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SHAPING MODERN INDIA'S POWER SYSTEMS

MAKING COAL-BASED POWER PLANTS FLEXIBLE TO EFFECTIVELY INTEGRATE RENEWABLE ENERGY: A PILOT INTERVENTION

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GTG-RISE

Innovative, evidence-based approaches

United States Agency for International Development (USAID)'s Greening the Grid-Renewable Integration and Sustainable Energy (GTG-RISE) initiative, the central component of Greening the Grid (GTG) program, is a bilateral program with the Ministry of Power, Government of India, under the U.S.-India Strategic Clean Energy Partnership (SCEP). GTG-RISE conducted a series of prioritized innovation pilots and demonstrations to validate technologies and solutions to support large-scale integration of renewable energy into the Indian power grid. The GTG-RISE initiative is implemented by Deloitte Consulting LLP. The pilot on coal-based flexible power generation was conducted with support from M/s Intertek, U.S.

"One third of India's coal based power generation capacity should be made ready for flexible generation and dynamic simulation models could play a key role. The study reports supported by USAID & IGEF are pre-cursor to ascertain flexible operations for many of these units."

Vivek Kumar Dewangan
Joint Secretary (Thermal & International Co-operation),
Ministry of Power, GOI

Photo Credit - GTG RISE

BACKGROUND

WHY FOCUS ON FLEXIBLE POWER GENERATION

India is witnessing unprecedented expansion of its renewable energy (RE) capacity, driven by the Government of India's strong commitment to decarbonization. The country has set ambitious clean energy goals, with a target of reaching RE capacity of 175 gigawatt (GW) by 2022 and 450 GW by 2030. As renewable sources like wind and solar are variable and have unpredictable generation, their increased deployment demands a fundamental change in how power systems operate. Studies suggest that integration of 175 GW of RE into the power grid will lead to daily net load swings of more than 80 GW and pose techno-commercial challenges, necessitating the overall power generation to be more responsive and flexible.

In India, given the country's limited gas and hydropower resources, coal-based thermal power plants is the preferred choice for flexibility to accommodate RE. Thermal power plants must adjust their output based on power generation from RE to ensure there is no 'over-generation' in the power system, which can lead to frequency-based grid instability, and subsequently even grid collapse. When there is more RE power in the system during daytime, coal plants must reduce their generation to the technical minimum but increase their output in the evening when RE generation starts declining. In some instances, coal plants may have to start and stop frequently to ensure grid stability. Ignoring such flexibility requirements can lead to severe grid imbalance. Proactive attention and effort toward securing flexibility in operations of coal-based power plants is thus an imperative.

PILOTING FLEXIBLE POWER GENERATION AT COAL-BASED POWER PLANTS

Large-scale integration of RE introduces additional variability and uncertainty into the power system, making conventional power stations' responsiveness and operational flexibility critical to sustain grid reliability and stability. The Government of India's Ministry of Power (MoP) and the Central Electricity Authority (CEA) have taken cognizance of this imperative and set an agenda for thermal units to operate in tandem with RE generation. In support of this new operating regime for greater integration of RE, the GTG-RISE initiative conducted a pilot on flexible generation of coal-based power plants.

OBJECTIVES OF THE PILOT

USAID's GTG-RISE pilot was conceived to mitigate the operational challenges that large-scale RE integration would pose for grid performance. The overarching aim was to ascertain coal-based generation units' technical and commercial feasibility for faster ramp up/ramp down of operations in response to variable RE and the technical minimums needed vis-a-vis the existing operational procedures, equipment, processes, and practices. The pilot also sought to identify the measures and interventions (including retrofits and operational changes) needed and the cost of such interventions. It also aimed to examine the compensation requirements due to cycling, conduct low-load test runs at select units, and strategize on fleet-wide operations of utilities with coal-based units.

The pilot's specific objectives were to:

- Study and recommend the changes required in coal-based power plants
- Estimate the cost of achieving flexibility, including initial capital investment and operational and maintenance expenses
- Support in building a business case with associated commercial compensation mechanisms for flexibility to inform discussions with MoP, CEA, and Central Electricity Regulatory Commission (CERC)
- Provide insights to CERC on compensation for generation units to act as flexible units
- Train and enhance capacity of stakeholders through knowledge dissemination workshops and other events
- Ensure scale-up and replicability of the pilot for larger adoption of flexible operations

The GTG-RISE pilot on coal-based flexible generation supports the Ministry of Power's efforts to build a resilient and self-reliant power sector and meet India's ambitious RE goals.

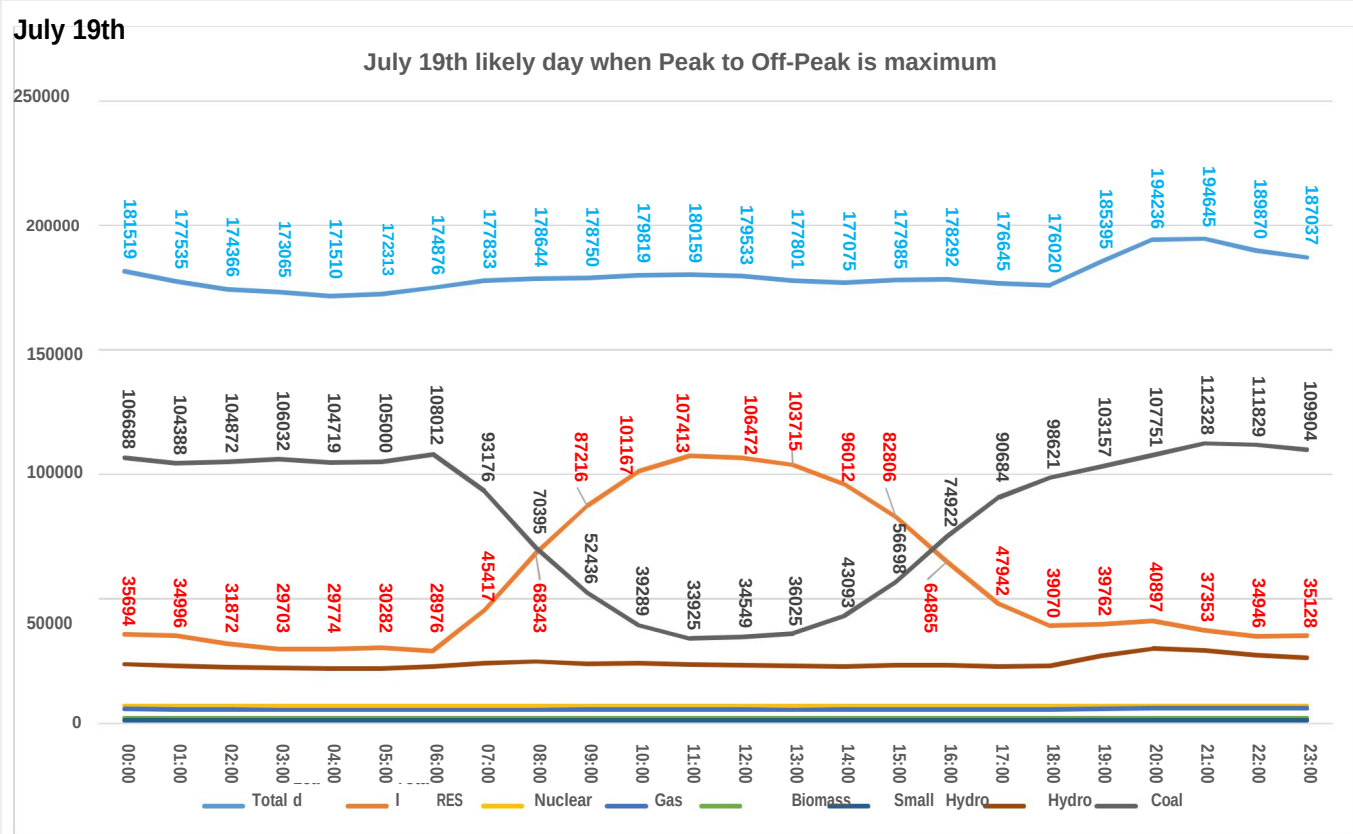
Facilitating India's RE integration through flexibility: A critical need

A grid modelling study was conducted by the National Renewable Energy Laboratory (NREL), U.S., under USAID's GTG program in collaboration with India's Power System Operation Corporation Limited (POSOCO) and U.S.'s Lawrence Berkeley National Laboratory (LBNL). The study established that the Indian power grid would be able to integrate and balance out variable RE in 2022 with minimal curtailment, provided coal-based power plants can achieve lower technical minimums and ramp rate. It emphasized the flexibility of India's coal fleet as critical to minimize RE curtailment.

The study also revealed that a technical minimum of **70% for coal-fired plants would require 3.7% RE curtailment** to maintain grid stability. RE curtailment would reduce to 0.76% if the plants operate at 40% technical minimum of their capacity. The flexibility requirement would be significant even with modest levels of RE penetration. As shown below, a typical future net demand curve for a day in India (in 2021¬–2022) predicts that ramp down rate requirements **(310 MW/min)** and peak hour ramp up rate (305 MW/min) will lead to partial loading and two shifting of conventional plants (mostly coal-based).

Such a scenario could result in utilities like NTPC Ltd. having a majority of its coal-based fleet needing to flex its coal units from an operating plant load factor (PLF) of 55% in today's regime to 20¬–25%, with significantly high ramp up and ramp down requirements.

Grid demand on July 27, 2021, and contribution from various sources, including coal

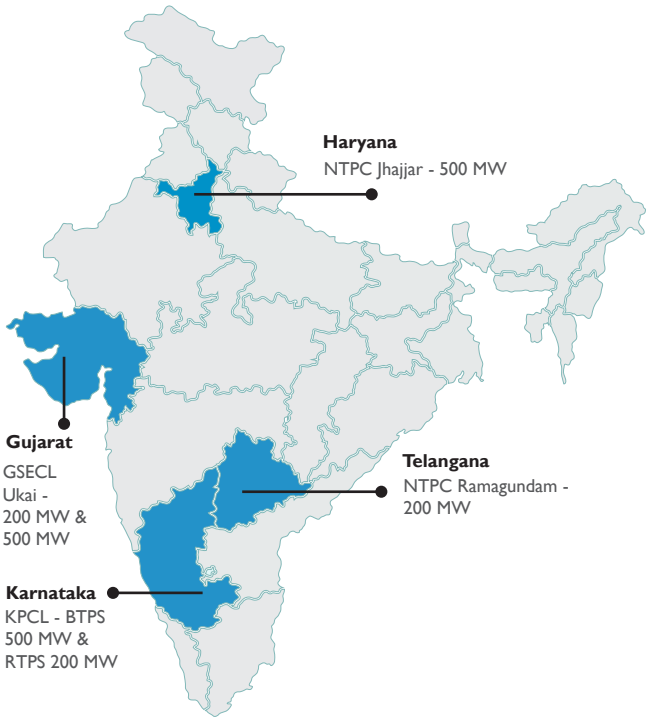


CEA report on Flexible Operation for Thermal Power Plant for RE Integration – Jan. 2019
BAU refers to 'business as usual'.

PILOT SITES

USAID through the GTG-RISE initiative, piloted flexible power generation at both national and state-level coal-fired power plants. At the national level, the pilot was implemented in partnership with NTPC, the central power generation utility that produces almost 74% of the country's coal-based power generation. The pilot was conducted at two of NTPC's coal units: i) a 200 MW unit at Ramagundam power plant, situated in Ramagundam in Peddapalli district of the state of Telangana and ii) a 500 MW unit at Jhajjar power plant, situated in Khanpur village, Jhajjar district, Haryana.

The state-level pilot was implemented in partnership with Gujarat State Electricity Corporation Limited (GSECL) at two of its coal-based units: i) a 200 MW unit at Ukai thermal power plant, located in Vagda in the state of Gujarat and ii) a 500 MW unit also at Ukai.



The four sites together made a representative sample of coal-based central and state power plants, with a mix of old and new units spread across Northern, Western, and Southern regions. The intervention at these plants aimed to pave the way for scaling flexible generation across India's coal-based generation fleet.

USAID's GTG-RISE pilot on coal-based flexible generation supports the Ministry of Power's efforts to build a resilient and self-reliant power sector and meet India's ambitious RE goals.

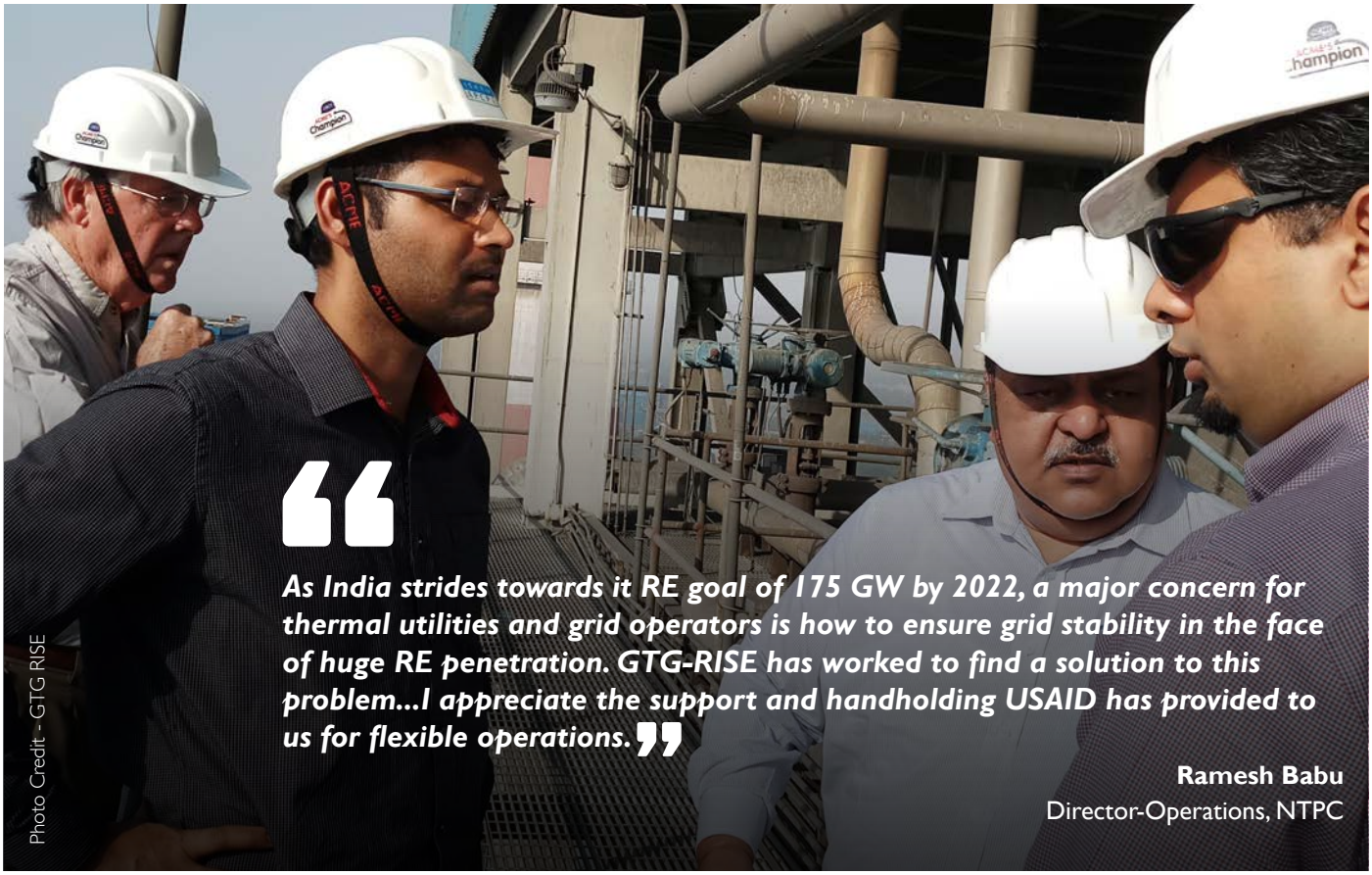


Photo Credit - GTG RISE

"As India strides towards it RE goal of 175 GW by 2022, a major concern for thermal utilities and grid operators is how to ensure grid stability in the face of huge RE penetration. GTG-RISE has worked to find a solution to this problem...I appreciate the support and handholding USAID has provided to us for flexible operations."

Ramesh Babu
Director-Operations, NTPC

PILOT'S APPROACH AND METHODOLOGY

The pilot, implemented closely with NTPC and GSECL, leveraged best practices and international experience to identify the technical interventions and operational changes needed to implement flexibility in coal-based generating units. The GTG-RISE team conducted site visits, carried out damage cost modeling studies, undertook test runs, and recommended specific measures. The pilot intervention was conducted over a period of four years (2017–2020) in a phased manner (see the figure below/alongside).

Pilot on coal-based flexible power generation: Summary of stage-wise initiatives

Stage 1: Techno Economic Assessment & Roadmap

- Technical due diligence and detailed feasibility assessment
- Establishing reliable costs of flexibilisation – capex as well as opex

Stage 2: Regulatory Pathway and Fleet Level Strategies

- Assistance in framing Regulatory Mechanisms for Flexibility
- Assistance in building fleet level strategies for NTPC / GSECL

Stage 3: Pilot Implementation

- Technical Assistance in pilot / fleet level implementation to NTPC
- Leverage private partnerships and contribution in investments

Stage 4: Scale up

- Assist in fleet-wide implementation and national scale up
- Capacity building of operators – Procedures and Operational Toolkits

The pilot began with detailed technical feasibility studies that assessed the selected units' preparedness, including the technical interventions needed for flexibility and their cost implications. The studies were followed by low-load test runs at pilot units; the procedure for test runs was developed by GTG-RISE in collaboration with Bharat Heavy Electricals Limited (BHEL).

During 2019–2020, a series of low-load test runs were conducted at NTPC's Mouda unit in Maharashtra and GSECL's Ukai unit, with gradual reduction of technical minimum up to 40% while still maintaining all other operating parameters under stable conditions and without any supplementary oil firing support. The test runs gauged the responsiveness of plant equipment when subjected to low loads on a sustained basis. After successful test runs, GTG-RISE analyzed the data and provided recommendations on the specific changes needed in operational practices and procedures and the retrofits/upgrades required. In future, this understanding will allow utilities to assess their ability and adaptability to reduce loading of their units to enable greater RE integration. The operational procedures emanating from the pilot have been captured in the "Minimum load/ ramp test procedure For coal based thermal power plants" are available at www.gtg-india.com/.

Evidence from the pilot's studies and test runs will guide the development and implementation of a long-term flexibilization roadmap for the county and boost integration of renewables.

Photo Credit - GTG RISE

GTG-RISE, BHEL and NTPC team during the test run at Mouda, Maharashtra

GTG-RISE, BHEL and GSECL team during the test run at Ukai Plant,Gujarat

Building plant operators' technical capabilities and knowledge dissemination to utility officials and other stakeholders on flexible operations was an area of equal focus for the pilot. Traditionally in India, the operations personnel at power plants are trained for base load operations. Rolling out flexible operations necessitates that key plant personnel be equipped with know-how on operational flexibility constraints and potential issues with regards their plant equipment. To this end, several training sessions, knowledge dissemination workshops, and executive exchanges were organized. More than 500 engineers and plant officials were trained on multiple aspects related to flexible operations.

Bootcamp Workshop on Coal Generation Flexing Operational Practices to Support VRE Integration at NTPC

Bootcamp Workshop on Coal Generation Flexing Operational Practices to Support VRE Integration at NTPC

Photo Credit - GTG RISE

Knowledge Dissemination Workshop on Coal Generation Flexing Practices to Support VRE Integration at GSECL (Gujarat)

Photo Credit - GTG RISE

USEA Bootcamp on "Incentivizing Coal Flexing to Support Variable Renewable Energy Integration and Grid Balancing".

Photo Credit - USEA

Peer-to-peer exchange on coal flexibility for renewable energy integration, U.S

Photo Credit - GTG RISE

Peer-to-peer exchange on coal flexibility for renewable energy integration, U.S

MAJOR CHALLENGES AND LESSONS

One of the biggest challenges the pilot faced was in securing the past 10 years' operational and maintenance data for each pilot unit. Pilot partners — NTPC and GSECL — proved very supportive in addressing this challenge, with site interviews providing in-depth information on the units' past operations. This information/data was analyzed by GTG-RISE and Intertek and presented to the respective units through site workshops, highlighting how the units had been run over the years and building a case for flexibilization.

Another equally big challenge was ensuring a smooth run of flexible operations with the coal quality with which units in India operate. The NTPC and GSECL units receive a blend of different grades of coal, with high ash content, volatile matter, and foreign particles. The varying quality of coal adds to the difficulty of plant operators working to ensure boiler flame stability during flexible operations and avoiding tripping of units during low-load operations. The pilot at GSECL's Ukai plant gave insights about running units at low loads with multiple coal mills in operation and recommended measures on flame scanners and burners.

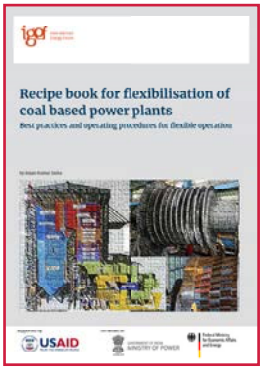
The third major challenge to implementing flexibilization, which the USAID's GTG-RISE pilot addressed proactively, pertained to human resources and their readiness for flexible operations. The pilot trained and capacitated coal plant operators and utility staff on operational procedures to run coal plants flexibly. The successful test run conducted at Ukai for 40% low load operations provided the right impetus and built plant officials' and engineers' confidence about their ability to run units at low loads without any fear of the units tripping even though no significant modifications to equipment had been made. The GSECL and NTPC staff actively participated in various knowledge dissemination workshops, webinars, and utility exchange initiatives supported under the GTG program.

Photo Credit - GTG RISE

"Our partnership with USAID's GTG-RISE on flexible operation has given us the confidence to balance our operations. Going forward, policy and compensation will play a critical role in scaling up flexible operations"

H N Baxi
Executive Director cum MD (A), GSECL

IMPACT AND SUCCESS



USAID's GTG-RISE pilot has resulted in a comprehensive set of recommendations that can prove the building blocks for nationwide rollout of flexible operations at coal power plants. In addition to NPTC and GSECL, the pilot also gave inputs and supported CEA nd CERC with the information needed to identify, address, and make changes in relevant policies, guidelines, and regulations. The key recommendations emanating from the pilot have been captured in a summary report, titled *'Transition towards flexible operations in India'* (available at https://www.gtg-india.com/). The pilot also provided inputs for the national roadmap for flexible operations being developed by a national committee constituted by CEA. Some key findings in the regulatory consultation paper, including increased operations and maintenance (O&M) cost due to life consumption on account of cyclic operation and higher cost from increased oil consumption due to frequent start/stop, etc., featured in CEA's report on coal flexibility, titled 'Flexible operations of thermal plants for integration of renewable generation' (2019).

The GTG-RISE pilot outcomes and learnings have also been captured in the *'Recipe Book for Flexibilization of Coal based Power Plants'* which is intended to serve as a guidebook for Power plant engineers intending to operate their units flexibly. Overall, this recipe book highlights O&M practices for enhancing flexible operation with safety, emission reductions, improvement in part load efficiency, reduced equipment damages and cost reduction, all based on demonstrated techniques and best practices worldwide.

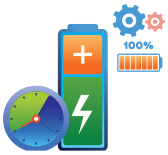
Development of a fleet-wide strategy and a business case for policy and regulatory change is a major success of the pilot. The detailed assessment of costs by GTG-RISE is crucial to designing appropriate regulations to compensate generation units for the additional costs they incur. Accurate plant- and fleet-level estimates of flexing costs are also informing the policy interventions being deliberated by MoP. The insights may also be considered in the design of a targeted government assistance scheme for the commissioned coal-based power plants in the country.

Some key recommendations of pilot study are already seeing adoption. NTPC has already moved ahead with a key recommendation: retrofitting of Nitrogen sparging and blanketing system across its country-wide thermal power plants to mitigate long-term corrosion damage during flexible operations. Further, based on the experience and learning from the flexibility study at Ukai TPS Unit #6 (500 MW), GSECL has finalized the scope for major renovation and modernization (R&M) at Ukai TPS Units #3 and #5, covering the majority of requirements for flexible operation. The scope covers the minimum technical load of 40% without oil support as well as control and instrumentation (C&I) upgrade to facilitate flexible operation.

In what is a crucial testimony to the pilot's success and part of its scalability efforts, GTG-RISE has also supported the Karnataka Power Corporation Limited (KPCL) to scale up its interventions and make its coal plants more flexible. Based on the project's inputs, KPCL is conducting similar studies at two of its units (BTPS Unit #2 500 MW and RTPS Unit #5 200 MW).

SUCCESS AT A GLANCE

2,120 MW
capacity of India's energy utilities supported for improved financial and operations performance



Low-load (flexible)
test runs (up to 40%) supported and procedures developed for nationwide scale-up

500+
power plant officials and engineers trained on flexible generation

44 GW
capacity of NTPC, India's largest public sector power generation utility, adopted improved operational performance recommendations (Nitrogen blanketing and condenser throttling)

~ USD 10 million
mobilized for improved operational performance by energy utilities

375 MW
of RE curtailment avoided due to coal flexibility pilot interventions

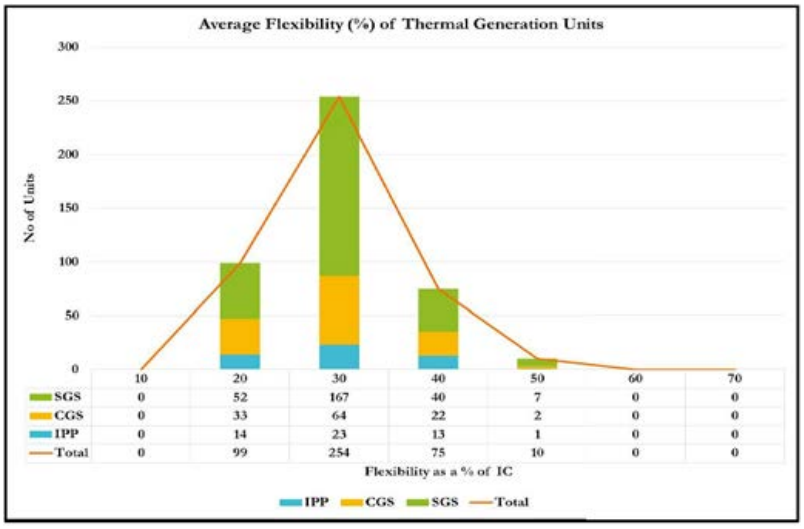
USAID's GTG-RISE pilot built a business case for policy and regulatory changes to implement coal flexing at a larger scale in India. Insights from the pilot are helping India build a strategy to address variability in RE generation and set a benchmark for the entire South Asia region.

SCALING UP: THE WAY FORWARD

Most RE rich states in India with substantial coal-based capacity have already begun witnessing frequent incidents of backing down of their coal generators, followed by shut down of units on a daily, weekly, or monthly basis. The need for flexibilization is clear. Having completed its demonstration pilots and low load test runs at NTPC and GSECL, USAID's GTG-RISE has identified specific state-level issues and the need to scale-up flexible operations.

The histogram below shows the flexible performance of different categories of coal units in the country as of May 2020. It indicates that a majority coal-fired stations in the country can flex in the range of 20–30% of their installed capacity (IC).* At the national level, 60% of the units have provided flexibility in the range of 20–30% of IC. Only 20% of the units can flex generation above 30% of IC.

Load average flexibility (%) of thermal generating units in India (May 2020)



Source: POSOCO

The impending large-scale RE integration in the grid (175 GW of RE by 2022) will require approximately 82 GW of conventional coal-based capacity to undergo flexible operations on a frequent basis. Given this requirement, it is crucial to look at the present flexibility potential of coal-based units in the country and get them ready for the influx of increased RE generation soon.

The coal flexibility pilot by GTG-RISE emphasized on choosing thermal generation sources for different flexible needs based on techno-economic criteria. The plants required to meet the baseload are designed in a cost-optimal manner, as they need to run round-the-clock and most times during the year. Accordingly, these are mostly pithead plants with lower fuel and variable costs. For peaking plants, it is the opposite: high fuel costs are not a problem, if fixed costs are low enough. Ironically, India's peaking coal plants are comparatively newer plants and have higher fixed cost, and as many of them are located far off from coal sources, variable costs are higher too. Moreover, most newer plants are supercritical plants and if run at lower loads they lose their advantage of higher efficiency. These factors make it important to choose generation sources from different categories based on existing applicable running costs and flexibility requirements.

Keeping the techno-economic criteria in view, GTG-RISE identified thermal generation sources from across the country for different flexible needs. It considered unit size, make of main components, age, coal quality, past PLF, location, design, variable cost with respective state merit order, etc. It inferred that out of the total coal-based installed capacity of 2,31,139 MW (231 GW), almost 82,050 MW (82 GW) of flexible capacity can be made available from 302 units (sub-critical and super-critical). Based on this understanding, GTG-RISE has prepared and submitted a scale-up strategy to NTPC and GSECL an operational framework for addressing the scaling up requirements.

Given that the need for flexibilization is now well appreciated and the understanding of what is needed is already in place, the efforts going forward must focus on securing the resources and support from multilateral institutions to carry out the changes needed to secure a reliable, stable grid for India.

**Source: Flexibility Analysis of Thermal Generation for RE Integration in India, POSOCO (May 2020)*

Flexibilization: A clear and present need

Several states in India with significant RE capacity, such as Andhra Pradesh, Karnataka, Tamil Nadu, and Gujarat, have started witnessing the impact that influx of variable RE has on the grid. These states also have ambitious targets for adding RE capacity (solar and wind) to contribute to the national goal of 175 GW of RE capacity by 2022 and 450 GW by 2030. High RE capacity addition in these states has resulted in their conventional coal-based capacity being reduced to the levels of 40–50% or even lower, causing shut down of units because unit operations are not capable of low load/cyclic operations. Absence of despatch schedules, that is made available by State Load Despatch Centres (SLDC), also force state generation utilities to shut down their units. States such as Tamil Nadu, Karnataka, and Andhra Pradesh are already experiencing frequent cycling and shut down of their units, resulting in huge technical and commercial losses.

The requirement for flexible operations is compelling for state utilities impacted by RE variability and unable to operate their units in cycling/ low load mode. In its initial discussions with Andhra Pradesh, Gujarat, and Karnataka, GTG-RISE found that their utilities are keen to take up feasibility and due diligence studies at some of their units to get insights on the capital investment needed for flexible operations. In addition to feasibility studies, state utilities are also considering investment in equipment retrofits in boiler, turbine, and generator systems; instrumentation and control system augmentation; asset management initiatives, etc. Emission management systems and control investments will also be needed. The states must now deliberate on further understanding and defining their requirements and work to secure support from multilateral institutions.

"With RE contribution of 31% in 2019-20, presently at 40%, it's high time for Karnataka to think about flexibilization. We need to take conservation, technical possibilities of balancing the grid and associated cost into consideration and our pilot with USAID's is guiding us in the right direction"

V Ponnuraj
Managing Director, Karnataka Power Corporation Ltd (KPCL)

Photo Credit - GTG RISE

Photo Credit - GTG RISE

**** Details about the pilot, its methodology, results, and recommendations are contained in a report that can be made available upon request.***

Kindly write to mhazra@usaid.gov for a copy of the report.

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