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Integrating Higher Share of Variable Renewable Energy in India

Demand-side management measures, building a large, well-connected national grid, deployment and efficient use of energy storage systems and flexible operation of thermal power plants can help pave the way for a clean energy future

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Key Findings

To cut emissions, India needs to increase renewable energy integration/absorption. Between 2016 and 2022, renewable energy's share in total electricity generation grew only by 6.5 percentage points, while its share in total capacity addition grew by 13.6 percentage points.

Demand-side measures and expanded transmission network will help in reducing grid balancing needs and will also help in integrating renewable energy.

Energy storage technologies can be utilised to provide a variety of grid balancing services.

Running existing coal or gas power plants at low load factors and flexibly to stabilise the grid will help increase the share of variable renewable energy in the electricity supply mix. A renewable energy rich power system will aid in decarbonisation of other sectors, such as transportation and manufacturing industry.

Executive Summary

While India has been adding renewable energy capacity at a fast pace, generation from such sources is increasing at a much slower pace. This is due to the inability of the Indian power system, which needs a new structure, to accommodate higher shares of renewable energy. To increase the share of renewable energy, India needs to take the following steps: introduce demand-side measures like time-of-use tariffs, develop a well-connected national grid, deploy various energy storage options for grid balancing services and convert its fossil-fuel powered fleet to operate in a flexible manner. Demand-side measures and expanded transmission network will help in reducing grid balancing needs and will also help in integrating renewable energy. Energy storage technologies can provide a variety of grid balancing services. India's plan to lower the coal power generation through flexible operation when renewable energy generation is high will reduce the share of coal power in the energy supply mix. This will reduce power costs by increasing the share of cheaper renewables and will help in decarbonising other sectors.

India faces a formidable challenge of ensuring energy security amid rising international tensions, increased electricity demand and climate concerns. In response, the country is tapping into all available energy resources, including coal reserves, despite its commitment to reduce the emissions intensity of its gross domestic product (GDP) by 45% below 2005 levels. India is also rapidly adding renewable energy capacity, in fact, at a faster rate than fossil fuel-powered capacity, to meet the growing electricity demand.

To cut emissions and achieve its ambitious targets, India needs to build capacity to absorb/integrate higher shares of renewable energy, which has not kept pace with capacity additions. From 2016 to 2022, renewable energy's share in total electricity generation grew only by 6.5 percentage points, while its share in total electricity capacity addition grew by 13.6 percentage points. A renewable-rich grid can also enable the decarbonisation of other sectors, including transportation and industry.

Given India's circumstances, the country can use a few potential levers to increase renewable energy integration in the power system. One of the immediate levers is introducing effective time-of-use (ToU) electricity tariffs to change consumption patterns to suit more renewable energy integration and lower grid balancing requirement. India should adopt a step-wise approach of introducing dynamic ToU electricity prices across consumer segments to reap the benefits.

Another lever is developing a well-connected, inter-regional national grid that optimises unevenly distributed renewable resources. India is on the right path in building the evacuation infrastructure through its Rs2.4 trillion (~US$29.6 billion) transmission infrastructure development plan to integrate over 500 gigawatts (GW) of renewable energy capacity by 2030. This would also help integrate more renewable energy capacity from remote regions into the power system and improve grid stability.

Energy storage technologies are evolving rapidly and could play a vital role in increasing the share of renewable energy generation. Pumped Hydro Storage (PHS) projects and Battery Energy Storage Systems (BESS) are promising among energy storage technologies. India is on the cusp of witnessing a spurt in energy storage activity, but it is largely limited to providing a stable renewable energy supply.

> **Energy storage technologies are evolving rapidly and could play a vital role in increasing the share of renewable energy generation.**

As a next step, the country should widen the scope of energy storage applications to provide a variety of grid balancing services rather than viewing energy storage in one dimension of firming renewable energy supply. A well-developed ancillary services market will improve the grid's flexibility, reliability and resilience, allowing a higher integration of variable renewable energy.

Lastly, the Indian government's plan to convert coal-based power plants to operate flexibly to accommodate more renewable energy may hold some benefits of lower capital expenditure requirements and reducing the curtailing of variable renewable energy in the medium term. Technical studies indicate that coal power plants could run at a minimum power load of 10%, and in India at 40%, after modernisation and upgradation of the equipment.

Converting India's coal power fleet to run flexibly will lead to some technical, financial, and regulatory/contractual challenges. The solutions include identifying suitable plants for conversion into flexible plants based on technical and financial parameters, redesigning coal power purchase contracts, and developing markets that allow flexible operations.

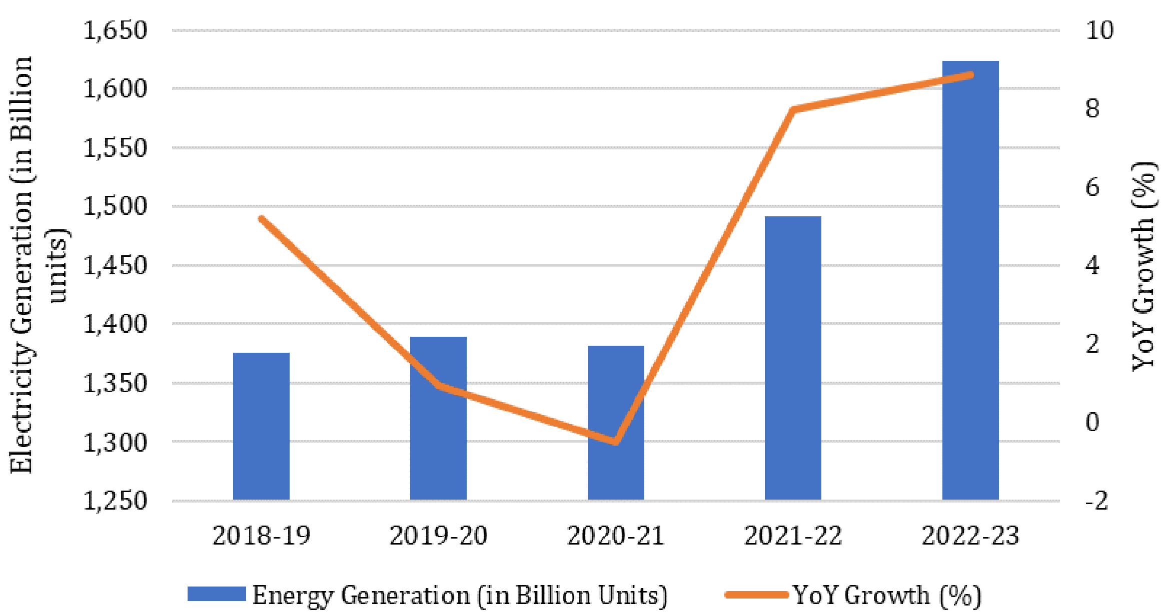
Introduction

Energy security concerns have come to the forefront of India's policymaking in recent months. The sudden rise in commodity prices in the international energy markets following the outbreak of the Russia-Ukraine conflict, coupled with the increasing electricity demand after the lifting of COVID-19 pandemic lockdowns, have turned the focus of the Indian government toward securing energy supplies. This is even as India plans a transition to a greener economy.

India's electricity generation grew from 1,376 billion units in the financial year (FY) 2018-19 to 1,624 billion units in FY2022-23 at a compounded annual growth rate (CAGR) of 4.4% (Figure 1) to meet the growing demand. The average annual power deficit (the gap between power generation and demand) was ~0.5%, with the average peak deficit at ~1.4% during the period. India's peak power deficit reached a high of 4% in FY2022-23 as the country struggled to meet the demand during the summer.

Looking ahead, India's Central Electricity Authority (CEA) expects the country's electricity demand to grow at an annual rate of about 6% in the next decade (2022-2032).

Figure 1: India Electricity Generation (in billion units) and YOY Growth (%), FY2019-FY2023



Source: CEA; IEEFA

New Power Capacity to Come from All Available Sources

The Indian government plans to increase the electricity generation capacity from all energy sources to meet the expected growth in electricity demand. As of March 2023, fossil fuel-based capacity accounts for 57% of the total installed electricity generation capacity, while renewables (including large hydro) account for 41.3%. According to the CEA's National Electricity Plan 2022-32, India plans to add 42.7 gigawatts (GW) of coal power capacity by 2031-32 in the Conservative Scenario.[1] This would take the total installed capacity of coal power plants to 254.6GW by 2031-32 (Table 1).

Table 1: India Electricity Generation Installed Capacity and Projected Capacity, by Source, (GW)

Energy Source	Installed Capacity as on March 2023	Conservative Scenario 2026-27	Conservative Scenario 2031-32	High Demand Scenario 2031-32
Coal + Lignite	211.9	235.1	254.6	262.6
Gas	24.8	24.8	24.8	24.8
Diesel	0.6	0	0	0
Large Hydro	46.9	52.3	57.7	62.3
Wind	42.6	61.4	92.1	121.9
Solar	66.8	174.6	338.6	364.6
Biomass	10.2	13	15.5	15.5
Small Hydro	4.9	5.2	5.4	5.4
Nuclear	6.8	10.1	16.9	19.7
Total	**416.1**	**547.2**	**767.1**	**861.4**

Source: CEA

India's plan to add new coal power capacity instead of being on a coal retirement pathway will make it increasingly difficult for the country to achieve its climate goals stated under the Nationally Determined Contributions (NDCs), which include a commitment to reduce carbon emissions by one billion tonnes by 2030.

New and existing coal power plants risk getting stranded in a carbon-constrained world.[2] The ideal pathway for India to ensure energy security while addressing climate change concerns is to increase the pace of renewable energy deployment along with energy storage options for higher integration of renewable energy in the power system.

India’s power market structure, where distribution companies procure close to 90% of the power generated through long-term power purchase contracts, limits the grid flexibility in absorbing higher shares of variable renewable energy.[3] The majority of power generated by India’s large (>210GW) existing coal power fleet has these fixed long-term contracts with distribution companies.

[1] CEA. National Electricity Plan 2022-32. March 2023.
[2] IEEFA. Cleaning Up the Last Pile of India’s Power Sector Non-Performing Assets. June 2023.
[3] Of the total electricity procured in India in 2021-22, the short-term power market comprised about 12.5%. CEA. Report on Short-Term Power Market in India: 2021-22.

Realising the need for more power system flexibility, the Indian government has initiated plans to usher in a new regime of operating coal power plants flexibly.[4] While the capital expenditure of retrofitting existing coal power plants appears to be much lower than setting up some other flexible options, such as pumped hydro storage and battery energy storage systems, the total cost (fixed and variable) of operating coal power plants flexibly will likely be high due to increased wear and tear of the components.

Regardless, operating coal power plants flexibly will create space for integrating higher shares of variable renewable energy in the power system. As solar energy and wind energy are variable sources, the power generated from these sources needs a flexible power system for greater shares of integration.

> **Battery energy storage systems (BESS) coupled with solar and wind hybrid projects would address the balancing problem to an extent.**

Battery energy storage systems (BESS) coupled with solar and wind hybrid projects would address the balancing problem to an extent. Other measures that would help integrate more variable renewable energy include demand-side management measures and expanding the power transmission network. Demand-side measures, such as time-of-use tariffs/dynamic pricing, would also help by changing the electricity consumption patterns and making energy storage more viable.

Also, building a large, well-connected national grid that can transmit renewable energy from energy-rich regions to high energy-demand regions. Such interconnections also help balance the grid in a high renewable energy scenario.

We discuss these measures and potential challenges in the later section of the report.

Increased Integration of Renewable Energy is Key for Achieving Climate Goals

For India to meet growing electricity demand while addressing climate concerns, increased integration of clean energy, including variable renewable energy (VRE), is essential. While India may plan to use all available energy sources to meet its growing electricity demand, the country has two primary climate goals to achieve:

[4] CEA. Flexibilisation of Coal Fired Power Plant. A Roadmap for Achieving 40% Technical Minimum Load. February 2023.

- Increase the share of non-fossil fuel power installed capacity from the current 40.4% to 50% by 2030 (a moving target – 50% of the increased capacity as of 2030)[5]
- Reduce emissions intensity of the economy by 45% by 2030 from 2005 levels.

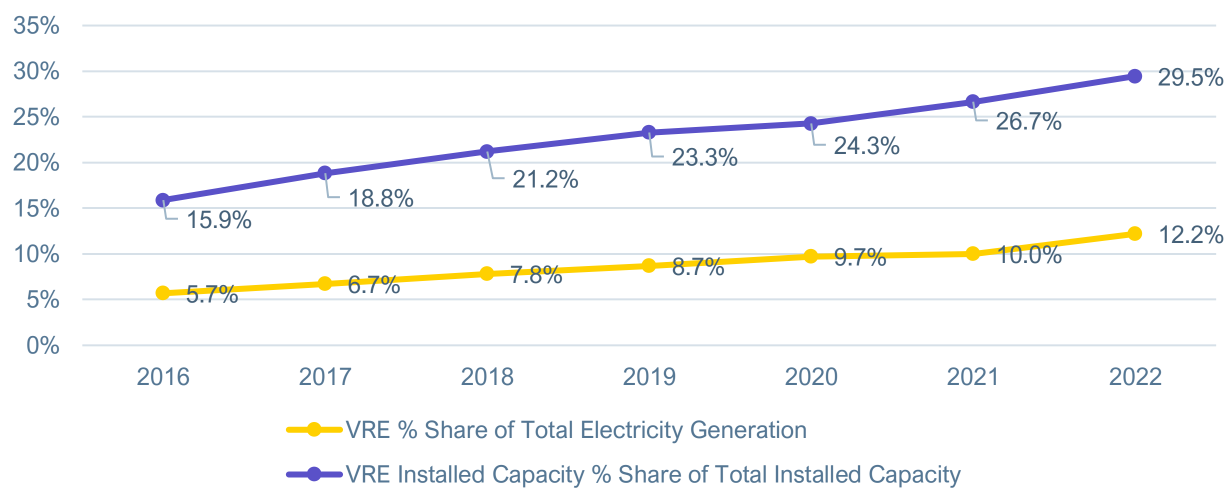
Further, according to India's Long-Term Low Emissions Development Strategy, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2022, the country aims to become a net-zero emitter by 2070.[6]

While raising non-fossil fuel power's installed capacity share to 50% by 2030 may be relatively easier to achieve, reaching the emissions intensity reduction targets requires increased integration of VRE in the power system.

The Goal: Integrating High Shares of Variable Renewable Energy

Over the years, India has witnessed a significant increase in renewable energy capacity additions but not an equivalent increase in its generation. The share of VRE in total installed capacity increased by 13.6 percentage points from 15.9% in 2016 to 29.5% in 2022. During the same period, VRE's share in total electricity generation increased only by 6.5 percentage points, from 5.7% to 12.2% (Figure 2).

Figure 2: Share of Variable Renewable Energy – Generation & Installed Capacity, 2016-2022



Source: CEA; BP Statistical Review of World Energy, 2022

[5] The Indian Government's target mentions "non-fossil fuel" capacity of 50% of total installed capacity by 2030. This includes large hydro and nuclear power in addition to variable renewable energies such as solar and wind power. However, the majority capacity installations contribution will likely come from solar and wind power due to the long construction times and high capital expenditures of large hydro and nuclear power.
[6] Ministry of Environment, Forests and Climate Change. India's long-term low-carbon development strategy, 2022.

The low share of renewable energy in the total generation is primarily because of the following reasons:

- The existing coal power plants have long-term power purchase agreements (PPAs) with two-part tariffs – a fixed payment based on capacity availability and a variable payment to cover the variable fuel costs. The fixed portion of the contract is on a take-or-pay principle, wherein the electricity distribution company (DISCOM) has to pay the power plant even if it does not offtake the electricity. This makes the contract inflexible leading to DISCOMs preferring to purchase coal power to meet peak demand and keep the overall costs low.
- The designs of old coal power plants were such that they would operate at a stable thermal load with a small range of flexibility.[7] Running these plants at a lower thermal load and frequent ramp-ups/downs will lead to a higher degradation of plant equipment and lower the plant's life. These plants need equipment retrofits to operate as flexible generation sources.
- The seasonality of wind power generation and concentration of wind power generation assets in six states leads to grid congestion in high wind power generation seasons. This results in the curtailment of wind power.
- The variable nature of solar and wind power makes them non-dispatchable power sources and hence not ideal for providing on-demand electricity unless supported by adequate energy storage capacity.
- Lack of depth in merchant markets and exchange trading markets limits flexibility in the power system. Merchant markets and/or power exchanges deal with only ~10% of India's electricity.

Pathways to Achieve the Goal

India needs a flexible power system with a combination of grid-balancing options to integrate higher shares of renewable energy. In this section, we discuss the issues, challenges and way forward of some of the promising flexibility and balancing options identified in the earlier sections.

Demand-Side Management

Time-of-Use Electricity Pricing Will Yield Multiple Benefits

Electricity demand management, or demand-side management, includes energy efficiency measures and demand response enabled through varying electricity prices. While energy efficiency reduces the overall electricity consumption, demand response helps shift demand from peak periods to off-peak periods using various mechanisms to reduce the load on the grid. Demand response is a critical tool for policymakers and regulators to lower the need for peak power generation capacity and grid balancing.

[7] The majority of the existing plants can operate at a minimum thermal load of up to 55% with minor retrofits and already do so in certain market conditions.

> **Globally, time-of-use (ToU) tariffs are helping change the electricity consumption pattern.**

Globally, time-of-use (ToU) tariffs are helping change the electricity consumption pattern. These tariffs encourage electricity consumption when the renewable energy supply is high and can even help balance the grid by regulating load from rooftop solar and electric vehicle users. Further, effective ToU tariffs can also improve the economics of energy storage projects by lowering tariffs when storing energy rather than when discharging energy.

ToU tariff designs vary across countries and provinces globally. For example, ToU tariffs in California (U.S.) vary by time of day, type of day and season. Denmark introduced a more dynamic (hourly) ToU pricing in 2020. The United Kingdom gradually moved from static ToU tariffs to dynamic ToU tariffs after undertaking consumer awareness and engagement programmes. The Californian pilot studies found that peak electricity demand decreased 6.5-11% for every 10% increase in the ratio between the peak and off-peak ToU rates.[8]

India Should Transition to a Dynamic ToU Pricing Regime

Historically, the objective of providing universal electricity access at affordable prices drove India's electricity tariff design. It involved a certain segment of users (e.g., commercial and industrial) compensating another segment (e.g., agriculture and residential) by paying higher rates. This kind of electricity pricing and tariff design complicates introducing truly market-driven ToU tariffs.

Some electricity distribution companies in India already charge different tariffs for different times of the day for industrial and commercial consumers. However, some of these tariffs have minor variations throughout the day and are pre-determined and static. Partially addressing this issue, the union government issued guidelines for the range of tariff variation to be achieved from normal tariff during solar power generation and peak periods, which is 10-20% lower and 10-20% higher, respectively.[9] Studies indicate that successfully implementing a dynamic ToU pricing regime can reduce peak demand by 5-25%.[10]

India should take the following step-wise approach to move to a dynamic ToU pricing regime:

- Introduce static ToU tariffs to all segments of consumers, including agriculture and residential.
- Undertake consumer awareness programmes and update infrastructure to introduce advanced metering infrastructure, energy management tools and digitisation of data/information, among others.
- Introduce dynamic ToU pricing that reflects spot market conditions for all consumer segments.

[8] IEA and NITI Aayog. Renewables Integration in India. 2021.
[9] Ministry of Power. The Electricity (Rights of Consumers) Amendment Rules, 2023.
[10] Shakti Sustainable Energy Foundation and ISGF. Design of Robust Time of Use Framework for Electricity Tariff in Gujarat. 2020.

The benefits of ToU tariffs outweigh the costs, with tariffs acting as an important market price signalling system with multiple benefits of lowering consumer costs, flattening the demand load curve and reducing the need for balancing services. India should prioritise implementing this regime for better load management and increased integration of renewable energy.

A Large Inter-Regional Connected Grid

A well-connected national grid that transcends several regions ensures optimal utilisation of uneven distribution of energy sources. This allows electricity transmission from low-demand, energy-resource-rich regions to high-demand, low-energy resource regions. Further, a strong inter-regional grid will better absorb and balance regional variations in renewable energy generation and reduce renewable energy curtailment.

> **A strong inter-regional grid will better absorb and balance regional variations in renewable energy generation and reduce renewable energy curtailment.**

Realising the importance of a national grid, India moved toward establishing a synchronous power grid, interconnecting all five regional grids by commissioning the Raichur-Sholapur line in 2013. The country now has a well-functioning, synchronised national grid.

In December 2022, India unveiled the plan "Transmission System for Integration of over 500GW RE [renewable energy] Capacity by 2030" to connect several areas with high solar and wind energy potential in Ladakh, Rajasthan, Gujarat, Andhra Pradesh and offshore regions of Tamil Nadu and Gujarat to the Inter-State Transmission System (ISTS).[11] The length of the transmission lines and sub-station capacity that India plans to set up by 2030 is an estimated 50,890 circuit kilometres and 433,575 megavolt-amperes (MVA), respectively. The government estimates the project to cost Rs2.442 trillion (~US$29.6 billion). The plan is to integrate 537GW of renewable energy capacity by 2030 to meet India's climate goals.

Further, as part of the Union Budget for 2022-23, the Indian government announced that it would integrate Ladakh's power grid with the inter-state transmission system for Rs207 billion (~US$2.5 billion).[12] The government expects this connection to help evacuate 13GW of renewable energy from the remote region of Ladakh.

Building solar and wind power plants takes relatively less time than building a transmission system to evacuate power from remote regions. India is on the right path in proactively building the

[11] CEA. Transmission System for Integration of over 500 GW RE Capacity by 2030. December 2022.
[12] Rs.8,300 billion (US$1.0 billion) will be sponsored by the Union Government.

transmission infrastructure, which would, in turn, help integrate more renewable capacity into the power system and improve grid stability.

Rethinking Energy Storage: From a Generation Asset to a Grid-Balancing Service

Energy storage can provide various grid services that facilitate higher integration of renewable energy and will play a critical role in helping India achieve its climate goals. It can store renewable energy during excess generation and supply during low generation. It can also provide ancillary services (system frequency regulation, load following), load shifting and/or voltage support.

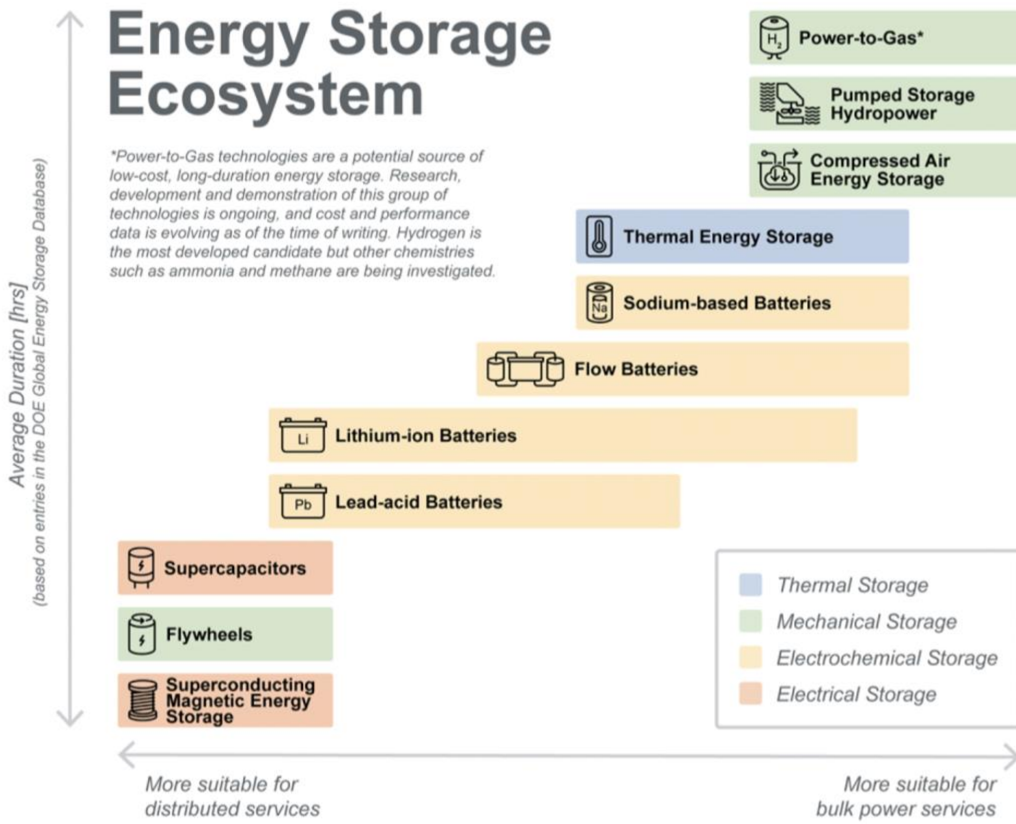
Pumped Hydro Storage (PHS) and Battery Energy Storage Systems (BESS) are two energy storage technologies that can play an important role in decarbonising India's electricity grid.

One can classify energy storage solutions in various ways, viz., technology (mechanical, electrochemical, thermal), duration of storage (quick-response, short duration or medium-response, long duration), size of storage (backup, transmission or distribution level, generation level) and place of interconnection (front-of-the-meter or behind-the-meter).

Different energy storage technologies can provide a range of flexibility, reliability and resilience services to the power system based on their nature, costs and design (Figure 3). PHS is the most evolved grid-scale and long-duration technology among the identified energy storage technologies. BESS, too, is rapidly advancing due to large-scale applications in other sectors, such as electric vehicles and electronics.

> **Different energy storage technologies can provide a range of flexibility, reliability and resilience services to the power system based on their nature, costs and design.**

Figure 3: Ecosystem of Energy Storage Technologies and Services



Source: USAID Energy Storage Guide for Policymakers, 2021, NREL

Noting the role PHS could play in grid stabilisation and meeting peaking power demand, the Indian government has drafted various measures for its deployment. Currently, India has eight operational PHS projects with a combined capacity of 4.8GW, four projects totalling 2.8GW under construction, and 27 projects, totalling 29.9GW under various preliminary stages of development.[13] The CEA estimates an on-river PHS potential of 103GW in India as of date.

PHS projects have inherent advantages in providing various grid-balancing services that can facilitate higher levels of VRE integration. PHS projects are clean, can have grid-scale, have quick response times (in minutes rather than hours compared to fossil fuel-powered plants) and have a long lifetime of 40-50 years.

Given the different response times (minutes for PHS versus seconds for BESS) and different cost structures, PHS and BESS can provide complementary grid services in addition to flexible thermal/coal power systems.

[13] Ministry of Power. Guidelines to promote development of Pump Storage Projects (PSP). 10 April 2023.

BESS has the potential to see a rise in the number of use cases. Technology advancements and increasing manufacturing capacity have led to a sharp fall in BESS costs (79% over 2013-2023), specifically, lithium-ion battery-based BESS.[14] Further, sodium-ion batteries, an alternative to lithium-ion batteries, are also witnessing increased interest among battery manufacturers, which could lead to a further decline in BESS prices.

India is witnessing a growing interest in round-the-clock (RTC) or dispatchable renewable energy from consumers and electricity distribution/aggregator companies (Table 5). Renewable energy producers are developing wind plus solar hybrid projects combined with energy storage or procuring storage-as-a-service to meet the demand for RTC renewable energy.

Table 2: Energy Storage Projects in India

Procurer	Developer	Project Capacity (MW)	Storage Capacity (Megawatt -hours (MWh))	Application	Storage Technology	Cost/Tariff	Tariff Structure	Notes
Solar Energy Corporation of India (SECI)	Greenko	900	-	Renewable energy + storage (supply of firm green power)	Technology Agnostic	Rs6.12(US$0.07)/ kilowatt-hours (kWh) peak; off-peak: Rs2.88 (US$0.03)/kWh	Two-part tariff: peak and non-peak	Under construction
SECI	ReNew Power	300	-	Renewable energy + storage (supply of firm green power)	Technology Agnostic	Rs6.12 (US$0.07) /kWh peak; off-peak: Rs2.88 (US$0.03)/kWh	Two-part tariff: peak and non-peak	Under construction
Gujarat Urja Vikas Nigam Ltd (GUVNL)	-	500	250MWh to provide six hours of supply	Renewable energy + storage (supply of firm green power)	Technology Agnostic	Off-peak: Rs2.29 (US$0.03)/kWh	Two-part tariff: peak and non-peak	Request for Selection
SECI	JSW ReNew Energy Five	-	1,000 (2X500 MWh)	Standalone storage system to provide grid ancillary services	Battery storage	Rs1.1 million/MWh (US$13,379/MWh)	Fixed capacity payment of Rs1.1 million/MWh (US$13,379/MWh) for 12 years	Received the Letter of Award. 60% of the storage capacity is tied up with SECI, while the remainder can be sold in the open market.
NTPC	Greenko	-	3,000	Standalone storage system to provide the storage solution to renewable energy producer	Technology Agnostic	Rs2.79 million/MWh/year (US$33,934/MWh/year)	25-year energy storage service agreement on an annual fixed charge basis	NTPC plans to use the storage facility to meet its RTC renewable energy supply requirements.
Tata Power Delhi Distribution	AES and Mitsubishi Corporation	10	10	Standalone storage system to provide various grid support services	Battery storage	Not Available	Not Available	Operational
Serentica Renewables	Greenko	-	1,500	Standalone storage system to provide the storage solution to renewable energy producer	Pumped Hydro Storage	Not Available	Not Available	Under construction

Source: News reports; IEEFA

[14] BloombergNEF. Top 10 Energy Storage Trends in 2023. 11 January 2023.

India is witnessing energy storage deployment largely in one area of application, i.e., energy supply/generation. But energy storage can play a much larger role at a system level.

Although the Central Electricity Regulatory Commission (CERC) notified Ancillary Services Regulations in January 2022, India is yet to see the deployment of energy storage specifically to provide ancillary services except for the 10MWh battery storage system in Delhi. India's power system can absorb larger shares of VRE if a much wider grid-ancillary services market[15] becomes operational.

We discuss some of the measures that policymakers and regulators could take to develop the energy storage market in India in the sections below.

Develop Policy and Regulatory Framework

India's grid ancillary services system, defined in a narrower sense, similar to Secondary Reserve Ancillary Services (SRAS), has been operational since 2017. Further, CERC notified a broader ancillary services regulation, which includes primary, secondary and tertiary reserves, in January 2022.[16] However, implementation guidelines by the National Load Dispatch Centre (NLDC) at the national level and by Regional Load Dispatch Centres (RLDCs)/State Load Dispatch Centres (SLDCs) at the regional/state levels are still pending.

Reserves can be broadly classified basis on the response times and duration of response as stated in Table 6:

Table 3: Types of Power Reserves

Reserve Type	Response Time	Full Availability/Deployment	Duration
Primary	Instantaneous	<=30 seconds	Up to 5 minutes
Secondary	>=30 seconds	<=15 minutes	Up to 30 minutes or until replaced by tertiary reserves
Tertiary	Typically >15minutes		

Source: POSOCO

Further, policies and regulations should favour procurement of ancillary services more through competitive and open markets for higher value realisation for energy storage systems.[17] BESS can provide a quick response (primary reserve) and meet the expected demand longer than earlier

[15] Ancillary services are grid balancing services that ensure reliability, safety and security of the grid and includes Primary Reserve Ancillary Service, Secondary Reserve Ancillary Service, and Tertiary Reserve Ancillary Service, active power support for load following, reactive power, black start and such other services defined in India's Grid Code. Primary, Secondary and Tertiary reserves are classified based on response time and duration of support.

[16] CERC. Ancillary Service Regulations, 2022. 31 January 2022.

[17] IEEFA. India's Power Market Design Needs to Evolve. 25 August 2022.

thought soon as grid-scale systems become cheaper. Further, BESS can meet secondary reserve requirements as well.

PHS is already suitable for secondary reserve capacity and can offer longer-duration backup power at relatively lower costs. Developing real-time markets in addition to day-ahead markets will allow energy storage systems to provide multiple services to the grid, in other words, value stacking. It can also help improve the overall economics of energy storage systems.

PHS can become more viable after the central government addresses certain taxation issues. These include avoiding double taxation (for input and output power; applicable also for BESS) and making the goods and services tax (GST) applicable equivalent to renewable energy projects. Further, treating PHS projects separately from conventional, multi-use hydro projects and relaxing environmental and forest clearances can help speed up their deployment. PHS projects can come up on existing hydro projects and have a smaller footprint even when built as greenfield projects.

Explore New Procurement Mechanisms

As India moves from considering energy storage assets as simply generation assets to grid-balancing assets, it will have to adopt different procurement mechanisms other than competitive bidding based on the lowest tariff.

Traditional simple metrics, such as Levelised Cost of Energy (LCOE) or Levelised Cost of Storage (LCOS), will not be appropriate as energy storage systems will operate in a more dynamic setting to provide grid-ancillary services. Here, the cost of grid electricity and the number of charge cycles will vary over time. India should adopt price discovery through real-time market-based mechanisms and procurement of energy storage-as-a-service.

In this respect, the CERC's approval for the Indian Energy Exchange to launch the High-Price Day Ahead Market (HP-DAM), which will allow electricity generators to sell power at a price as high as Rs50 (US$0.61) per kWh, is a step in the right direction.[18] This would apply to power-generating units running on imported natural gas and coal as well as BESS.[19]

Address Financing Challenges

Both PHS and BESS projects are at an early stage of development in India and would need financing support to scale up. While the costs of these projects should fall with time, these technologies have not yet had a large-scale demonstration, especially for providing grid balancing services.

> **Both PHS and BESS projects are at an early stage of development in India and would need financing support to scale up.**

[18] At present, the applicable price limit in the Day Ahead Market on the power exchanges is Rs12 (US$0.15) per kWh.
[19] The Economic Times. Indian Exchange to launch High Price Day Ahead Market segment next month. February 2023.

Lithium-ion battery prices have decreased globally in the last decade, driven by increased mining of battery minerals, such as lithium, nickel, and cobalt, and more refining capacity coming online. According to the BloombergNEF data, the volume-weighted (by end-use category) average[20] lithium-ion battery pack prices have reduced from US$732/kWh in 2013 to US$151/kWh by 2022.[21] These are further expected to fall below US$100/kWh by 2026, driven by investments in research and development, manufacturing process improvements and capacity expansion. However, supply chain constraints and rising demand will continue to keep upward pressure on prices.

BESS costs will vary according to the storage application and region. They are often difficult to forecast. According to a study by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy, the battery capital cost for a 4-hour lithium-ion battery system will likely reduce to a range of US$143-248/kWh by 2030 from US$350/kWh in 2020.[22]

In India, energy storage costs (technology agnostic – but most likely to include PHS and BESS) in the recent tenders discovered LCOE costs of supplying peak green power at Rs6.12/kWh (US$0.07/kWh). Storage/battery technologies and use cases form the basis for multiple price estimations and forecasts.[23] However, these costs will evolve with greater deployment of storage projects for various applications/use cases via different procurement mechanisms.

Despite studies, such as the ones by BloombergNEF and NREL, predicting a fall in battery prices across applications, financing for grid-scale energy storage projects will be challenging as financiers lack real-life data and an understanding of costs associated with such projects. India is yet to witness a pure-play, grid-scale BESS deployment. Further, the lifetime costs and revenues of BESS as a generation asset and as a balancing asset will vary and needs demonstration.

> “ **Procurement and financing mechanisms must evolve given the nascency of using PHS and BESS for grid-balancing services.**

Procurement and financing mechanisms must evolve given the nascency of using PHS and BESS for grid-balancing services. Competitive bidding may not always be a suitable procurement mechanism, especially for new technologies and applications. Energy storage projects for grid-ancillary services will require demonstration projects with financing support through viability gap funding or capital subsidies.[24] Developers will need to tap concessional finance from multilateral development banks

[20] Weighted average survey value includes 178 data points from passenger cars, buses, commercial vehicles, and stationary storage.
[21] BloombergNEF. Top 10 Energy Storage Trends in 2023. January 2023.
[22] NREL. Cost Projections for Utility-Scale Battery Storage: 2021 Update. 2021.
[23] Mercom. Levelized Cost of Storage for Standalone BESS Could Reach Rs. 4.12/kWh by 2030: Report. June 2020.
[24] Government of India announced that it would support the deployment of 4,000MWh of BESS through viability gap funding (VGF) mechanism designed to provide capital support to public-private partnership (PPP) projects.

and climate funds for energy storage projects with the help of the Indian government to lower the cost of capital.

One of the ways the Reserve Bank of India could ease international borrowing is by categorising clean energy projects (including energy storage projects) as a separate sector and relaxing the sectoral norms for external commercial borrowings. It can also ease domestic lending in several ways, including designating sustainable bonds from top-rated corporate issuers as Statutory Liquidity Ratio (SLR)-eligible, extending priority sector lending and introducing a climate risk capital buffer linked to loan composition.[25]

For hydropower projects specifically, the Indian government is drafting an action plan to lower the costs by extending budgetary support to develop enabling infrastructure.[26] Further, the government may develop pathways for low-cost, longer-term finance while mandating a hydropower purchase obligation to lower the hydropower cost to the average national power purchase cost range. These measures would likely help in reducing the cost of hydropower in India.

Tackle the Knowledge Gap

There is a significant gap in knowledge and understanding among the stakeholders concerning energy storage, as technologies and applications are not only new but are rapidly evolving. Therefore, grid operators (at regional and state levels – RLDCs/SLDCs) and DISCOMs require theoretical and practical training programmes on energy storage on a priority basis to ensure the effective deployment of energy storage systems and their efficient use.

Flexing Coal Power Plants

Globally, various methods, depending on the availability of resources and the country's energy mix, address the issue of flexible generation. Technically, among fossil/thermal power sources, gas-based power plants are more suitable for flexible generation due to their quick ramp-up and ramp-down capabilities.[27] However, due to its small installed base (24.8GW versus 210.4GW[28] for coal power plants) and competing demand for natural gas from city gas distribution and fertiliser production sectors, the gas-based power fleet is inadequate to provide flexible power generation at scale in India.

> **Although flexible coal power generation is a sub-optimal solution, it may be one of the cost-effective solutions in terms of capital expenditure in the near term.**

[25] The Hindu Business Line. RBI's crucial role in energy transition. 5 June 2023.
[26] The Economic Times. Tweaking of funding norms for hydropower projects in works. March 2023.
[27] IEEFA. Flexible Generation: A role for India's stressed and stranded gas-based power plants?. 6 October 2022.
[28] As on December 2022

The lack of readily available flexible options, such as gas-fired power plants and PHS, pushed the Indian government to look to the coal fleet to provide flexible power generation, given the latter's large installed capacity base coupled with abundant domestic availability of coal. Although flexible coal power generation is a sub-optimal solution, it may be one of the cost-effective solutions in terms of capital expenditure in the near term. A 2021 study published in the journal *Energy Policy* estimated that the upfront capital costs required to retrofit existing coal power plants to be lower than other flexible sources, such as PHS (4x higher) and lithium-ion battery storage (20x higher) at various plant-load factor levels.[29]

Other studies and reports (by the CEA and others, Table 2) indicate that the capital costs of PHS and BESS are approximately 12-26 times higher than the indicative retrofitting cost of existing coal power plants. The cost of retrofitting a coal plant will depend on several factors, such as the size of the plant, the age of the equipment and the plant design type.

Table 4: Capital Expenditure (Rs Million/MW)

Coal Plant Retrofit	Pumped Hydro Storage	Battery Energy Storage System
0.41-1.00	12	26

Source: Central Electricity Authority, India; Media Reports

Besides accommodating more renewable energy generation, there are some additional advantages to the flexible operation of coal plants. First, it saves already-established coal power plants from getting stranded. Second, it increases the per unit cost of coal power, making renewable energy plus storage more competitive in the merit order dispatch system.

Noting the positives of having flexible coal power plants, the CEA issued Flexible Operation of Coal-based Thermal Power Generating Units Regulations in 2023 after years of studying the technical and economic feasibility.[30] According to the regulations, all grid-connected and load dispatch centres-connected coal-based power plants, whether state-owned or privately owned, should be capable of providing flexible power generation.

Coal plants that are unable to achieve a minimum power level of 55% at present have to complete the target within one year from the notification of these regulations. Further, the CEA specified a roadmap (timeline) for all the coal power plants to be suitably designed or retrofitted to operate flexibly with a minimum power level of 40% in a phase-wise manner in a February 2023 report.[31]

The generating units shall have a ramp rate capability of a minimum of 3% per minute for their operation between 70-100% of maximum continuous power rating, a minimum of 2% per minute for

[29] G. Shrimali via Energy Policy. Managing power system flexibility in India via coal plants. March 2021.
[30] CEA. Flexible Operation of Coal based Thermal Power Generating Units Regulations. 2023.
[31] CEA. Flexibilisation of Coal Fired Power Plant. February 2023.

their operation between 55-70% of maximum continuous power rating and a minimum of 1% per minute for their operation between 40-55% of maximum continuous power rating.

While the CEA has issued broad regulations and a potential roadmap, implementing these will fall under the purview of State Electricity Regulatory Commissions (SERCs) for some of the plants. Converting existing coal power plants and building new ones to operate flexibly will likely usher technical, financial and contractual challenges. We discuss these issues and potential solutions below.

Technical

Every coal power plant connected to the grid in each state needs technical feasibility studies. Some of the technical parameters that these technical feasibility studies must consider for the flexible operation of coal power plants are:

- Minimum thermal load possible
- Ramp-up and ramp-down rates
- Startup and shutdown times

Coal power plants in India have traditionally operated as base load power plants, i.e., continuous power generation with minimum power generation requirements. According to the previous Indian regulations, the minimal technical load of a coal power plant is 55%. The new flexible operation regulations revise this to 40%. As a result, some older plants will likely require significant equipment retrofits to meet the specified operations criteria.

While achieving a minimum power load of 40% may appear challenging, an 875 megawatt (MW) coal power plant in Heyden, Germany, successfully demonstrated stable operation at a minimum thermal load of 10%.[32]

Financial/Contractual

The existing coal power plants in India, designed for base load operations, have long-term power purchase agreements (PPAs). The PPAs have a two-part tariff – an annual fixed (capacity) charge for recovering capital expenditure and return on equity and a variable (energy) charge for each unit of energy supplied to recover the fuel expenses.

Conversion of coal power plants into flexible power plants (retrofitting) will increase their fixed and variable costs and warrant resetting the power purchase prices. Flexible operation of coal power plants will involve additional capital expenditure and operations and maintenance (O&M) expenditure and reduce plant life and, thereby, return on equity.

[32] CEA. A Roadmap for Flexible Operation of Thermal, Gas, and Hydropower Stations to Facilitate Integration of Renewable Generation. January 2019.

Capital expenditure to retrofit old plants will depend on the equipment's age and the unit's size, among other factors. The following are the capital cost estimates from the pilot studies done so far (Table 3).

Table 5: Retrofitting Coal Power Plant - Capital Cost

Unit Name	Unit Size (MW)	Cost (Rs million)	Cost per MW (Rs Million)	Minimum Thermal Load
Siemens – NTPC Dadri Unit 6	490	200	0.41	40%
GE – NTPC Talcher Unit 2	500	500	1.00	40%
Agora, 2017 – German power plant			7.0-23.0	40%

Source: Central Electricity Authority, India; Agora Energiewende

Flexible operation of coal power plants leads to faster deterioration of power plant components and frequent replacement of some parts leading to higher O&M costs. We provide the estimated increase in O&M costs in Table 4.

Table 6: Operations and Maintenance Costs Increase Due to Flexibility Measures

Unit Size (MW)	Per MW (CERC, 2017 – Rs million)	Percentage Increase (Range based on event)
200	2.87	0.01-1.59%
500	1.92	0.03-2.73%

Source: Central Electricity Authority, India

In total, combining the fixed and variable components, a study estimates the additional cost of converting a coal power plant to operate flexibly is estimated to be in the range of 5-10% of the baseload plant's total cost in net present value (NPV) terms and 8-22% of the plant's total cost in levelised terms.[33]

The PPAs of the coal power plants converted to operate flexibly would need revision to recover the costs incurred for retrofitting and operating as flexible capacities. In addition, the government should develop a regulatory framework to allow coal power plants to offer flexibility as a service through market mechanisms.

[33] G. Shrimali via Energy Policy. Managing power system flexibility in India via coal plants. March 2021.

India should first focus on converting the coal plants with the highest variable cost as they face the highest risk of getting stranded in the future electricity markets with a larger share of renewable energy. This would help keep the impact of converting the coal power fleet into flexible power plants on the overall system cost lower. The key is to find suitable coal power plants for flexible operation with reasonable investment and low-cost impact on the electricity system.

Conclusion

India's inability to integrate/absorb more VRE will only exacerbate with more renewable energy capacity addition every year. While renewable energy capacity addition is growing at a healthy rate, its share in the energy supply mix is not.

Increasing the absorption of VRE in the power system requires a combination of flexibility and grid-balancing measures. This includes introducing demand-side management measures through dynamic ToU electricity prices for all consumer segments. When implemented effectively, ToU prices will yield multiple benefits by shifting demand and reducing the need for load balancing.

> **Dynamic electricity prices coupled with a large, well-connected national grid would help integrate a higher share of VRE by matching supply and demand across regions at market-determined prices.**

Dynamic electricity prices coupled with a large, well-connected national grid would help integrate a higher share of VRE by matching supply and demand across regions at market-determined prices. Adequate transmission infrastructure will also help reduce the seasonal curtailment of VRE in some regions at present.

Energy storage technologies, such as PHS and BESS, hold promise and could play a vital role in providing grid-balancing services. However, India's perception of energy storage has to change from simply assets that allow a round-the-clock supply of renewable energy to assets that provide various grid services. Widening the use of energy storage technologies requires a favourable policy and regulatory framework, financial support, and personnel training.

Lastly, converting existing coal power plants to operate flexibly will ensure the utilisation of a large existing fleet to provide load-balancing services and create space for integrating higher shares of VRE. However, operating coal power plants flexibly will likely give rise to several technical, financial and contractual challenges. There is a need for policy and regulatory changes to redesign the coal power contracts and offer flexible services through market mechanisms.

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