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DST – NIAS Stakeholder Consultation Workshop to discuss the

NIAS Transition Plan for an Integrated Approach to Development and Environment in the Power Sector

National Institute of Advanced Studies
Bengaluru, India

NIAS Workshop Report NIAS/NSE/EEP/U/WR/03/2021

DST – NIAS Stakeholder Consultation Workshop to discuss the

NIAS Transition Plan for an Integrated Approach to Development and Environment in the Power Sector

Workshop Report of DST – NIAS Virtual Workshop

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Cover photo: (Front cover) Sri Damodaram Sanjeevaiah 2 X 800 MW Thermal Power Station,
Nellore, Andhra Pradesh
(Back cover) Raichur Power Corporation's 2 X 800 MW Yeramarus Thermal Power Station,
Yegnur, Raichur, Karnataka

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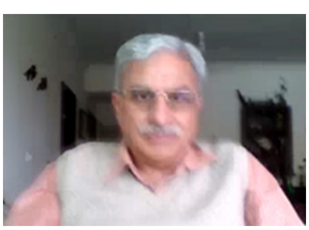
Executive Summary

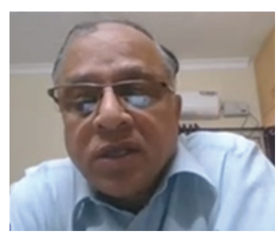
The Energy and Environment Program, NIAS organized a half-day virtual workshop to discuss the "Transition Plan for Thermal Power Plants (TPPs) in India" from 10.30 am to 1.30 pm on January 23, 2021. This workshop was organized to bring together researchers, industry personnel, policymakers, and civil society to discuss NIAS's proposal for a Transition Plan for TPPs in India with specific reference to the Southern Region. The implementation of the Transition Plan will improve the performance of the TPPs by reducing specific coal consumption, specific CO_2 emissions and air pollution, and freshwater requirement while enhancing the flexibility of the Electricity Grid ("Grid") to increase the penetration of Variable Renewable Energy (VRE) in the Grid.



The workshop was divided into inaugural, presentation, and discussion sessions. The inaugural session started with a welcome address and opening remarks by Dr. Shailesh Nayak, Director, NIAS, who emphasized that the primary concern was on how to handle the CO_2 emissions mainly due to climate change. He stated that a developing country like India must have a diverse electricity mix of RE, Nuclear, Hydro, and Thermal to ensure energy security. There are other issues in the projections as the energy requirement and peak demand projections are not very robust. We need to have a dialogue on how the electricity demand predictions can be made more reliable to develop a more robust approach to frame the optimal electricity mix for the next 10-20 years. He also pointed out that our analysis of the air quality around several TPPs indicates that FGDs are not required in every TPP, irrespective of its location and type of coal used, while high-efficiency Electrostatic Precipitators (ESPs) are required in all TPPs to reduce PM concentrations and comply with the 2015 stack emission standards. The graded priority of pollutants (which gives priority to PM and CO_2 over SO_2) as recommended by NIAS is also under the consideration of the Government of India so that the country can minimize the expenditure of huge amounts of money to procure FGDs based on imported technologies. While FGDs may be required for some specific TPPs located in urban or critically polluted or sensitive areas, NIAS's study proposes that all old and inefficient TPPs can be progressively retired in the current power-surplus situation in India. While there may be some hard decisions to be taken by the Government, NIAS is conducting evidence-based research based on the ground reality to gain the confidence of all key stakeholders so that the workshop recommendations may be acceptable and implementable. He requested the delegates to provide their honest and frank opinion to provide solutions to these problems ultimately.

Dr. R. Srikanth, Dean and Professor of School of Natural Sciences & Engineering, NIAS Bengaluru addressed the gathering on the background of the workshop by stating that the DST Clean Coal Project supporting this research at NIAS is based on the impetus given by Dr. Rajagopala Chidambaram (former Principal Scientific Advisor) who stated that "we cannot forget coal in our country". The Southern Region (SR) that is the focus of this Workshop has approximately 50% of India's RE installed capacity but is facing challenges (on both the RE and Thermal sides) mainly because the SR Grid absorbs over 20% of RE in its electricity mix compared to the All-India average of 10%. This is also affecting the ultimate stakeholders, i.e., the power consumers because retail tariffs are going up due to the idling of TPPs for which capacity charges have to be paid as per the Power Purchase Agreements (PPAs) they have signed with DISCOMs in SR. The research forming the core of this Workshop is focused on the optimal electricity mix as part of NIAS's integrated approach to "Sustainable Development" that includes the economic as well as people aspects in addition to the environment. Through this project, we are trying to see how these three aspects can be kept in balance. We need to work towards environment-friendly energy generation technologies. This progress can be made in two major ways, (i) Increase the contribution of baseload generated by non-fossil fuel sources in the energy mix, and (ii) enhance the sustainability of coal mining and utilization since coal will continue to be a major part of India's energy mix.

On the mining side, we have submitted a draft sustainable coal mining bill to the Government to enhance the effectiveness of Environmental Governance in the coal mining sector. After coal is mined, it has to be washed to reduce its ash content as per universal practice. In India, the Government had mandated the use of washed coal or coal with an ash content of less than 34% in TPPs which are more than 500 km away from the coal mines. Unfortunately, this mandate was diluted suddenly last year after which NIAS has justified the need for coal washing in our policy brief and other documents. Further, India must utilize coal more efficiently by reducing, specific coal consumption, water requirement, CO2 emissions, and air pollution. In the Southern Region (SR), sub-critical power plants are producing far more power than the supercritical power plants even as modern, supercritical TPPs like Kudgi and Yermarus are severely underutilized. Fortunately, we have a vast supply-demand mismatch due to the over-optimistic projections in the 18th and 19th Electric Power Survey (conducted by Central Electricity Authority). In this DST-supported Project, we have developed a transition plan to progress towards an optimal electricity mix for the Southern Region which generates nearly 50 percent of the electricity generated by RE sources in the country.



Mr. B.P. Rao, former CMD, BHEL delivered the Keynote address and set the tone for the workshop. In his address, he said that India's power sector is diversified as we derive power from various sources. The demand of the country has also rapidly increased compared to the past. But from 2013-14 onwards the power demand has not increased at the same rate as the rate of increase in generation capacity. This is mainly due to three reasons: lesser than expected economic growth, a rapid increase in energy efficiency, and tepid demand growth in rural areas. Since energy security is essential, India will depend upon coal for fulfilling its growing demand for electrical energy. Besides, as the entire world moves towards clean energy, India must also focus more on making TPPs more environment-friendly by implementing emission reduction technologies. However, the roll-out of these emission-control technologies can be expedited only by increasing the indigenous design and manufacturing of such expensive equipment and facilities.

The current gap between the generation capacity and power demand in the country offers an excellent opportunity to retire the inefficient and obsolete TPPs which cannot be retrofitted with FGDs. However, several super-critical TPPs are also being operated at the subcritical level due to a lack of adequate power demand. These sub-optimal operations are not helping to reap the full environmental and economic benefits of super-critical technology.

The Ministry of Road Transport and Highways is on the verge of announcing a vehicle scrappage policy to scrap all Government vehicles that are older than 15 years along with the levy of a green tax on private vehicles more than 15 years old. Similar bold decisions are required in the power sector. While Germany has announced an aggressive plan to phase out TPPs by 2038, we need to develop transition plans for our power sector based on our energy security and economic scenario. Apart from the Southern Region, we must also focus on studying the power sector in other regions of the country as well. In the past, the Government had closed down certain obsolete TPPs in Patratu (Jharkhand), Kothagudem (Telangana), and Ennore (Tamil Nadu). The implementation of this approach has been rather slow, which indicates the need for more analysis to enable the Government to issue appropriate policy directives.

NTPC is already planning to implement the indigenous advanced ultra-supercritical technology developed as a collaborative research project between NTPC, BHEL, and IGCAR to showcase the highest efficiency that can be achieved in TPPs using high-ash coal. There is a huge requirement to improve the environmental aspect of the TPPs as such initiatives will lead to a sustained saving in water and fuel consumption besides a steep reduction in emissions of CO_2 and air pollutants. With increasing levels of intermittent RE in the Grid, TPPs must be operated more efficiently with high flexibility in the future. Finally, he stated that the coal-based research will only reside in countries like India and China. Therefore, we need to concentrate on the more efficient utilization of TPPs for which we need to conduct more in-depth research on clean coal technologies to become self-sufficient.

The second session consisted of a presentation on the NIAS Transition Plan for Thermal Power Plants by Prof A.V. Krishnan in the Energy & Environment Program at NIAS. His presentation covered the background of the DST-sponsored project and brought out the various issues which are addressed by implementing the proposed 'End of Life' policy for Thermal Power Plants in India. The presentation was focused on the power scenario in the Southern Region covering the States of Andhra Pradesh, Karnataka, Tamil Nadu, and Telangana. The profile of all Coal and Lignite based TPPs in the Southern Region covering their age, power plant rating was presented along with data collection and analysis related to emissions, water consumption, generation, and PLF for the year 2018-19.

The key issues and the need for a Transition Plan brought out by Prof Krishnan in the presentation are summarized below:

1. Energy security, reliability, and affordability are critical for the sustainable development of a country like India which has a higher

cost of capital. The efficient operation of TPPs is very important for India since TPPs provide energy security by ensuring that the peak demand and off-peak demand for electricity are met continuously at affordable costs.

2. TPPs collectively form the largest contributor to CO_2 emissions in India, generating approximately 51% (1183 Mt) of the 2308 Mt of CO2 emissions from fuel combustion during 2018. TPPs also emit gaseous pollutants like SOx, NOx, and PM pollutants which contaminate the water and air, and also impact the human respiratory system.

3. To reduce VRE curtailment during periods of high VRE penetration, TPPs must be run at minimal loads (technical minimum) and be capable of ramping up/down quickly as per the variations in VRE generation to ensure grid stability. Regional (inter-state) TPPs are currently mandated to operate at a technical minimum of 55 percent which may have to be lowered in the future to accommodate higher VRE penetration.

4. The +25-year-old, sub-500 MW TPPs in India are in large part unable to meet these specifications for ramp rates and technical minimum operating levels. These limitations impose constraints on optimal VRE penetration due to the high share of sub-critical TPPs in the total installed TPP capacity in SR.

5. Even with the extended deadline for installation of pollution control equipment, the vast majority of TPPs in India are facing major challenges to retrofit FGDs in their existing layout inter alia due to high capital and operating costs which will also hike the generation tariff. Besides, the shutdown period required to retrofit FGDs in operating TPPs will also lead to revenue losses for the TPPs. FGDs also add to the environmental impact in terms of an increase in water consumption and auxiliary power consumption (higher specific coal consumption and CO_2 emissions). Similarly, the limestone mining, handling, and transportation associated with the operation of FGDs will also require the disposal of large amounts of waste material (gypsum) which will create another set of environmental issues.

6. TPPs installed before the year 2003 did not provide additional space and hence retrofit of FGDs was not feasible (23 GW of TPPs identified). Out of the 448 TPPs mandated to install FGDs, only six TPPs have installed FGDs till December 2020, and MoP has already sought an extension of the deadline up to December 2024.

The presentation covered the actionable points to address these issues through a Transition path by progressively implementing an "End-of-Life" policy to retire all sub-500 MW, inefficient TPPs with obsolete technology in the SR which will complete more than 25 years of operation by December 2022. Prof Krishnan also presented the results of the power flow analysis to assess the capability of the SR Grid to implement the proposed transition plan. Finally, the direct and indirect economic and environmental advantages that will accrue on the implementation of this transition path were brought out in the presentation.

The third session chaired by Shri B.P. Rao was devoted to discussions on the NIAS Transition Plan for Thermal Power Plants. The key recommendations of this Workshop are as follows.

- Shri R.S. Sharma, former CMD of NTPC opined that only those TPPs of 200/210 MW capacity and below which have very poor performance and cannot be upgraded must be recommended for retirement. There is a need for a policy directive so that TPPs do not operate below 37-38% cycle efficiency. Subsequently, he also stressed that the benefits of washed coal which is used exclusively by certain power plants must be analyzed by CEA and results must be made public.
- Shri S.R. Narasimhan, Director (System Operations) of POSOCO stated that a more serious issue for the Power Grid is transmission planning for mega solar parks and wind farms where we need to devote more time rather than pushing out bids for RE generation.
- Shri V.P. Raja, former Chairman of MERC opined that regulators must decide whether it is worth investing more CAPEX for retrofitting or is it better to close the older TPPs. Besides, while approving the CAPEX one must investigate the residual life of the TPPs which may also depend on the operation and maintenance practices of the TPPs.
- Shri Venkataramana, Chief Scientist/TCS Research acknowledged that the presentation and discussions during the Workshop were thought-provoking. He suggested that coal washing and drying of coal can reduce the emission of pollutants more cost-effectively than post-combustion techniques.
- Shri D N Prasad also weighed in on the economic and environmental benefits of coal washing. There is a need to study the benefits of coal washing and its overall impact on the environment and power tariffs. Case studies can be brought out from the experiences of TPPs which are already using washed coal.
- Dr. Pradip suggested that the ash content of coal also influences the cycle efficiency of boilers. Therefore, ash content should be minimized by coal washing before the coal is fed into the boiler. This is in the interest of overall plant efficiency.
- Prof Sudha Mahalingam suggested that there is a need to develop a more efficient market design for the present power surplus scenario since this will be crucial in determining the optimal electricity mix. The Electricity Regulator(s) should also play a role in integrated resource planning and act as the voice of small consumers.
- Dr. Tejal Kanitkar stated that the crux of the issue is that RE units enjoy "must-run" status and do not follow the "merit-order." This implies that regardless of the tariff, all RE generated must be procured which is not the same case for conventional generation sources like TPPs. For an optimal mix of electricity, we must consider all solar energy generators (both old and new) and evaluate all technologies using the same benchmark.
- Dr. Rahul Tongia stated that currently, the tariffs for round-the-clock power from a combination of solar energy backed up by battery storage exceed those of conventional sources mainly due to the price of battery storage.
- The criteria for the proposed retirement of TPPs should also consider key performance factors of the plants like efficiency, coal consumption, etc., in addition to the age of the plant.

- Some of the failures occur in the "Balance of Plant" (BOP). Apart from boilers and turbines, sometimes coal and ash handling units do not work properly in old TPPs and this affects the efficiency of the plants. There is a need to study the improvements required in all aspects related to the Balance-of-Plant (BOP) of the TPPs so that the overall performance of the TPPs is improved.
- Energy Requirement and Peak Demand projections in India are not very robust. We need to have a dialogue on how to improve the predictions.
- Coal-based research will only reside in countries like India and China for which we need to concentrate on the more efficient utilization of TPPs to achieve self-sufficiency in energy technologies. We should have our indigenous standards and analysis rather than depending on foreign research outcomes.
- Studies on the optimal energy mix must consider the Nuclear Power Plants which are under construction in the Southern Region.
- There is a need to conduct a life-cycle analysis of Solar vs Thermal vs Battery. We also need to calculate the cost of grid integration for different technologies in the Indian scenario.
- Several panelists suggested that to get a comprehensive picture, NIAS's study can be extended to all regions of the Indian Power Sector. This would also validate the import/export of power between different regions of the country. Dr. Kiran Challa, DST appreciated the workshop and stated that DST support will be available for research programs like this.

The workshop ended with a vote of thanks to all dignitaries by Dr. Tejal Kanitkar, Associate Prof at NIAS, who specifically acknowledged DST's support for the research project to develop an "Integrated Approach to Development and Environment in the Power Sector" (DST/CERI/Clean Coal 2013/(033)C dated 30 June 2018.)

Annexure - 1

Energy and Environment Program
NATIONAL INSTITUTE OF ADVANCED STUDIES, BENGALURU

DST – NIAS VIRTUAL SEMINAR AGENDA

23rd January 2021 (Saturday)

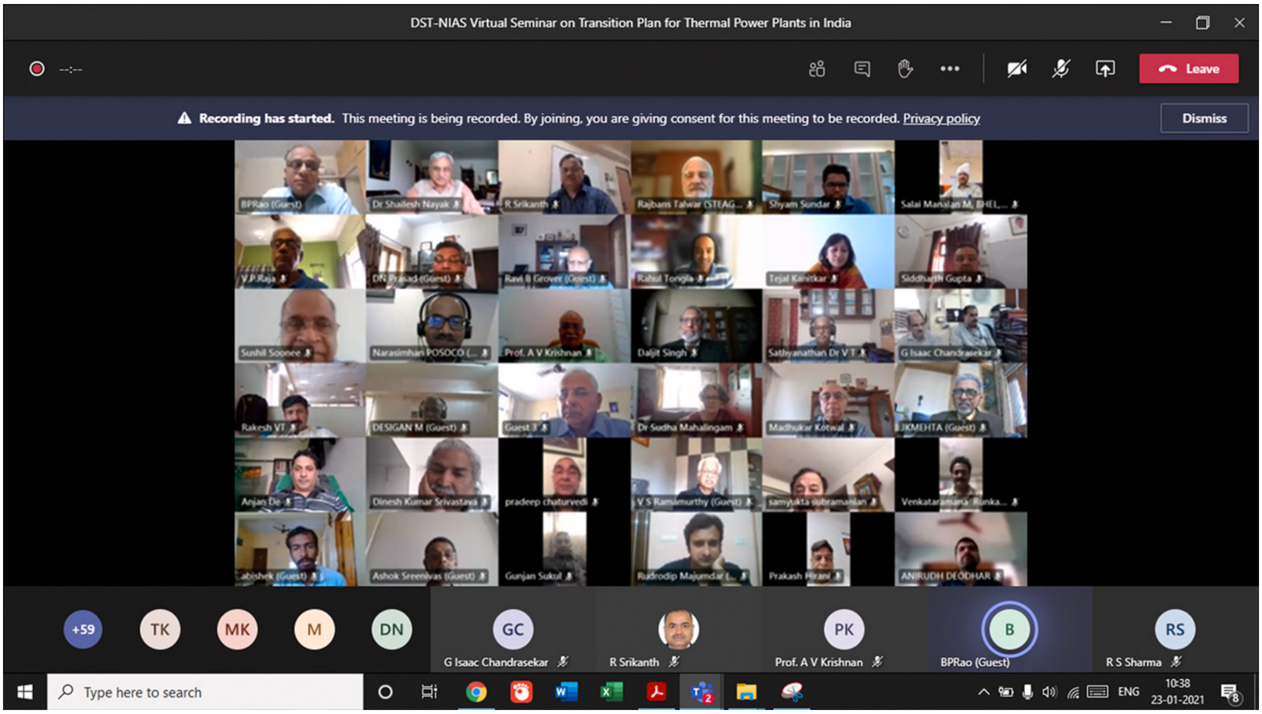
Session	Time	Speakers	Topics
Inaugural	10.00-10.40 a.m.	Dr. Shailesh Nayak, Director NIAS	Welcome Address
		R. Srikanth, EEP, NIAS	Introduction to the Workshop
		Mr. B P Rao (Former CMD, BHEL)	Keynote Address
Session I	10.45 a.m. - 11.30 a.m.	A V Krishnan EEP, NIAS	Transition Plan for Thermal Power Plants in India
Session II	11.30 a.m. – 13.30 p.m.	**Chairman** Mr. B P Rao **Moderator** R Srikanth	Deliberations
	13.35	Dr. Tejal Kanitkar EEP/NIAS	Vote of Thanks

Annexure - 2

List of participants in the Virtual Workshop held on January 23, 2021

No	Name	Affiliation
1	**B P Rao**	Former CMD of BHEL
2	**Dr. Shailesh Nayak**	Director/NIAS
3	**Dr. Ramamurthy V.S.**	Emeritus Professor/NIAS
4	**Prakash Hirani**	Expert Member – DST
5	**Navin Kumar Singh**	Expert Member - DST - Coal India
6	**Dr. Pradip**	Expert Member – DST
7	**Dr. HL Bajaj**	Former Chairman – CEA
8	**R.S. Sharma**	Former CMD, NTPC
9	**Madhukar V Kotwal**	Former President, L&T
10	**Pradeep Chaturvedi**	VP, World Environment Foundation
11	**V P Raja**	Former Chairman of MERC
12	**S.K. Soonee**	Former MD, POSOCO
13	**Narasimhan SR**	Dir/System Operation, POSOCO
14	**Prasad D.N.**	Former Advisor/ Coal Ministry
15	**J.B.V. Reddy**	Scientist E/DST, GOI
16	**Dr. Kiran Challa**	Scientist/DST
17	**JK Mehta**	
18	**Venkataramana Runkana**	Chief Scientist, TCS Research Pune
19	**Trinath Gaduparthi**	TRDDC, TCS Research, Pune
20	**Abhishek Yadav**	TRDDC, TCS Research, Pune
21	**Yogesh Tambe**	TRDDC, TCS Research, Pune
22	**Rajkumar Sadanandam**	TCS
23	**Anirudh Deodhar**	TCS
24	**Rajbarath K.R.**	TCS
25	**Dr. R. R. Sonde**	Thermax
26	**Shailendra Roy**	Former Director/ L&T
27	**Gunjan Sukul**	L&T-Power
28	**Chirag Shah**	L&T-Power
29	**Anjan De**	L&T-Power
30	**Deepak K Sinha**	L&T-MHI

31	**Arup Bhattacharya**	L&T-Power
32	**Siddharth Gupta**	L&T-MHI
33	**Rajbans Talwar**	STEAG Energy Services
34	**Dr. VT Sathyanathan**	Former GM/R&D, BHEL, Trichy
35	**R S Yadav**	Former Dir/RPV&ESG, BARC
36	**Prof. R.B. Grover**	Emeritus Professor, HBNI and Member, AEC
37	**Prachi Gupta**	Consultant (Energy) NITI Aayog
38	**Ms. Sweety Pandey**	NITI Aayog
39	**Ratnakar P**	CE/Generation, TSGENCO
40	**Madhukar**	SRLDC
41	**Sharath**	SRLDC
42	**MG Shunmuga Velayutham**	SDGM/Planning, BHEL, Ranipet
43	**Anil Ghanwat**	L&T
44	**Salai Manalan**	BHEL
45	**Mahesh A**	BHEL
46	**Desigan M**	BHEL
47	**Sridharan RK**	BHEL
48	**Shankar Narayan**	BHEL
49	**Ashish Shrivastava**	BHEL
50	**Manish Singh**	TCS
51	**Udayan Dasgupta**	
52	**R. Srikanth**	Professor and Dean, NIAS
53	**A.V. Krishnan**	Visiting Professor, EEP/NIAS
54	**Mrs. Sudha Mahalingam**	Raja Ramanna Chair Prof/NIAS
55	**D.K. Srivastava**	Homi Bhabha Chair Prof/NIAS
56	**Tejal Kanitkar**	Associate Prof/EEP/NIAS
57	**Rudrodip Majumdar**	Asst Prof/EEP/NIAS
58	**Harini Santhanam**	Asst Prof/EEP/NIAS
59	**Harikrishna M**	Former Post Doc/EEP/NIAS
60	**Soumyadeep Das**	Ph.D. Scholar/EEP/NIAS
61	**Kumar Saurabh**	Ph.D. Scholar/EEP/NIAS
62	**Shyam Sundar R**	JRF/EEP/NIAS
63	**Nikhil Thejesh**	RA/EEP/NIAS
64	**Daljit Singh**	Brookings
65	**Rahul Tongia**	Brookings
66	**Karthik Ganeshan**	CEEW
67	**Ashok Sreenivas**	Prayas Energy Group
68	**Maria Chirayil**	Prayas Energy Group



Glimpses of the Workshop Participants

Annexure - 3

TRANSITION PLAN FOR THERMAL POWER PLANTS IN INDIA

Abstract:

India's power sector is undergoing a "green energy" transition in which the Southern Region (SR) is leading the way. While SR contains 50 percent of India's Variable Renewable Energy (VRE) capacity, the region is facing challenges in VRE integration since the SR Grid also draws power from 52 Thermal Power Plants (TPPs) with obsolete technology. This report details a transition plan for TPPs involving the progressive retirement of specific, obsolete +25-year TPPs selected considering critical performance parameters like efficiency, specific coal consumption, etc coupled with the integration of new High-Efficiency-Low-Emission (HELE) TPPs and Nuclear Power Plants (NPPs) into the SR Grid. Power flow studies validate the Grid operation during the evening peak demand and indicate that the power flow through each transmission element is largely within prescribed limits up to March 2023. However, certain transmission elements of the SR Grid must be reinforced by 2026 to meet the peak demand in SR during 2027 and 2030. The optimal utilization of existing and under-construction HELE TPPs with faster-ramping capabilities and lower technical minimums also facilitates VRE integration. The transition plan proposed has operational, economic, and environmental benefits with savings in retrofit costs in the obsolete TPPs, reduced energy charges, lower emissions, smoother VRE integration, and efficient Grid operations.

1. Introduction

Coal and lignite-based Thermal Power Plants (TPPs) are the backbone of India's power sector. As of March 31, 2019, TPPs constitute over 56 percent of the total installed generation capacity of electricity utilities in India, while VRE sources (solar, wind, bio-energy, and small-hydro) make up less than 22 percent. TPPs generated 74 percent of the 1376 TWh of electricity generated by utilities and over 80 percent of the 175 TWh of electricity generated by non-utilities in India during FY 2018-19. However, the installed capacity of VRE sources has increased at a Compounded Annual Growth Rate (CAGR) of 17.47 percent between FY 2009-10 and FY 2018-19 while the generation capacity of TPPs has recorded a CAGR of 9 percent only (CEA, 2019a, MoSPI, 2020).

Energy security, reliability, and affordability are critical for the sustainable development of a country like India which has a higher cost of capital (compared to OECD countries) and a per capita electricity consumption that is only one-third of the world's average (IEA, 2020a). The efficient operation of TPPs is very important for India since TPPs provide energy security by ensuring that the peak demand and off-peak demand for electricity are met continuously at affordable costs. However, TPPs collectively form the largest contributor to CO_2 emissions in India, generating approximately 51% (1183 Mt) of the 2308 Mt of CO_2 emissions from fuel combustion during the year 2018. TPPs also emit gaseous pollutants like Sulphur-di-Oxides (SO_2), Nitrogen-di-Oxides (NOx), and Particulate Matter (PM) pollutants which contaminate the water and air, and also impact the human respiratory system. Therefore, there is a need to develop a transition plan for TPPs in India to optimize the electricity mix during various time horizons which will also reduce power sector emissions besides reducing tariffs.

Further, to reduce VRE curtailment during periods of high VRE penetration, TPPs must be run at minimal loads (technical minimum) and be capable of ramping up/down quickly as per the variations in VRE generation to ensure grid stability. While regional (inter-state) TPPs are currently mandated to operate safely at a technical minimum of 55 percent, this limit may have to be lowered shortly to accommodate higher VRE penetration (GTG, 2019). However, +25-year old, sub-500 MW TPPs in India are unable to meet these specifications for ramp rates and technical minimums. This imposes constraints on optimal VRE penetration in India due to the high share of sub-critical TPPs in the total installed TPP capacity in the country.

In line with the above objectives, NIAS has developed a transition plan based on the implementation of an “End-of-Life” policy to progressively retire all +25-year old, below 500 MW TPPs in the SR by December 2022 (Phase 1) and December 2027 (Phase 2). This transition plan is then extended till 2030. The capability of the SR Grid to implement the proposed transition plan is validated by using power flow analysis (NREL, 2017) with the assistance of POSOCO’s Southern Region Load Despatch Centre (SRLDC). Finally, the direct economic and environmental advantages that will accrue on the implementation of this transition plan are quantified.

2. Background

CEA projected the country’s requirements of peak demand and electricity generation in the 18th and 19th Electric Power Survey (EPS) reports that were released in 2011 and 2017, respectively. As shown in Figure 1, the 18th EPS report significantly overestimated the All-India peak demand from 2013-14 onwards. In the 19th EPS report, peak demand projections were accordingly reduced by approximately 22% based on reduced power demand growth due to various reasons like demand-side management, energy efficiency measures, etc. However, there is a growing gap between the peak demand projected in the 19th EPS and the actual demand from 2017-18 onwards. As a result, the peak demand of 239 GW projected for FY 2022-23 in the 19th EPS is expected to be achieved more than two years later (after 2024-25). The actual figures and projections of peak demand for the Southern Region are shown in Figure 2.

Because of the growing gap between the projected figures in the 19th EPS and actual peak demand in the country, CEA released a fresh set of detailed long-term projections for the power sector based on an econometric modeling framework. In contrast to the bottom-up approach used in the 19th EPS, the CEA Partial Aggregate Method (PAM) model uses an econometric model based on parameters such as GDP, real electricity price, weather parameters, and past electricity consumption for which 14 years of monthly data was collected. CEA has also stated that “*the in-sample data forecasting and comparison of the demand projection with actual electrical energy requirement during past two years suggest that Partial-Aggregated-Method (PAM) model under 7.3% GDP scenario is fitting better and therefore, the results obtained through that is recommended as the most preferred scenario*.”

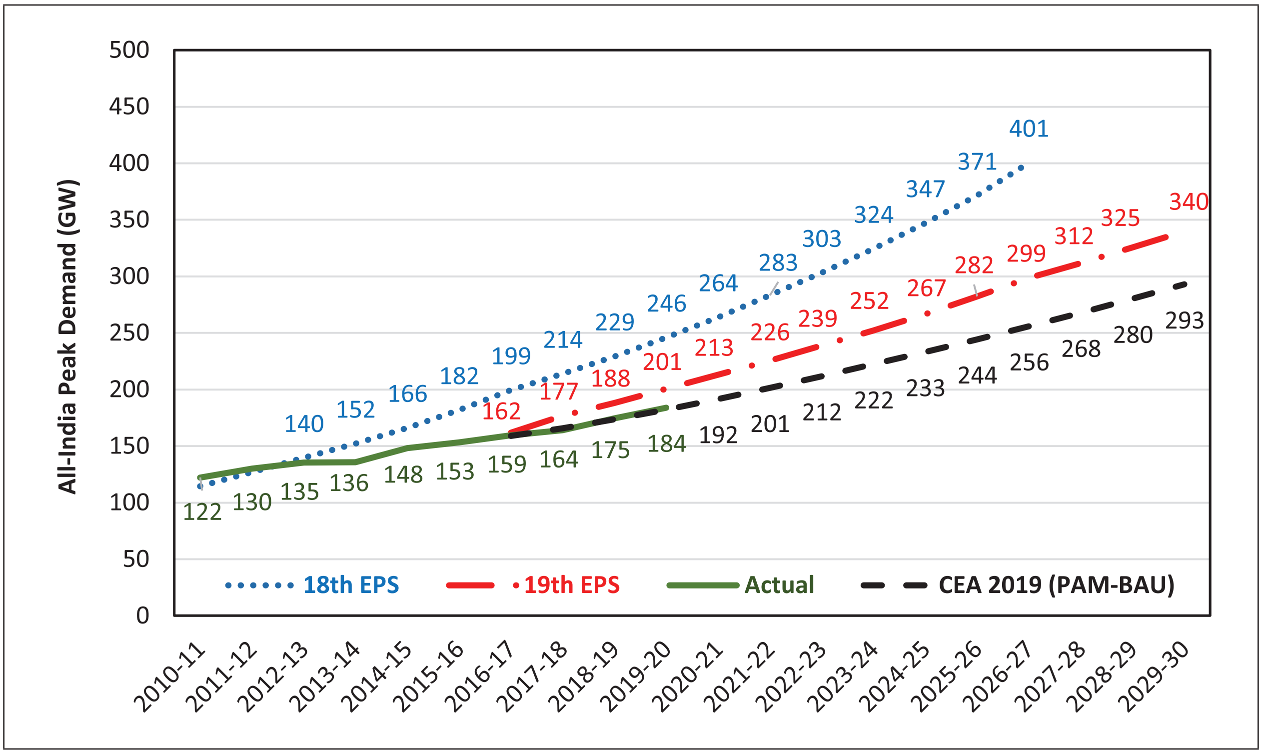


Figure 1: CEA Projections *versus* Actual Peak Demand in India (CEA, 2018a; 2019d)

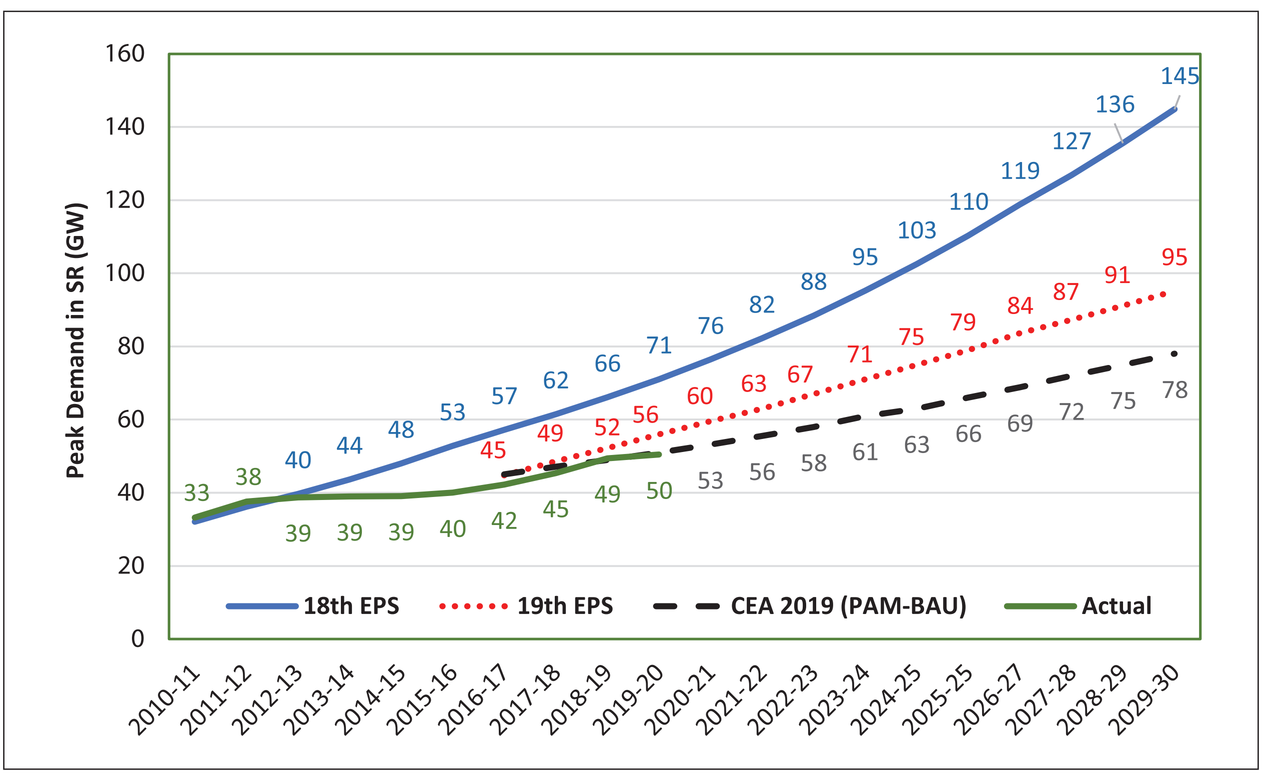


Figure 2: CEA Projections *versus* Actual Peak Demand in the Southern Region (CEA, 2018a; 2019d)

Over and above this, grid-connected captive TPPs (which supply more than 50 percent of the electricity generated to dedicated industrial units and sell the surplus electricity to DISCOMs) have a generation capacity of 34.8 GW (MoSPI, 2020). Therefore, the combined (utilities and non-utilities) generation capacity of TPPs of 240 GW exceeds the peak demand of 184 GW in India during FY 2019-20 by a wide margin. In addition to TPPs, other "dispatchable" electricity generation sources like Nuclear Power Plants (NPPs) and Hydroelectric power plants (HEPs) are also able to meet the peak demand in India. Given the emerging gap between the installed generation capacity of "dispatchable" power generating sources and the projected peak demand in India, there is an opportunity to develop a transition plan to progress towards a cleaner power sector without investing in costly, imported FGDs in TPPs which are located outside the critically polluted/ urban/sensitive areas in India.

This report is based on NIAS's ongoing research on the power sector in the Southern Region (SR) of India's National Power Grid which encompasses five States in South India, viz., Andhra Pradesh (AP), Karnataka (KA), Kerala (KL), Telangana (TS), and Tamil Nadu (TN) and has cleanest electricity mix in the country. TPPs constitute 43 percent of the total installed generation capacity of 107 GW in the SR while VRE sources constitute the next biggest chunk of 36 percent. Specifically, nearly 50 percent (38.6 GW) of the total installed capacity of VRE sources in India (77.6 GW as of March 31, 2019) is located in SR (CEA, 2019a). As of March 2019 (considered as the base case for this study), the total installed capacity of TPPs in SR (including 1500 MW from Talcher Stage II which is dedicated for SR) was 42,413 MW drawn from 123 TPPs with varying size (50 - 800 MW) and age (1 year to 50 years) profiles (CEA, 2019e). The profile of TPPs in SR as of March 2019 is shown in Figure 3.

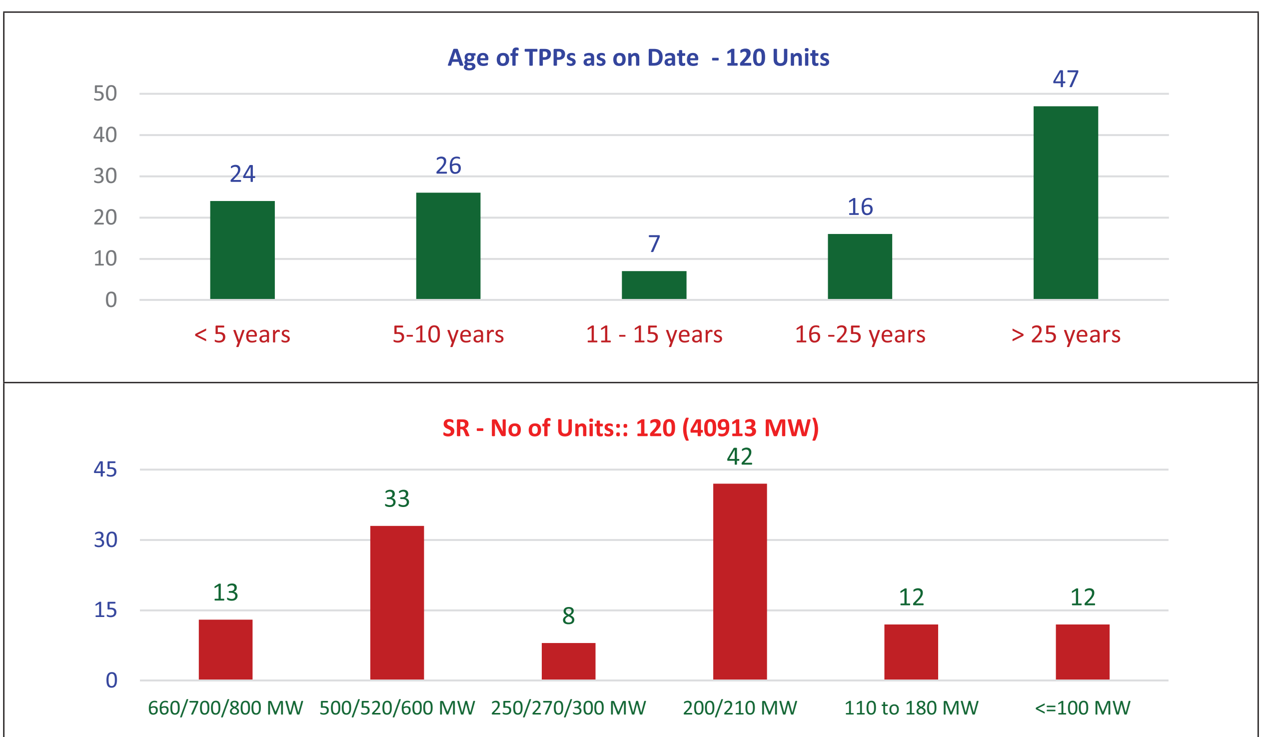


Figure 3: Profile of Thermal Power Plants (TPPs) in Southern Region (SR)

India's power grid consists of transmission lines that operate at voltage levels of 765 kV, 400kV, or 220 kV and lower voltage ranges (CEA, 2019f). The length of transmission lines operating at various voltages (220 kV and above) is indicated in Table 1. As of March 2019, the inter-regional transmission capacities between the southern-western regions and the southern-eastern regions were 12.12 GW and 7.83 GW, respectively (CEA, 2019f). To increase the power flow between the Western Region (WR) and SR, the Warora-New Warangal line with a capacity of 4,200 MW and the Raigarh-Pugalur Direct Current (DC) line with a capacity of 6,000 MW is likely to be commissioned by FY 2022-23 (CEA, 2020e). With this, the total inter-regional transmission capacity between the SR and the Western/Eastern regions of India's power Grid will be enhanced from 19.95 GW in FY 2018-19 to 30.15 GW in FY 2022-23 with the addition of substations and interconnecting transmission lines (CEA, 2017; 2020e). The projected increase in the number of 220 kV/400kV/765 kV substations and interlinking transmission lines by March 2027 (as shown in Table 1) will enhance the reliability, flexibility, and stability of the SR Grid to transfer power within and outside the region.

The vast gap between the actual power demand and the total installed capacity of TPPs which have tied up Power Purchase Agreements (PPAs) with the DISCOMs in SR is one of the reasons for escalating DISCOM losses in SR. For example, the total availability of electrical energy in Karnataka during FY 2020-21 is estimated to be 104,959 GWh while the total energy requirement of all the DISCOMs is only 75,366 GWh as per KERC. This surplus electrical energy of 29,593 GWh during FY 2020-21 as per the November 2019 estimates (three months before the arrival of the COVID 19 pandemic in Karnataka) is higher than the surplus electrical energy of 17,530 GWh in Karnataka during FY 2018-19 "*which was backed down/reserve shut-down for want of demand*". As per KERC (2020) estimates, the total capacity charges to be paid by the five DISCOMs in Karnataka for this surplus energy during FY 2020-21 is approximately Rs.4802 Crores, which has to be recovered from the consumers through the power tariff. The prevalence of a similar power surplus situation in other states in SR is one of the prime drivers behind the development of the "End-of-Life" policy proposed for TPPs in this study. This policy is based on key parameters that affect the performance of a TPP like, age, boiler technology (sub-critical vs super-critical), and unit size as well as TPP retrofit costs.

Table 1: Details of SR Power Grid (220kV and above)

Voltage (kV)	March 2019			March 2023			March 2027		
	Sub-stations	Lines	Length (km)	Sub-stations	Lines	Length (km)	Sub-stations	Lines	Length (km)
765	14	23	5,419	14	37	11,262	15	41	11,862
400	156	385	43,934	186	479	54,369	197	532	59,369
220	651	1,235	50,970	715	1,411	61,323	725	1,451	66,323

Notes:

1. Details of substations (220kV and above) extracted from (CEA, 2019f).
2. Details of transmission lines connected to SR Grid collected during discussions with POSOCO.
3. Likely additions to the transmission network by March 2023 and March 2027 are taken from CEA (2020e)

3. Research methodology

Study methodology

Data of emissions and water consumption were collected from Annual Environment Statement and analysis was carried out for the 120 units nearly 41 GW of coal and lignite TPPs in SR. In parallel, data on ground-level emissions for PM and SO_x were collected in Telangana where coal mines and TPPs are situated.

The Newton-Raphson load flow study is a numerical analysis of the flow of electric power in an interconnected system that approximates a set of nonlinear equations into a set of linear equations. The significant information obtained from the studies is the flow of active power and reactive power through each line, voltage magnitude, and phase angle at each bus. Newton-Raphson method is applied to solve the power network model as it can converge to within a small tolerance ($\in$) of 0.1 MW in a limited number of iterations (k), which is detailed out in Annexure 4 (Afolabi et al. 2015). The maximum and minimum values of the normalized AC voltage are bounded within [0.9pu, 1.1pu]. To solve the power grid model using the Newton-Raphson method, the power generating units, buses, transformers, transmission and distribution networks, and constant power loads are modeled in the PSSE software. As of March 2019, the data of the transmission network in the SR detailed in the power grid model was used. To study the 2022-23 scenario, the grid infrastructure proposed to be added in the SR by 2022-23 is modeled and integrated with the India power grid detailed network model in PSSE software.

Key assumptions – Generation side

- To derive an economically efficient way of power dispatching for FY 2022-23 and FY 2026-27, it is assumed that the TPPs owned by state entities will generate at 70% of their rated capacities, while the TPPs owned by regional entities will operate at 85% of their rated capacities. These values equal the average Plant Load Factors (PLFs) of the state and regional TPPs during FY 2009-10 (Lok Sabha, 2020). Further, the electricity dispatched from new hydro and wind power plants is assumed to be 10% of their respective installed capacities.

- As of March 2020, excess generation capacity exists at the All-India level since 17 GW of commissioned TPP capacity is financially stressed without coal and PPAs even as the average PLF of operating TPPs has dropped steeply from 77.5 percent in FY 2009-10 to 56 percent in FY 2019-20 (Lok Sabha, 2020). To meet the peak demand scenario for FY 2022-23 and FY 2026-27 without depending on Grid storage of VRE Power, it is assumed that all stressed TPPs which are already commissioned will be operating at 85% of their cumulative rated capacity.

Key assumptions - Network and Load

- The projected FY 2022-23 and FY 2026-27 model assumes that the 220 kV and above voltage level transmission elements are available for operation within their physical constraints. In FY 2018-19, 35 transmission lines are under outage due to various reasons including, reduced voltage operation, maintenance, restoration, automatic triggering, or grid disturbance as per the POSOCO 2019 report. A similar emergency/planned transmission line outage scenario is considered for FY 2022-23 and FY 2026-27.

- The 220 kV (and above) transmission lines between the existing and new substations in the model are augmented as per the details indicated in the monthly progress report of SRPC (CEA, 2020e). Therefore, the planned 220 kV (and above) transmission elements are not loaded more than 60% of their rated capacity.

As of March 2019, the peak demand met in SR was 47,147 MW. The present study assumes that the peak demand in SR will reach a level of 58 GW in FY 2022-23 and 69 GW in FY 2026-27 as projected by CEA in the PAM-BAU scenario.

4. Transition Plan for Thermal Power Plants (TPPs)

TPPs based on subcritical technology (plant size up to 600 MW) constitute approximately 75% of the total installed TPP capacity of 201 GW in India while TPPs equipped with supercritical technology (plant size of 660 – 800 MW) constitute the remaining 25%. However, the proportion of supercritical TPPs is gradually increasing, since 93 percent (35,520 MW of the 38,100 MW) of the total generation capacity of under-construction TPPs by Central and State Government companies in the country are based on supercritical technology. The design efficiency of a supercritical TPP is about five percent higher than that of a 500 MW subcritical TPP due to which supercritical TPPs have correspondingly lower fuel consumption as well as CO_2 emissions. Further, the +25-year old TPPs also consume more water per unit of electricity generated (Krishnan AV, et al., 2019).

PM pollution from TPPs is a major concern in many parts of India even as the ambient concentrations of SO_2 in the atmosphere around TPPs using Indian coals are well within the National ambient air quality standards (CPCB, 2019). Therefore, the Ministry of Environment, Forest, and Climate Change (MoEFCC) of the Government of India (GoI) has mandated the use of various pollutant control technologies to control the stack emissions from TPPs. On December 7, 2015, MoEFCC notified the Environment (Protection) Amendment Rules (MoEFCC, 2015) *inter alia* to reduce stack emissions of SO_2 from TPPs by retrofitting Flue Gas Desulphurisers (FGDs) by 2017. Considering the major challenges in the design, procurement, manufacturing, and commissioning of capital equipment like FGDs and the limited facilities available for FGD manufacture, the Supreme Court of India extended the deadline for the installation of FGDs in TPPs located beyond the vicinity of the National Capital region (CEA, 2020b) to December 2022. However, TPPs in India are facing the following major challenges to retrofit FGDs in existing plants.

- FGDs are expensive (~Rs.54 lakhs per MW of installed capacity) due to high import content and saddle consumers with hikes in generation tariff by ~30 percent (CERC, 2018).

- FGDs have a gestation period (~27 months) due to the limited manufacturing capacity available and necessitate a partial shutdown of the TPP for about 6-9 months during the installation period. This will reduce the electricity available in the grid and lead to revenue losses for the TPPs (CERC, 2018).

- FGDs increase auxiliary power consumption in TPPs by 1.5–2 percent due to the operation of electrical motors and other connected equipment which in turn leads to higher coal consumption and enhanced CO_2 emissions per unit of electricity generated.

- The continuous operation of FGDs requires a significant amount of water (~0.3 m^3/

MWh) as well as large amounts of limestone which must be mined and transported from distant mines, thereby creating additional environmental impacts.

- Besides, FGDs will also produce large amounts of waste material (gypsum) per day which creates several issues related to storage and disposal.

- Finally, TPPs installed in India before the year 2003 did not have any space provision for the installation of FGDs and require extensive construction activities to install and commission FGDs. CEA has already identified 23 GW of TPP capacity where it is not feasible to install FGDs due to the non-availability of space in the layout. Of these, 32 TPPs with a capacity of 5019 MW that have completed 25 years of operation have not submitted any plan to install FGDs and will be retired progressively (MoP 2020d).

Of the 448 TPPs mandated to install FGDs, only six TPPs have installed FGDs till December 2020 as per the CEA monitoring report. Considering the time required to retrofit FGDs in existing TPPs and the ongoing disruptions caused by the COVID 19 pandemic, the Ministry of Power (MoP) has stated that, "*70% of thermal power stations will miss the December 2022 deadline and have sought extension of the target date by two years to December 2024 citing the unavailability of domestic power equipment and the lack of finance amid the Covid-19 pandemic as issues in meeting the December 2022 deadline (Prabha Raghavan, 2020).*" These issues highlight the urgent need for a transition plan for TPPs in India to create a sustainable thermal power sector that can provide affordable, reliable, and clean electricity for Indians.

Based on the "End-of-Life" policy developed during this study, 47 obsolete TPPs with a total capacity of 7,993 MW are proposed for progressive retirement in SR by December 2022. The shortfall in power generation due to the retirement of such obsolete TPPs can be compensated by integrating 14 HELE TPPs with a cumulative capacity of 5,850 MW and one 500 MW NPP that are currently at an advanced stage of construction in SR and will be commissioned progressively by the year 2022. Extending this policy to 2027, five more TPPs (210 MW each) can be retired progressively between 2023 and 2026 as and when they achieve an operating life of 25 years since eight TPPs (800 MW each) and two NPPs (1000 MW each) that are currently under construction will be commissioned between 2023 and 2026 (CEA, 2020a, 2020d, DAE, 2019).

The resultant changes in the installed power generation capacities of various technologies in SR by the progressive implementation of this transition plan by March 2023 and March 2027 are projected in Figure 4.

It is seen that TPPs based on subcritical technology (Coal (Sub)) account for 32 percent of the 104 GW of the total installed generation capacity in SR, while TPPs based on supercritical technology (Coal (SC)) account for only nine percent of total installed capacity in March 2019 (CEA, 2019e). In March 2023, based on the progressive retirement of +25-year old TPPs with obsolete technology and the commissioning of under-construction HELE TPPs by 2022, Coal (Sub) and Coal (SC) are projected to account for 22 percent and 13 percent of the 119 GW of total installed generation capacity in the SR, respectively. Extending the same "End-of-Life" policy to TPPs in SR up to 2026, the share of Coal (Sub) in the total installed capacity in SR (148 GW) is projected to reduce from 32 percent in March 2019 to 17 percent in March 2027, while the share of Coal (SC) is likely to increase from nine percent in March 2019 to 15 percent in March 2027. Simultaneously, the share of the installed capacity of VRE sources in SR is projected to increase from approximately 37 percent in March 2019 to 45 percent in March 2023 and 50 percent in March 2027 (Figure 4).

It is prudent to consider the replacement of the old (+ 25 years old) inefficient TPPs HELE TPPs due to the following major advantages:

- The "Life-extension" activities and investments for FGDs and other pollution control equipment required in the +25-year old TPPs and the additional operating expenditures associated with FGDs due to the increase in auxiliary power consumption, higher water consumption and limestone consumption can be avoided by retiring the +25-year old, sub-500 MW TPPs. This

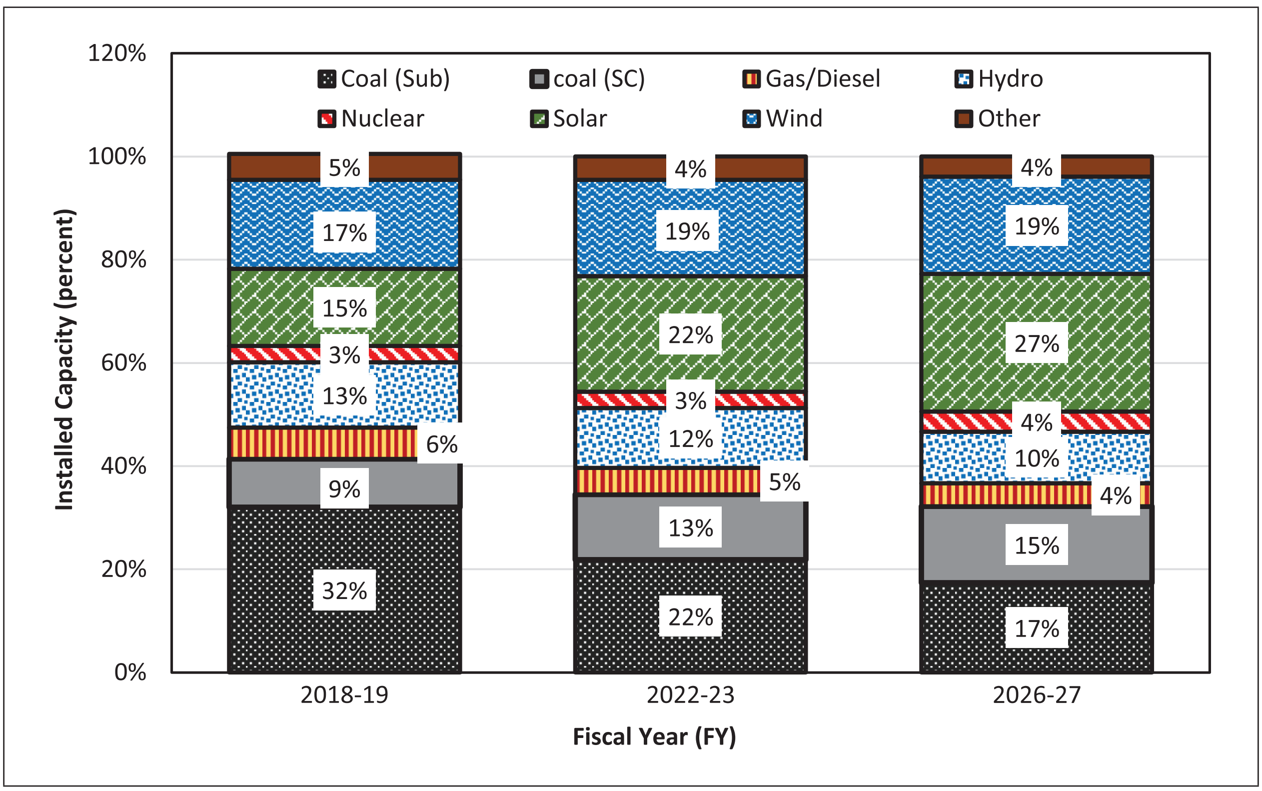


Figure 4: Source-wise installed capacity in SR based on the NIAS Transition Plan

Notes:

1. The Coal (Sub) and Coal (SC), hydro, diesel/gas installed capacities in the SR as of March 2019 are taken from CEA (2019e). The installed capacities of wind, solar and other electrical energy sources in the SR as of March 2019 are taken from MNRE (2019).
2. The list of Coal (Sub) and Coal (SC) power plants likely to be commissioned by FY 2022-23 and FY 2026-27 are extracted from CEA (2020d).
3. The list of Hydro and Gas/Diesel power plants likely to be installed by FY 2022-23 and FY 2026-27 are based on CEA (2018a).
4. During the period, 31st March 2019 – 31st March 2023, the installed generation capacities of solar, wind and other VRE sources are projected to increase by 12,000 MW, 5000 MW and 300 MW, respectively (PGCIL, 2019). A similar increase in the installed generation capacity of VRE sources is assumed to occur between 31st March 2023 and 31st March 2027.

will prevent tariff hikes which reduce the affordability of electricity in a developing country like India.

- HELE TPPs enhance VRE integration with their ability of quick start-stop, faster ramping, and technical minimum operation even at 40 percent of their rated capacity to produce balancing power to cater to the off-peak demand and peak demand scenarios.

- Compared to +25-year old obsolete TPPs with sub-critical technology that have an average thermal efficiency of 35 percent, HELE TPPs (operating at higher steam temperatures and pressures) have 5-8 percent higher thermal efficiency, this, in turn, leads to lower fuel consumption and reduced CO_2 emissions for equivalent electrical power output.

- With the retirement of old TPPs, the utilization of existing HELE TPPs can also be enhanced to meet the future peak demand which will reduce air pollution as well as CO_2 emissions.

5. Key results

The key results of power flow analysis to validate the proposed transition plan for TPPs was carried out in terms of power generation using various power generation technologies, power flow through the transmission elements, and the loading of these elements during FY 2018-19, FY 2022-23 and FY 2026-27.

Key results – Power generation

The SR experienced a record-high (for FY 2018-19) peak demand of 47,147 MW on March 29, 2019. The electricity generated by TPPs is projected to increase from 29 GW in March 2019 to 33 GW in FY 2022-23 and 38 GW in FY 2026-27 as per the proposed transition plan. This growth in thermal power generation will particularly enhance the operating efficiency and PLF of existing HELE TPPs as well as the new HELE TPPs that will be commissioned during this period. This will also lead to reductions in energy charges of the TPPs since the specific coal consumption of TPPs will improve with higher PLFs. Further, the increase in PLF of existing and new HELE TPPs to meet the projected peak demand as per the BAU scenario after the retirement of +25 years old TPPs in SR will also reduce the capacity charges of such new environment-friendly TPPs and reduce the overall power tariffs for all consumers in SR.

The details of power generated at 7 pm (to meet the evening peak demand) from all sources (except, solar energy) during FY 2018-19 and the projections for FY 2022-23 and FY 2026-27 are also analyzed and summarized in Table 2. Based on the difference between total power generation and evening peak demand, SR is likely to be in deficit to the tune of 12,863 MW in FY 2022-23 and 17,141 MW in FY 2026-27. This deficit in peak demand must be bridged by power imports from the Western and Eastern regions which have surplus TPP generation capacity. However, the power imports into SR can be reduced if there are significant changes in the economics of grid-scale battery technology in India.

The baseload is the minimum amount of electricity needed to provide a continuous power supply. TPPs and NPPs have traditionally been operated to fulfill the base load, which is approximately 80% of the peak demand in India (CEA, 2019g). The sum of the installed capacities of TPPs and NPPs in SR to meet the projected peak demand during FY 2018-19, FY 2022-23, and FY 2026-27 is presented in Figure 5. As of March 2019, SR's total installed TPP

Table 2: Summary of Peak demand and power generation in SR (all figures in MW)

Load/ Generation	FY 2018-19						FY 2022-23						FY 2026-27					
	AP	TS	KA	KL	TN	Total	AP	TS	KA	KL	TN	Total	AP	TS	KA	KL	TN	Total
Peak demand	7,468	9,324	10,101	3,948	15,924	**47,147**	9,331	10,720	13,497	4,846	19,668	**58,062**	11,037	12,680	15,860	5,598	23,627	**68,802**
Technology	**Power generation within the SR**																	
TPP	8,317	6,596	5,273	247	8,895	**29,328**	8,090	7,998	7,293	247	10,276	**33,904**	9,157	11,234	6,446	247	10,821	**37,905**
Gas/Diesel	347	0	0	0	263	**610**	347	0	0	0	263	**610**	347	0	74	0	263	**684**
Hydel	441	376	2,684	1,316	367	**5,184**	553	376	2,684	1,316	367	**5,296**	553	414	2,953	1,448	409	**5,777**
Wind	256	0	563	0	568	**1,387**	368	0	563	0	770	**1,701**	417	0	713	0	885	**2,015**
Nuclear	0	0	785	0	596	**1,381**	0	0	784	0	2,358	**3,142**	0	0	748	0	4,199	**4,947**
Biomass, etc.	161	0	127	0	1117	**1,405**	161	0	117	0	1,173	**1,451**	**161**	0	117	0	1,173	**1,451**
Total generation from SR						**39,295**						**46,104**						**52,779**
Total imported power from other regions						**8,652**						**12,863**						**17,141**

Notes:

1. Peak demand for FY 2018-19 and power generation during FY 2018-19 is based on the Power supply position report of Southern region for 29-03-2019 (POSOCO, 2019).
2. Projected peak demand for FY 2022-23 and FY 2026-27 are based on the Business As Usual (BAU) scenario projected by CEA (2019d) using the Partial Adjustment Model (PAM).
3. The share of NTPC's Talcher TPP is distributed in all states of the SR as per CEA's Load Generation Balance Report (CEA, 2020f).
4. Peak demand of Puducherry (460 MW) is included in Tamil Nadu state figures (PGCIL 2019).
5. The power generation from solar power plants is nil during the evening peak hour conditions (Geetha et al., 2015)
6. Total peak demand in SR is met by the addition of the total power generation supplied by SR and total imported power from other (western and eastern) regions. A power mismatch of around 800 MW (in FY 2018-19), 905 MW (in FY 2022-23), 1,118 MW (in FY 2026-27) is noticed due to inter-regional transmission system losses (POSOCO 2019).

capacity and NPP capacity added up to 46 GW which exceeds the baseload requirement of 80% of the peak demand in the same period (39 GW). The combined installed generation capacity of TPPs and NPPs in SR is projected to be 46 GW in FY 2022-23 and 54 GW in FY 2026-27. These capacities closely match the base load requirement during the projected peak demand (as per the PAM-BAU scenario) and any deficit can be bridged by importing power from other regions into the SR as is being done in SR today (TNERC, 2019).

Contribution to energy generation is more important than the proportion of total capacity since the energy contribution also reflects the diurnal variation of VRE which demands system flexibility. The source-wise distribution of energy generation in SR in FY 2018-19 is compared with the FY 2022-23 and FY 2026-27 scenarios in Figure 6. As shown in Figure 6, the share of Coal (SC) in the total energy generation in SR is projected to increase from seven percent in FY 2018-19 to 23 percent in FY 2022-23 and 28 percent in FY 2026-27.

Key results –inter-regional electricity flows

India's power grid consists of transmission lines that operate at voltage levels of 765 kV, 400kV, or 220 kV and lower voltage ranges. As of March 2019, the inter-regional transmission capacities between the southern-western regions and the southern-eastern regions were 12.12 GW and 7.83 GW respectively. To increase the power flow between the Western Region (WR) and SR, the Warora-New Warangal line with a capacity of 4,200 MW and the Raigarh-Pugalur Direct Current (DC) line with a capacity of 6,000 MW are likely to be commissioned by FY 2022-23. With this, the total inter-regional transmission capacity between the SR and the Western/Eastern regions of India's power Grid will be enhanced from 19.95 GW in FY 2018-19 to 30.15 GW in FY 2022-23 with the addition

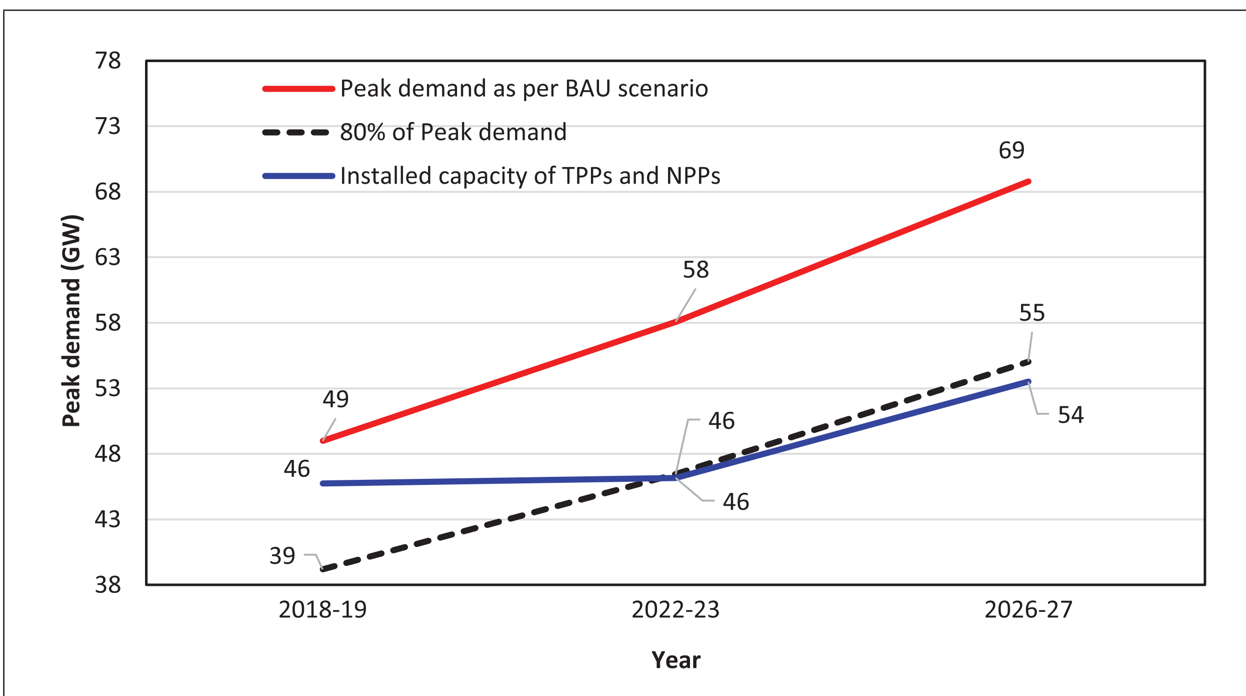


Figure 5: Growth in peak demand in SR met by increasing generation from existing and under-construction TPPs and NPPs (after CEA, 2019a; CEA, 2019d).

of substations and interconnecting transmission lines (CEA, 2017, 2020e). The projected increase in the number of 220 kV/400kV/765 kV substations and interlinking transmission lines by March 2027 will enhance the reliability, flexibility, and stability of the SR Grid to transfer power within and outside the region.

The inter-regional power transmission flows are shown in Table 3. The power flow results obtained from the simulation model are compared with the power supply position data of FY 2018-19 (POSOCO, 2019). During the year FY 2018-19, 8,572 MW of power was imported from the western and eastern regions. In comparison, the power flow model developed during this study indicates the need to import 8,652 MW of power into SR, thereby satisfying one of the key validation criteria adopted during this study.

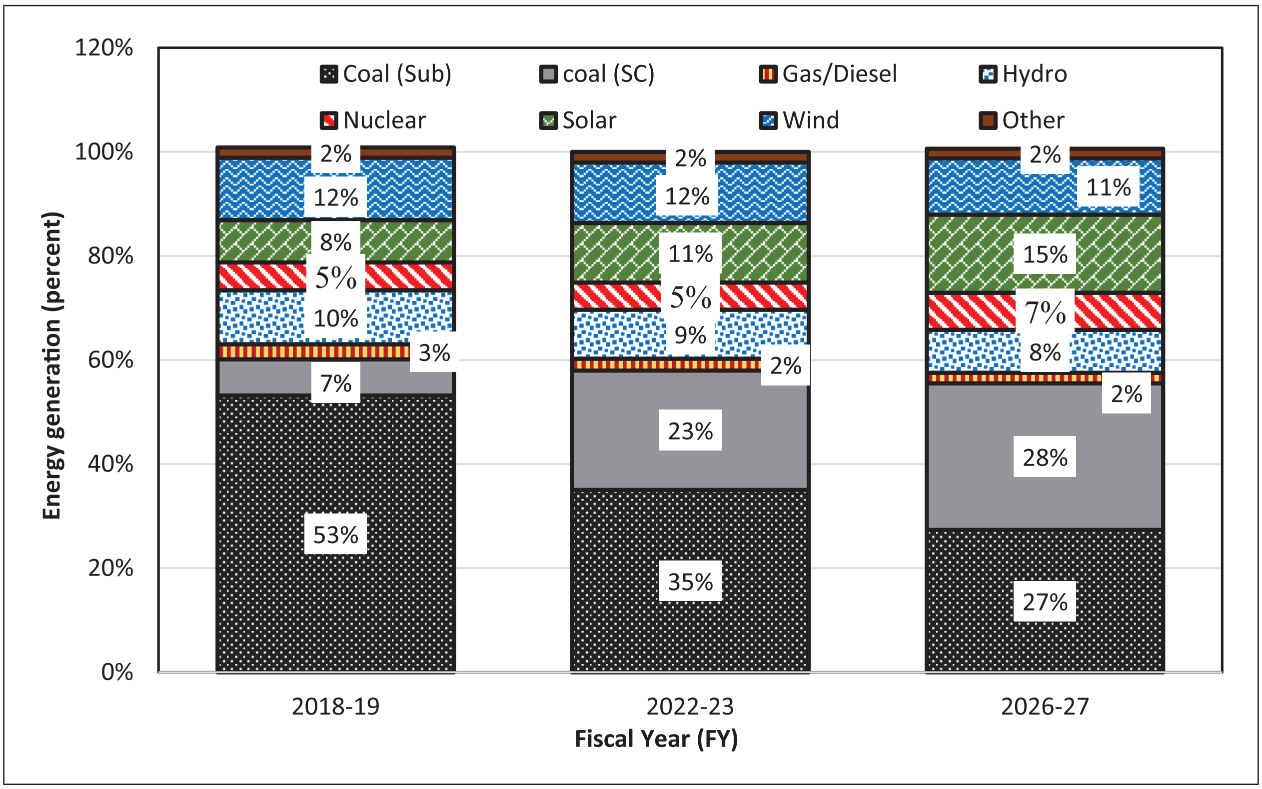


Figure 6: Actual and projected electricity generation by utilities in Southern Region

Notes:

1. The energy generation in SR for FY 2018-19 is extracted from CEA (2019c).
2. To estimate electricity generation during FY 2022-23 and FY 2026-27, it is assumed that the additional capacities of TPPs (state and central only) and nuclear power plants are operating at 70% Plant Load Factor (PLF) (CEA, 2018a). The additional capacities of Gas/Diesel, hydro and VRE (solar, wind and others) are assuming to be operating at 25%, 40% and 20% PLF, respectively (CEA, 2018a; PGCIL, 2019).
3. The quantum of electrical energy generated in SR during FY 2022-23 is estimated by summing up the energy generation during FY 2018-19 and the projected energy generation (based on the PLFs assumed in step 2) from the new capacity addition between FY 2018-19 and FY 2022-23 (CEA, 2020d; PGCIL, 2019).
4. Similarly, the electrical energy generated in SR during FY 2026-27 is estimated by adding the electrical energy generated from the new capacity addition between FY 2022-23 and FY 2026-27 to the projected electrical energy generated during FY 2022-23 as estimated in step 3 (CEA, 2020d; PGCIL, 2019).

Similarly, the simulation results for FY 2022-23 and FY 2026-27 based on the implementation of the proposed transition plan are depicted in the last four columns of Table 3. As shown in Table 2, 12,863 MW and 17,141 MW of power are projected to be imported into the SR to meet the evening peak demand during FY 2022-23 and FY 2026-27, respectively. These levels of power imports are well within the system limits of the inter-regional Grid.

Key results - loading of transmission elements.

As of March 2019, the SR consists of 290 transformers with a mix of 400/220kV, 765/400kV voltages to which 55 and 60 transformers are proposed to be added by FY 2022-23, and FY 2026-27, respectively (CEA). The number of 400kV transmission lines will increase from 385 in FY 2018-19 to 479 in FY 2022-23 and 532 in FY 2026-27. Our analysis shows that the proposed transition plan has enhanced the utilization of substation capacity in FY 2022-23 and FY 2026-27 compared to FY 2018-19. The average loading of transmission elements decreases from 23 percent in FY 2018-19 to 20 percent in FY 2022-23 and then increases to 24 percent in FY 2026-27. The 400/220 kV transformers that are loaded to the extent of at least 60 percent of their rated capacity during

Table 3: Summary of inter-regional transmission capacity connecting SR to other regions

With Region	S. No	Transmission element	Capacity	FY 2018-19		FY 2022-23		FY 2026-27	
				Power	%Load	Power	%Load	Power	%Load
Western Region	1	Chandrapur-Ramagundam (DC)	1,000	994	99.4	994	99.4	994	99.4
	2	Wardha-Nizamabad	4,200	2,489	59.2	2,468	58.8	3,628	86.4
	3*	Raigarh-Pugalur (DC)	6,000	-	-	1,950	32.5	3,026	50.4
	4	Sholapur-Raichur	4,200	2,305	54.8	3,139	74.7	2,575	61.3
	5	Ponda-Nagajhari	260	125	48.1	158	60.8	257	98.8
	6**	Warora-New Warangal	4,200	-	-	1,162	27.7	2,660	63.3
	7	Chikkodi-Mudasangi	260	84	32.3	160	61.5	190	73.1
	8	Kolhapur-Narendra	2,200	-169	7.6	-1467	66.7	-598	27.2
Eastern Region	9	Talcher-Kolar (DC)	2,500	511	20.0	1,015	40.6	1,016	40.6
	10	Jeypore-Gajuwaka (DC)	1,000	663	66.3	932	93.2	928	92.8
	11	Angul-Srikakulam	4,200	1,650	39.2	2,352	56.0	2,465	58.7
	Total power imported from other regions			**8,652**		**12,863**		**17,141**	

Notes:

1. Inter-regional transmitted power: positive sign (+) indicates import from other regions to SR, while negative sign (-) indicates export from SR to other regions.
2. *As on 06th October 2020, transmission capacity of 3000 MW between Raigarh - Pugalur (DC) has been commissioned for evacuation of power from the Western region to the Southern region. The remaining transmission capacity of 3000 MW between Raigarh - Pugalur (DC) is likely to be commissioned by December 2022 (CEA, 2020e).
3. **Warora-New Warangal transmission scheme is likely to be implemented by December 2022 (CEA, 2020e)

FY 2022-23 and FY 2026-27 are summarised in Table 4. The simulation results indicate that the power flow through each transmission line is within the prescribed limits after providing an additional transformer (up to 500 MVA capacity) at specific substations to satisfy single outage contingencies.

Table 4: Details of transmission elements proposed to be reinforced in SR by 2022/2026

S.No.	Name (No. of transmission elements)	Power Flow (MW)	Rated Capacity (MW)	%Load
December 2022				
1	Sriperumbudur (1-2)	225	315	71
2	Neyveli-II (1-2)	176	250	70
3	Alamathi (1-2)	142	200	70
4	Manali (1-2)	135	200	68
5	Neyveli New (1-2)	332	500	66
6	Narendra (1-2)	320	500	64
7	Guttur-Hiriyur (1-2)	583	874	67
8	Somanahalli-Bidadi (1-2)	525	874	60
December 2026				
1	Hassan (1-2)	243	315	77
2	Sriperumbudur (1-2)	222	315	71
3	Hoody (1-3)	360	500	72
4	Salem (1-2)	222	315	70
5	S V Chatram (1-2)	135	200	67
6	Kudanakulam (1-2)	211	315	67
7	Nelamangala (1-2)	333	500	67
8	Tiruvalam (1-2)	209	315	66
9	Yalwar (1-2)	327	500	65
10	Shankarpally-Narsarpur (1-2)	650	874	74
11	Nellore-Sriperumbudur (1-2)	648	874	74
12	Tirunelvelli-Kudankulam (1-2)	1067	2182	74
13	Guttur-Hiriyur (1-2)	596	874	68
14	Ramagundam-Ghanapur (1-2)	561	874	64
15	Shannkarpalli-Nizamabad (1-2)	549	874	63
16	Kayathar-Kanarpaty (1-2)	537	874	61

Note:

As per POSOCO norms, any transmission element loaded more than 60% must be considered for reinforcement to ensure the reliability and stability of the grid (CEA, 2019h).

Key results – Grid flexibility

The installed capacity of VRE sources in the SR increased from 7,940 MW to 38,620 MW between FY 2009-10 to FY 2018-19. It is projected to increase to 59 GW by FY 2022-23 (CEA). In real-world market operations, the flexibility of TPPs is the key strategy in terms of faster ramp rates and the lower technical minimum level during the daytime to accommodate the renewable power or at the time of lower demand. The system integration of solar PV will require investment in storage and distribution networks and ramping capability to cope with the "duck curve" in the morning and evening hours. HELE TPPs are capable of generating sufficient balancing power during the evening peak hours since they have faster ramping-up and ramping-down and technical minimum capabilities (Ulbig A & G. Andersson, 2015). Considering the VRE-rich states in the SR may not always have the capacity to absorb the surplus electricity generated, the proposed transition strategy can facilitate the evacuation of the enhanced VRE generated without curtailment of these "green" energy sources at their peak which unfortunately coincides with the off-peak demand period in SR.

The improvement in the flexibility and ramp rate of the entire TPP capacity in the SR due to the implementation of the proposed transition plan was estimated. The ramp rate (% of capacity) signifies the actual flexibility based on the size of TPP. During FY 2018-19, 123 TPPs with a total installed capacity of 42,413 MW (including 1,500 MW from Talcher stage II which is dedicated for SR) provided a ramp rate of 1,522 MW/min and a technical minimum level of 20,899 MW. After the implementation of the proposed transition plan by FY 2022-23, the 90 operational TPPs with a total capacity of

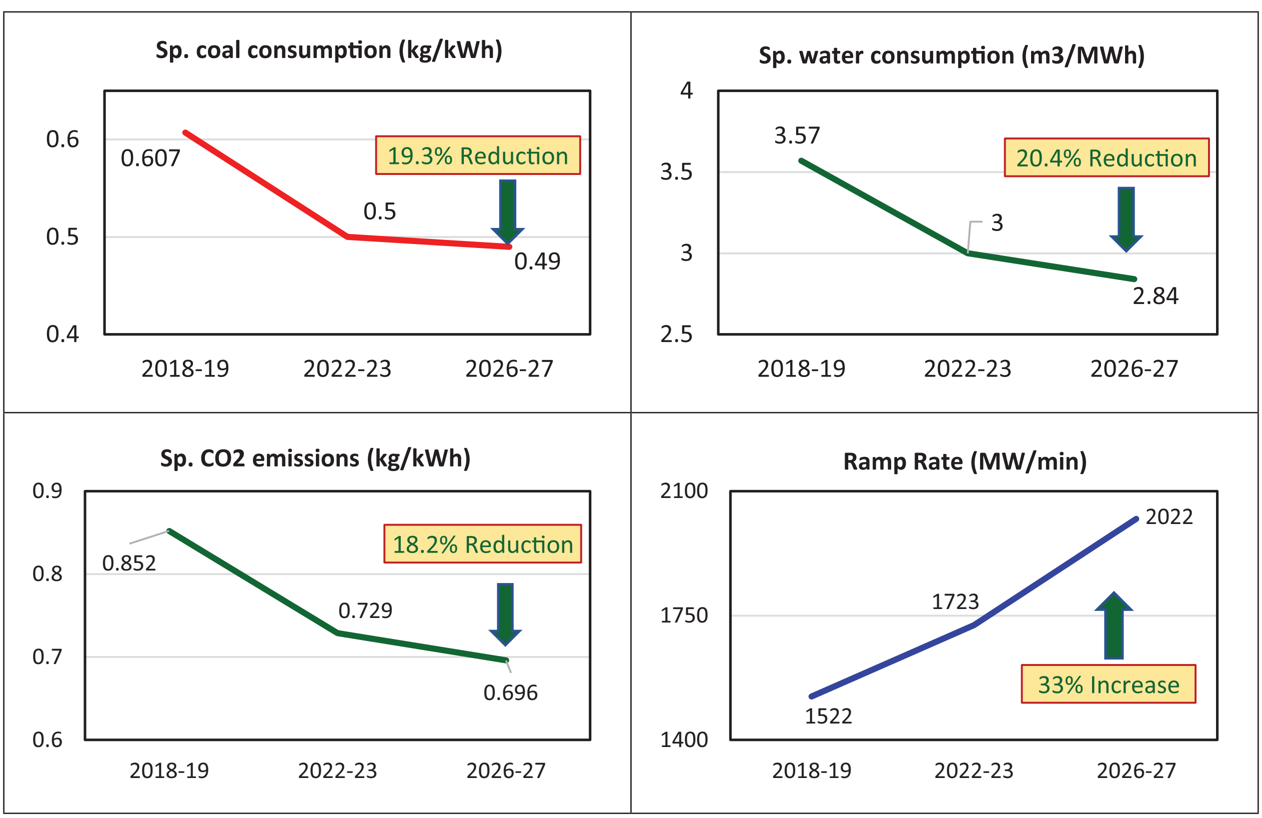


Figure 7: Environmental benefits by implementing the NIAS Transition Plan for TPPs

Table 5: Potential to enhance flexible operations of TPPs in SR to facilitate smoother VRE integration

TPP size (MW)	Ramp rate (% of Capacity)	Technical min (% of capacity)	FY 2018-19				FY 2022-23				FY 2026-27			
			No. of TPPs	Capacity (MW)	Ramp Rate (MW/ min)	Technical min. (MW)	No. of TPPs	Capacity (MW)	Ramp Rate (MW /min)	Technical min. (MW)	No. of TPPs	Capacity (MW)	Ramp Rate (MW/ min)	Technical min. (MW)
660/700/ 800 MW	5	40	13	9740	487	3896	21	15580	779	6232	29	21980	1099	8792
500/520/ 600 MW	4	50	36	19340	774	9670	38	20340	814	10170	38	20340	804	10170
250/270/ 300 MW	3	55	8	2100	63	1155	10	2680	80	1474	10	2680	80	1474
200/210 MW	2	55	42	8790	176	4835	11	2280	46	1254	6	1230	25	677
110 to 180 MW	1	55	12	1700	17	935	10	1460	15	803	10	1460	15	803
<=100 MW	0.8	55	12	743	6	409	0	0	0	0	0	0	0	0
			123	**42413**	**1522**	**20899**	**90**	**42340**	**1733**	**19933**	**93**	**47690**	**2022**	**21916**

Notes:

1. The number of TPPs and the total installed TPP capacity in SR for the FY 2018-19 are based on (CEA, 2019e). This capacity includes 1500 MW of generation capacity in NTPC's Talcher Stage II which is dedicated for the Southern Region.
2. The share of NTPC's Talcher TPP is distributed in all states of the SR as per CEA's Load Generation Balance Report (CEA, 2020f)
3. The ramp rate (% of capacity) and technical minimum (% of capacity) parameters for various TPP unit sizes are given in (CEA, 2018b).

42,340 MW can increase the ramp rate to 1,733 MW/min and reduce the technical minimum level of 19,933 MW. Similarly, in FY 2026-27, the 93 operational TPPs with a total capacity of 47,690 MW will increase the ramp rate to 2,022 MW/min and reduce the technical minimum to 21,916 MW. Therefore, the proposed transition plan increases the flexibility of TPPs in the SR grid through improvement in ramp rate by 33% as shown in Table 5 and Figure 7.

Key Results - Economic and environmental benefits

A technically feasible and cost-effective "Transition Plan" for the power sector in the Southern Region has been developed which will result in a more economic and environment-friendly power sector by 2022. The implementation of this transition plan will lower specific coal consumption by 19.3 percent, reduce specific CO_2 emissions by 18.2 percent, and also cut down specific water consumption by 20.4 percent (Table 6 and Figure 7).

Further, the implementation of the proposed transition plan by December 2022 will also help the four State-owned generation companies (GENCOs) in SR to save Rs.3,500 Crores in retrofit costs (Figure 8) which they will otherwise spend on making their +25-year old TPPs compliant with the environmental norms mandated by MoEFCC (2015). In addition to savings in capital investments which will increase the capacity charges of TPPs after the retrofit of FGDs, the Energy Charges (largely, coal cost) of TPPs in SR will also reduce by six percent after the implementation of the transition plan described in this study.

Table 6: Projected economic and environmental benefits of implementing the proposed transition plan for TPPs in the Southern Region

Parameters	FY 2018-19	Retire-ments by 2022	Addi-tions by 2022	FY 2022-23	Savings 2022-23	Retire-ments by 2027	Addi-tions by 2027	FY 2026-27	Overall Savings
Total Coal and lignite Consumption (Mt)	136	50	28	114	**16%**	5	25	134	
Generation Total (GWh)	224,267	46,945	47,282	224,604		6148	54,505	278,994	
CO_2 Emissions (Mt)	191	67.1	39.8	163.8	**14%**	5.95	35.78	194.29	
Water consumption (Mi. cubic meters)	800	254	139	686	**14%**	29	111	773	
Sp. coal consumption (kg/kWh)	**0.607**	1.060	0.596	**0.51**	**16%**	0.765	0.464	**0.49**	**19.3%**
Specific CO_2 Emission (kg/kWh)	**0.852**	1.428	0.843	**0.729**	**14%**	0.968	0.656	**0.696**	**18.2%**
Specific Water consumption (m^3/MWh)	**3.57**	5.41	2.94	**3.05**	**14%**	4.74	2.03	**2.77**	**20.4%**
Savings in FGD/ESP Retrofit CAPEX for four State-owned Generation companies (GENCOs) in SR	8,037	4,538			**Rs. 3500 Crores (35 Billion)**	525			**Rs. 4024 Crores (40.24 Billion)**

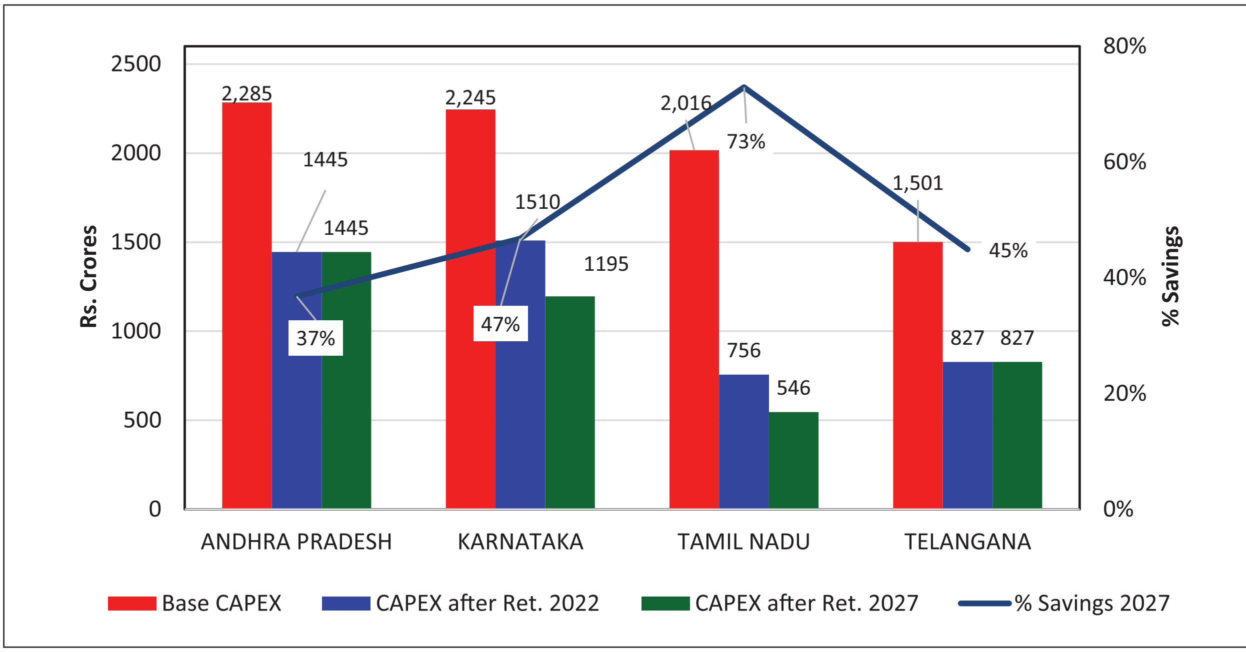


Figure 8: Savings for State GENCOs by implementing the NIAS transition plan (Note: 100 Crores = 1 Billion)

6. Scenario 2030

The detailed analysis of the SR power sector up to 2027 was extended to 2030 based on the peak demand projections as per CEA's PAM-BAU model and CEA's National Electricity Plan (NEP) - Vol II – Transmission. CEA had finalized the NEP-Perspective Transmission Plan (PTP) (CEA 2019b) for 2022-27 based on the peak demand projections given in CEA's 19th EPS report (299 GW – All India and 83.65 GW - SR) and the associated generation capacity additions (CEA2020a). Therefore, these projections for transmission capacity additions were considered during the power flow simulation study and analysis during this study.

Subsequently, CEA brought out the PAM-BAU model (CEA 2019a) where the peak demand was validated with the actual demand for 2016-17 & 2017-18 and then extrapolated up to 2037. However, the Perspective Transmission Plan (2022-27) remains unaltered. The projected Peak Demand as per the 19th EPS report for 2027 (299 GW) is slightly higher than the projected Peak Demand as per CEA's PAM-BAU model for 2030 (293 GW). The Peak Demand projections for SR as per CEA's PAM-BAU model are shown in Table 7.

Table 7: Peak Demand projections for SR between 2027 and 2030 (MW)

Year	AP	TS	KA	KL	TN	PC	Total
2027	11037	12680	15860	5598	23627	564	68802
2028	11490	13201	16483	5792	24414	587	71967
2029	11955	13734	17121	5990	25176	610	74586
2030	12430	14281	17772	6191	26281	634	77584

NIAS's power flow analysis to meet the Peak Demand of 68802 MW in SR by 2027 indicates that nine substations were loaded beyond 60%, which is the norm for loading substations as per the Standing Committee report of POSOCO. Comparison of the loading percentage in these substations during 2022-23 and 2026-27 indicates that, wherever the substation load is 50-60% during 2022-23, these substations were overload due to the increased power flow requirement in 2026-27. However, substations with 3 or more transformers did not show overloading since redundancy is already built-in into these substations. Applying the same logic, the 400 kV substations in SR with only one or two transformers whose loading is greater than 55% in 2026-27 are likely to be overloaded if they have to meet the 2030 projected Peak Demand of 77584 MW as per the PAM-BAU model. Therefore, each of the seven substations containing only one or two transformers in the SR Grid (Table 8) must be augmented with at least one more transformer of suitable capacity between 2027 and 2030 to meet the aforesaid Peak Demand.

Table 8: Substations to be strengthened for 2030

Sl. No.	Substation	Loading
1	Ottapidaram (TN)	60%
2	Yelahanka (KA)	60%
3	Narendra (KA)	59%
4	Salem (TN)	59%
5	Kethireddypalli (TS)	58%
6	Maradam (AP)	57%
7	Kudgi (KA)	57%

For all Inter-Region 765 kV transmission systems, there are no issues of overloading in the 2030 scenario since the current norms allow loading up to 100%.

As per the latest CEA 'Broad Status' report, there are no new additions of TPPs or NPPs between 2027 and 2030 in SR. Hence the installed capacity and contribution of TPPs/NPPs and other sources to the peak demand of 2029-30 is considered to remain at 50705 MW, which is identical to the 2026-27 scenario. Also, no retirements are proposed between 2027

Table 9: Simulation summary for March 2030

Peak Demand (MW)						**77584**
1. Met by State and Central Source						
Source	AP	TS	KA	KL	TN	Total
Thermal*	8984	11032	6170	0	10293	36479
Gas/Naptha/Diesel	347	0	0	0	263	610
Hydel	553	414	2953	1448	409	5777
Wind	317	0	613	0	745	1675
Nuclear	0	0	748	0	4199	4947
Others	0	0	104	0	1113	1217
						50705
2. Import From other regions (WR and ER)						**26879**

*** Note:** TALCHER is added

and 2030 as per the NIAS 'End of Life' policy. Accordingly, the simulation results to meet the Peak Demand for 2030 are shown in Table 9.

7. Conclusions and policy implications

India's dependence on TPPs will continue for several years since coal is only the fuel catering to the energy security of the country in an affordable manner. The transition plan for TPPs proposed in this study includes the phasing out of 52 obsolete TPPs with a capacity of 9 GW and the addition of 22 under-construction HELE TPPs in the SR with a total capacity of 14.32 GW by FY 2026-27. The fifty-two + 25-year-old TPPs recommended for retirement were selected after considering several key performance parameters like Heat Rate, Specific Coal Consumption, Auxiliary Power Consumption, etc, as shown in Table 10. It is seen that the performance of these plants is below the specified CEA norms. The list of TPPs and NPPs which are in various stages of construction by the State and National GENCOs are detailed in Table 11 (MoP, 2020a, 2020c).

To validate the feasibility of the proposed transition plan, power flow studies are conducted to meet the projected peak demand of 58 GW in FY 2022-23 and 69 GW in FY 2026-27. The results of these power flow studies indicate that the power flow through each transmission element is within prescribed limits with the addition of a suitable transformer at a few substations to satisfy single outage contingencies. Further, the retirement of the +25-year old sub-500 MW TPPs by 2026-27 has a negligible impact on the SR Grid's operation mainly due to the availability of power from newer TPPs and neighboring regions of the country. The policy implications of this study are as follows:

- The loss of generation from the retirement of +25-year old, obsolete TPPs in SR as proposed in this study can be compensated by increasing generation from already commissioned, under-utilized HELE TPPs in SR. This will also enhance the operational efficiency and cost-effectiveness of the entire system by reducing specific coal consumption which also results in lower energy charges. Besides, the implementation of the transition plan will also result in reductions in water consumption, CO_2 emissions, and air pollution while avoiding the capital investments (approximately, Rs.3500 crores for four State GENCOs in SR) required to retrofit FGDs in the obsolete TPPs proposed for retirement. The avoidance of tariff hikes due to increase in capacity charges and energy charges to retrofit FGDs in the obsolete TPPs will also enable India to progress towards the attainment of Sustainable Development Goal 7 (clean and affordable power to all).

- India's coal resources are situated in the eastern and western regions of India. The energy charges and CO_2 emissions from the electricity sector can also be reduced by utilizing the inter-regional grid to transmit the bulk power from pithead TPPs in the Eastern and Western regions to the SR since pithead TPPs have lower energy charges and lower CO_2 emissions compared to the old TPPs located near the load centers. As shown in this study, power imports into the SR are expected to increase in FY 2022-23 and FY 2026-27 to accommodate the increase in projected peak demand. Therefore, the augmentation of power transmission capacity at strategic locations is the key to achieve the benefits of low-cost power while reducing emissions and meeting the envisaged power

Table 10: Key performance parameters of TPPs proposed for retirement in 2022 & 2027 as per the NIAS Transition Plan

No	Station	Units	Generation in MU (2018-19)	PLF in %	PAF in %	Station Heat rate in kCal/ kWh	% APC	Specific Coal Consumption (Kgs/kWh)	Specific CO_2 Emissions (tons/ MWh or Kgs/kWh)	Specific Water Consumption (m^3/MWh)	Age as on Dec 2022 (years)
1	Dr N Tata Rao TPS, Vijayawada, APGENCO	6x210 MW	7759.36	70.3	90.76	2797	10.4	0.82	1.16	179.7 (Once thro' cooling)	27-43
2	Rayalaseema TPS 1, APGENCO	2x210 MW	2363.93	63.42	92.98	2720	11.3	0.75	1.03	7.5	27-28
3	Raichur TPS, KPCL	7x210 MW	8917.97	59.3	87.3	N.A.	9.6	0.72	1.01	5.4	20-37
4	Mettur TPS, TANGEDCO	4x210 MW	5807.19	78.9	92.07	2495	8.5	0.70	0.99	6.4	32-35
5	North Chennai, TANGEDCO	3x210 MW	3998.72	72.45	86.3	2466	9.2	0.77	1.09	Sea Water	26-28
6	Tuticorin TPS, TANGEDCO	5x210 MW	6306.31	68.5	86.9	2559	7.9	0.72	1.02	Sea Water	30-43
7	Kothagudem (Old) TPS, TSGENCO	3x60+2x120+ 2x250 MW	7412.71	89.9	93.2	2623	11	1.02	1.44	13.7	24-65
8	Ramagundem – B TPS, TSGENCO	62.5 MW	423.01	77.26	87.63	2890	12.8	0.68	0.97	5.9	41
9	Neyveli TPS 1, CGS	6x50+2x100 MW	3105.87	62.35	90.8	4000	13.4	1.08	1.22	7.5	52-60
10	Neyveli TPS 2, CGS	7x210 MW	10744.53	83.4	91.5	2890	10.2	0.90	1.01	6.6	29-36
11	Neyveli TPS 1 Exp, CGS	2x210 MW	2949.64	80.2	81.7	2770	8.2	0.9	1.01	6.4	20-21

References for Table 10

Document	Parameter	Unit	Value	Document	Parameter	Unit	Value
CEA Norms for Tariff	Heat Rate	kCal/kWh	2450	CEA V15 on Emissions	Weighted Average Emission Rate	tons/ MWh	0.97
CEA Norms for Tariff	Auxiliary Power Consumption	%	8.5	MoEF&CC Notification dated 07.12.2015	Specific Water Consumption	m^3/MWh	3.5

Table 11: List of TPPs and NPPs likely to be added in SR by 2022 and 2027

State	Plant name	Owner	Sector	Unit No	Capacity (MW)	Likely by year	Type of Plant
Thermal Power Plants							
Andhra Pradesh	Dr. N. Tata Rao TPS Expansion	APGENCO	State	8	800	2022	Super-Critical
Andhra Pradesh	Sri D. Sanjeevaiah TPS	APGENCO	State	3	800	2026	Super-Critical
Tamil Nadu	New Neyveli TPS	NLC	Central	1	500	2019	Sub-Critical
Tamil Nadu	New Neyveli TPS	NLC	Central	2	500	2020	Sub-Critical
Tamil Nadu	Uppur Power Station	TANGEDCO	State	1	800	2024	Super-Critical
Tamil Nadu	Uppur Power Station	TANGEDCO	State	2	800	2025	Super-Critical
Tamil Nadu	Ennore SEZ Super Critical TPP	TANGEDCO	State	1	660	2020	Super-Critical
Tamil Nadu	Ennore SEZ Super Critical TPP	TANGEDCO	State	2	660	2021	Super-Critical
Tamil Nadu	North Chennai TPS Stage III	TANGEDCO	State	1	800	2021	Super-Critical
Tamil Nadu	Udangudi Power Station	TANGEDCO	State	1	660	2023	Super-Critical
Tamil Nadu	Udangudi Power Station	TANGEDCO	State	2	660	2024	Super-Critical
Telangana	Telangana Super TPP Stage I	NTPC	Central	1	800	2025	Super-Critical
Telangana	Telangana Super TPP Stage I	NTPC	Central	2	800	2025	Super-Critical
Telangana	Bhadradri Power Plant	TSGENCO	State	1	270	2019	Sub-Critical
Telangana	Bhadradri Power Plant	TSGENCO	State	2	270	2020	Sub-Critical
Telangana	Bhadradri Power Plant	TSGENCO	State	3	270	2020	Sub-Critical
Telangana	Bhadradri Power Plant	TSGENCO	State	4	270	2021	Sub-Critical
Telangana	Yadadri Power Plant	TSGENCO	State	1	800	2020	Super-Critical
Telangana	Yadadri Power Plant	TSGENCO	State	2	800	2021	Super-Critical
Telangana	Yadadri Power Plant	TSGENCO	State	3	800	2023	Super-Critical
Telangana	Yadadri Power Plant	TSGENCO	State	4	800	2024	Super-Critical
Telangana	Yadadri Power Plant	TSGENCO	State	5	800	2024	Super-Critical
Nuclear Power Plants							
Tamil Nadu	IGCAR, Kalpakkam Power Station (BHAVINI)	IGCAR	Central	1	500	2021	PFBR
Tamil Nadu	Kudankulam NPS (KKNPS)	NPCIL	Central	3	1000	2025	VVER -1000 (PWR)
Tamil Nadu	Kudankulam NPS (KKNPS)	NPCIL	Central	4	1000	2026	

demand in SR during FY 2022-23 and FY 2026-27 (IEA, 2020a).

- There is a need for a National Electricity Council in India (Srikanth R, 2017) to enable the Central and State Governments to work together in the overall interest of the country's power sector which is facing severe financial stress while struggling to meet the challenges posed by climate change.

- As per NIAS's analysis, SR will not require any further investment in the power plants till 2030 beyond those TPPs and NPPs which are already at an advanced stage of construction. The installed capacity of 2027 considering the additions and retirements as per the Transition plan will be capable of meeting the Peak Demand of SR for 2029-30 in a cost-effective manner by supplementing the generation in SR with power imported from already commissioned TPPs in WR and ER.

This study covers the peak demand scenario which normally occurs around 7 pm in SR. Therefore, the generation studies considered in this report do not include the following in their ambit:

- Thermal Power Plants owned by the Private sector (IPPs) that are currently under construction (23.7 GW on All India Basis – 2.7 GW in SR).

- Grid-Connected Captive Plants in India consisting of 35 GW of coal-fired capacity, 13.5 GW of diesel generation plants, and 7.75 GW of gas-based generation capacity.

- Potential for Round-the-Clock (RTC) power from RE sources with battery storage as per CEA's projections (CEA, 2020h).

- Optimal utilisation of the 6.48 GW of Gas based power generation capacity that is being operated with a PLF of 10.78% in SR due to ever-increasing shortfall in the supply of domestic natural gas.

In particular, the availability of cost-effective RTC power from RE sources with battery storage can change the optimal electricity source mix by creating opportunities for the retirement of inefficient TPPs beyond those that are included in this study.

Even without considering the slowdown in electricity demand-growth due to the COVID 19 pandemic, the authors of this study conclude that further investments in power generation in SR are required only to meet power demand beyond 2030. The cost of power procurement accounts for approximately 80 percent of the Annual Revenue Requirement (ARR) of DISCOMs in SR today. The ARR submissions made by several DISCOMs in SR include 000's of crores in capacity charges for under-utilised TPPs in the region due to the supply-demand mismatch and the must-run status granted to RE sources. Therefore, the recommendations of this study have significant policy implications for the Government-owned DISCOMs and GENCOs, electricity regulators, and most importantly all power consumers in SR.

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Annexure - 4

Power Flow Analysis Methodology

For the sake of completeness, this appendix gives the NRLF method in the polar domain. At the bus i, the relation between P, Q, and V w.r.to the injected current (I) for an iteration k are as follows

$$I_i^k = \frac{P_i^k - jQ_i^k}{V_i^{k*}} \qquad \text{(A1)}$$

where j is used for the imaginary number and V_i^* is the complex conjugate of V_i .
Further, the injected current in terms of admittance (Y) and voltages can be written as

$$I_i^k = Y_{ii} V_i^k + \sum_{j=1, j \neq i}^{n} Y_{ij} V_j^k \qquad \text{(A2)}$$

where n is the total no. of buses.
By equating Equations (A1) and (A2), the voltage can be written as,

$$V_i^k = \frac{P_i^k - jQ_i^k}{Y_{ii} V_i^{k*}} - \frac{1}{Y_{ii}} \sum_{j=1, j \neq i}^{n} Y_{ij} V_j^k \qquad \text{(A3)}$$

Equation (A3) is used to determine both voltage magnitude ($|V|$) at the load buses, as well as voltage angle (δ) at the load and regulated buses. The apparent power in terms of the voltage and admittance is written as

$$S_i^{k*} = V_i^{k*} \sum_{j=1}^{n} Y_{ij} V_j^k \qquad \text{(A4)}$$

Equation (A4) can be expanded into real and reactive components as given below.

$$P_i^k = \sum_{j=1}^{n} \left|V_i^k\right| \left|V_j^k\right| \left|Y_{ij}\right| \cos\left(\theta_{ij} - \delta_i^k + \delta_j^k\right) \qquad \text{(A5)}$$

$$Q_i^k = -\sum_{j=1}^{n} \left|V_i^k\right| \left|V_j^k\right| \left|Y_{ij}\right| \sin\left(\theta_{ij} - \delta_i^k + \delta_j^k\right) \qquad \text{(A6)}$$

Equations (A5) and (A6) are used to compute the real power (P) at the load and regulated buses and, the reactive power (Q) is at the load buses. The Newton-Raphson power flow formation in the matrix form can be written as

$$\begin{bmatrix} P_i^s \\ Q_i^s \end{bmatrix} - \begin{bmatrix} P_i^k \\ Q_i^k \end{bmatrix} = \begin{bmatrix} \Delta P_i^k \\ \Delta Q_i^k \end{bmatrix} = \begin{bmatrix} \partial P_i^k / \partial \delta_i & \partial P_i^k / \partial V_i \\ \partial Q_i^k / \partial \delta_i & \partial Q_i^k / \partial V_i \end{bmatrix} \begin{bmatrix} \Delta \delta_i^k \\ \Delta V_i^k \end{bmatrix} \qquad \text{(A7)}$$

where the superscript s indicates specified active and reactive powers. To solve for the voltage and load angles, the inverse of the matrix is required for every iteration. Then new values are calculated:

$$\begin{bmatrix} \delta_i^k \\ V_i^k \end{bmatrix} = \begin{bmatrix} \delta_i^{k-1} \\ V_i^{k-1} \end{bmatrix} + \begin{bmatrix} \Delta \delta_i^k \\ \Delta V_i^k \end{bmatrix} \qquad \text{(A8)}$$

The iterative process stops when the mismatch between calculated and scheduled quantities is within

$$\begin{bmatrix} \Delta P_i^k \\ \Delta Q_i^k \end{bmatrix} \leq \in$$

Document Control Sheet

1	**Document No and Year**	:	NIAS/NSE/EEP/U/WR/03/2021
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11 **Abstract:**
India's power sector is undergoing a "green energy" transition in which the Southern Region (SR) is leading the way. While SR contains 50 percent of India's Variable Renewable Energy (VRE) capacity, the region is facing challenges in VRE integration since the SR Grid also draws power from forty-seven +25-year-old, below 500 MW, Thermal Power Plants (TPPs) with obsolete technology working at low-efficiency levels.

As part of a DST-sponsored Project, NIAS has formulated a "End-of-Life" policy for TPPs as an integral part of a journey towards an "Optimal Electricity Mix" for SR. This policy involves the progressive retirement of such TPPs by December 2022 coupled with the integration of High-Efficiency-Low-Emission (HELE) TPPs and Nuclear Power Plants (NPPs) that are already at an advanced stage of construction. By implementing this transition plan, the four State-owned power generation companies in SR can save approximately Rs.3500 crores required to retrofit imported Flue-Gas Desulfurizers (FGDs) associated with significant environmental and economic impacts.

Power flow studies conducted to validate the SR Grid operations during the evening peak demand indicate that the power flow through each transmission element is largely within prescribed limits up to March 2023. However, certain transmission elements of the SR Grid must be reinforced by 2026 to meet the peak demand in SR during 2027 and 2030 by importing power from the power-surplus Western and Eastern regions of the country through the National Grid after retiring five more obsolete and inefficient below 500 MW TPPs by 2027. The optimal utilization of existing and under-construction HELE TPPs with faster-ramping capabilities and lower technical minimums also facilitates VRE integration.

The proposed transition plan has operational, economic, and environmental benefits with savings in retrofit and life extension costs in the obsolete TPPs, reduced energy charges, lower CO2 emissions and pollution levels, reduction in specific coal consumption and water requirement as well as smoother VRE integration, and efficient Grid operations.

12 **Keywords:**
Thermal Power Plants, Transition Plan, Power Flow analysis, Optimal Electricity Mix, Peak Demand

13 **Security Classification** : Unrestricted

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