Exploited So far (GW)
Afghanistan	25	0.5	1.84
Bhutan	30	2.3	7.78
Bangladesh	0	0.3	90.9
India	150	49.4	32.9
Nepal	83	1.0	1.21
Sri Lanka	2	1.7	86
Pakistan	59	7.5	12.7
Total	349.33	62.7	17.9

Figure 7: South Asia Hydro Power Potential



Note: Bhutan is excluded as most of its capacities are for export to India; Data are not available for Afghanistan.

Source: Bangladesh: IAEA (2013) and Bangladesh Power Development Board online database; India: CEA (2012) and Ministry of Power Website: https://powermin.nic.in/en/content/power-sector-glance-all-india; Nepal: Kafle (no date) and NEA Annual reports various issues; Pakistan: Khan and Ashraf (2015) and WAPDA various reports; Sri Lanka: Cylon Electricity Board Statistical Reports, various issues.

Figure 8: Share of Hydro Power in different South Asian Countries.

Figure-8 indicates that only Nepal has increased its percentage share of hydropower over the last 50 years. In other South Asian countries such as India, Pakistan, Sri Lanka, Bangladesh, the hydro development is almost at a standstill, with the share of hydro at a declining phase. This signifies that all these countries developed their conventional resource technologies during this period, rather than exploiting their hydro potential.

10.3 Capacity and potential in neighboring nations

Hydropower development through cross-border electricity trade is essential in the South Asia region for the following reasons:

- Opportunity for sustainable exploitation of surplus hydropower resources in Bhutan and Nepal;
- Improved hydro-thermal ratio-system balancing and peak load supply;
- Clean energy to mitigate climate change and other environmental targets;

- Opportunity for optimization of existing capacities due to difference in monthly/daily/hourly load curves across the electricity grids;
- Regional balancing resources and peak load management, leading to effective renewable energy grid integration; and
- Strong economic incentives for all countries

11. Off- river closed loop PHES: Building a business case

PHES Technologies:

The Pumped Hydroelectric Energy Storage facilities can be of two types:

- Off-river Closed Loop PHES, wherein the same water is used for pumping and generation, with make-up water for evaporation through melting snow and/or rain
- Hybrid (open loop) PHES, wherein both pumped and natural flow water is used to generate electricity

Advantages associated with Closed Loop PHES

It has been observed that in the recent timings, Closed Loop PHES technology is gaining popularity as it has several advantages, including:

- ✓ Reduced environmental impact and minimum environmental review
- ✓ Minimal aquatic life interaction
- ✓ Natural or artificial reservoirs
- ✓ Less cost in case of natural reservoirs
- ✓ Minimal displacement and resettlement needed
- ✓ Flood control is unnecessary
- ✓ Each system being quite similar to another system, minimize the efforts towards custom-design, and hence greatly reduce the risk of cost over-runs.

Thus, closed loop off-river PHES could present a cheaper option for grid balancing and renewable energy grid integration in India.

Basic Design and Features of a Closed Loop PHES:

In this type of plant, the upper and lower reservoirs are located “off stream.” An advantage of this approach is minimal aquatic life interaction, which reduces the environmental impacts and concerns. The closed-loop design thus minimizes or avoids the environmental permissions and review process. Development of a closed-loop system requires identification of a water source to provide the initial charge and additional water to replace losses from evaporation and leakage.

Closed loop PHES is a relatively new approach for developing pumped storage projects, wherein the reservoirs are located in areas physically separated from existing river systems. These projects are termed "closed-loop" pumped storage as they present minimal-to-no impact on existing river systems.

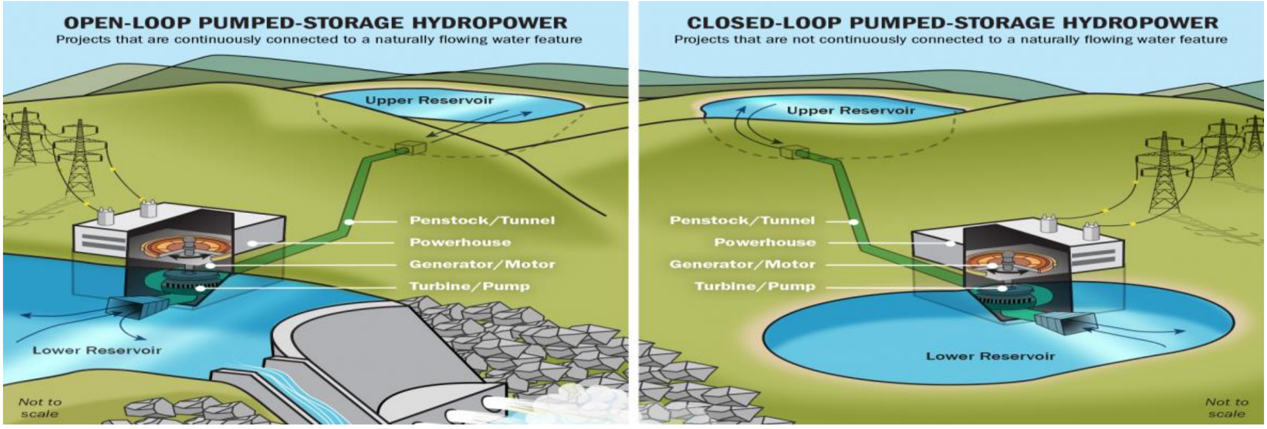


Figure 9: Open Loop and Closed Loop PHES-Source-https://www.energy.gov/eere/water/pumped-storage-hydropower

After the initial filling of reservoirs, the only additional water requirement is the minimal operational make-up water required to offset evaporation or seepage losses. By avoiding existing complex aquatic systems entirely, these types of projects have the potential to greatly reduce the most significant aquatic impacts associated with project development. In addition, since closed-loop pumped storage systems do not need to be located near existing river system or body of water, with the right topographical features, they can be located wherever needed to support the grid. Off-river closed loop PHES can be an efficient & cost-effective option, and requires further dialogue and deliberation. This option also helps to offset the environmental mitigation costs largely, since river ecosystems are not altered in a significant manner and the need for human displacement/ resettlement is lower. This is an important factor for a country such as India, where environmental activism opposing dam construction is quite strong. In contrast, Australia has tried to avoid as much of contentious sites as possible by attempting off-river PHES sites.

Some Facts & Figures related to PHES Capacities based on ANU's Studies:

The Australian National University (ANU) found 16,000 off-river sites in India with a combined energy storage capacity of 56,000 Gigawatt-hours. If each site has storage for 18 hours, then this corresponds to storage power of 3100 GW. These are:

- 2.5 times larger than global installed river-based hydro generation capacity (1200 GW)
- 18 times larger than India's target for renewable energy by 2022 (175 GW)
- 18 times larger than global pumped hydro storage capacity (170 GW)
- 20 times larger than India's potential river-based hydro generation capacity (150 GW)
- 36 times larger than India's potential river-based pumped hydro capacity (85 GW)
- 660 times larger than India's current pumped hydro storage capacity (4.7 GW)

The ANU's global pumped hydro storage atlas is accessible via http://re100.eng.anu.edu.au/global/index.php. Some of the potential sites from the global pumped hydro storage atlas are given below.

Few images from India & South Asia Region based on ANU's Global Pumped Hydro Storage Atlas

Based on ANU's Global Pumped Hydro Storage Atlas, four (4) images are produced below in order to substantiate the huge PHES potential in India and South Asia Region:

Image 1:

The image below shows the thousands of potential off-river pumped hydro sites in South Asia

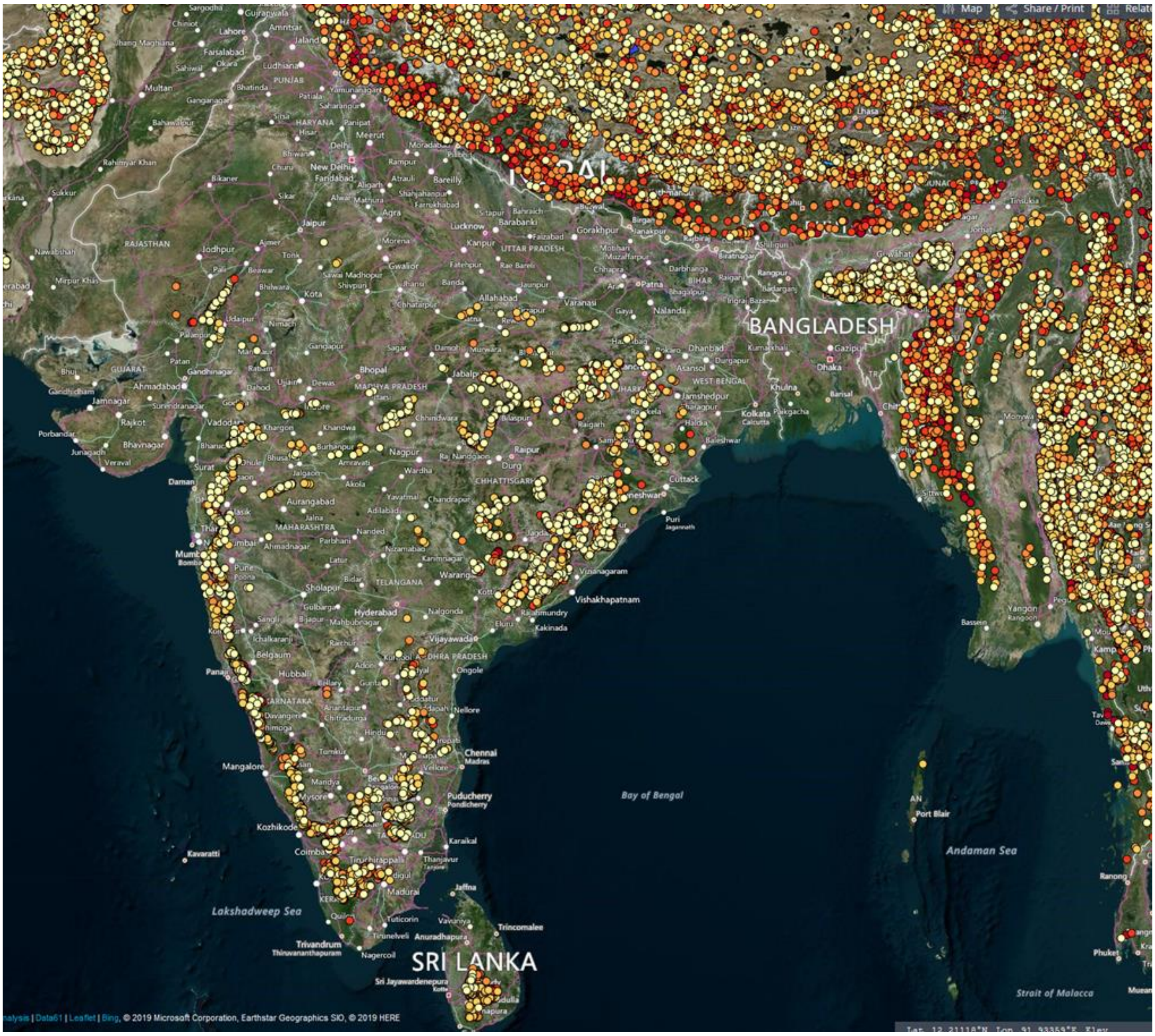


Image 2:

The image below shows thousands of potential off-river pumped hydro sites in Southern India

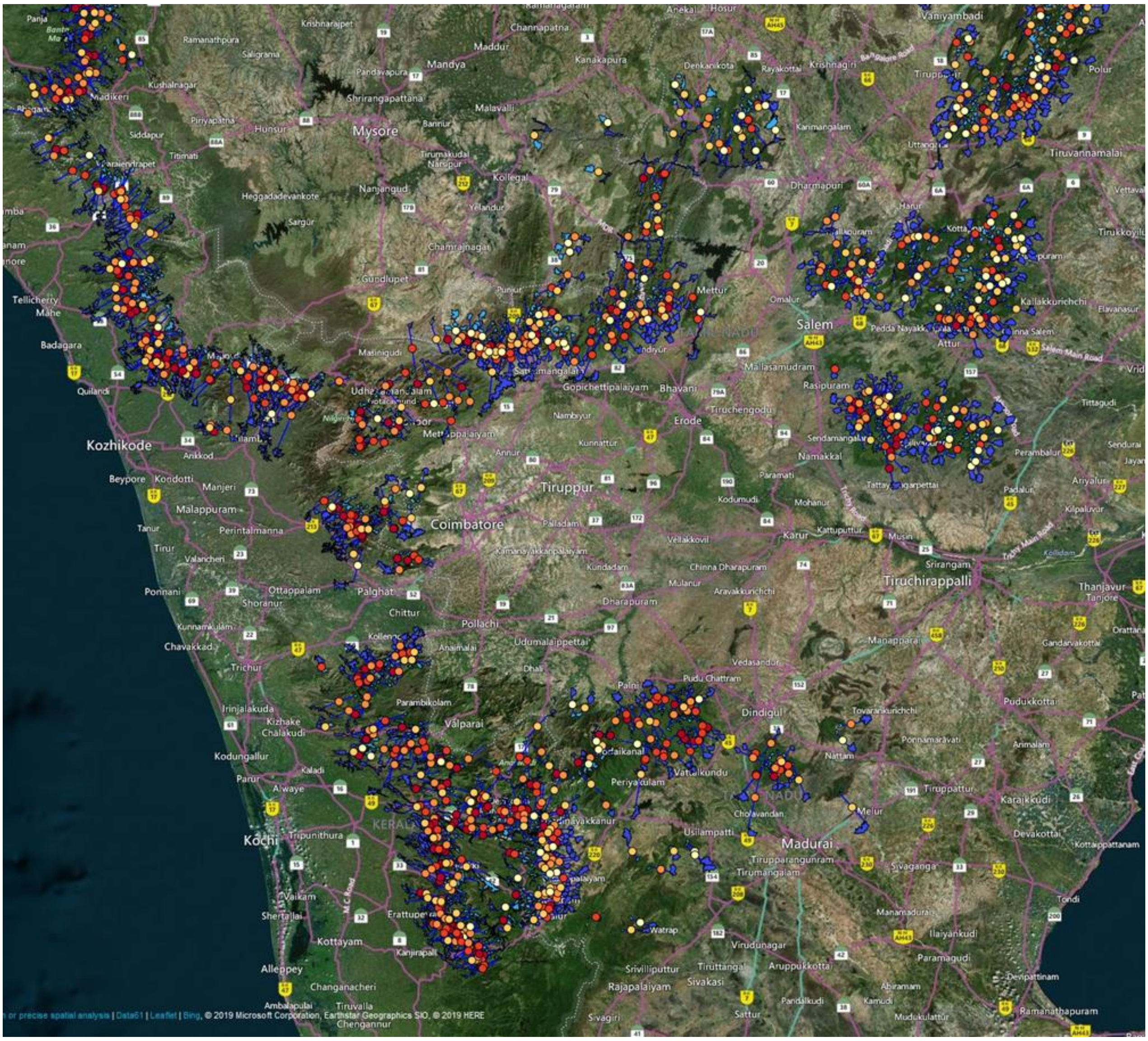


Image 3:

The image below shows the potential off-river pumped hydro reservoir pairs in southern India showing upper (light blue) and lower (dark blue) reservoir pairs, and including routes for the connecting tunnels or pipes

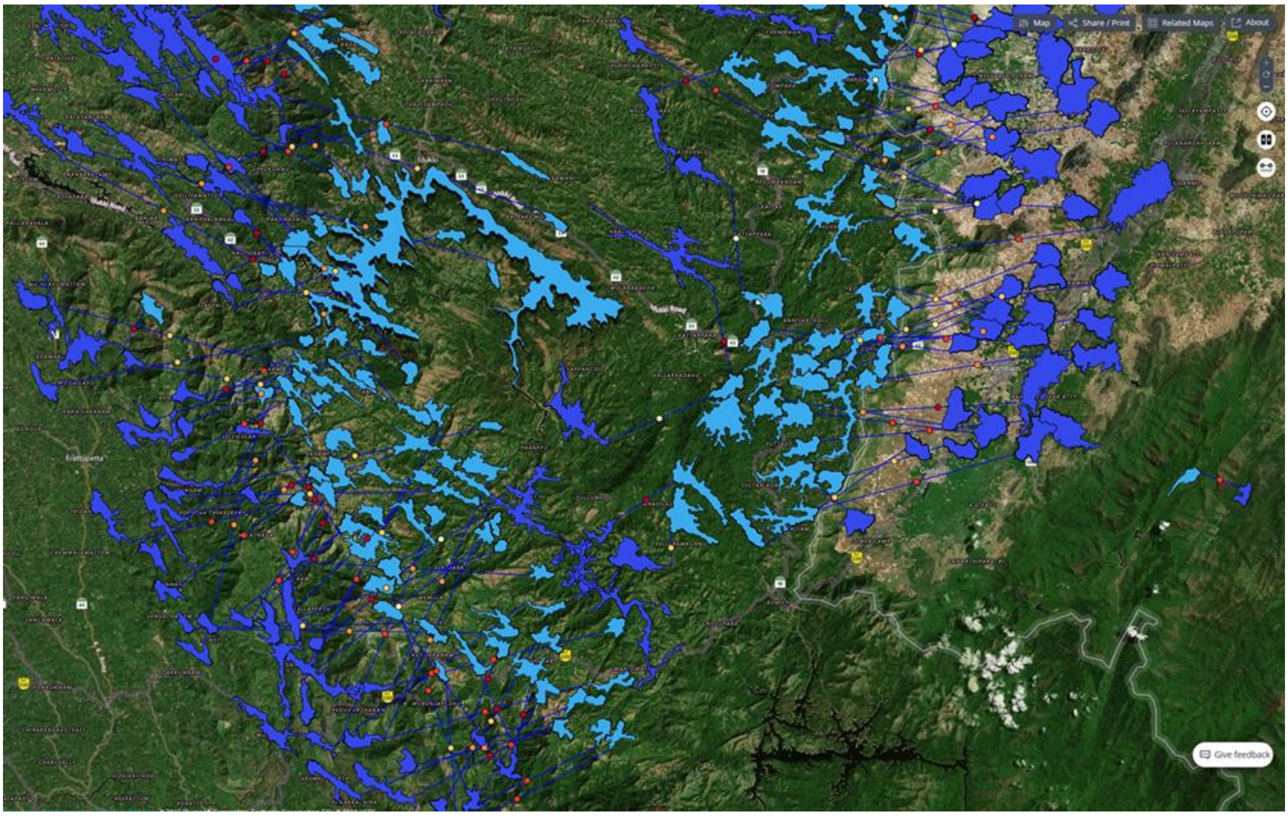
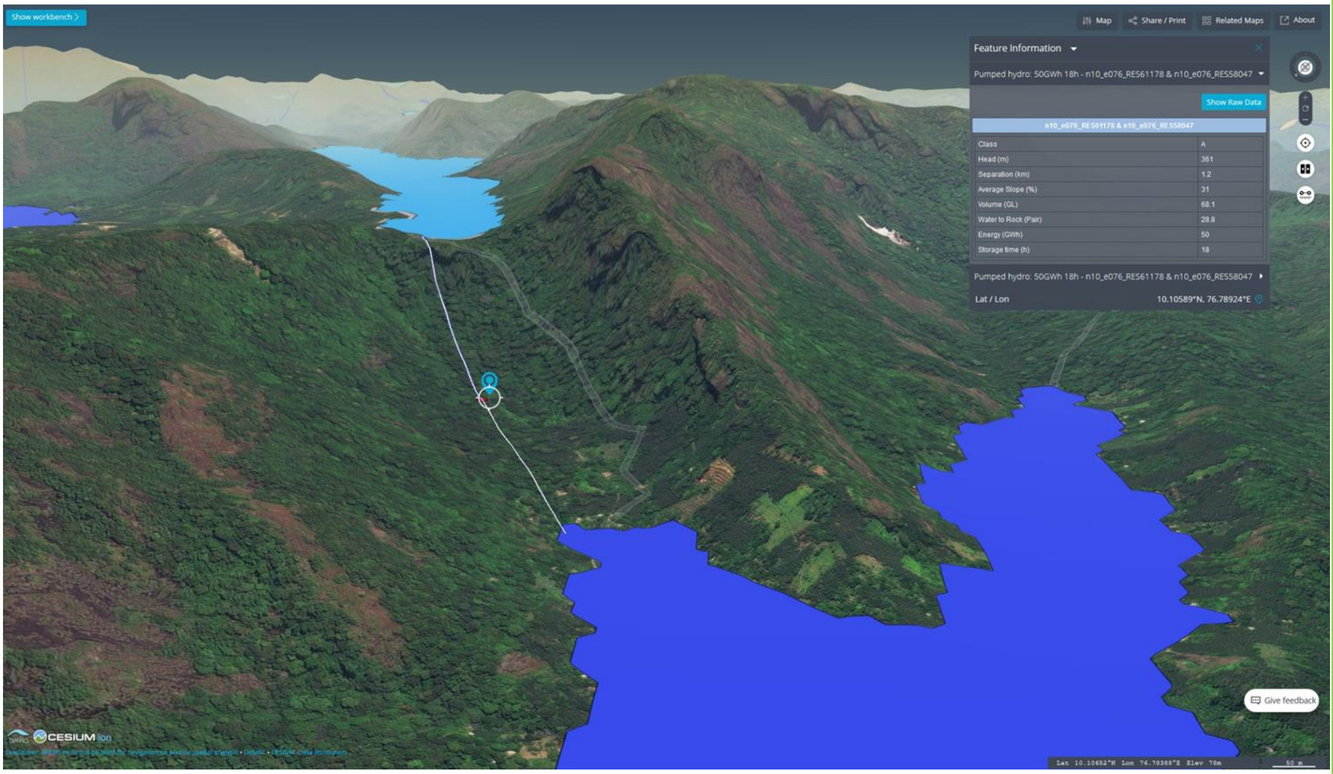


Image 4:

The image below shows the potential off-river pumped hydro reservoir pair in Southern India.



PHES Business Model

Assuming that a PHES with 75% overall efficiency pumps for 8 hours a day, it can generate for around a 6-hour period. In such a situation, the negative energy component is neutralized as long as the price for the 6 hours [peak hrs.] is more than 1.33 (8/6) times the pumping [off-peak] price. Hence, the entire operational financial viability of PHES depends on the differential between peak and off-peak period. Going forward, if we envisage a large difference between peak and off-peak period rates, then in addition to addressing the issue of negative energy factor, there may be some component from the differential in peak and off-peak rates towards the capacity charges as well.

Further, given the need for balancing, PHES cannot be compared with a conventional hydro plant and its capacity to the grid should not be viewed just on basis of the volumetric tariff. The flexibility benefits that could be rendered by PHES need to be broken down into different components, and a provision should be built to pay/incentivize for each of it. This approach would ascertain the value of flexibility to the grid, that is, the values for fast response, each start/stop, grid resilience and inertia, as well as for black start etc.

Any viable PHES business model viable has to consider the available technological options and the potential differential cost between peak/off-peak power. This allows operating PHES projects as market based ancillary service. The alterative business models are given herewith.

- The Existing Conventional Model
  - ✓ Being a negative energy source, the tariffs work out to be quite high
  - ✓ Does not stand competitive in the face of declining tariffs of other sources
  - ✓ Reluctance of beneficiaries/users to use this technology due to high costs
  - ✓ Lack of private sector participation and competition due to high investment and long gestation period.

The PHES presently working in India were, therefore introduced by the public sector to take care of above issues.

- As a Regulatory Asset [towards Grid supporting measures]
  - ✓ Treated as regulatory assets and extension of all benefits - Brought on the lines of Grid/Transmission element by intervention of system planning and operating agencies;
  - ✓ To be operated as per the requirement of national grid operator, mainly towards load levelling [on the lines of Reserves Regulation Ancillary Services (RRAS) /Security Constrained Economic Dispatch (SCED)];
  - ✓ Tariffs for the input power for pumping and output power to be decided by regulator;
- As Market Based Asset under Ancillary Services
  - ✓ Energy for pumping to be charged on the basis of cheapest source of power, with an option to procure cheaper power from market;
  - ✓ Assured certain minimum duration of operation by the operator;
  - ✓ Full capacity charges payable in case of availability for the agreed minimum duration of operation, with incentives for extra duration of operation;
  - ✓ Competitive bidding can take place for the cost of output (balancing) power to take care of input energy cost and capex

12. Recommendations for Renewable Transition and the Way Forward

Key recommendations towards renewable transition and balancing the grid in the face of large-scale renewable integration are as follows:

- India's massive target of adding 175 GW plus of renewable energy installations by 2022 poses serious challenges to grid integration. This issue needs critical attention, and measures such as Demand Side Management, peaking of existing hydro and gas generation, flexing of existing thermal generation to maximum possible extent, and provision of storage devices including Pumped Hydro Energy Storage (PHES) and Electrical Batteries, would be essential.

- In order to find out a long term and cost-effective solution towards the renewable transition and balancing of the grid, it is important to examine in detail the suitability and efficacy of each of the available options. Apart from these, alternatives such as Demand Side Management, flexing of thermal generation and storage solutions, mainly pumped hydro energy storage and electrical batteries, would require detailed cost analysis.
- Out of the different storage devices, PHES and Electrical Batteries are the two main prevalent and commercially operating devices. However, due to the inherent advantages in terms of flexibility, suitability towards long hours of operation and higher rated power, PHES has emerged as the world's largest energy storage system, representing 96% of the installed storage capacity worldwide (169 GW out of a total storage capacity of 176 GW).
- Basing the requirement and sustainability of PHES capacity to the grid only through volumetric tariff (paise/unit) may be a misnomer as it misses out the aspect of flexibility, which is essential to the grid. Hence the factors that need to be incorporated in arriving at the true cost of PHES for balancing power should give due weightage to flexibility, which include ramp-up/ramp-down rates, start/stop ability, reliability, resilience and black start capabilities among others. Each of the above component needs to be valued and a tariff be appropriated.
- PHES has the potential to provide all type of services under ancillary service, and with variable speed drive, it would be more suitable to provide ancillary service to the grid.
- The financial viability of PHES largely depends on the differential between peak and off-peak period. Going forward, there is a need to carry out financial modelling to forecast the difference between peak and off-peak tariffs.
- PHES can certainly aid in grid operations to meet the peak demands of power due to its inherent advantages. However, who would own and operate these projects is an issue that needs to be addressed, and the specific purpose of each project needs to be clearly defined in order to arrive at a prudent solution.
- In order to optimize economies on per unit costs, PHES plants need to be operated for extending generation support to the grid for longer duration, say to around minimum 8 hours a day in two blocks. Pumping during off peak hours & night hours, and generation during evening peak and morning/day peak hours would be required.
- The business model of PHES can possibly be based on the following two criteria:
  - ✓ Grid supporting asset (on the lines of grid/transmission elements)
  - ✓ Market based asset under ancillary services, with minimum assured off-take

  The above needs to be further deliberated to develop the project in a financially viable and speedy manner. Regulatory provisions in this respect also need to be developed.

- There is a need to develop electricity market with provisions towards ancillary services, intra-day and real time electricity markets. Such provisions shall be of relevance towards bringing PHES as ancillary services.
- Supporting regulatory provisions should also be extended for PHES in respect of the following:
  - ✓ Assured connectivity and transmission access
  - ✓ Low tariffs for input power towards pumping
  - ✓ Generation output tariffs with considerations/premium towards grid balancing
- Attractive terms for financing of Capex by financial institutions and hand holding by government agencies towards statutory clearances and other issues are required.
- There is significant potential in South Asia for off-river PHES projects, and exploiting such potential on regional basis can help all countries economically, as well as towards achieving RE integration to the regional grid. Technical feasibility and cost benefit analyses in this respect needs to be undertaken.
- Formulation of Standard Bid Documents in respect of PHES in order to expedite the procurement process and addressing some of the common issues is desirable.
- Public awareness and necessary support by think tanks nd civil society is necessary for fast development of PHES.

Annexure-1: Summary of Discussions from the First Roundtable | March 27, 2019

Soft Landings for Indian Renewable Integration through

Balancing Technologies

Summary of discussions from the First Roundtable | March 27, 2019

Background

The aggressive target of achieving 175 GW of renewable energy installations by 2022 has significantly altered the paradigm of Indian energy scenario. Simultaneously, this rapid deployment has also raised justifiable concerns about grid balancing and stability.

Several initiatives have been undertaken to address this challenge, including changes in policy and regulations, pro-active deployment of technical efforts by Indian industries and optimizing capacities of existing units. Considering the large capacities of renewables that ultimately need to be integrated with the grid, it is essential that adequate capacity of balancing sources, including storage, be deployed in the grid. These would be critical to smoothen out the gap between overall peak and off-peak availability, as well as intermittency of renewables. However, there are several technical, economic and regulatory concerns that need to be addressed before these sources can achieve critical deployment levels in India.

In this context, Integrated Research and Action for Development (IRADe) and The Asia Foundation have joined hands to conduct series of interactions involving different stakeholders within the industry. In the first interaction held on 27th March 2019, energy experts from across think tanks, academic institutions and industry bodies were invited for a roundtable discussion titled **'Soft Landings for Indian Renewable Integration through Balancing Technologies'** at the Marigold Hall, India Habitat Centre, New Delhi. The roundtable, chaired by Dr. Kirit Parikh, Chairman, IRADe, was also attended by the Department of Foreign Aid and Trade, Government of Australia, as well as by Professor Andrew Blakers from Australian National University (ANU), Australia (through video conferencing). The list of the participants has been attached in Annexure – 1.

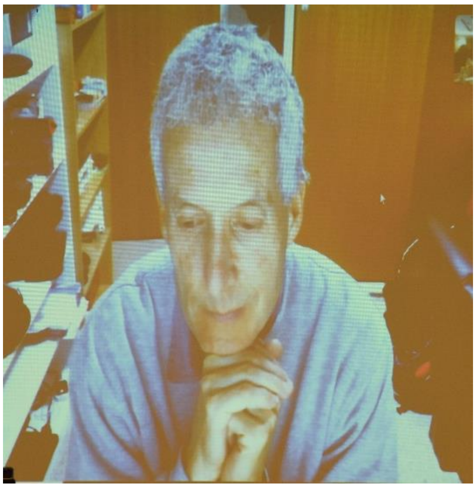
Introduction and Context Setting

Mr Pankaj Batra, then Senior Advisor, IRADe and currently Project Director, IRADe, welcomed and briefed participants on purpose of the event. Mr Batra showcased the consultative approach being undertaken by IRADe to promote dialogue on the various options available for Renewable Energy (RE) integration, Grid balancing and storage technologies.

Ms Nandita Baruah, Country Representative, The Asia Foundation, India, also welcomed the participants and thanked them for sparing their valuable time to attend the event.

This was followed by a technical presentation by Mr V K Agrawal, Technical Director, IRADe, setting the context for the discussions ahead. The presentation highlighted the several storage technology options available to serve various purposes, such as - electric energy time shift, renewable capacity firming, electric supply capacity, peak shaving and electricity bill management etc. It was pointed out that of the 176GW of storage systems installed globally, about 96% of the systems are essentially Pumped Hydro Energy Storage (PHES) systems. This data sufficiently highlights the important role played by PHES in terms of storage. The Government of India is also actively considering the installation of PHES as storage system towards RE integration. In April 2016, a high-level Committee set up by the Ministry of Power, Government of India, had recommended the need to have additional balancing resources like PHES. In his presentation, Mr Agrawal highlighted the off-river closed loop PHES technology as well, which basically represents the category of pumped storage plants not continuously connected to a naturally flowing river/water feature.

Experience sharing by Australian expert



Post the introductory technical presentation, Professor Andrew Blakers from Australian National University, shared his presentation through video conferencing. Prof. Blakers highlighted that Australia is adding the most renewables on a per capita basis, and that storage and intermittency concerns are being tackled head-on by the country through various storage options. He pointed out that PHES is a feasible option and the concerns about environmental impact can be offset by identifying particular off-river storage sites. In this context, Prof. Blakers highlighted the work done by ANU - 'Atlas on PHES Sites'. Other points highlighted by Prof. Blakers are as follows:

- ANU's PHES Atlas takes into account land use factors as well. Further, Australia's focus on off-river sites is deliberate due to several advantages, especially avoidance of river systems. Land requirement for PHES in such a scenario is one-tenth of the land needed for solar and wind projects.
- Australia has also installed a 100 MW Tesla battery, which is the first of its kind in Australia, and has proved to be extremely valuable.
- Gas Turbine (GT) companies were putting in less than needed power and pushing up the prices. Battery technology has helped to contain the GT monopoly in Australia.
- While battery is cheap for power, it is expensive for energy. Also, on an energy unit basis, PHES builds up capacity much faster than battery. For instance, the battery system of 0.13GWh storage was built in 100 days, while 350 GWH PHES was built over a period of four years. Thus, it is evident that PHES energy storage could be built 200 times faster than battery.
- Prof. Blakers stated that the approximate figures for a typical off-river PHES systems are as follows:
    - Power cost (capital cost) and energy cost (reservoirs) – 700$/kW and 50$/kWh
    - Maximum of 10 hours usage would be adequate
    - Big storage may be essential only for high intermittency periods; otherwise in respect of grid balancing, mostly small reservoirs will be adequate to provide desired level of storage
    - In order to achieve RE balancing by way of PHES, for most wind solar power stations of say, 100GW RE capacity, storage equivalent to 25GW capacity would be required
- Environmental activism that oppose dam construction is strong in India. In contrast, Australia has tried to avoid contentious sites as much as possible by attempting off-river PHES sites.
- Further, through a consultative and assimilative process, 2GW/350GWh sites are being constructed in Australia in middle of a world heritage area with support of environmentalists.
- Climate and environmental stresses need to be factored in while considering PHES. Further, water evaporation and fluctuation of rainfall across years due to climate change are realities that need to be tackled. Roughly, 1Giga litres/GWh initial fill storage is locked, not consumed.
- However, Prof. Blakers added that depending on rainfall, weather, evaporation losses etc., while some water may be needed, that too can be majorly eliminated with suitable measures, including floating discs etc.

- This quantum of water is good enough to last for 50-100 years. Hence, in PHES system the quantum of water required as make up water is very small and can easily be met with local rainfall.
- Further, in a pure wind PV-PHES system, the required amount of water would be one-seventh of the water required in an equivalent capacity thermal power station as cooling water.
- While the RE timeframe is less, the Transmission and Distribution (T&D) network challenges are significant. It is important to note that Australia already has 22% of its energy coming from RE, and can move to 45% with minor changes. The key is to understand that the biggest constraint for India and Australia is the same, that is, the need for adequate transmission to avoid grid curtailment. There is a big jostle within Australia to connect more renewables into the grid. Till upto 30% of RE penetration in the total generation, T&D management is sufficient, however after reaching 30-35% penetration, Australia will have to augment the grid.
- Most of the PHES in Australia are open loop, but new ones coming up are all closed loop. 500MW of closed loop has been there for 30 years. The PHES capacity in Australia at present is 2.5GW.

Key Takeaways: Roundtable Discussion

- There are concerns about the impact and results of 175GW of RE being integrated into the grid. However, the larger vision must not be forgotten – the integration of RE must consider a horizon wider than the post 2022 perspective. RE is needed in India for two reasons – Climate Change and Energy Security. Coal will not be able to answer India's energy challenges for long, as extractable coal reserves may not last more than 40-45 years at the present rate of consumption.
- Thermal flexing of power plants is one option for accommodating RE into the grid. However, the heat rate of power plant will be important, and one has to be careful to avoid more coal consumption and subsequent GHG emission just to absorb RE. A key aspect often ignored is demand side management, which presents several options. For instance, agricultural load for pumping does not require firm power all the time. This load can be fed during periods of excess RE. Further, different office timings (based on availability of daylight) must be used efficiently to diversify the peak load (morning-evening). However, with electric energy time shift (Arbitrage) requiring storage for large periods of time, viz. in terms of number of hours, PHES can play an important role.
- Studies regarding storage and flexibility options have so far focused mostly on the cost side. The need to conduct stability studies has been realised and ought to be addressed in the earnest. Further, intra-state transmission line issues also need to be addressed on priority.
- Experts deliberated on whether individual device/plant level storage to combat intermittency of solar or wind should be mandated, or a combined grid level storage is desirable. It emerged that since India is a large connected grid, providing storage at each RE site would not be an optimal solution. Such individual site-wise replication can be very expensive, and therefore grid connected PHES is being adopted the world over for reasons such as electric energy time shift (load levelling/energy arbitrage).
- Several challenges exist with battery storage, such as safe disposal of the waste generated. This problem does not arise with PHES. Batteries will be useful in some places like solar rooftop and

frequency regulation etc. but not elsewhere, such as for electrical energy time shift. Metering, billing and settlement systems also need to be addressed.

- The most pondage type hydro schemes have minimum three-hour storage capacity. However, to make full use of all the capabilities of hydro projects, more PHES projects can be planned. Strengthening of transmission systems, alongside empowering of Load Dispatch Centres are needed to make PHES more efficient.
- There is enormous possibility for PHES based balancing technologies in India. There is, however, a need to undertake detailed cost studies, prioritizing among the relative options available, and deciding on the best course of action.
- A major challenge to PHES is that of economic viability. Input power cost (off-peak, peak and plant cost) needs to be minimized to make such plants viable. One option could be to make such plants regulatory assets for optimal utilization by Load Dispatch Centres. While the cost of PHES compared to normal generation is of course expensive, it cannot be compared with a regular hydro project, given its purpose for balancing RE. They can be considered as ancillary services, which are expensive, but essential for grid stability.
- Most Power Purchase Agreements (PPAs) in India do not have clauses to address the issue of RE curtailment. To stabilize demand, PPAs will have to include such clauses. However, new bidding documents have started addressing these concerns, except for transmission constraints when curtailment can be undertaken. Weak transmission sectors can pose a challenge, but strong interconnection is the key to integration.

Concluding Remarks by Dr. Kirit Parikh

Dr Kirit Parikh stated that the PHES Atlas presented by Prof. Blakers, ANU, highlights the enormous possibility of PHES balancing in India. However, there is a need to undertake detailed cost studies to prioritize among various feasible projects. Dr Parikh added that the target of 175GW of RE has to be seen in the right perspective, given that more considerable amount of RE may come up beyond 2022. Grid integration is essential for RE, and therefore the state of technology, involved costs, and learning curves of other options need to be examined. Awareness on management issues and ease of operation also need to be considered before taking decisions. Thus, a holistic approach should be adopted while evaluating the options. Eventually, a mix of options would be needed and therefore some idea of relative importance of different technologies is required. The roundtable discussions ended with a vote of thanks to the Chair and all the participating members.

List of Participants at the First Roundtable

S.No.	Name	Organization
1	Sukanya Bhadra	CII
2	Srirupa Bhowmik	CII
3	Rahul Tongia	Brookings India
4	Rohit Magotra	IRADe
5	Prof. Kirit Parikh	IRADe
6	Pankaj Batra	IRADe
7	V K Agrawal	IRADe
8	Rohit Pathania	IRADe
9	Manu Chawla	CEEW
10	V K Kanjilia	CBIP
11	Dr S K Dube	TERI
12	K Ramanathan	TERI
13	A K Saxena	TERI
14	Dr. Jami Hussain	REWS
15	Lydia Powell	ORF
16	Himanshu Shekhar	ICRIER
17	Stuart Kinsella	DFAT
18	Mandakini Surie	DFAT
19	Nandita Baruah	The Asia Foundation
20	Preeti Thapa	The Asia Foundation
21	Malavika Thirukode	The Asia Foundation
22	Prof. Andrew Blakers	ANU, Australia (Through V C)

Annexure-2: Summary of Discussions from the Second Roundtable | April 16, 2019

Soft Landings for Indian Renewable Integration through Balancing Technologies

Summary of Discussions from the Second Roundtable | April 16, 2019

Background

With India geared up to meet its target of 175 GW of Renewable Energy (RE) installations by 2022, grid integration for such large capacity of RE is a challenge that needs critical attention. In this context, Integrated Research and Action for Development (IRADe) and The Asia Foundation (TAF) have joined hands to conduct a series of interactions involving different stakeholders and experts. As part of this initiative, the first roundtable discussion on the topic **'Soft Landings for Indian Renewable Integration Through Balancing Technologies'** was held with energy experts from across think tanks, academic institutions and industry bodies on 27th March 2019 at India Habitat Centre, New Delhi. The roundtable saw enthusiastic participation by thought leaders from the industry who brainstormed on the challenges, various alternatives and potential of grind integration for RE.

To build up on the path indicated by the program, the second roundtable discussion was organised on 16th April 2019 at the Hotel Le Meridien, New Delhi. Chaired by Dr. Kirit Parikh, Chairman, IRADe, the second roundtable saw participation by senior representatives from government agencies and other statuary bodies. The list of the participants has been attached as Annexure – 1.

Introduction and Context Setting

The participants were welcomed by Prof. Jyoti K Parikh, Executive Director, IRADe. She briefed the participants about the purpose of the event, and highlighted the consultative approach that IRADe is undertaking for a dialogue on the various options available for RE integration, grid balancing and the subject of storage technologies.

Ms Malavika Thirukode, Program Officer, The Asia Foundation, India, welcomed the participants and thanked them for sparing their valuable time to attend this event.

This was followed by a technical presentation by Mr V K Agrawal, Technical Director, IRADe, on the various storage technology options available, the different purposes they serve, such as - electric energy time shift, renewable capacity firming, electric supply capacity, peak shaving and electricity bill management etc. It was highlighted that around 176 GW of storage systems have been installed globally, out of which around 96% of systems are essentially Pumped Hydro Energy Storage (PHES) systems. Mr Agrawal informed the audience that the Government of India is also actively considering installation of PHES as storage system towards RE integration.

Technical Presentations

Dr Mattew Stocs from Australian National University (ANU), Australia, set the tone for the roundtable discussions with a technical presentation (through VC). Dr Stocs highlighted that renewables capacity is on a rising trend in Australia, and that the intermittence of RE is being addressed by different options, including PHES. Dr Stocs also explained about off-river closed loop PHES technology, which represents the category of pumped storage plants not continuously connected to a naturally flowing river/water body. The presentation also covered the work done by ANU on 'Atlas on PHES Sites'.

Mr Surjit Chakarborty from West Bengal State Electricity Distribution Company Limited (WBSEDCL), presented next on the topic 'Pumped Hydro Energy Projects in West Bengal'. Mr Chakarborty talked about the '900 MW Purulia Pumped Storage Project', a closed loop off-river project successfully operating in the West Bengal Grid since 2007.

He also highlighted the 1000 MW capacity 'Turga Pumped Hydro Project', which too is being planned as a closed loop off river project, and is currently under the construction phase.

High Level Expert Panel Deliberations, followed by Open Discussions

The deliberations started with valued comments from high level experts from the Government Sector, including Mr Aniruddha Kumar, Joint Secretary, Ministry of Power, Government of India; Mr Dinesh Chandra, Member (Hydro), Central Electricity Authority (CEA); and Mr Sushil Kumar Soonee, Advisor, Power System Operation Corporation (POSOCO).

The experts rendered their comments on varied subjects, ranging from - the need for balancing, specific quantum of storage capacity essential for such balancing, different types of storage available in the market and comparison of their capabilities and prices, current state of PHES in India, how its availability can be increased, and the regulatory and commercial framework needed for brining different storage technologies to the Indian system.

Mr Aniruddha Kumar, Joint Secretary, Ministry of Power, talked about the huge progress made over the past few years across different domains of the power system, including generation capacity, transmission and system operation. He added that in spite of the progress in all other domains of power system, pumped storage has not taken off due to policy dilemma in the Government, mainly due to the high cost associated with PHES.

Mr Kumar also stated that since the power sector is a commercial activity, therefore any tariff structure activity has to be self-sustainable. It is a well-known fact that the financial health of Discoms is suffering due to huge under-recoveries. Hence, any solution proposed has to be cost-effective for consumers, else it would be difficult to push it through in spite of all its merits. He reiterated that if PHES is to be brought into the grid, it has to fulfil both the criteria, viz. possess technical superiority compared to other prevalent storage technologies, particularly battery storage, as well as be cost effective.

Mr Dinesh Chandra, Member (Hydro), CEA, stated that economics is the major challenge in bringing out PHES in a big way. However, with the increase in RE capacity, there is need to add much more flexible capacity in the grid, which PHES meets very aptly. PHES has an expeditious ramp up/ramp down capability, which cannot be achieved in case of flexing of generation from thermal sources. He added that out of the 96 GW pumped hydro potential identified in India, excluding the 27 GW of potential from reserve forests and coal mines etc., and adding about 15.6 GW of the potential separately identified by States, the net overall pumped hydro potential comes out to be about 85 GW. Out of this, around 11.2 GW capacity has been identified for implementation under 14 schemes.

Mr Sushil Kumar Soonee, Advisor, POSOCO, stated that judging the requirement and sustainability of PHES capacity to the grid only by way of volumetric tariff (paise/unit) may be a misnomer. Such an approach misses out the aspect of flexibility, which is essential to the grid. He suggested to break down flexibility into different components, that is, define the flexibility matrix, measure and value each of the components, and incentivise for each of it. This approach would ascertain the value of flexibility to the grid, that is, the values for fast response, each start/stop, grid resilience and inertia and for black start etc. These can further be fructified if PHES is brought out as a market product under ancillary services.

Dr Kirit Parikh, Chair of the session, observed that the important issue emerging out of the discussions is to identify the measures that can be taken to integrate PHES into the grid. At the same time, it is vital to scrutinise the best strategy for balancing the grid and the costs involved with each of the technology. Dr Parikh added that while doing so, as pointed out by the experts, one needs to break down volumetric tariff into fixed and variable costs, and attach the cost of flexibility. Dr Parikh reiterated that while comparing the cost of generation from hydro resources vis-a-vis coal, the costs related to environmental impact and local air pollution also need to be factored in. During the current times, ways and means are available to make coal generation less polluting by using electrostatic precipitators and other means. However, these would add to the cost of coal and combined with the sustainability and environmental factors, coal may have to be to be dispensed off ultimately. He concluded with the remarks that the integration of PHES to the grid is an important aspect and based on the inputs rendered by different experts, the best manner for integration has to be evaluated.

Deliberations by the expert panel were followed by open discussions among the participants at the roundtable. Key takeaways based on the comments of experts as well as other participants of the roundtable are captured below.

Key Takeaways: Roundtable Discussion

The key points that emerged out in the roundtable are as follows:

- Case study of Gujarat: The variation in wind generation of 500MW is observed on most days of the year. This is apart from the variation in solar generation. It was observed that during 2017-18, around 60% of the days had variation of more than 1000 MW between the maximum and minimum wind generation. Looking at the targeted wind generation of 8800 MW and solar generation of 8020 MW by 2022 for the state of Gujarat, this variation is going to increase further in the coming years and hence the avenues towards grid balancing appear to be important.
- Energy Banking Between States (EBBS): Energy banking between states without any financial transaction seems to be a viable solution. The Hon'ble Commission may consider a real time product of energy trading (banking) between utilities, which needs to be flexible and allow changes in schedule in four time blocks.
- In order to balance the grid with higher RE penetration, all inoperative pump mode hydro plants need to be made operative on highest priority. To this effect, plant-wise follow up and monitoring at the highest level of MoP, CEA and by the Utility is needed. Regulatory framework for pump mode operation shall also be required from the Central Electricity Regulatory Commission.
- All operative hydro stations should be pooled at the national level and its dispatch needs to be controlled by NLDC. For this, an appropriate policy should be framed which allows the generation from such pool to RE rich states. Special merit order can be displayed on the website and allocations be accordingly scheduled. Neighbouring countries with good hydro generation potential, such as Nepal & Bhutan, may be considered by India in the final policy mechanism.

- Although PHES technology is the most popular form of energy storage across the globe, it is yet to take off in India due to cost considerations. The cost of PHES station comes out to be approximately in the range of Rs. 6-7 Crore/MW. With most Discoms in India already operating under deficit conditions, the sensitivity towards cost is very high, and thus there is less acceptability for power with conversion cost in the range of Rs 6/ plus.
- In order to make the power from PHES commercially viable and acceptable to the utilities, in addition to approximately Rs. 2.5 Crore/MW planned budgetary support towards enabling infrastructure and flood moderation, some sort of financial restructuring is also being considered. This would be undertaken by increasing the project life to 40 years, extending the debt repayment period to 18 years, and back loading the tariff and escalating it every year by 2%. With such financial restructuring, the per-unit cost during the initial period is expected to be brought down by 30%, i.e. from a level of Rs. 6/unit to about Rs. 4/unit.
- It was noted that the PHES technology is considered to be a negative energy source (pumping consumes energy to the order of around 1.2 times of generation) by the utilities. Therefore, even the above-restructured cost may be found to be on the higher side, and utilities may prefer achieving balancing of the grid with flexing of the existing thermal stations.
- The drawback related to the flexing of generation in case of thermal stations was also discussed. When these plants are operated on part load conditions, their efficiency goes down drastically. For instance, in case a thermal plant is operated at a load factor of around 50% instead of 80%, its variable cost goes up substantially. This is apart from the heavy stress on the machine, entailing additional cost towards excessive wear and tear. Hence, in case of reduced load operations in thermal stations, the consolidated costs do not come out to be economical.
- PHES stations can also be justified with the fact that some of the consumers categories, such as IT and other critical industries, look for power with a good degree of reliability and firmness, where rates in the range of Rs. 7-8/unit prevail. These are quite high in comparison to the costs projected from Pumped Hydro. At the same time, as the whole South Asia region gets interconnected, the higher rates prevalent in some parts of the Region need to be considered, which can economically be replaced with the combined RE plus storage power.
- Closed loop off-river Pumped Storage projects do not require a large reservoir. With a reasonably small storage for 4 to 6 hours capacity at upstream and downstream of the power house and a short water conductor system, it can generate large power during peak demand period. Additionally, it does not require perennial flow in the river.
- Hence, while deliberating on the cost aspects of PHES stations, a detailed examination needs to be carried out to determine its necessity. This would provide the requisite storage capacity towards RE integration and grid balancing. The need to develop a cost model was duly observed. The scope for such studies may include the following:
    - Actual need for storage capacity, particularly PHES;
    - Cost of PHES stations with different technologies, viz. off-river etc.;
    - Implications of such costs on the consumers;
    - How the costs of PHES is compared with the cost of other storage technologies;
    - What could be the business model towards bringing the PHES in the grid and:
    - What regulatory framework needs to be put in place in this respect

The roundtable discussions ended with a vote of thanks to the chair and all the participating members.

List of Participants at the Second Roundtable

S.No.	Name	Organization
1	Mr. Anirudha Kumar	Ministry of Power
2	Mr. Dinesh Chandra	CEA
3	Dr. Kirit Parikh	IRADe
4	Dr. Jyoti Parikh	IRADe
5	Mr. Surjit Chakarborty	WBSEDCL
6	Mr. Mathew Stocs	ANU, Australia (Through V C)
7	Mr. S K Soonee	POSOCO
8	Mr. S R Narsimhan	POSOCO
9	Mr. R K Sinha	Member (River Management), CWC
10	Mr. V K Agrawal	IRADe
11	Mr. B B Mehta	SLDC Gujrat
12	Mr. Y K Sehgal	Greenko Group
13	Mr. Manoj Chander	Greenko Group
14	Mr. Mahendra Singh	DERC
15	Mr.Aditya Gautum	NHPC
16	Mr.Ratnesh Kumar	NHPC
17	Mr.Kulwinder Singh	SJVNL
18	Mr.Satish Yadav	SJVNL
19	Ms.Malavika Thirukode	The Asia Foundation
20	Mr.Rohit Magotra	IRADe
21	Mr.Gaurav Jain	IRADe
22	Mr.Rohit Pathania	IRADe
23	Mr.Vinay Saini	IRADe

Soft Landings for Indian Renewable Integration through Balancing Technologies

Summary of Discussions from the Regional Conference | June 12, 2019

Background

The target for India to achieve 175 GW plus of Renewable Energy installations by 2022 raises critical concerns over grid integration for such large capacity of RE. However, considering the diversity of demand and resources amongst the different countries of South Asia, the challenges of grid integration can be mitigated to a certain extent through optimal regional energy mix and sharing of resources. In this context, Integrated Research and Action for Development (IRADe) and The Asia Foundation (TAF) collaborated to conduct a series of interactions involving different stakeholders and experts. As part of this initiative, two separate roundtable discussions on the topic **'Soft Landings for Indian Renewable Integration through Balancing Technologies'**, were held on 27th March 2019 at India Habitat Centre, New Delhi, and on 16th April 2019 at the Hotel Le Meridien, New Delhi, respectively. The first roundtable had participants comprising energy experts from across think tanks, academic institutions and industry bodies in order to deliberate on the technical aspects of the subject and different options available towards resolution. The second roundtable was organised with senior representatives from government agencies, in order to understand the government push and policy brief on the subject.

The roundtables were followed by a Regional Conference, held on 12 June 2019, with the objective to disseminate the findings of both the roundtables and to share the regional dimensions of the transition. The participants of this regional conference included – Government representatives from India, Bhutan, Nepal and Bangladesh; India's hydropower and private renewable sector players; key representatives from the energy policy community; multilateral agencies and other experts on renewable integration and grid transitions. A high-level panel discussion took place in the conference, comprising experts from government sector, energy community, hydropower generators, statutory bodies and academic institutions. Dr. Andrew Blakers from Australian National University (ANU), travelled from Australia to participate in this event and addressed the participants on the Pumped Hydro Energy Storage (PHES) Atlas tool and the potential of sustainable pumped hydro in India. The participants from Bhutan, Nepal and Bangladesh also shared details of hydropower development in their respective countries and their views on regional co-operation in this respect. The conference witnessed enriching and fruitful discussions and successfully concluded with certain important resolutions.

The list of the participants in the conference has been attached as Annexure – 1.

Conference Opening Session and Context Setting

Prof. Jyoti Parikh, Executive Director, IRADe, welcomed the guests and apprised them on the multidisciplinary work done by IRADe in the fields of policy and research and the considerable work done towards promotion of energy cooperation in South Asia. She stated that the Regional Conference is organised by IRADe and TAF to discuss closed loop pumped hydro system, as analysed by Professor Andrew Blakers of ANU. She mentioned that India's goal of reaching 175 GW of RE by 2022, as well as the COP 24 goal (wherein India agreed to reduce Greenhouse gases intensity and use of fossil fuel and bring the share of non-fossil fuel capacity to 40%), require exploring new ideas and technologies. Further, within South Asia, Nepal and Bhutan's hydro potential can promote energy cooperation.

Ms Nandita Baruah, Country Representative, TAF, welcomed the guests and participants. She expressed pleasure that TAF, with the support of DFAT (Department of Foreign Affairs and Trade), Australia, joined hands with IRADe. She hoped the discussions would bring to the table cutting-edge technologies with government and colleagues across the region, with the objective of making Renewable Energy (RE) more cost-effective, sustainable and usable. She mentioned that there are certain challenges to the speed with which India can achieve its RE goal for 2022, particularly on the aspects of grid balancing. However, she added, that with advanced technologies these challenges can be addressed at a faster pace than earlier thought. Ms Baruah hoped that the collaboration would put forth some more doable policies, technologies and ideas that give a push to the agenda.

Mr Anirudh Kumar, Joint Secretary (Hydro), MoP, congratulated IRADe and TAF for taking up the work in the area of Renewable Transition. He mentioned that the most pertinent topic currently in the global energy sector is the smooth transition from fossil fuels to non-fossil based fuels. India has made tremendous progress in the areas of RE, with RE capacity as on date being 80 GW, one of the largest in the world. He added that the Government of India has initiated work on achieving and exceeding the 2022 RE targets. However, seasonal variation in RE generation, as well as the demand profile are serious challenges for India and need due attention. Mr Kumar informed that studies have indicated that to integrate 440 GW of Renewable capacity in the grid, around 35 GW of storage would be required, in addition to the existing pumped storage capacity available in the country. The question that then arises is to how such large amount of storage can be created out of the only two viable storage options - pumped storage and electrical batteries.

Mr Kumar added that the reason for pumped storage not taking off in India is due to the cost-benefit analysis. There are two aspects to this problem – firstly, there has not been an economic value attached to this benefit; secondly, this value has to be realised from the perspective of market mechanism. According to Mr Kumar, the thumb rule for valuing this benefit should be to find out the difference between off peak tariff and peak tariff. If the cost of storage is more than the difference between peak tariff and off-peak tariff, then it may not be economically viable for the consumer. He emphasized the need for financial modelling to forecast the increase in difference between peak and off-peak tariff going forward, as it would help to prepare a strong case for creating storage solutions in the country. He concluded with the remarks that the country has to travel a long way to establish this viability and find the best solution for various methods of balancing the grid, including storage technologies.

Mr. Rod Hilton, the Australian Deputy High Commissioner to India, remarked that RE is rightly playing an increasingly important role in improving energy access for millions of people worldwide. He informed that Australia too is increasing its proportion of RE and has built up storage systems to address the intermittency. Since RE supply is intermittent, as the production cost of RE continues to fall and the proportion of RE increases, system inability can occur unless there is enough reserve power backup. In Australia, it has been demonstrated that advances in electricity storage have dramatically improved system reliability, increased the amount of RE that can be integrated into the grid supply and helped to cope with increased demand.

Mr Hilton added that there are a number of different storage technologies in use and Pumped Hydro is already showing great promise as a mechanism to increase energy availability. To help build an understanding of the potential for using it more widely in South Asia, Australia recently provided technical assistance to develop the Pumped Hydro Energy Atlas, in which Prof Blakers and his team have contributed immensely. The Atlas will allow identification of sites that could be developed over the coming years in India and other parts of the South Asia region to augment growing energy demand. However, it is important to note that the energy dynamics in the region are volatile, and therefore the choice of sites need to be evaluated carefully in that context. For example, the cost of pumped hydro has proven to be lower than a similar quantity of energy from lithium-ion and other large-scale chemical storage systems. However, the cost of alternative battery technology is falling. This will, over time, change the relative economics of different storage options. It is therefore critical to have a clear idea of cost of pumped hydro over the next 10-15 years, in order to ensure that the right investment decisions are made. Mr Hilton added that Governments, industry and civil society will need to work together to identify clear avenues towards integrating storage technologies to realise the RE ambitions. He concluded with the remarks that energy cooperation is a critical focus of Australia's Indo focus.

Mr KVS Baba, CMD, POSOCO, complimented IRADe and TAF for organising the regional conference and rendering an opportunity to organisations across the region to deliberate on the important issue of grid balancing. He stated that currently almost 10 - 11% energy in India comes from wind and solar. With continuously increasing demand in the grid as well as increased variability due to addition of more and more renewables, the requirement of flexibility is also increasing in the system. To address this, new and economical technologies need to be looked into.

Mr Baba added that it is not only the flexibility of generation that needs to be tackled, but also inadequate demand forecasting. We are yet to master the art of demand forecasting, which shall bring-in more certainty and render some relief to the system operators. With the increased penetration of renewables in the grid, it is necessary to have reserves in the grid. However, we are stuck in the process of finding where such reserves would come from. Mr Baba stated that looking into the existing resource break-up, thermal would continue to operate as the base source for generation. However, looking at the limited capability of the generation from thermal in terms of flexibility, the closed loop pumped hydro scheme appears to be an attractive proposition and can provide a viable solution to address the challenge towards renewable transition. He added that India enjoys the advantage of having an excellent grid, where any resource from any corner can be harnessed, provided the proper market is available. Under such situation, integration of surplus hydropower resources in the neighbouring countries, particularly in Bhutan and Nepal, can be carried out for effective renewable energy grid integration and peak load management. He concluded by saying that there has been a remarkable improvement in this regard and the actions are clearly visible.

High Level Panel Deliberations followed by Open Discussions

Dr Kirit Parikh, Chairman, IRADe, opened the session by briefing audience on the background of the discussions to take place. He mentioned that variability of Renewable Energy (RE) is a major challenge and each of the alternative for RE integration has to be evaluated in terms of principal characteristics, advantages under particular circumstances and cost. Though flexible thermal operation is readily available, there are hidden costs attached as it increases specific energy consumption, reduces life of the plant and increases maintenance charges. Demand-Side Management (DSM) has huge options and opportunities; however, the only challenge is to motivate consumers, wherein smart metering solutions for high value consumers can be a solution.

Concerning storage, Dr Parikh pointed out, that cost of batteries is a factor, though it can be put up quickly. However, scarcity of lithium ion is a challenge to be considered while designing the strategy. The other factor is the life cycle time of batteries and disposal of scrap from the batteries, once their life is over. In case of pumped storage, the timing and cost involved need to be analysed, while closed loop off-river PHES are relatively smaller and easier to set up. There may be significant opportunities in exploiting closed loop sites.

Dr Parikh highlighted that regional integration is an important alternative. There is now a great opportunity and desire among the South Asian countries to have an integrated and cooperative solution.

Dr Anoop Singh, Centre for Energy Regulation (CER), IIT Kanpur, mentioned that variability and uncertainty are the two challenges that need to be addressed through storage technologies. In order to address variability-based issues, it is important to consider energy-based storage – which can store energy for a longer period of time. To address uncertainty-based issues, accurate forecasting, both on generation and demand side, would be essential.

For storage technologies, particularly Pumped Storage and Electrical Batteries, the value has to be ultimately found either from the ancillary services market or from the energy market, to make these implementable. Further, in case of batteries, investment has to be made every 8-10 years, as compared to 20 years in case of RE plants and 40 years in case of PHES, which would affect its economics.

Mr PK Shukla, the succeeding speaker, informed the audience that there is around 84000 MW of feasible pumped hydro energy storage system potential in the country, of which about 4700 MW is operational. In addition, around 1200 MW of PHES is under construction by TERI Hydro project in the Northern region. Mr Shukla emphasized that with increased RE penetration of grid, hydro plants can play an important role. There is a need to sensitise State Governments to come forward; developers need to go to the State Governments to get the projects allotted to them, conduct the DPR, Survey Investigation, come up with clearances and initiate the work on immediate basis

Mr S C Shrivastava, Chief (Engineering), CERC, highlighted that for grid operation, real time variation is a major concern. Important aspects to consider in this regard are variability of renewables and error in forecasting. He informed the audience that CERC has come out with a roadmap for ancillary services, while the process of introducing market based ancillary services is also under consideration of CERC. Further, CERC has also provided provisions for flexibility in the grid code.

Mr Shrivastava pointed out that despite huge potential in the country for pumped storage technologies, these are not picking up, and thus there is a need for further emphasis by the Government on this technology. He mentioned that CERC has already come out with tariff regulation on pumped storage projects. Further, in order to encourage storage technologies, the commission has also amended the connectivity regulation, where they have provided for granting connectivity to standalone storage projects and hybrid storage projects.

Mr S R Narasimhan, Director (System Operation), POSOCO, continued the dialogue with a focus on diurnal variation, viz. how load would fan out over the coming years, what lessons have been learnt by looking at the flexibility from existing resources and pumped storage projects, as well as the future projects coming up. Mr Narasimhan shared that Load Factor Reports have indicated that the daily load factors in summers are quite high to around 95% plus; while during winters, these fall to 87%. Another important factor in this regard, he stated, is the minimum to maximum ratio. Here summers are not an issue as this factor varies in the ratio of 90-92%, while in winters it drops to 75% and that's where flexibility of conventional resources become important.

Regarding the flexibility, during the last high hydro season, Mr Narasimhan said, as much as 36 GW peak could be generated from the existing hydro, out of 45 GW installed capacity. Further, with regard to the ramping capability of coal fired stations as per last year data, it could be seen that out of 435 coal fired units, only 35% of the units could give a ramp rate of over 1% per minute. He congratulated CERC for taking the welcome step of incentivising ramp ups. As regards to the pumped storage projects, he added, these and other storage technologies will only grow in the coming future. There is a need to utilise these plants for 10 hours during two blocks, i.e. pumping during the day, and night and generation during evening and morning/day peak.

Mr Prabodh Mallick, Sr. Advisor (Power), Marubeni Corporation Project Office, stated that by 2022, most of the eight states identified for RE potential will have variable renewable power generation more than the base load power generation. To address this, storage would be essential and the possible storage technology which is both proven and bankable and in use for over 40 years, is that of Advanced stage Pumped Storage.

Mr Mallick made some valuable suggestions that included – pumped storage hydro to be declared as a grid element and should be a regional regulatory asset, owned predominantly by the Central or State power sector utilities as it may not be viable for private sector due to the time and cost involved. He further suggested that no customs duty be charged on Pumped storage hydro; further there is a need to adapt smarter technology, i.e. adjustable speed, to reduce the number of units and commission time, as well as prepone the revenue generation.

Prof Andrew Blakers, ANU, Australia, informed the audience that India has about 50 GW hours of potential off river pumped storage. He mentioned that developers can be choosy about these sites, as most of these are feasible from an environmental point of view. Therefore, India is well endowed with unlimited potential for low cost storage.

Prof Blakers highlighted that off-river pumped hydro is cheaper than on-river pumped hydro due to several reasons. The real cost and speed of construction of off-river pumped hydro is very advantageous compared to on river pumped hydro. Hence, the environmental and social pushback against off-river pumped hydro is also much smaller.

Prof Blakers stated that while one may worry about how hard it is to transition from a thermal generated system to a RE system, in case of a country like India with growth rates of 4-5% per annum, high population and rising affluence, these factors become trivial in the scheme of next 20 years. In the near future, with high electrification, heating in the cities and high usage of electric vehicles, the need for Renewables would only increase.

Prof Arun Kumar, IIT Roorkee, reiterated that in order to meet the grid balancing requirements as well as energy security needs, pumped storage systems are essential for the Indian grid. He shared that in respect of PHES too, closed loop systems have huge potential. State Governments need to mobilise in this respect and joint ventures can be looked into as an option. He informed that Pumped storage infuses 30-40% money into the local economy, which is higher than any other technology. Prof Kumar highlighted the need for certain regulatory actions from a clearance point of view that are required particularly with regard to PHES. For example, no clearances are required for solar, but needed for pumped storage systems, even for the closed loop. Similarly, certain financial mechanisms also required to be eased out.

Technical Presentation by Prof. Andrew Blakers, ANU, Australia

Prof. Andrew Blakers stated that as we move towards more and more PV and wind in the system, transmission needs to get constantly upgraded. High Voltage DC transmission has witnessed tremendous improvement all over the world and storage allows the existing power lines to run full load on a 24/7 basis. Pumped hydro is the lowest cost storage and comprises 96% of power capacity and 99% of energy storage globally. Pumped hydro-system benefits include a heavy rotating generator similar to a coal plant, and a black start can be done quite readily. Unlike a coal plant, it has a rapid response in the time range between 20-200 seconds, which can be of great help to the grid in terms of flexibility. Another type of storage, viz. electrical batteries have high power, but hardly any energy. Pumped hydro also has the advantage of scale compared to batteries, as it can provide 100-1000 times larger storage than batteries.

As far as difference between on-river and off-river pumped hydro storage is concerned, both are fully mature storage technologies. However, on-river is the traditional system, and in the past, most of PHES has come in this category. Off-river is a relatively new and efficient technology, and in this case, the combined reservoir area is much smaller. Further, it does not require any flood control, and has a faster construction period - say in the time scale of about 2-3 years after receiving the approvals. Further, there is much less environment and social pushback. Regarding the avenues in terms of sites, there are about 100 times more off river sites than on-river.

ANU's global off-river Pumped Hydro Atlas reveals 616,000 off-river sites, 23 million Gigawatt-hours of energy storage. Further, all these sites are outside national parks and urban areas. For India, apart from the huge potential in the Himalayas, many sites are also scattered across the country, especially in the Southern part.

Presentations by Representatives from Bhutan, Nepal and Bangladesh

Representatives from neighbouring South Asia countries, including officials from Bhutan, Bangladesh and Nepal, also participated in the conference. They presented their views on the subject and made brief presentations. The summary points from their presentations are captured below.

Mr Sonam Gyeltshen, Ministry of Economic Affairs, Bhutan, made a presentation on Hydropower and Bhutan's renewable energy ambitions. He deliberated about Bhutan's energy sector structure, existing power system and future renewable energy prospects of Bhutan.

Mr Moniruzzaman, Bangladesh Power Development Board, Bangladesh, made a presentation about the 'Present Status & Future plan of Power Sector of Bangladesh and Prospects of Renewable Energy in Bangladesh'.

Mana Devi Shreshtha, Ministry of Energy, Water Resources and Irrigation, Nepal made a brief presentation about Nepal's power sector, current perspectives and plan, as well as how energy security is being enhanced in their country.

Concluding Remarks

Dr Kirit Parikh concluded the panel discussion by recapping the major discussion points. He said that while it has been made clear that renewable integration is crucial, the various alternatives to achieve it need to be carefully examined. The pumped storage possibility, particularly closed loop pumped storage seems to be an interesting option, with its huge potential been demonstrated by Prof Blakers.

Dr Parikh highlighted that the South Asia region has a large hydro potential that is yet to be exploited. Many run of the river schemes can easily have a day storage, giving certain flexibility in trading. He concurred that there is a lot of action that needs to be taken in renewable integration - the need to have a grid of the right kind, the need for states to be brought together, and to analyse if the storage systems should be owned by the private sector or a larger public utility.

Mr Soonee surmised the discussions by stating that renewables are here to stay, and coal is to be dispensed off. He said one must analyse why pumped storage has not picked up even after many discussions and demonstrated benefits, and that some of the major reasons could be shortage of energy and inefficient markets earlier. However, with a large grid, robust market, rules and regulations, the required reserves and focus on renewables, pumped storage will now pick up pace. The stage is set to have more flexible generation, which is essential for renewable integration. He also asked to delve into why some pumped storage have not been successful, or completed and what could be the possible solutions. The other important aspect is that socialisation has to go and the model has to work on its own, and for that to happen, price differential is important to reflect the variability in RE.

Mr Soonee highlighted that the fact that India has a large and strong grid with diversity of around 5%, will help in integrating renewables. He acknowledged that the neighbouring countries too are integrating with India very well.

He mentioned the need to consider certain hygiene factors such as basics of the market, disciplines, rules and regulations, that are taking some time to be aligned. However, these are likely to pick up pace soon. He concluded by saying that for long last lasting solutions, all kinds of technologies need to be integrated.

Key Takeaways: Roundtable Discussion

- Electric Batteries and Pumped Hydro Electric Storage (PHES) are the two main storage technologies prevalent in the grid towards balancing. They however, may serve different purpose under different conditions and therefore, suitability of these has to be established based on the exact requirements and range of services.
- Integrating PHES with the grid are under consideration of policy makers in India for a long time. However, the issues of cost and economic viability have held back further movement on it. The Government of India has come out with a target of 10 GW of such capacity to be set up in the near future, with 3 GW already in place.
- PHES can certainly aid in grid operations to meet the peak demands of power due to its inherent advantages. However, who owns and operates these projects needs to be deliberated and addressed. In countries such as Australia, such projects are owned both by the Government and private sectors. In order to plan judiciously and optimally, the purpose of the project needs to be clearly defined.
- Cost overruns of hydro power projects is an often-recurring challenge that needs to be addressed in all earnest. The reasons behind it need to be understood and clearly addressed during the planning stages itself, else it leads to the project becoming unviable over time, as the final tariff can rise sharply.
- Off-river closed loop PHES is an efficient & cost-effective option that needs further dialogue and deliberation. This option also helps to offset the environmental mitigation costs to a large extent, since river ecosystems are not altered significantly.
- Any business model that makes PHES viable has to consider the latest technology options as well as the prevalent market conditions, particularly the differential cost between peak/off-peak power. This allows for certain options to be considered, like operating PHES projects as market based ancillary service.
- Inclusion of hydro energy into the category of renewables has been a step in the right direction, given its inherent clean advantages. However, there needs to be discussion on extending the benefits of this to off-river PHES projects for storage purposes as well.
- Tariff determination has to suitably account for intermittency of the project's operations. This should not lead to an exorbitant tariff burden on the end consumer, which can potentially derail efforts in this direction.

- In arriving at the true cost of balancing power, factors related with flexibility need to be incorporated, which include the different components such as ramp-up/ramp-down capability, start/stop ability, grid inertia and resilience as well as black start capability, among others.
- There is significant potential in South Asia for off-river PHES projects, and an inter-connected region can help all countries economically while addressing increasing power demands. However, feasibility and cost benefit analyses need to be undertaken for the same.
- Nepal and Bhutan governments have identified sites that can be used for PHES projects to be set up, and are eager to set up such projects for power trade under the SAARC Framework Agreement for Energy Cooperation (Electricity), which has been signed to enable cross-border trade of electricity.

The roundtable discussions ended with a vote of thanks to the chair and all the participating members.

REGIONAL CONFERENCE PARTICIPANT LIST

S. No.	Name	Country	Organization
1	Anirudhha Kumar	India	Ministry of Power
2	Rod Hilton	Australia	Australian High Commission to India
3	Andrew Blakers	Australia	Australian National University
4	K V S Baba	India	POSOCO
5	Kirit Parikh	India	IRADe
6	Jyoti S Parikh	India	IRADe
7	S C Shrivastava	India	Central Electricity Regulatory Commission
8	P K Shukla	India	Central Electricity Authority
9	S K Soonee	India	POSOCO
10	S R Narasimhan	India	POSOCO
11	Arun Kumar	India	IIT Roorkee
12	Anoop Singh	India	IIT Kanpur
13	Mana Devi Shreshtha	Nepal	Ministry of Energy, Water Resources and Irrigation
14	Roshani Shrestha	Nepal	Ministry of Energy, Water Resources and Irrigation
15	Nirjan Rai	Nepal	Policy Entrepreneurs Inc.
16	Sonam Gyeltshen	Bhutan	Ministry of Economic Affairs
17	Ugyen Chophel	Bhutan	Ministry of Economic Affairs
18	Moniruzzaman	Bangladesh	Bangladesh Power Development Board
19	Nur Mohammad	Bangladesh	Power Grid Company of Bangladesh ltd. (PGCB)
20	Shebonti Ray Dadwal	India	Institute of Defence Strategies and Analysis
21	Sukanya Bhadra	India	Confederation of Indian Industry
22	K Ramanathan	India	The Energy and Resources Institute
23	Mahesh Kumar	India	Central Board of Irrigation and Power
24	P P Wahi	India	Central Board of Irrigation and Power
25	Vishan Dutt	India	Central Board of Irrigation and Power

26	Brian Dawson	Australia	SDIP
27	Mandakini Surie	Australia	DFAT
28	R K Jindal	India	Sutlej Jal Vidyut Nigam
29	Praveen Saxena	India	Tehri Hydro Development Corporation
30	Deovrat Sharma	India	Tehri Hydro Development Corporation
31	Sandeep Checker	India	Tehri Hydro Development Corporation
32	Aditya Gautam	India	National Hydro Power Corporation
33	Ratnesh Kumar	India	National Hydro Power Corporation
34	Neeraj Gupta	India	International Finance Corporation
35	Roli Aggrawal	India	International Finance Corporation
36	Shaina Sethi	India	International Finance Corporation
37	Pradeep Kumar	India	Suzlon
38	S S Barpanda	India	Northern Regional Load Despatch Centre
39	Rajiv Porwal	India	Northern Regional Load Despatch Centre
40	Jami Hussain	India	Renewable Energy Welfare Society
41	Y K Sehgal	India	Greenko Group
42	P S Ahluwalia	India	Greenko Group
43	Rajiv Jain	India	Customised Energy Solutions
44	Ashok Kumar Agrawal	India	Kreate Technology
45	Probodh Mallick	India	Marubeni Corporation
46	Nandita Baruah	India	The Asia Foundation
47	Malavika Thirukode	India	The Asia Foundation
48	Pankaj Batra	India	IRADe
49	V K Agrawal	India	IRADe
50	Rohit Pathania	India	IRADe

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We heartily thank all the eminent speakers and delegates for their participation and valuable comments during the roundtable discussions and regional conference, especially Mr Dinesh Chandra, Member (Hydro), Central Electricity Authority; Mr Anirudha Kumar, JS (Hydro), Ministry Of Power, GoI; and Mr. KVS Baba, CMD, POSOCO; Mr R K Sinha, Member (River Management), CWC; Mr. S K Soonee, Advisor, POSOCO and many others. We acknowledge and express our sincere thanks to all other participants in these events, comprising representatives from different stakeholders, including Government officials, industry representatives and think tanks, academicians and thought leaders from the energy sector, without whose participation and contribution, successful accomplishment of the events and preparation of this report would have not been possible.

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We acknowledge and express heartfelt appreciation for all those individuals whose names could not be penned here but whose contribution have helped make this report a reality.

About IRADe

Integrated Research and Action for Development (IRADe) is an independent advanced research institute which aims to conduct research and policy analysis to engage stakeholders such as government, non-governmental organizations, corporations, academic and financial institutions. Energy, climate change, urban development, poverty, gender equity, agriculture and food security are some of the challenges faced in the 21st century. Therefore, IRADe research covers these, as well as policies that affect them.

IRADe's focus is effective action through multi-disciplinary and multi-stakeholder research to arrive at implementable solutions for sustainable development and policy research that accounts for the effective governance of techno-economic and socio-cultural issues. Being Asia Center for Sustainable Development, we have been carrying out policy research and its implementation for enabling socio-economic growth and charting pathways for sustainable development in South-Asia.

IRADe was established under the Society's Act, in 2002 at New Delhi. It is certified as a Research and Development Organization by the Department of Scientific and Industrial Research (DSIR), Ministry of Science and Technology (MoST). It has also been selected as a Center of Excellence by the Ministry of Urban Development (MoUD) for urban development and climate change. In addition, it provides expertise to other ministries, national and international institutions and partners with other reputed organizations. For more details, visit www.irade.org. Follow our social profiles on: www.facebook.com/IRADeNewDelhi/ | www.twitter.com/IRADe_Delhi/ | www.linkedin.com/in/irade-new-delhi-280019169/

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Headquartered in San Francisco, The Asia Foundation works through a network of offices in 18 Asian countries and in Washington, DC. Working with public and private partners, the Foundation receives funding from a diverse group of bilateral and multilateral development agencies, foundations, corporations, and individuals. In 2018, we provided $82.9 million in direct program support and distributed textbooks and other educational materials valued at $10.4 million.

About Australian Aid

Australia's aid program promotes Australia's national interests by contributing to sustainable economic growth and poverty reduction. The aid program focusses on two development outcomes: supporting private sector development and strengthening human development. Australia's Ministerial Statement on engaging the private sector in aid and development - Creating shared value through partnership was launched on 31 August 2015. The statement invites business to work with the Australian Government to help solve our region's development challenges. The Strategy recognises the private sector as a driver of economic growth, incomes and jobs, and as a partner for government to achieve more effective and sustainable aid outcomes. For more information, visit www.dfat.gov.au.