Indo-German Energy Forum

Market conditions for operating coal fired power plants flexible to adapt to fluctuating renewable energies

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Federal Ministry for Economic Affairs and Energy

Imprint

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Version
V1.2

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Abbreviations

PAT	Perform, Achieve & Trade
MoEFCC	Ministry of Environment, Forest and Climate Change
CEA	Central Electricity Authority
RLDC	Regional Load Despatch Centre
SLDC	State Load Despatch Centre
AGC	Automatic Generation Control
ISGS	Inter-State Generating Stations
RGMO	Restricted governor mode of operation
FGMO	Free governor mode of operation
RRAS	Reserves Regulation Ancillary Services
POSOCO	Power System Operation Corporation
PLF	Plant Load Factor
FGD	Flue-Gas Desulfurization
AS	Ancillary Services
MCR	Maximum Continuous Rating
BMCR	Boiler Maximum Continuous Rating
SCR	Selective Catalytic Reduction
APC	Auxiliary Power Consumption
CHP	Combined Heat and Power
CCGT	Combined Cycle Gas Turbine

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1. Introduction

India's renewable power generation capacity has more than doubled during the past eight years. The installed capacity touched 50.1 GW in January 2017. Wind energy accounts for 57% of the renewable energy capacity, with 28.7 GW of installed capacity, making India the world's fifth-largest producer of wind energy. Small hydro power (4.3 GW), bio-energy (7.9 GW) and solar (9.0 GW) constitute the remaining capacity[1]. With total installed capacity of India reaching 3,14,642 MW, it makes renewable capacity share around 16% of the total capacity. This is fairly big number in comparison to the renewable share that exists few years back. With govt. target of 175 GW renewable power installed capacity by the end of 2022, this share will further increase.

India is blessed with vast potential of solar and wind generation. However, generation from renewable energy sources especially solar and wind is variable in nature and therefore, requires huge balancing capacity in the system. Another big challenge faced by Indian power sector now and in the future is how to integrate higher shares of renewable energy with the grid. There are many elements attached to the grid integration challenge and solution lies in implementing multilevel approach to tackle such a situation.

Presently, Indian generation is predominantly coal based. With increased sourcing of power from the power sources which are variable and intermittent in nature, the need of flexible generation will also increase. Flexible generation sources will help counter the variability and intermittency of generation output of the renewables. Since, India has limited pump storage and insufficient gas sources, coal based generation is the major option to meet and match the fluctuating requirements of the grid.

This report details out the framework required for operating coal based power plants in a flexible manner. Report also reviews the existing framework of regulations and standards under which coal based power plants are operating. The views of the different stakeholders on the "coal fired power plants flexible operation" in India has been taken into consideration while formulating recommendations on the way forward to create a market for flexible operated coal fired power plants.

Flexibility being a prized characteristic in any power system with significant power coming from variable renewable energy, it mandates that there should be adequate financial compensation for flexible operation by coal based plants. An effort is also made during study to analyse the various factors which should be considered in the compensatory framework for flexible operation of coal fired power plants.

[1]CEA Report , ALL INDIA INSTALLED CAPACITY (IN MW) OF POWER STATIONS http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf

Key Findings of Project

1 Limited flexible operation capabilities already available in the present system

- Present system is already catering to the ramps of around 200 -300 MW/min during peak time in evening.
- In existing scenario coal plants provides flexibility to the system by lowering PLF to as low as 50-60%.
- Thermal flexibility index has gone up by 300% in the last 8 years.

2 Limited regulatory support for the flexible operation of coal based plants in the existing scenario

- No regulation that stops plant from operating in a flexible manner, but at the same time there is inadequateincentive framework to support the financial implications of flexibility. Thus there is no correct valuation offlexibility in current scenario.
- Existing compensation framework focus on the flexible services only from CGS/ ISGS stations.
- No consideration on the compensation for flexible operation of plants in the existing tariff guidelines.

3 Limited ancillary services available for grid operation

- Present ancillary framework focuses only one aspect of ancillary services i.e frequency control.
- Ground implementation of Secondary Control (AGC) has still not happened.
- Present primary reserves are not adequate.

4 No consideration of emission changes from the flexible operation of the plant in the existing emission regulations.

- Present framework does not take account for the variation in emissions from the flexible operation of plants.

5 Relatively rigid market conditions limits the flexible operation of plants

- No ancillary services based products available on the power exchange in the current scenario.
- Share of total short – term transactions is around 10% (2015-16) of total country power generation.

6 Transmission constraints hinders the efficient utilization of the existing flexible capabilties.

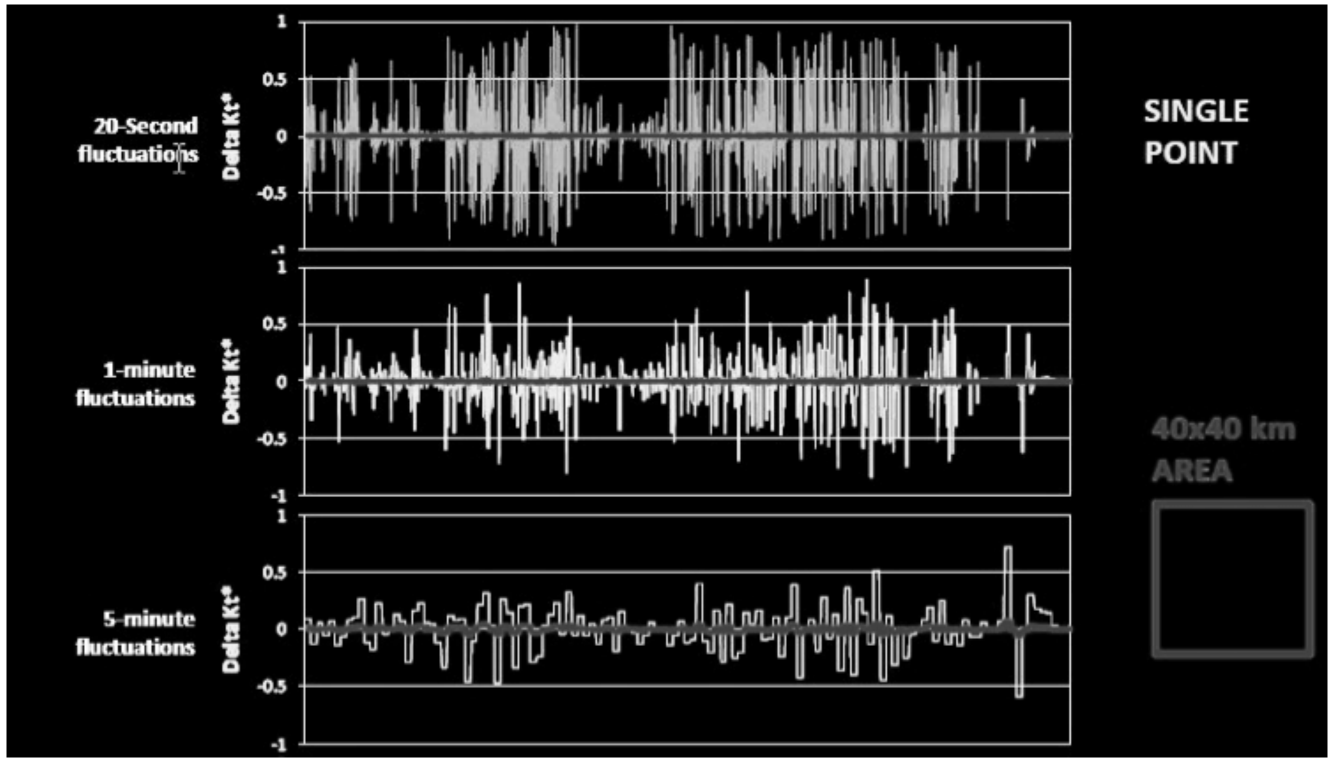
- Transmission constraints from limited inter regional link capabilities leads to low utilization of existing flexibility present in the system.

2. Summary Chapter

2.1 Need for Flexibility

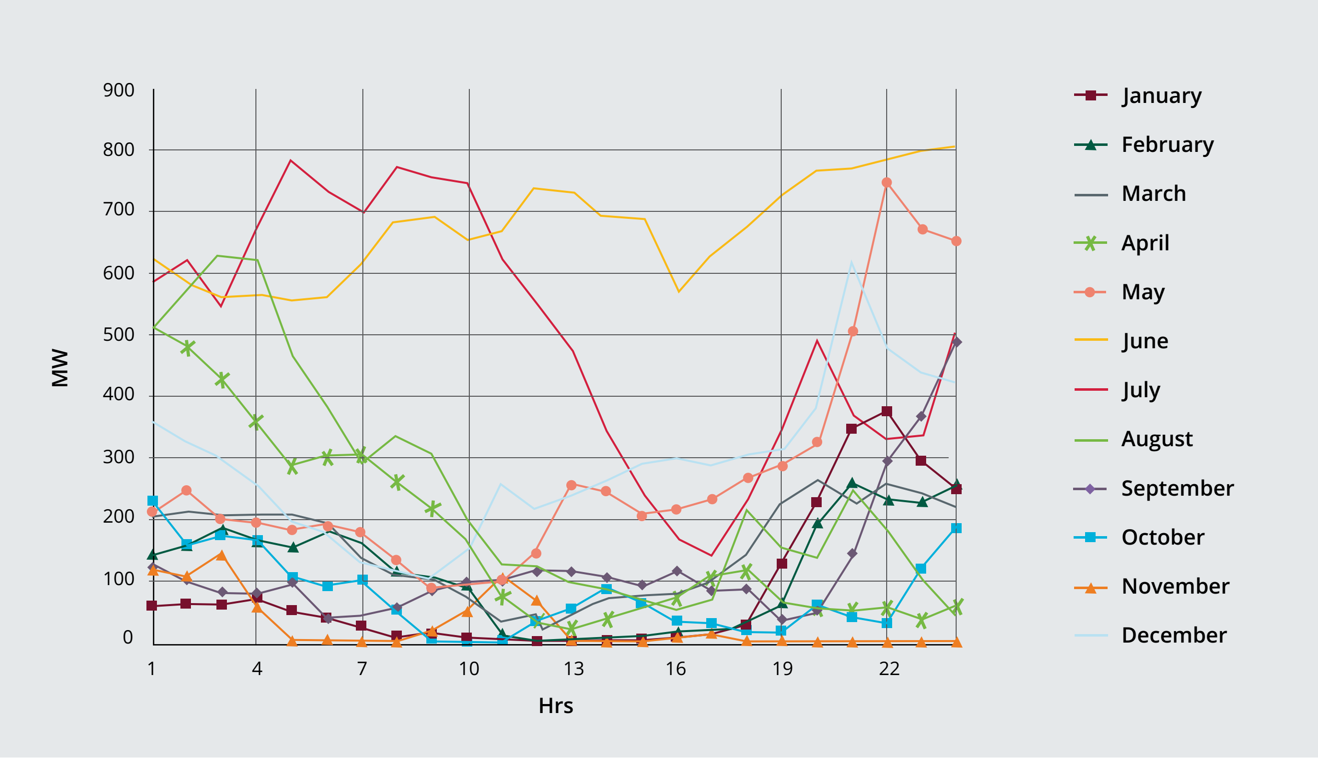
There is an additional need of flexibility with increased share of renewable installed capacity in the Indian power system. This need arises because of the reasons mentioned below:

- **Real Time Output Variability from Renewable Sources:** This variability means that the remaining sources must respond in real time to change in renewable output to keep the system balanced. Below graph shows an example of the fluctuations due to the variability in real time output from the renewable sources for the following intervals
  - Twenty seconds
  - One minute
  - Five minutes



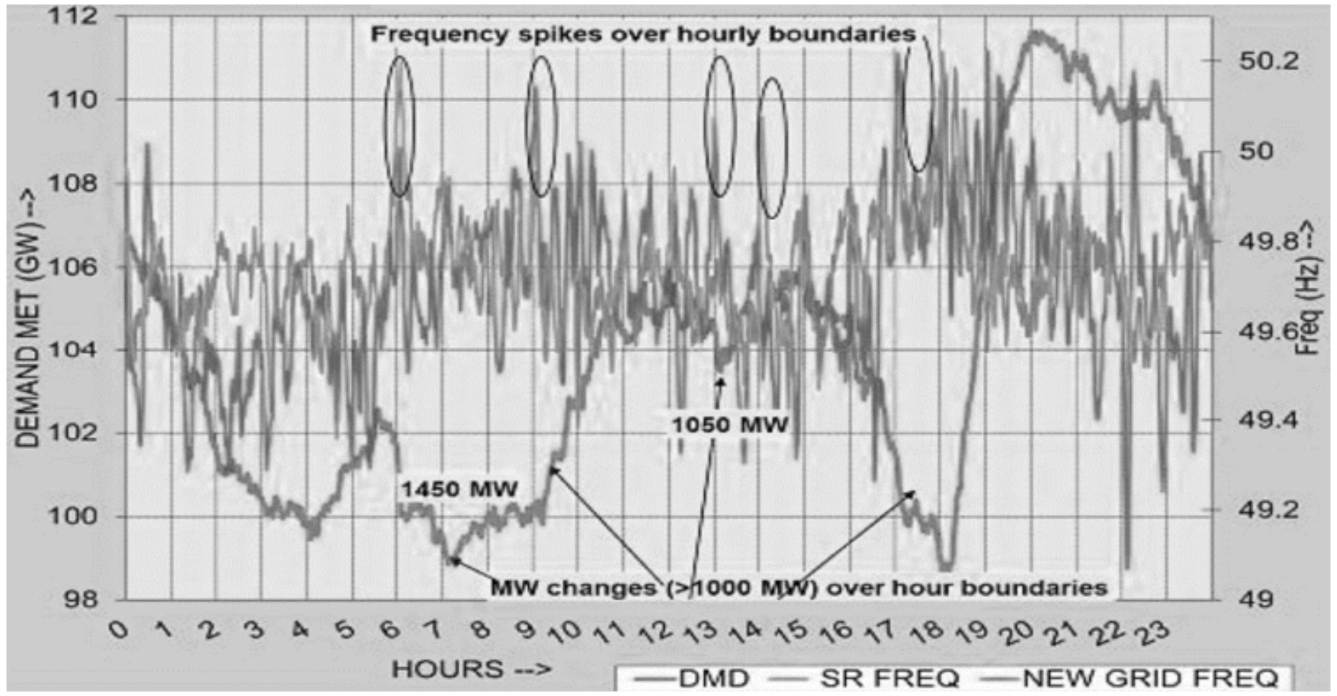
- **Daily/ Seasonal Load Curve :** Daily and seasonal variation in renewable generators output due to change in weather conditions necessitates the implementation of measures which can enhance the power system flexibility.Following chart shows typical daily wind generation month- wise pattern in Rajasthan

Rajasthan Typical Daily Wind Generation Pattern Monthe Wise



- **Load Forecasting Error :** Load forecasting is essential in order to maintain load and generation balance. Data analysis of actual and scheduled load of Indian distribution companies suggest that a typical absolute error of day-ahead load forecasting (yearly average of absolute difference of 15-min-intervals between scheduled and actual load) is around 5.5% - 7% of schedule. For Germany and Europe an absolute error of around 2% is commonly stated in relevant literature. During the on-site investigations in India and during data analysis it was noticed that SLDCs focus in respect to quality analysis of their load forecasting especially on the "simple averages" of forecasting errors (average of negative and positive deviations) which lead to an underestimation of the impact of the load forecast error. The "simple average error" is around 3.3% – 5.2%. Both error types for the data of three DISCOMs of a state in India are shown in form of yearly averages for each quarter of an hour of the day. It is clearly visible that the absolute average error lies above the "simple average".

2.2 Impact of the variation in generators output on the grid frequency

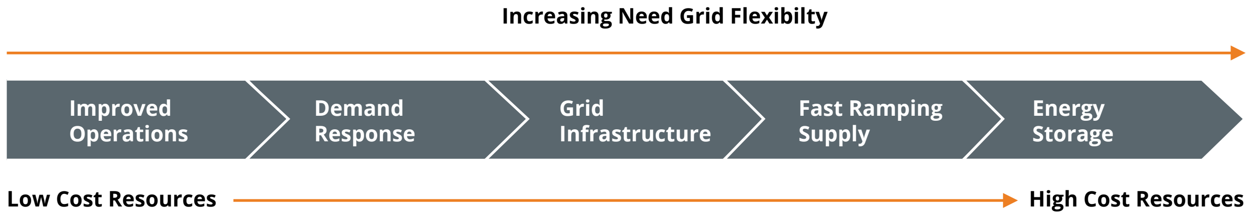


Above chart shows the typical impact on the grid frequency due to the variation in the generation from various sources connected to grid.An essential feature of system stability is whether generation is able to match demand variations at any instance of time. For this to happen in a system with high renewable energy sources, a certain degree of flexibility in terms of the ability of the system to respond rapidly to the changing overall demand and variations in output from renewable energy sources is required. With limited pump storage & with overall hydro potential of India limited to 100 GW and gas sources being insufficient, the coal based generation is the major option to meet and match the fluctuating requirements of the grid. Various features of flexible coal fired plant are:

- Stable low load operation
- Improved ramp rate
- Reduced house load operation (without oil support)
- Reduce effect on the life of equipment due to cyclic loading
- Efficient operation at low load

2.3 Different Measures for Enhancing Grid Flexibility

The following section describe different measures to improve the grid flexibility. Many different resources are already available to increase the grid flexibility in the short-term operational timeframe and the long-term planning timeframe. Options can be segregated on the basis of cost associated with these resources:



- **High Cost Resources:** Flexibility can come from physical assets, such as batteries and fast-ramping natural gas plants. It is seen that highly flexible coal based plants can also enhance the grid flexibility.
- **Low Cost Resources:** The lowest-cost options fall into the category of improved operations such as shorter dispatch intervals and improved weather forecasting, which can take advantage of existing infrastructure, making relatively small operational changes or introducing advanced information technology to more efficiently match electricity supply and demand.

2.4 Analytical Framework to Assess Flexibility of the System

Analytical frameworks to measure flexibility of a system is an evolving area. Following gives an example of three category of metrics available to assess the system flexibility. Categorisation has been done on the basis of the complexity of framework:

Increased Framework Complexity

1. FLEXIBILITY CHARTS GIVAR IN VISUAL	2. FAST 2	3. INSUFFICIENT RAMPING RESOURCE EXPECTATION (IRRE)
Flexibility Chart: The charts summarize capacities of a subset of different types of physical sources of flexibility: dispatchable plants (hydropower, combined cycle gas turbine (CCGT), combined heat and power (CHP)), pumped-hydro storage, and interconnection. GIVAR III Framework: In this framework, power area size, grid strength, interconnection, number of power markets, and flexibility of dispatchable generation portfolio serve as proxies for flexibility.	The tool assesses the technical ability of a power system to integrate increasing penetration levels of variable renewable energy. It does this by measuring the maximum magnitude of change in the supply/demand balance that a power system can meet at a given time	Insufficient Ramping Resource Expectation (IRRE): It helps to assess whether planned capacity allows the system to respond to short-term changes in net load. IRRE tool highlights time horizons of most risk, and measures the flexibility of the overall power system, not just the generation resource

It is important to understand that flexibility needs can be mitigated with greater geographical diversity of renewable resources over a strongly interconnected grid. Total output of all renewables over the whole grid at any given time is less variable than from any individual source or location due to geographical diversity (anti – correlation) of wind strength and cloud cover. One of the metric of flexibility, defined as below, has shown that flexibility has increased over the period of last few years. This proves that there is some inherent level of flexibility that is present in Indian power system.

- **Critical factors governing flexible operation of power plants**

Flexible behaviour of a plant is based upon certain plant characteristics. Operational flexibility solutions can be categorised on the factors that they impact. These critical factors are mentioned below:

Start-up time requirement: Start- up times govern how quickly a resource can provide upward flexibility when offline.

Operating Range: It governs the capability of resources to remain online during periods of low demand or high variable generation production.

Ability to cycle on and off: Challenges with cycling and low loads are as follows:
- Stresses on components and turbine shells resulting from changing pressures.
- Wear and tear on auxiliary equipment used only during cycling.
- Corrosion caused by oxygen entering the system during start-up and by changes in water quality and chemistry.
- Condensation from cooling steam during ramping down and shutting down, which can cause corrosion of parts, water leakage, and an increased need for drainage.

Ramping speed:
Ramp rates govern how fast a resource can respond when online.
- Ramp rates are important as the concerned generators have to do fast ramp up and down during the sudden variations in the output of the renewables or in the event of any contingency.
- Fuel quality variation directly corresponds to temperature variations and therefore is very essential factor for ramping capability.

Sliding pressure operation:
- Modern control systems, along with sliding pressure procedures or variable pressure operation, can assist plants in decreasing load without significant decrease in efficiency.
- Sliding pressure offers advantages over throttle control during start up as well as part load operation. Units where the control system is limited to fixed-pressure operation can consider retrofitting the plant to sliding-pressure operation based on cost benefits associated with retrofitting.

■ Thermal Power Plants Flexibility

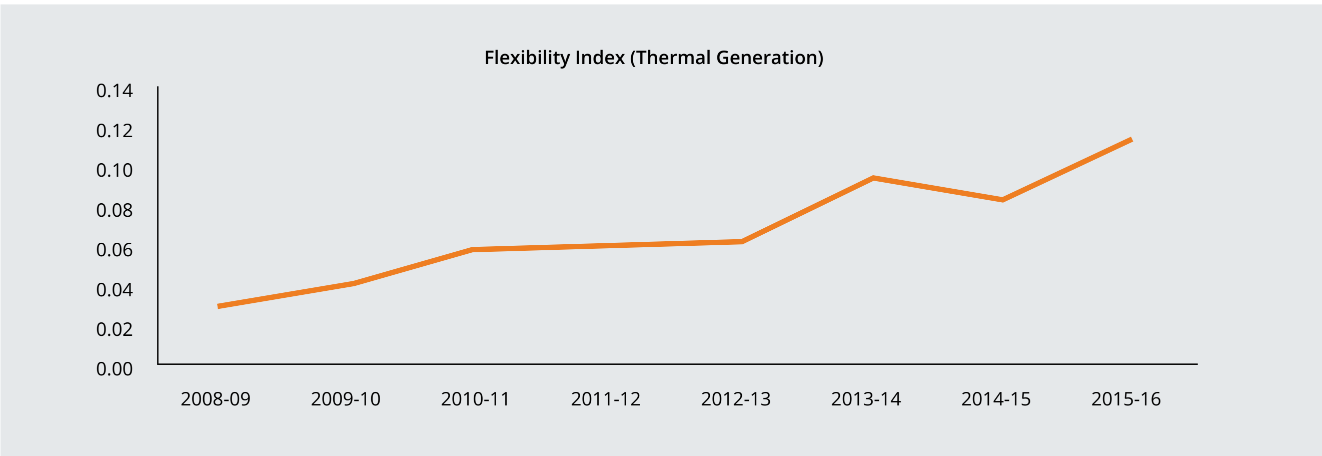
Flexibility index of thermal generation in simpler terms can be defined as the ratio of "Difference of Minimum and Maximum Thermal Generation" and "Maximum Thermal Generation". Increase in value of this indicator means an increase in operational flexibility of thermal based generators.

$$\frac{\text{Maximum Thermal Generation - Minimum Thermal Generation}}{\text{Maximum Thermal Generation}}$$

It is important to understand that current trend of increase in thermal flexibility is also due improvement in operation practices and, after a certain limit, significant improvement can only be possible through design changes.

Below chart shows an increase in the value of the flexibility index of thermal generation over the period from 2008-09 to 2015 -16[2] . Chart has been generated on the basis of average of flexibility index data for the following seasons provided in "Flexibility Requirement in Indian Power System" by POSOCO.
- July – September (2008-2016)
- October – December(2008-2016)
- April – June(2008-2016)
- January to March (2008-2016)

Figure 1: Flexibility Index (Thermal Generation)



[2] Data Source: Flexibility Requirement in Indian Power System

Similar to the calculation of thermal flexibility index, flexibility index for coal fired power plants in simpler terms can also be calculated as follows:

$$\frac{\text{Maximum generation - Minimum generation}}{\text{Maximum generation}}$$

Over the years, PLF of plant has decreased because of fuel shortage and increase in 'Peak-to-off-Peak Ratio' which is becoming higher leading to less despatch and reserve shutdowns. Further, this change in peak-to-off-peak ratio has resulted in a scarcity for ramping sources. Enhancing the flexible capabilities of existing plants can help resolve this issue.

2.5 Existing Flexible Capability Analysis

Generation data was collected for the following to assess the flexible capabilities of the existing coal fired plants
- Coal fired power plants providing Ancillary Services in India[3].
- Minimum load data of natural gas, coal and lignite based power plants in Gujarat for 2014 from all sources of energy.
- Monthly generation data (2015-16) of thermal power stations in Tamil Nadu.
- Daily generation data of a thermal power stations in Tamil Nadu of a typical data in June 2015.

■ Flexibility Analysis - Coal Fired Plants providing Ancillary Services

Data of present coal fired plant providing Reserves Regulation Ancillary Services (RRAS) was analysed to assess the flexible capabilities of plant. Following points would be worth noting:

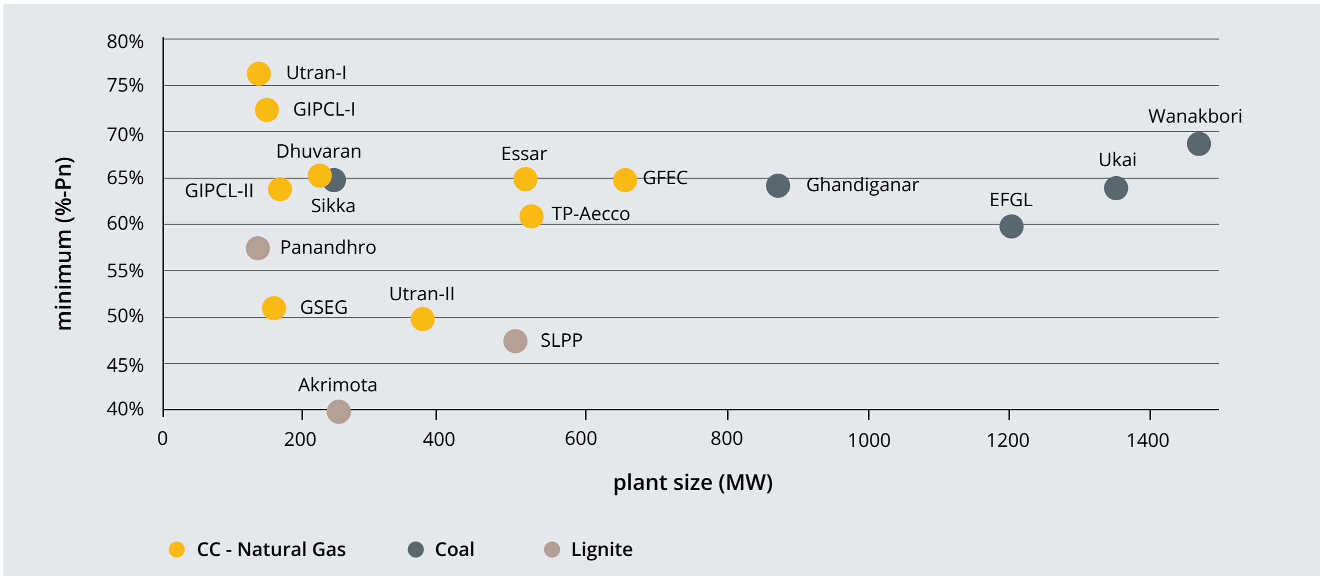
Regulation 7(4) of the CEA (Technical Standards for Construction of Electrical Plants and Electrical Lines) Regulations 2010 states "The unit shall have a minimum rate of loading or unloading of 3% per minute above the control load (i.e., 50% MCR)". However, the ramp rates being adopted by the RRAS providers are less than those specified in the CEA Standards.

It was observed that the technical minimum generation level supplied by coal based RRAS provider varies in the range 50% (CGPL- Mundra) to 76% (NLC-I).

■ Flexibility Analysis - Gujarat

Following figure provide the minimum load of natural gas, coal and lignite based power plants in Gujarat[4].

Figure 2: Minimum load of natural gas, coal and lignite based power plants in Gujarat.

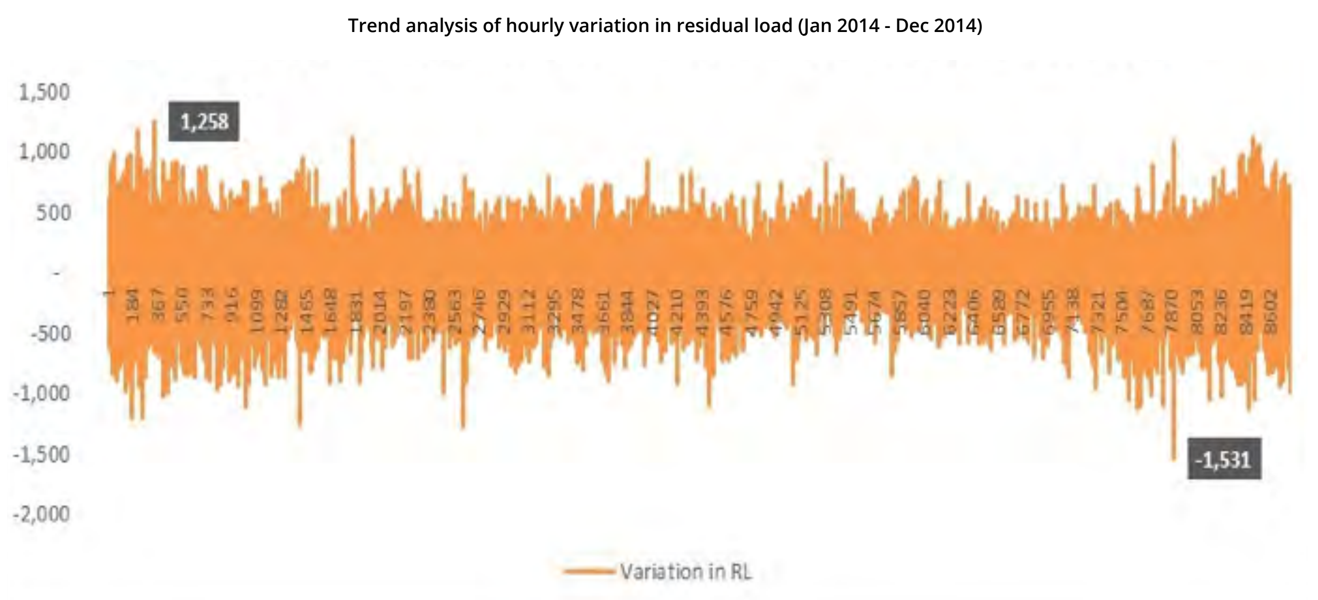


[3] Data provided in the annexure of report
[4] Source: Fraunhofer IWES, data: Gujarat SLDC

- Most values for minimum load in Gujarat are below the value of 70%. For some units minimum load is as low as 40%. The capacity weighted average is around 62%.
- Information about ramp rates, hot-start and cold-start times, minimum stand still or operation times of power plants in India has not been found in public domain. Some stakeholders at SLDC level state that bringing up power plants on bar again might take up to around 48 hours[5]. Shut-down of plants is therefore often avoided[6]. Flexibilization of plants can help improve the start-up time and increase the flexible capacity of the state.
- Following hourly data was analysed to do a trend analysis of hourly variation in residual load in 2014.
  - Total Load (Average hourly load is 10852 MW)
  - Power generation from plants based on biomass, mini hydro, solar, wind
  - Residual load

Trend below shows the hourly variation in residual load in 2014 for Gujarat. It is evident that maximum increase in residual load between any two subsequent hours is 1258 MW, which is a represents 16% ramp up of residual load in an hour. Also, maximum decrease in the residual load in any two subsequent hours is 1531 MW, which is a 14% ramp down of residual load in an hour.

Figure 3: Residual load hourly variation trend analysis (Jan 2014 - Dec 2014)



Flexibility Analysis – Tamil Nadu

To analyse the present flexibility characteristics of various thermal stations, following data has been analysed:

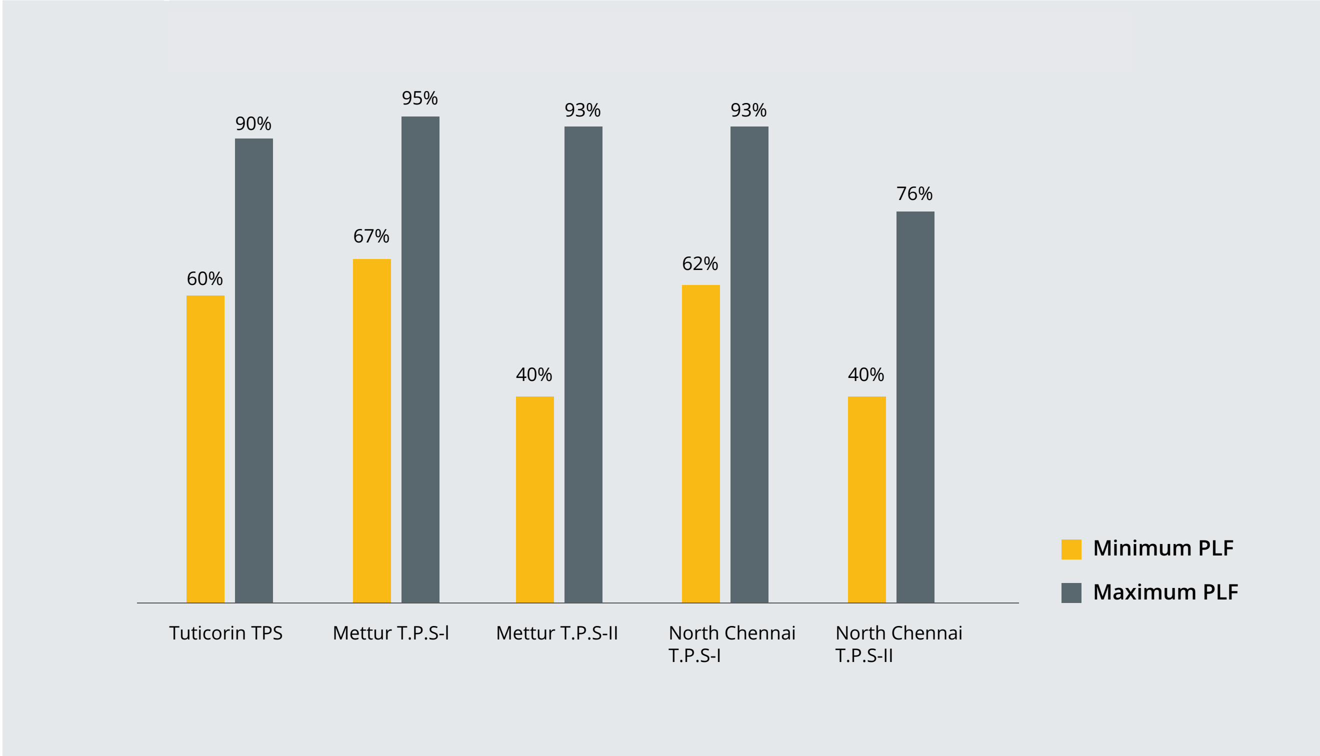
- Monthly plant generation data for April 2015 – March 2016
- Daily plant generation data for 20th June 2015[7]

Below table shows the variation in the monthly load factor of various thermal power stations in Tamil Nadu for the period 2015 -16[8].

Analysing above table shows that there is a variation from 40% to 95% in the monthly PLF of the various thermal stations in Tamil Nadu. This again proves that certain level of flexibility is already present in the system.

[5]Interview with staff at the SLDC in Gujarat, 19.02.2015 during Green Energy Corridor Project
[6] Also mentioned during interview with staff at the SLDC in Andhra Pradesh, 25.02.2015 during Green Energy Corridor Project
[7] Daily generation data for thermal power stations was collected during formulation of Green Energy Corridor Report (Work Package -4)
[8] TANGEDCO : http://www.tangedco.gov.in/linkpdf/PLF14-15.pdf

Figure 4 : Monthly Load Factor Variation (2015 -16) of TPPs in Tamil Nadu

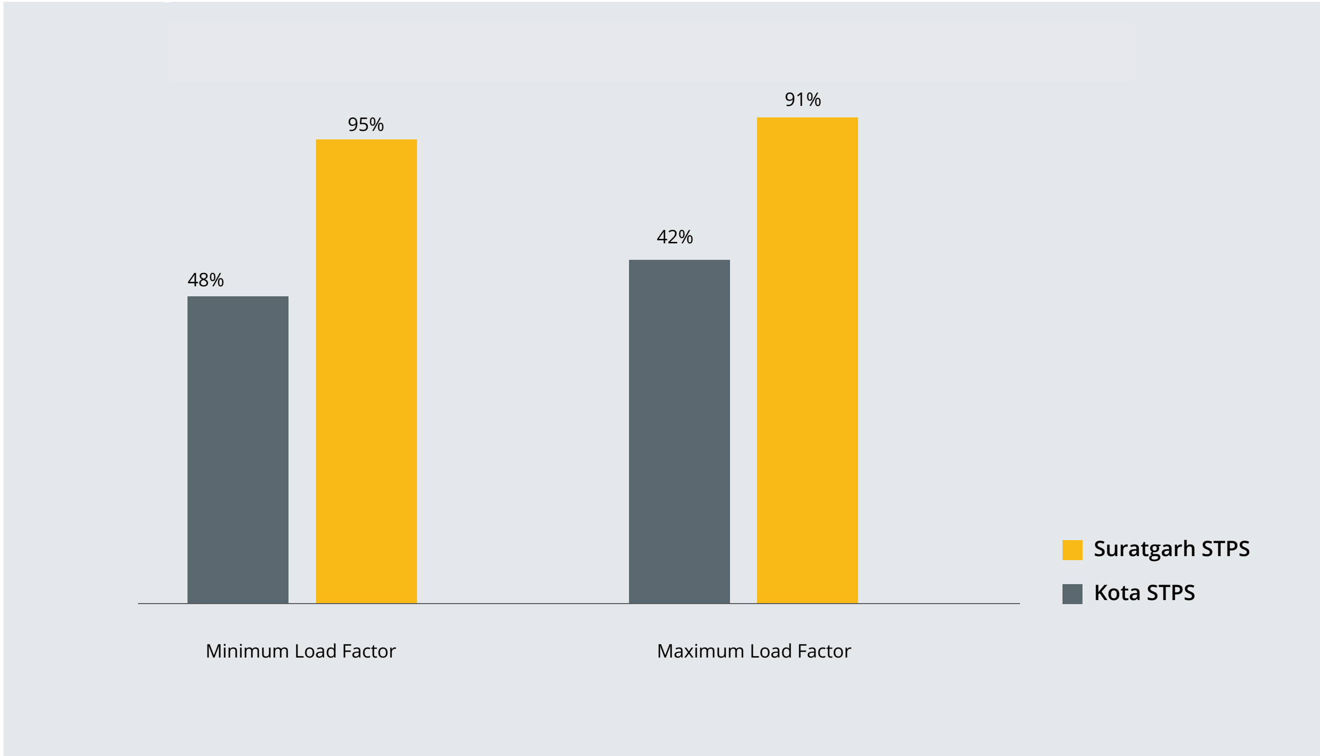


Flexibility Analysis – Rajasthan

Following chart analyse the hourly load data of following two thermal power stations in Rajasthan.

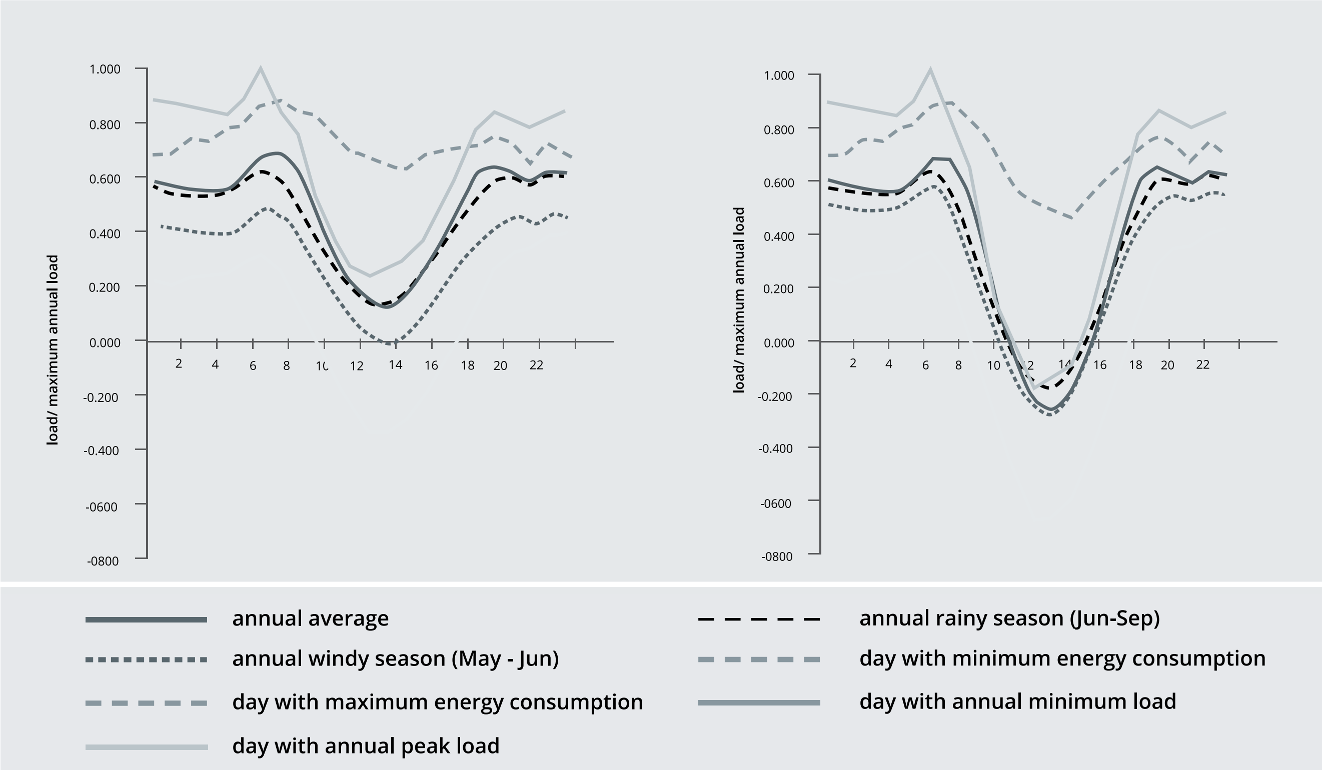
- Kota STPS
- Suratgarh STPS

Figure 5: Minimum and Maximum Load Factor – Hourly Analysis Data (May 2014 – August 2014)



Above thermal plants generation data set was analysed for period from May to August 2014. Minimum hourly load factor recorded was 42% and maximum hourly load factor was 95% in the period of May 2014 to August 2014[9] . This shows that these plants are already ramping up and down with a range of 40% to cater to the load variation. Figure below shows the average daily profiles of the residual load in the two scenarios in 2022. The impact of the load during the day is clearly visible. Conventional power plants do have to drastically decrease their generation in order to integrate a large share of RE power during almost all days. The annual average residual load during midday is only around 18% of the maximum load in the base scenario and negative in the fast PV growth scenario.

Figure 6: Daily residual load profile (average and single days) – base scenario (left) and fast PV growth (right)



The rate of change of load or residual load is an additional parameter which can be regarded as important for system operation as it affects the need for generation flexibility e.g. fast increase or decrease of production. The hourly gradient is here defined as power available in one hour subtracted by the power in the previous hour. For the Rajasthan load projection for 2022 the highest positive gradient is 3,987 MW/h, the highest negative gradient is -4,060 MW/h. For the residual load they are respectively 4,177 MW/h and -5,895 MW/h in the base scenario and 6,789 MW/h and -7,280 MW/h in the fast PV growth scenario. Thus, there is a higher demand for flexible generation with an increasing share of RE which needs to be met by conventional sources. Similar extreme values occur very seldom. In 80% of the hours of the year the residual load gradient is between 1,818 MW/h and -1,688 MW/a in the base scenario and between 2887 MW/h and -2805 MW/h in the fast PV growth scenario.

To collate the findings on requirement of flexible operation need in future, following three different future energy scenarios for Rajasthan have been analysed:

- The transition scenario for 2018 with an RE share of 25% of total electricity demand (installed wind energy: 6 GW, PV: 7.5 GW)
- The base scenario for 2022 with an RE share of 35% (installed wind energy: 8.7 GW, PV: 15 GW) And the fast PV growth scenario with an RE share of 50% (installed wind energy: 8.7 GW, PV: 25 GW)

Thus, the scenarios represent very ambitious strategies. For each scenario, feed-in time series have been modelled based on historic weather data characterizing the electricity supply from RE. To analyse the impact on conventional plant operation a power plant dispatch model is used which simulates the electricity generation from conventional sources for every hour of the year taking into account economic parameter and technical restriction (least cost dispatch, flexibility parameters of plants).

The electricity consumption has been escalated with a growth rate of 6% per year, the characteristics has been adopted from the historic load of 2014. It is to be noted that under these assumptions the maximum feed-in from fluctuating RE reaches up to 40% of the load in 2018. For the scenarios in 2022 these values reach 130% (base scenario) and 190% (fast PV growth scenario). These values indicate that balancing such large amounts of the RE require a regional approach and that export to other Indian states is necessary for system integration. Along with increasing RE share the operation of conventional power plants has to significantly change compared to the usual case today. The impact which can be expected in the future has been assessed in detail by the conducted power plant dispatch simulation for all scenarios.

The key findings resulting from the analysis can be summarized as follows:

- The full load hours of coal power plants decrease significantly with increasing installed power capacity of RE. Based on the present scenarios assumption from 2015 to 2022 a decrease in the order of magnitude of up to 20% can be expected if the maximum RE power is to be integrated in Rajasthan. However, it is likely that regional integration is envisaged in the future. This will lead to the effect that more power plants are affected by lower plant load factors and thus lower generation, but cuts will be less significant in terms of quantity.
- In general inflexible base load power plants reduce the RE integration potential as they are not able to quickly react on changes in RE supply. This is for example the case for nuclear power plants which do not have the flexibility for fast starts and shut downs as well as operating on deep part load limits. Therefore they need to produce on a higher level of operational hours. This is especially problematic if a large share of RE generation is to be integrated in Rajasthan and plants which are catering to Rajasthan are used for technical balancing.
- During the night - especially in lean wind season – net load can be almost identical to the load due to lacking RE generation. Therefore in many cases it is not economically worthwhile to totally shut down a larger number of power plants even if this is technically feasible. The possibility of operating plants at low minimum load is therefore very important to integrate high shares of fluctuating RE within the time horizon up to 2022.
- Fast cycling and frequent starts and shut downs are additionally necessary for balancing variable renewable energy generation and will become and essential feature for system operation. In general, the higher the minimum load of the power plants used for balancing RE, the less start and stops are required.
  - Detailed analysis example: The number of starts and shut downs per coal power plant and year increases in 2022 up to an average number of around 45 when assuming high flexibility parameters and mainly an integration of RE in Rajasthan. The reference simulation for 2015 showed that roughly 10 are sufficient today. Especially important in this regard is the average minimum load: it has been assumed with 36.4% for this high flexibility sensitivity.
  - In general it can be concluded that the minimum load is a decisive plant parameter influencing necessary start and stops: Lower or higher minimum loads influence the number of necessary starts and shut-downs significantly reaching roughly 25 with optimized flexibility (including retro-fits for all existing plants) and roughly 60 with low flexibility[10] . The average minimum load in these cases has been assumed to be 25.8%

[9] Green Energy Corridor Report, Work Package 4

and 54.5% respectively. The analysis showed that in terms of flexibility the effect of the minimum load is the decisive factor. The effect of different start-up times is negligible at least as long as it is in the order of the assumptions made in the study. If for supply security reasons power plants are not shut-down, but only operate on minimum load start and stops can be reduced significantly, but at the same time surplus energy or the need for exports increases.

- Power plants with low flexibility are limited in meeting the needs for a system with high shares of fluctuating renewables. The demand for exports to other regions or states will therefore increase
  - Detailed analysis example: In the sensitivity low flexibility, surplus energy or the need for exports to neighbouring states reaches an order of magnitude of at least 3,000 GWh/a for the base scenario for 2022 (15 GW PV and 8.7 GW wind energy, 6% annual growth of electricity consumption) representing 3% of total electricity consumption in 2022 or 9% of production from wind and solar energy. These numbers are half as high when assuming high flexibility parameters for existing and new power plants which are internationally common today. With optimized parameters an additional reduction of 30% can be achieved.

- However, in general the RE integration potential of Rajasthan is high. The results show that also large shares of RE can be integrated by the state. It is to be noted that these results are based on theoretical simulations which reduce complexity of real plant operation implying for example that production of RE is known and high quality forecasting is applied. Furthermore it is assumed that power plants are able to achieve the assumed flexibility parameters technically at any point of time and on demand (e.g. minimum load, start-up time). This might not be achievable in real operation due to various reasons such as unexpected outages, other technical problems or even economic disincentives.

- As it has been described in previous work within this project regional integration and balancing of RE is the most cost effective solution and especially recommendable when the RE share of the complete region is lower than for a single state (results from work package 1 of this project, task 3). In contrast optimizing flexibility parameters and retro-fitting of fossil power plants requires investment costs and seems – for the achievable benefit – relatively costly compared to regional integration.
  - Analysis example: The integration potential with high flexibility instead of low flexibility assumptions for the conventional power plants has led to an increase in integration potential of Rajasthan from roughly 91% to 97% of the RE supply (scenario 2022, fast PV growth). To achieve this, a significant improvement in plant characteristic is necessary for a large number of units. In the analysis the assumption for minimum load has been 25.8% in the high flexibility sensitivity instead of 54.5% in the low flexibility sensitivity.

- However, it is to be noted that a minimum functionality of power plants is required to avoid a drastic reduction of integration potential. These are especially the ability for (frequent) starts and shut downs of all power plants and the required operational expertise and information base (certain knowledge about load development, high quality RE forecast).
  - Detailed analysis example: Simulation sensitivities show that excess energy from RE or need for export is increasing from 0.2 TWh/a to 2.4 TWh/a for the transition scenario in 2018 (7.5 GW PV, 6 GW of wind energy) if power plants are not able to shut down or start operation if required. This value represents 12% of the RE supply and 3% of the electricity consumption in the respective scenario.

- Renewable excess power of more than 10 TWh/a in the 2022 PV+ scenario shows clearly that a ratio of almost 2 between rated RE power and maximum electricity demand can only be integrated on a regional level by exporting to neighbouring states and by implementing additional flexibility options as demand side management or electricity storages.

[10] Parameters have been assumed referring to discussions during the interview phase of the project (various interviews with state SLDCs, discussion during the Stakeholder workshop „forecasting, balancing and REMCs", 22./23.04.2015, Delhi, [see also GIZ 2015]). The assumptions are supposed to reflect the (disputed) flexibility of Indian power plants existing today.

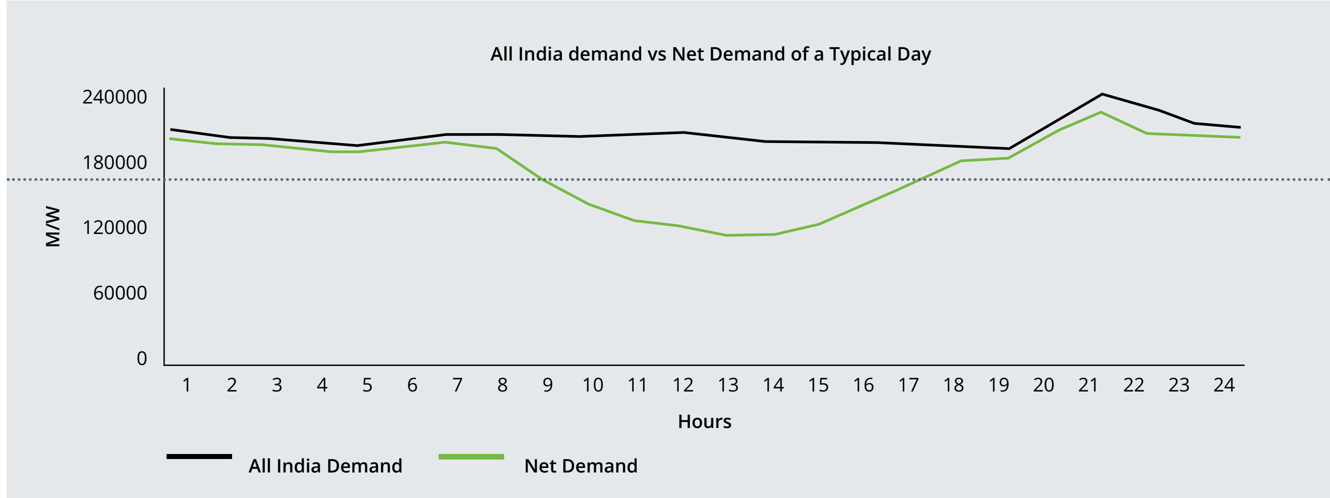
2.6 Future Flexibility Requirements

With the future plans of increased generation from renewable energy, it becomes imperative that requirement of the flexibility is assessed properly for the present and future scenario. There is no denial that more measures are required to increase the flexibility of the current system. As each power system is different, therefore measures required to increase flexibility of the system will vary from one system to another. Flexible operation of coal fired power plants is definitely a competitive option to resolve the present and future challenge of variable output from the solar and wind plants in India.

Following chart shows the typical 24 hours trend of "All India Demand vs. Net Demand of a Typical Day" Above All India net hourly load profile has been generated by treating renewable energy generation as negative load.

It is worth noting that over the years, difference between "All India maximum and minimum demand met" has increased gradually. Similarly, the difference between daily peak and lean has increased and is on an increasing trend. This again emphasizes the need for more flexible generation to counter this gap[11].

Figure 7: All India demand vs Net Demand of a Typical Day



2.7 Plant Retrofits - Cost Benefit Analysis

As discussed before, existing coal based plants already have certain degree of flexibility. This flexibility can be increased through the hardware modifications or retrofitting. With hardware modifications, certain changes in operational practices may also be required.

Retrofits options can be classified for a coal based plant on the basis of area that has been targeted. One of the classification is as follows:

- Boiler Retrofits
- Coal Mill Retrofits
- Emission Control Retrofits
- BOP Retrofits
- Turbine Retrofits
- Retrofit options for chemistry-related improvements

Significant improvement in flexible operation can also be achieved through modifications in the operational procedure of plants. Some of them are mentioned below:

- Increase in frequency of scheduled inspections or replacements for the components susceptible to damage.
- Boiler optimization using revised procedures for cycling the plant
- Modifying and following cycle chemistry guideline limits during plant startup, shutdown, and ramping up and down.
- Improving Selective Catalytic Reduction (SCR) inlet temperatures to mitigate low load operation issues at the SCR.
- Operator training to reduce and monitor damaging trends while operating in cycling mode.

[11] Source: Paper on "Flexibility Requirement in Indian Power System" by POSOCO

Table 1 Various retrofit improvement potential

Source: NREL 2013	Gas Turbine	CC	Coal
Start-up or shut down time Improvement	Up to 50%	Up to 60%	~30-50%
Start-up fuel cost Improvement	~50-60%	~Up t030%	~30%-50%
Ramp rate Improvement	~100%	~100%	~30%
Turn down improvement(minimum load)	~5-10%	~5-10%	~30%-50%

It is worthwhile to note that there are certain negative impacts of the flexible operation of coal fired generating stations. Few of them are mentioned below:

- Increased wear-and-tear on balance-of-plant components.
- Decreased thermal efficiency at low plant load factor.
- Increased fuel costs due to more frequent unit starts.
- Difficulties in maintaining optimum steam chemistry.
- Potential for catalyst fouling in NOx control equipment.
- Increased risk of human error in plant operations

Cost benefit analysis of various retrofits have been provided in the annexure.

Table 2 Existing Regulatory Framework Analysis

SCOPE	ORGANISATION	REGULATIONS/ STANDARDS/ PROCEDURE / REPORT	CURRENT STATUS	KEY PROVISIONS	COMMENTS
55% technical minimum and reserve shut down	CERC	Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fourth Amendment) Regulations, 2016	Regulation is still to be implemented. Compensation mechanism formulated by RPC is still in draft stage.	1) Propose that the technical minimum schedule for operation in respect of ISGS shall be 55% of MCR loading of unit/units of generating stations. 2) The generating companies are also required to keep a record of the emission levels from the plant due to part load operation and submit a report to the commission every year. 3) Provision to compensate for increase in station heat rate, secondary fuel oil consumption and auxiliary energy consumption after prudence check 4) In case of generating stations not regulated by the Commission, generating company shall have to factor above provisions in their PPAs for sale of power in order to claim compensations for operating at the technical minimum schedule	Regulation is a good step towards future flexible operation as it takes into account the SHR degradation due to decrease in PLF. Percentage increase in SHR for supercritical and sub critical units at different levels of loading by the thermal units has been prescribed in the regulation. It would be interesting to see how emissions are affected due to the part load operation.
Ancillary Services	CERC	Detailed Procedure For Ancillary Services Operations	Implemented	1) The objective of AS Regulations is to help in restoring the frequency level to the nominal level and to relieve the congestion in the transmission network 2) All Generating Stations that are Regional Entities and whose tariff for the full capacity is determined or adopted by the Central Electricity Regulatory Commission (CERC) shall provide the Reserves Regulation Ancillary Services (hereinafter to be referred as “RRAS”)	1) Regulation in present form focusses more on the frequency control. 2) Framework for secondary control (AGC) still to be implemented. 3) Limited primary reserves at the moment. Flexibilisation can improve the plants capabilities to provide the primary and secondary reserves. 4) In future ancillary services framework should consider the compensation for other range of services from flexible operation of plant.

2.8 Framework for flexible operation

During the research on the existing regulations, it was found that regulators have already initiated an effort to move towards flexible operation of plants. But there is no existing framework for complete range of services provided by the flexible operation of coal based power plants. To create the framework for complete range of services from the “Flexible Operation of Coal Based Power Plants”, it is necessary that following steps are taken till the time a complete market based framework is created for flexible services:

Suggested Steps for Regulator Makers

- Correct valuation of flexible operation services through a regulatory framework
- Provision for complete range of flexible services: Regulator shall make provisions in the existing regulations to define a complete framework for the flexible operation of coal fired power plants. Following regulations shall be revised to :
  - Tariff Principles
  - Regulations on Ancillary Services
  - CERC (Indian electricity grid code regulations) 2015
- Provisions in existing CEA technical standards to include the operational standards for flexible operation of plants.
- Provisions in the existing emission framework for coal based plants to treat flexible operation of plants differently

Table 2 (contd.)	Existing Regulatory Framework Analysis				
SCOPE	**ORGANISATION**	**REGULATIONS/ STANDARDS/ PROCEDURE / REPORT**	**CURRENT STATUS**	**KEY PROVISIONS**	**COMMENTS**
Spinning Reserves	CERC	Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fifth Amendment) Regulations, 2016	Draft	1)To separate out the primary reserves (to be utilized through Governor action) from the secondary reserves (to be utilized through AGC), spinning Reserves may be revised as "The Capacity which can be activated on the direction of the system operator and which is provided by devices including generating stations/units, which are synchronized to the grid and able to effect the change in active power" 2) For the purpose of ensuring sustainable primary response, RLDCs/SLDCs shall not schedule the generating units beyond ex- bus generation corresponding to 100% of the Installed capacity.	Creation of adequate system reserve margin and spinning reserve of 5% at national level is required, as also pointed by the report of technical committee on spinning reserves.
	CERC	Report of committee on spinning reserves	Report		
	Ministry of Power	National Electricity Policy, 2005	Policy - Implemented	Stipulates that 5% Spinning reserve is to be provided.	
Primary Reserves	CERC	IEGC, 2010 Regulations	Implemented	Mandates that all thermal units of 200 MW and above and hydro units of 10 MW above to provide primary response.	1) Inadequate primary response from the system at present. 2) Implementation of a reliable telemetry and communication framework for improvement in the secondary control reserves. 3) Flexibilisation of existing coal based plants can increase the capabilities of existing plants to provide primary and secondary response. Implemented framework should support plants to increase the flexible capabilities
	CERC	Report of the Committee on Free Governor Mode Operation of Generating Units (October 2015)	Report	The secondary and tertiary control may be introduced through operationalising Automatic Generation Control (AGC), Ancillary support Services and Demand Response. In this regard Committee recommends that periodic check-ups to ensure desired RGMO/ FGMO response be made mandatory and should be conducted at regular intervals, through independent third parties selected by POSOCO/ SLDCs. The cost of such tests may be recovered by the RLDCs/SLDCs as part of RLDC/ SLDC Fee and Charges.	
Secondary Reserves	CERC	Roadmap to operationalise Reserves in the country	Order	Implementation of AGC is necessary along with reliable telemetry and communication. The AGC may be planned to be operationalised in the power system from 1.4.2017	
Operational Capabilities of Coal Based Power Plants 1) Ramp up / Ramp down 2) Minimum Technical Load 3) Number of startup and shut down	CERC	Standards Technical Specification for Main Plant Package of Sub - Critical Thermal Power Project 2X (500 MW or above) Supercritical 660/ 800MW Thermal Units	Existing Standards	Document provides operating standards on the following aspects of the thermal power plant: 1) Step Load Change – Boiler 2) Ramp Rate- Boiler 3) Step Load Change – Turbine 4) Ramp Rate- Boiler – Turbine 5) Type of starts and No. of starts 6) Other Operational Capabilities	1) Operating capabilities of flexible coal based plants differs a lot from the most of the existing coal based plants. 2) Formulating standards on flexible coal fired plants would be a progressive step in future.

Table 2 (contd.)	Existing Regulatory Framework Analysis				
SCOPE	**ORGANISATION**	**REGULATIONS/ STANDARDS/ PROCEDURE / REPORT**	**CURRENT STATUS**	**KEY PROVISIONS**	**COMMENTS**
Eissions Framework	Ministry of Environment, Forest and Climate Change (MoEFCC)	Notification by MoEFCC on 7th Dec 2015	Two year time period to comply with new norms: TPPs shall meet limits within two years from date of publication of this notification	Norms became stringent for SPM, SOx, Nox and PM10	Flexible operation may lead to following: 1) Transient increases in coal plants emissions rates 2) Increased cost and emissions due to the increased need of standby of units. Necessary that above factors are considered in the emission framework.
Compensatory Framework / Tariff Guidelines	CERC	Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2014	Implemented		Current framework does not provide compensation on complete range of services from flexible operation of plants.

2.9 Case Study

There are certain examples from international experience which proves that coal based plants designed to run at constant output (baseload operation) can be operated as a cycling plant post redesigning. One of the example is discussed below:

Suggested Steps for Regulator Makers

Output: 4110 MW
Plant Type: Conventional Thermal
Location: Majuba, South Africa
Completion: 2001
Sponsor: Eskom
Lead Equipment Supplier: Siemens

- Post redesigning, the plant can compete in the South African power pool, cycling on /off twice daily despite its original baseload design.
- Plant operates in two shift operation (ie operating for two of the eight hour shifts in a day): Typically the plant shuts down in the evening around 10 PM and restarts at 5 am.
- Plant Technology and Parameters
  Once Through Boiler (Benson Type)
  Main steam pressure: 174 bar
  Main Steam temperature: 540 Deg C
- Plant can handle coal of high ash (around 35 percent) coal, with a calorific value between 19 and 24 MJ/ kg.

2.10 Comments by Stakeholder

Comments by CEA

- Standards for plants operating flexible services such as ramping capabilities, turndown etc. has to be mentioned in the guidelines.
  Competitive market should be created by allowing different flexible service providers to compete with each other.
- Example: Market should allow service providers providing flexible services from battery storage to compete with flexible service providers based on coal based generation.
- Cost benefit analysis of different technology shall be performed to create a better framework structure

Comments by CERC / FOR

Comment on 55% minimum technical load: Even with this regulation there is no technical bar with respect to the minimum load. With decrease in load efficiency on plant will deteriorate and there will be increase in Station Heat Rate. Another effect of frequent daily ramping on plants not designed for flexible operation will be the increase in O&M cost.

Comments by TNERC

- It is important to consider the following impacts before implementation of the framework on flexible operation of plants:
- Increased maintenance of plant: Frequent shut down and ramping of plants will mandate higher maintenance of plant.
- Per unit emission: Flexible operation of plants is expected to increase the per unit emission from plant.
- Cost of flexible operation and remuneration to plant owners to has to be evaluated before such an operation

3. Legal Framework and emmision

3.1 Existing Legal Framework

Legal framework for emissions from power plant is governed by the guidelines of Ministry of Environment, Forest and Climate Change (MoEFCC) in India. The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal agency in the administrative structure of the Central Government for the planning, promotion, coordination and overseeing the implementation of India's environmental and forestry policies and programmes. Latest notification by MoEFCC on air emissions mandates power plants to operate in the stringent environment norms.

Table below enlists new emissions standards notified by MoEFCC for thermal power plants installed at different point of time:

Table 3 MOEFCC Notification on Emissions from Thermal Power Plant

Notification by MoEFCC on 7th Dec 2015[12]			
PARTICULATE MATTER	100 mg/Nm3	50 mg/Nm3	30 mg/ Nm3
SULPHUR DIOXIDE (SO2)	600 mg/Nm3 (Units smaller than 500MW capacity units) 200 mg/Nm3 (for units having capacity of 500MW and above)	600 mg/Nm3 (Units smaller than 500MW capacity units) 200 mg/Nm3 (for units having capacity of 500MW and above)	100 mg/ Nm3
OXIDES OF NITROGEN (NOX)	600 mg/Nm3	300 mg/ Nm3	100 mg/ Nm3
MERCURY (HG)	0.03 mg/Nm3(for units having capacity of 500MW and above)	0.03 mg/ Nm3	0.03 mg/ Nm3

* TPPs (units) shall meet the limits within two years from date of publication of this notification.

3.2 Flexible Operation Impact on Emissions

With flexible operation PLF of plant goes down. Flexible operation of a plant affects the efficiency of the plant, as efficiency goes down at part load. The lower the efficiency, the smaller the power produced with a given fuel input and vice versa. This will also have effect on the plant emissions as plant operated at part load will emit more CO2 and other atmospheric pollutants per KWh than what is produced if plant will be run at the rated load.

[12] MoEFCC Notification on emission from Thermal Power Plants http://www.cpcb.nic.in/Industry-Specific-Standards/Effluent/TPP.pdf

Impact on Emissions

- Transient increases in coal plants emissions rates: This can happen during start- up, shutdown, and other ramping periods, as compared to steady-state operations at full load. Temporary increases in emissions rates can be due to incomplete combustion and incomplete warm-up of emissions control devices.
- Increased cost and emissions due to the increased need of stand by: Placing large fossil fuel plants on hot standby for lengths of time may increase costs and/or emissions by keeping cooling water circulators, fans, and other devices running despite the lack of power generation.
- Uncertainty may exist in emissions estimates: This could be due to the technical challenges in accurately measuring emissions of chemicals during startup and shutdown,

Following table elaborates the impact on various parts of the emission control system during part load operation of a coal based power plant.

Table 4 Flexible Operation Impact on Emissions Control System

EMISSION CONTROL SYSTEM TYPE	IMPACT DUE TO FLEXIBLE OPERATION	ADDITIONAL CONTROLS
NOx removal systems	SCR are usually placed after the economiser. There is a possibility of low flue gas temperature that can occur.	Additional controls/ modification may be required to correct the temperature at low loads for efficient control of NOx.
FGD Systems (Flue Gas Desulphurisation)	The chemical processes involved in conventional wet FGD systems require precise control of the reaction conditions, which are influenced by reagent flow, water flow, and flue gas temperature.	Sophisticated controls may be required for efficient control during part load operation.
Particulate Removal System	**1.** Temperature of the inlet flue gas need to be monitored **2.** May lead to increase in the percentage auxiliary energy consumption as decrease in energy consumption in ESPs due to part load operation may not be directly proportional to load reduction of the plant.	Intelligent control systems may be required to vary the residence time of the flue gas which calls for an additional cost.

3.3 Impact of PAT (Perform, Achieve & Trade) Scheme on Flexible Operation of Coal Based Plant.

PAT (Perform, Achieve & Trade) is a regulatory instrument to reduce specific energy consumption in energy intensive industries, with an associated market based mechanism to enhance the cost effectiveness through certification of excess energy saving which can be traded.
PAT assigns targets for improvement in specific energy consumption to the most energy intensive

industrial units in the country. This mandatory scheme sets benchmark for consumers in designated sectors (Thermal power plants, Steel, Cement, Aluminium, Chlor Alkali, Textiles, Pulp & Paper, and Fertilizers). Current PAT cycle has identified 154 designated consumers in thermal power plants with total possible energy savings of 3.13 million TOE.
As coal based power plants are also a part of this scheme, it would be interesting to see how the two positive aspects related to "decreased specific energy consumption" and "Flexible operation of coal based power plants" will be linked to each other. Definitely a boundary needs to be defined for the operation of coal based power plants in a flexible manner.

In the present format, PAT do considers the impact of several factors on station heat rate through Normalization. However, flexible operation of plant will demand frequent variations in output and frequent start-up and shut down of plant. It is still to be seen how such large and frequent variations is tackled in existing framework of the PAT. As per PAT, net heat rate with Normalization is calculated as follows:
Operating Station NHR of station with Normalization = Actual Operating Station NHR of this station without Normalization - (Coal Quality Normalization +PLF normalization +APC Normalization + Other Normalization)
Normalization helps to consider the impact of PLF, auxiliary power consumption (APC) and other factors on Station Heat Rate. However, flexible operation of coal based plants will require the following:

- Increased part load operation which will result in decrease of PLF
- Significant increase in the number of start –up / shut downs in a year: Flexible plants may require to start up and shut down twice on daily basis.

Thus, PAT in present format provides no clarity on how above aspects will be dealt.

PLF Normalization

All factors which affects the generation, ultimately affects the PLF. It is understood that the plant may not be operating on the same PLF in the Assessment Year as in Baseline Year for internal as well as external reasons. Hence, in PLF normalization, all such factors which were beyond the control of the plant management, has been taken care off and due advantage has been given. In PLF normalization, like other normalizations, the benefit has been calculated and given in terms of Heat rate which will directly be subtracted from the Net Operating Heat Rate.

APC Normalization

The normalization of APC can be subdivided into three categories:
- APC normalization due to external factors
- APC normalization for PA Fan loading due to change in coal quality
- APC normalization for Coal Grinding Mill, ID Fans and Ash Handling Plant loading due to change in coal quality

Other Normalization

- Heat rate impact due to shut down/ start-up is considered here. Plant may shut-down due to various reasons and on every start-up, there is a certain amount of energy which increases the heat rate. This energy varies for type of start-up, i.e., cold, warm or hot start-up. Impact of external factors are considered in the variation in number of start-up in assessment year in the baseline year.
- Other factors that can be considered here are factors related to environmental concerns, unforeseen circumstances etc. that can impact the heat rate.

4. Legal Framework for Technical Standards

Coal based power plants in India are designed for full load operation as this results in the maximisation of efficiency and revenues. However, the need for flexible operation from coal based power plants will impact them in the following ways:
- More frequent shutdown and start- ups of plant as per the grid fluctuations
- More aggressive ramp rates will be required
- Lower desired minimum sustainable load, as this provides a wider operating range.

Technical standards for coal plants are prescribed by CEA in India. Following provide the details on the relevant sections from the existing standards by CEA that impacts the flexible operation of coal based power plants:
- Operational capabilities
  - No. of start ups
  - Rate of loading/unloading
- Minimum load without oil support for flame stabilization

Table 5 CEA Technical Standards

ASPECTS	SUB- CRITICAL THERMAL POWER PROJECT 2X (500 MW OR ABOVE)	SUPERCRITICAL 660/ 800MW THERMAL UNITS
Step Load Change – Boiler	Minimum + 15%	Minimum ± 10% to facilitate fast loading/ unloading of the unit.
Ramp Rate- Boiler	Minimum + 3% per minute under variable pressure operation Minimum + 5% per minute under constant pressure operation	Minimum ±3% per minute above 30% load
Step Load Change – Turbine	Minimum + 15%	Minimum ± 10% to facilitate fast loading/ unloading of the unit.
Ramp Rate- Boiler – Turbine	Minimum + 3% per minute under sliding pressure operation Minimum + 5% per minute under constant pressure operation	Minimum ± 3% per minute above 30% lo ad.
Type of starts and No. of starts	Hot start (within 10 hours of unit shut down): 4000 Warm start (between 10 hours and 72 hours of unit shut down): 1000 Cold start (after 72 hours of unit shut down): 150	Hot Start (after shut down period less than 10 hours) : 4000 Warm Start (after shut down period between 10 hours and 72 hours) : 1000 Cold Start (after shut down period exceeding 72 hours) : 150

ASPECTS	SUB- CRITICAL THERMAL POWER PROJECT 2X (500 MW OR ABOVE)	SUPERCRITICAL 660/ 800MW THERMAL UNITS
Other Operational Capabilities		The design of Steam Generator shall be such that it does not call for any oil support for flame stabilization beyond 40% BMCR load when firing any coal from the range specified, with any combination of mills/ adjacent mills in service. The Turbine shall be suitable for two-shift operation & cyclic load variations.

Now let's have a look at the flexible capabilities of coal fired units[12] that can be achieved with retrofits and through operational procedure improvement.

Following table provides a snapshot on the flexible capabilities with respect to minimum load, operating range, start up time etc.

Table 6 Capabilities of Flexible Plant

	STATE OF THE ART	DEVELOPMENT (NEW AND EXISTING PLANTS)
Start-up:	2-6 hours depending on starting condition	1-4 hours depending on starting condition
Minimum load (hard coal)	New power plants: 25% Existing power plants: 40%	Conventional firing 15-20% Indirect firing 10-15%
Minimum load (Brown coal)	New power plants: 40% Existing power plants: 50%	Conventional firing 35-40% Indirect firing 10-15%
Load change cycles	Moderate	High to very high
Primary frequency control	2-5%/30 s possible to 5%/30 s	10%/10 s
Secondary frequency control	2%/min	10%/min

From the above tables, it can be concluded that there is a huge difference in existing standards (minimum load, start up time etc.) of base load coal based plant and capabilities of flexible coal based plants.

Suggestions on Technical Standards
Existing standards are prepared with the perspective of operating coal based plants at the base load. In future, standards should include operating standards related to following three typical services from the flexible operation of plant:

- Start-up/ Shut Down
- Ramping Services
- Turndown Services

5. Other Existing Framework Aspects

There has been efforts by the regulator to increase the flexibility of the power system through various measures in the recent years. Few of the critical measures taken are as follows:

- Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fourth Amendment) Regulations, 2016
- Central Electricity Regulatory Commission (Ancillary Services Operations) Regulations, 2015

Following sections suggests provisions in the various existing regulations to enable market framework for flexible operation of coal based power plants.

5.1 CERC "Terms and Conditions of Tariff Regulations (2014 -19)"

Suggestions: Tariff principles should treat different cycling modes of plants differently. Flexible plants can operate in one or more duty cycles as mentioned below. Compensation shall be different for each of the above mentioned operating modes as plants will incur different cost. Different cycle option can be provided to existing and upcoming coal based plants depending upon their technical capabilities, as not all plants can fit in the same category with similar ease.

Two-shifting in which the plant is started up and shut down once a day.

Double two-shifting in which the plant is started up and shut down twice a day.

Weekend shutdown in which the plant shuts down on weekends. This is often combined with load-following and two-shifting.

Load-following in which the plant operates for more than 48 hours at a time, but varies output as demand changes.

On-load cycling in which, for example, the plant operates at base load during the day and then ramps down to minimum stable generation overnight.

- Compensatory mechanism for flexible operation of plants should be inclusive of the following:
  - Start- up cost / Shut down costs
  - Ramping Abilities (Ramp Up and Ramp Down Rates)
  - Minimum technical load possible without oil support

- **Flexible Retrofits Cost Impact on the Coal Based Power Plant Tariff**

An approximate estimate of the impact on tariff due to additional capital expenditure related to flexible retrofits has been calculated for the supercritical coal based power plants.
From the secondary research, it was identified that impact of many hardware retrofits may have benefits related to more than one aspect of the flexible operation. For example: One of the available retrofits related to boiler - Steam flow redistribution and metallurgy improvements in Superheater /Reheater - will have an equivalent impact on all the three different flexibility solutions from the coal based power plant. Occasionally, a single retrofit option may only impact one flexible operation mode. For example, turbine electric heating blankets provide a significant improvement to start/stop cycling, but may not benefit other

flexible operating modes measurably. Following table represents the cost (INR Cr.) per MW for various hardware retrofits related to different flexible services/options from the supercritical coal based power plant[13].

Following table represents the cost (INR Cr.) per MW for various hardware retrofits related to different flexible services/options from the supercritical coal based power plant:

Table 7

AREA	START-UP / SHUT DOWN (INR CR./MW)	RAMP RATE (INR CR./ MW)	TURNDOWN (INR CR./ MW)
Boiler	0.205	0.080	0.179
Coal Mill	0.308	0.308	0.344
Emission Control	0.052	0.000	0.052
Turbine	0.101	0.063	0.071
Chemistry Related Improvement	0.063	-	-
Balance of Plant	0.243	0.118	0.243
Total	0.972	0.570	0.889

Impact of the additional capital cost due to the flexible retrofits on the tariff of the plant was studied through a tariff model of a supercritical power plant. Following table represents the percentage increase in the tariff of a plant due to the additional cost of different flexibility options.

Table 8

FLEXIBLE SERVICES	TOTAL CAPITAL COST FOR THE VARIOUS RETROFITS SOLUTIONS (INR CR./ MW)	TOTAL COST FOR 800 MW PLANT (INR CR.)	BASE TARIFF (WITH NO ADDITIONAL CAPITAL EXPENDITURE ON THE FLEXIBLE RETROFITS)	TARIFF WITH CAPITAL EXPENDITURE ON THE FLEXIBLE RETROFITS	PERCENTAGE INCREASE IN TARIFF (INR/KWH)
Start- Up / Shut Down flexible services	0.972	778	2.13	2.36	10%
Ramp Rate flexible services	0.570	456	2.13	2.27	6%
Turndown flexible services	0.889	712	2.13	2.34	9%

[13]Source: NREL Above Cost per MW has been calculated on the basis retrofit cost given for 750 MW supercritical plant in the source document US Dollar to INR conversion rate considered: INR 67/ US Dollar

- **Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fourth Amendment) Regulations, 2016[14]**

  Salient features of this regulation are mentioned below:
  - Section 6.3 B of the regulation has proposed that the technical minimum schedule for operation in respect of ISGS shall be 55% of MCR loading of unit/units of generating stations.
  - Below 55% of MCR loading, station may undergo reserve shut down.
  - Regulation has proposed that CGS or ISGS may be compensated when concerned RLDC has directed generator to operate below normative plant availability factor but at or above technical minimum. Compensation will be depending on the average unit loading.
  - Regulation speaks on the compensation on account of the following factors:
    - Heat rate degradation
    - Auxiliary energy consumption
    - In case of reserve shut down due to scheduled generation falling below technical minimum, start up fuel cost over and above 7 start/ stop in a year to be considered for compensation.
  - Generating station whose tariff is neither determined nor adopted by the Commission, the concerned generating company shall have to factor the provisions specified in the aforementioned CERC Regulations in their Power Purchase Agreements (PPAs) entered into it for sale of power or in order to claim compensation for operating at the technical minimum schedule.

  This regulation is a good step towards future flexible operation of plants as it takes into account the SHR degradation due to decrease in PLF. Percentage increase in SHR for supercritical and sub critical units at different levels of loading by the thermal units has been prescribed in the regulation. However, it would be interesting to see how emissions are affected due to the part load operation.

- **Regulation on Ancillary Services[15]:**

  Central Electricity Regulatory Commission published a draft on 1st May 2015 called as Central Electricity Regulatory Commission (Ancillary Services Operations) Regulations. Key features are as follows:
  - Regulation in present form focusses on the frequency control Objective of this regulations is to help in restoring the frequency level to the desired level and to relieve the congestion in the transmission network.
  - The Ancillary Services Operation Regulations defines the guidelines for participation in Reserves Regulation Ancillary Services (RRAS).
  - The RRAS is the first of the ancillary services which will help in limiting the grid frequency within operational limits by calling on participants to increase/decrease generation.

  Applicability of regulation: Generating Stations that are Regional Entities and whose tariff for the full capacity is determined or adopted by the Central Electricity Regulatory Commission (CERC).

- **Primary, Secondary and Tertiary Response**

  Following three levels of frequency control services are generally used to maintain the balance between generations and load. Three levels differ as per their time of response to fluctuation.

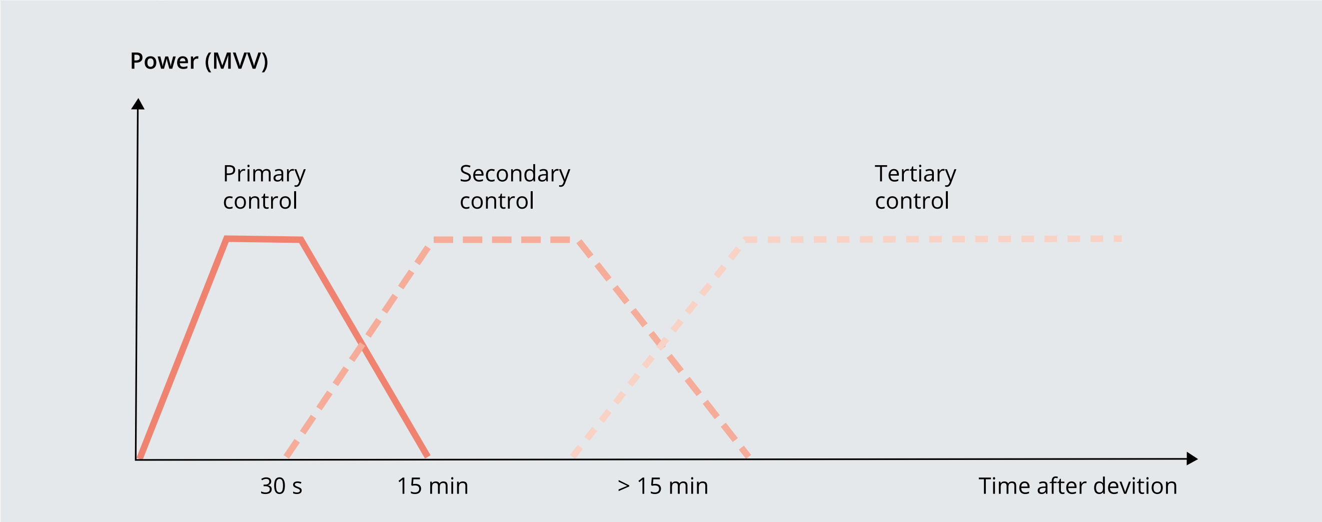
  Following three levels of frequency control services are generally used to maintain the balance between generations and load. Three levels differ as per their time of response to fluctuation.

  Primary Frequency Control:

  Primary control (governor control) is used for frequency stabilization after a large disturbance which operates in seconds (proportional control). Time frame for primary governor control action is of the order of a few seconds i.e. 5-30 seconds and should last for at least 3-4 minutes to enable secondary control to take over which will allow the primary reserves to be restored. For primary control to work properly, most of the generation has to be under governor control so that adequate primary reserve is available at all times. Primary control in India is provided through Restricted Governor Mode of Operation /Free Governor Mode of Operation with manual intervention. Primary control tend to arrest the fall in frequency[16].

[14]Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fourth Amendment) Regulations, 2016 http://www.cercind.gov.in/2016/regulation/124_1.pdf
[15]Ancillary Services Operations - Detailed Procedure http://www.cercind.gov.in/2016/regulation/revisedSOR.pdf
[16]Ancillary Services Operations - Detailed Procedure http://www.cercind.gov.in/2016/regulation/revisedSOR.pdf

Figure 8: Primary Secondary and Tertiary Response



Present Status of Primary Response:

- Overall primary response in the grid is not adequate.
- Primary response of the generating stations is much less than the desired for various reasons. Inadequate primary response by generators could be due to generators not keeping sufficient reserves from their maximum capacity. Other reasons for non-compliance could be technical difficulties and no existing penalties for defaulters, as also pointed by the CERC report on the "Report of the Committee on Spinning Reserves pointed out.

Secondary Frequency Control:

- Secondary control restores the primary reserves & frequency to 50 Hz and operates in minutes (Integral control).
- For large interconnection system, the secondary control is achieved through Automatic Generation Control (AGC). AGC is used to help continuously balance the power system, maintain a constant frequency and eliminate area control error.

Present Status of Secondary Response:

- Secondary control has not been implemented in India as yet. To implement Secondary control, some infrastructure is needed. Units have to be wired under AGC (Automatic Generation Control) and both sides communication between control room and generators has to be provided. AGC (Automatic Generation Control) software is needed to implement and handle the calculations, as this is an automatic process. Thus a necessary condition for AGC activation , units as well as load dispatch centers have to be equipped with necessary communication infrastructure, as it involves sending automated control signals from the LDC to the generator based on grid conditions.
- As per the CERC order dated 13.10.2015 in the matter of "Implementation of AGC is necessary along with reliable telemetry and communication", the AGC may be planned to be operationalized in the power system from 1.4.2017.

Tertiary Frequency Control:

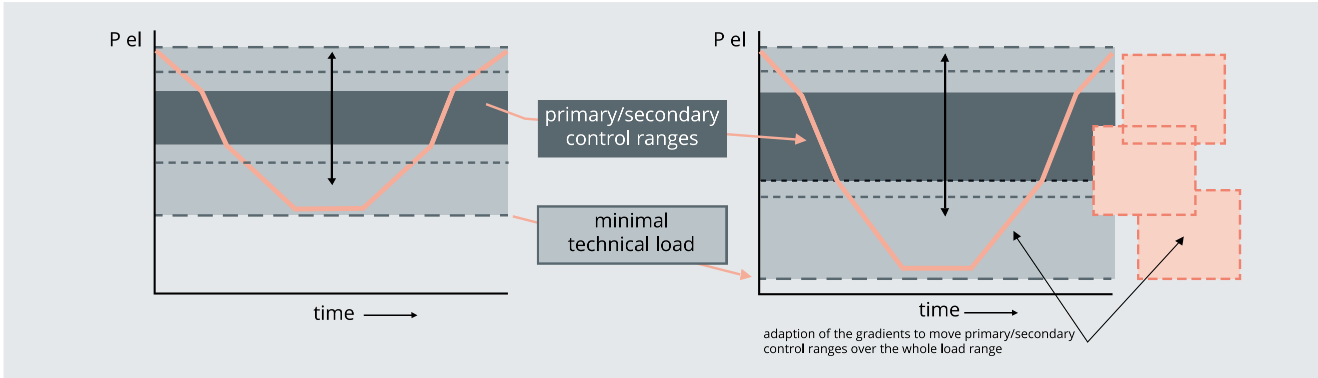
- Tertiary control restores secondary reserves and operates in tens of minutes.
- Manual change in the dispatching and unit commitment in order to restore the secondary control reserve, to manage eventual congestions, and to bring back the frequency and the interchange programs to their target if the secondary control reserve is not sufficient. Tertiary control refers to rescheduling of generation to take care of deviations in a planned manner during real time operation and leads to restoration of primary control and secondary control reserve margins.

Primary and Secondary response from the units capable of flexible operation:

Highly flexible units are capable of the reducing the minimum technical load and increasing the permissible rate of load change. Thus flexible units can help in following[17]:

- Increase of load control range by reducing the minimum technical load
- Increase of primary and secondary control range
- Increase of load change velocity

Figure 9: Primary and Secondary Response from flexible units



Load range can also be increased by the installation of thermal storage system in plant.

- **Suggestion for Regulator:**
  - Regulators shall plan to bring more coal based generators under this regulation to enhance the flexible capacity in India.
  - Existing regulation focus on "Regulation Up/ Down" which means either increase or decrease in generation. Range of different services related to flexible operation can be valued in the framework on ancillary services in future. For example: Ancillary services framework should consider the compensation of plant on the basis of ramping rates. Regulators shall plan to implement secondary control (AGC) by tackling issues related to telemetry. Flexiblisation of plants can improve the plants capabilities to provide the primary and secondary reserves.
  - CERC shall review the clause 5.2f of IEGC code – 2010 regarding the restricted governor mode of operation, and free governor mode of operation should be introduced. Plant should be encouraged to provide the primary response. For primary response, regulatory compensatory mechanisms should also be evaluated for plants using method like installation of thermal storage.

- **Primary Frequency Control through thermal storage**

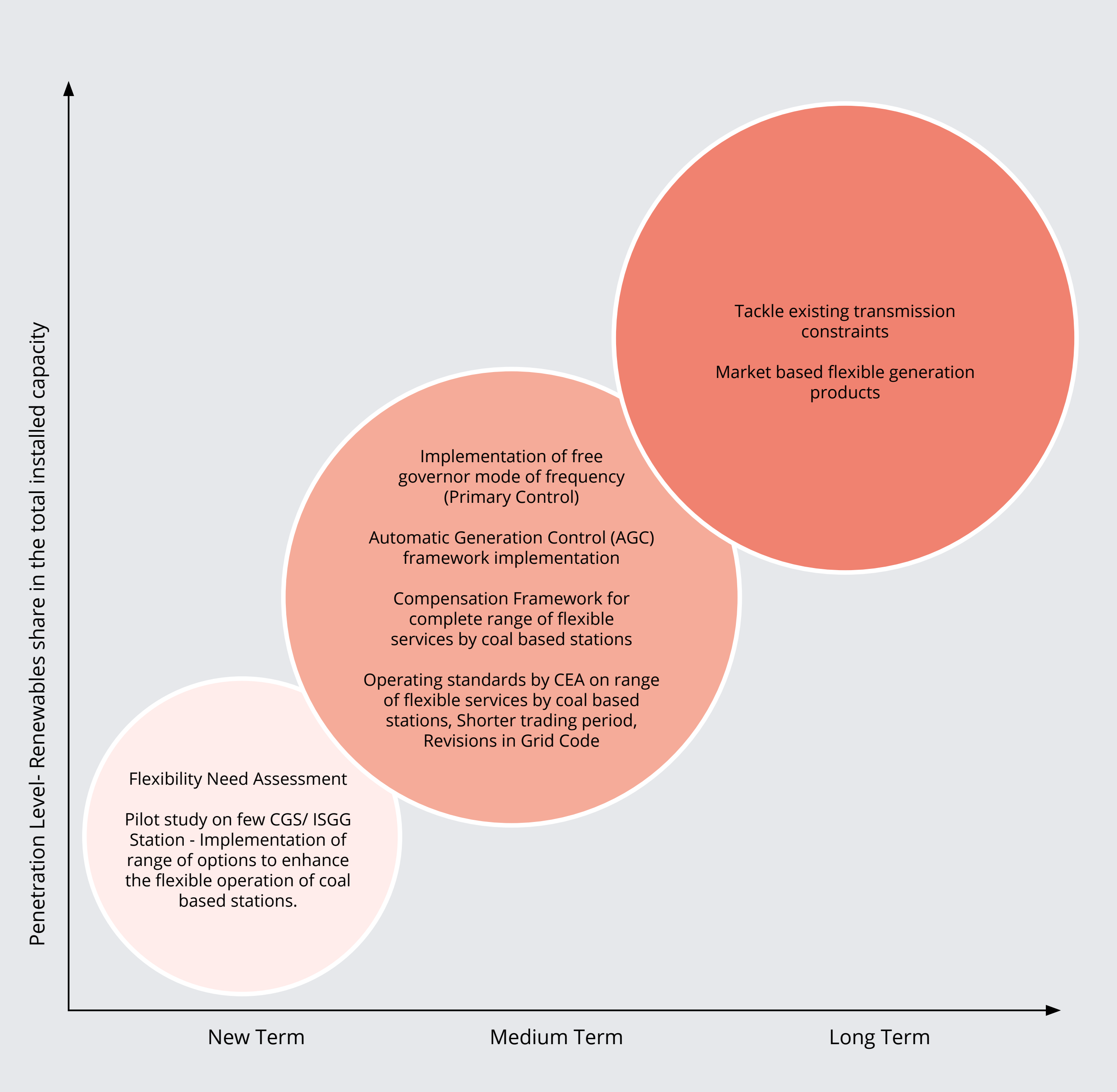
  By pass of feedwater heaters is already a prevailing method to increase steam flow for frequency control, but even more flexibility can be achieved by installing storage systems for the low pressure or high pressure feed water. Advantage of frequency control with Steam Storage System: The increase in output is greatest at full load, because then the impact of the reduced extraction steam mass flow is maximised. Approximately 5% of MCR can be produced. Steam storage system advantage is that associated capital cost is much lower and the efficiency associated with the system is much greater than for energy storage alternatives such as batteries or compressed air storage. The usable load range is also extended, as there is no need for other means, such as throttling, to provide frequency control.

[17] IEA Clean coal Center, Increasing the flexibility of coal-fired power plants (Colin Henderson)

6. Recommendations for Way Forward

Various measures can be undertaken to enable the flexible operation of coal fired power plants. Three phase approach can be taken by the regulators depending on the time required to implement the measures. Following chart lists down recommendations to create market for flexible operation of coal fired power stations over a period of time.

Figure 10: Measures for increased flexible operation from coal based stations with higher renewables share



Near Term Measures

- **Quantification of the flexibility need and presence through a suitable metric**
  As discussed in previous chapters, coal based generators is already flexible up to certain extent. Variable renewable energy output is becoming noticeable to system operators. It is necessary that flexibility of the existing system and future requirements of the flexibility is assessed to properly formulate the strategy to enhance the flexibility of the system. This can be done through the various flexibility metrics such as:
  - Flexibility Charts
  - GIVAR III visual
  - FAST2 Visuals

  Assessment will help to identify future regulatory actions required to make plants more flexible.

- **Conducting a pilot study on CGS/ ISGS coal stations:**
  Pilot projects could be undertaken in few CGS/ ISGS coal based power plants where plants could be upgraded technically to enhance the flexible operation of station. This will help to test the performance of plant in the real time conditions. Post-performance testing in different scenarios (under frequency and over frequency), a better regulatory framework on incentives could be developed on the basis learnings from these projects. These pilot projects will help to identify the following factors for further implementation in other plants:
  - Model cost framework related to investment made by plants.
  - Ramp up and ramp down standards for flexible operating plants
  - Standards on minimum technical load.
  - Other limits of flexible plants.
  - Compensatory framework for flexible coal fired plants.

- **Possible Business Model for Pilot Study:**
  Collaboration between technology provider and plant owners to enhance the flexible operation of plants. As regulatory framework around flexible operation is still evolving, a model based on sharing of savings can be adopted by the technology provider and plant owner. Such pilot study will help to showcase the constraints and benefits of different technology options in flexible area. Regulators should also take clue from the outcomes of such projects in developing a better regulatory framework around flexible operation of coal fired plants in India.

Medium Term Measures

- **Implementation of Primary Control Reserves**
  - Continuous load changes result in mismatch of generation and load leading to variation infrequency of interconnected power system.
  - Keeping governors free to operate would enable smooth control of frequency fluctuations as well as security against grid disturbances.
  - For primary control to work properly most of the generations have to be under governor control so that adequate primary reserve is available at all times.
  - Primary control through methods like “Installation of Thermal Storage” should also be explored.

- **Implementation of Secondary Control in India**
  Enabling secondary control through Automatic Generation Control (AGC) will require two way communications from generators to control room and AGC software. For this to happen telemetry has to be improved. Secondary control will help automatic change of output of generators participating in AGC to match the real time load.

Operating guidelines for flexible operation of coal fired plants needs to be drafted by CEA.
Operating standards shall be mentioned for the following aspects of the flexible operation of plant
- Ramping Up capabilities
- Time for Start- up/ Shut down services
- Turndown services

Compensation framework providing adequate compensation for complete range of flexible operation services by coal based stations
Flexibility for any power system is a prized characteristic. Therefore an adequate compensation is required to properly incentivise the generators operating in a flexibly. Compensation structure shall focus on all the costs related to flexible operation. It is necessary that compensation structure should be inclusive of the following parameters:

- Investment in the modifications of plants to make it more flexible.
- Heat Rate of plant
- Ramp abilities of plant
- Time required to start up and shut down

Long Term Measures

Tackle the existing transmission constraints:
Improved transmission infrastructure will increase grid flexibility. Increased transmission capacity connecting balancing areas means that operators in different regions can buy and sell electricity from each other. This will allow operators to draw on the resources of multiple regions to balance out variability, and similarly will also allow operators to import electricity when local prices are high, or export electricity when there is a surplus and prices are low.

- With a strongly interconnected grid, total output of all renewables over the whole grid at any given time is less variable than from any individual source or location, due to geographical diversity (anti-correlation) of wind strength and cloud cover.

Introduction of ancillary based products in the market:
Ancillary service products are currently procured only from ISGS with URS. Ancillary services should also be explored from other generators which are more optimally located and economical to provide such services.

While base load power by the states is usually procured through long term contracts, intermediate load requirements is fulfilled by medium term or short term bilateral contracts/markets. However, share of total short – term transactions is only around 10% (2015-16), in volume terms, of total country power generation. Short term transactions mentioned here include the following[18]:

- Bilateral transactions through traders
- Bilateral transactions between DISCOMS
- Power exchange transactions
- Transactions through DSM

In the future it is recommended that ancillary services and associated reserves also be procured on the PXs from a pool of eligible and certified players. Various products based on the primary, secondary reserve can be introduced in the market. Products based on the flexible operation of plants can help to provide a better response in the emergency situations.

[18] S Report on Short-term Power Market in India: 2015-16

Annexure

1. Technical minimum load and ramp rates of various coal based ancillary service providers

PLANT NAME	REGION	INSTALLED CAPACITY (MW)	MAXIMUM POSSIBLE EX-BUS INJECTION (MW)	MAXIMUM RAMP RATE AS PER CEA STANDARD (MW/MINUTE) ON INSTALLED CAPACITY	RAMP UP (MW/MINUTE/UNIT)	RAMP DOWN (MW/MINUTE/UNIT)	TECHNICAL MINIMUM ON INSTALLEDCAPACITY OF STATION (MW)	TECHNICAL MINIMUM % OF INSTALLED CAPACITY (MW)
BGTPP	AR	250	239	8	1	1	175	70%
Barh TPS	ER	1320 (2*660)	1244	40	3	3	871	66%
Farakka-I&II	ER	1600(3*200+2*500)	1497	48	1 for 200 MW; 2.5 for 500 MW	1 for 200 MW; 2.5 for 500 MW	1048	65%
Farakka-III	ER	500(1*500)	472	15	2.5	2.5	330	66%
Kahalgaon-I	ER	840 (4*210)	803	25	1.5	1.5	588	70%
Kahalgaon-II	ER	1500 (3*500)	1442	45	2.5	2.5	1050	70%
Talcher-I	ER	1000 (2*500)	960	30	1.6	1.6	700	70%
Dadri- I	NR	840(4*210)	798	25	20MW/Block	20MW/Block	588	70%
Dadri -II	NR	980(2*490)	931	29	50MW/Block	50MW/Block	686	70%
Jhajjar	NR	1500(3*500)	1500	45	3.33	3.33	900	60%
Rihand -I	NR	1000 (2*500)	940	30	3.33	5	700	70%
Rihand-II	NR	1000 (2*500)	960	30	3.33	5	700	70%
Rihand-III	NR	1000 (2*500)	940	30	3.33	5	700	70%

Source: Reserve Regulation Ancillary Services (RRAS) Implementation in Indian Grid, Half Yearly Feedback

PLANT NAME	REGION	INSTALLED CAPACITY (MW)	MAXIMUM POSSIBLE EX-BUS INJECTION (MW)	MAXIMUM RAMP RATE AS PER CEA STANDARD (MW/MINUTE) ON INSTALLED CAPACITY	RAMP UP (MW/MINUTE/UNIT)	RAMP DOWN (MW/MINUTE/UNIT)	TECHNICAL MINIMUM ON INSTALLEDCAPACITY OF STATION (MW)	TECHNICAL MINIMUM % OF INSTALLED CAPACITY (MW)
Singrauli	NR	2000 (5*200+2*500)	1863	60	1 for 200 MW, 2 for 500 MW	1 for 200 MW, 2 for 500 MW	1400	70%
Unchahar-I	NR	420 (2*210)	350	13	1	1	294	70%
Unchahar-II	NR	420 (2*210)	400	13	1	1	294	70%
Unchahar-III	NR	210 (1*210)	200	6	1	1	147	70%
NLC- II Exp	SR	500(2*250)	450	15	1.2	1.2	340	68%
NLC- I Exp	SR	420(2*210)	395	13	1.2	1.5	320	76%
NLC- I	SR	630(3*210)	567	19	1.2	1.5	422	67%
NLC- II	SR	840(4*210)	756	25	1.2	1.5	566	67%
NTPL -I & II	SR	1000(2*500)	948	30	1.67 1.6 for 500 MW	1.67 1.6 for 500 MW	330	66%
Ramagundam	SR	2100(3*200+3*500)	2010	63	0.6 for 200 MW,	0.6 for 200 MW,	1453	69%
Ramagundam- III	SR	500(1*500)	484	15	1.6	1.6	326	65%
Simhadri- II	SR	1000(2*500)	960	30	1.93	1.93	658	66%
Talcher- II	SR	2000(4*500)	1900	60	1.6	1.6	1400	70%
Vallur	SR	1500(3*500)	1400	45	1.67	1.67	1050	70%
CGPL	WR	4150 (5*830)	3800	125	2	2	2090	50%

PLANT NAME	REGION	INSTALLED CAPACITY (MW)	MAXIMUM POSSIBLE EX-BUS INJECTION (MW)	MAXIMUM RAMP RATE AS PER CEA STANDARD (MW/MINUTE) ON INSTALLED CAPACITY	RAMP UP (MW/MINUTE/UNIT)	RAMP DOWN (MW/MINUTE/UNIT)	TECHNICAL MINIMUM ON INSTALLEDCAPACITY OF STATION (MW)	TECHNICAL MINIMUM % OF INSTALLED CAPACITY (MW)
Korba(I & II)	WR	2100(3*200+3*500)	1960	63	1 for 200 MW, 2 for 500 MW	1 for 200 MW, 2 for 500 MW	1372	65%
Korba(III)	WR	500(1*500)	472	15	2	2	330	66%
Mouda-I	WR	1000(2*500)	989	30	2.33	2.33	550	55%
NSPCL	WR	500(2*250)	465	15	1	1	320	64%
Sasan	WR	3960(6*660)	3722	119	2	2	2400	61%
SIPAT-I	WR	1980(3*660)	1866	59	30 MW/Block	30 MW/Block	1120	57%
SIPAT-II	WR	1000(2*500)	943	30	35 MW/Block	35 MW/Block	566	57%
Vindhyachal-I	WR	1260(6*210)	1160	38	15 MW/Block	15 MW/Block	802	64%
Vindhyachal-II	WR	1000(2*500)	950	30	35 MW/Block	35 MW/Block	562	56%
Vindhyachal-III	WR	1000(2*500)	960	30	35 MW/Block	35 MW/Block	562	56%
Vindhyachal-IV	WR	1000(2*500)	960	30	35 MW/Block	35 MW/Block	562	56%
Vindhyachal-V	WR	500(1*500)	480	15	35 MW/Block	35 MW/Block	281	56%

2. Implementation of RGMO / FGMO Status- Western Region

The details of generators eligible for RGMO status in Western Region is given below. Following details are as on 31st May 2016.

	RGMO ELIGIBLE UNIT		RGMO/FGMO AVAILABLE AT		RGMO/FGMO NOT AVAILABLE A	
NAME OF ENTITY	NUMBER	MW	NUMBER	MW	NUMBER	MW
Maharashtra	101	21781	37	7939	64	13842
NTPC	28	10840	22	8420	6	2420
Gujarat	35	10196	19	7790	16	2406
Madhya Pradesh	58	7025	14	3305	44	3720
CGPL	5	4150	5	4150	0	0
SASAN	6	3960	6	3960	0	0
JPL	7	2800	7	2800	0	0
Chhattisgarh	11	2460	4	120	7	2340
NCA	11	1450	10	1400	1	50
GMR-CG	2	1370	0	0	2	1370
JP Nigrie	2	1320	2	1320	0	0
KSK	2	1200	2	1200	0	0
DB POWER	2	1200	1	600	1	600
MB Power	2	1200	1	600	1	600
Balco	3	1200	0	0	3	1200
RKM	2	720	0	0	2	720
ESSAR_Mahan	1	600	1	600	0	0
KWPCL	1	600	0	0	1	600
LANCO	2	600	2	600	0	0
EMCO	2	600	0	0	2	600
Jhabua	1	600	0	0	1	600
NSPCL	2	500	2	500	0	0
Dhariwal	1	300	0	0	1	300
MCCPL	1	300	0	0	1	300
WR_Total	288	76972	135	45304	153	31668

Source: Operating Procedure for Western Regional Grid (July 2016), POSOCO

3. Cost Benefit Analysis of Flexibility Retrofits

RETROFITS OPTIONS	PLANT AREA IMPACTED THROUGH RETROFITS	SEGREGATION OF IMPACT ON DIFFERENT FLEXIBLE SERVICES THROUGH RETROFIT (%)			COST TO INSTALL IN MILLIONS (US $)		
		IMPACT ON RAMP RATE	IMPACT ON TURNDOWN	IMPACT ON START-UP / SHUT DOWN	SMALL SUB CRITICAL (200 MW)	LARGE SUBCRITICAL COAL (500 MW)	SUPERCRITICAL COAL (750 MW)
Improved and automated boiler drains	Boiler	-	50%	50%	3	5	5
Steam flow redistribution and metallurgy improvements in in SH/RH	Boiler	33%	33%	33%	2.5	5	7
Steam coil air heater to pre warm boiler and airheater	Boiler	33%	33%	33%	0.5	1	2
Gas bypass to keep air heater warm	Boiler	-	50%	50%	0.7	1.5	3
Improved APH basket life when cycling in or through the wet flue gas temperature region by installing traveling APH blowers to remove deposits prior to cycling down in load	Boiler	-	50%	50%	0.75	1	1
Improved APH basket life with improved materials when cycling in or through the wet flue gas temperature region	Boiler	-	50%	50%	1.2	2	2
Improved selected expansion joints. This is not a complete replacement of all expansion joints.	Boiler	-	-	100%	1.5	2	3
Add steam cooled enclosure min flow protection for balanced flow with blow down or dump to LP turbine	Boiler	-	50%	50%	0.3	0.5	-
Improved flame proving equipment for burners	Coal Mill	33%	33%	33%	0.5	1	1.5
Low load gas ignitors to allow min generation on gas fuel only	Coal Mill	-	100%	-	2	3	4
Dual Fuel burners – use NG over coal (Add NG to all burners). Gas supply is not included	Coal Mill	33%	33%	33%	10	12	16
New feeders with gravimetric type feeder with improved weighing of coal feed to mill	Coal Mill	33%	33%	33%	3.6	7.2	10
Automatic pressure control on roll and race to adjust the grinding pressure of the coal mill.	Coal Mill	33%	33%	33%	3	5	7

Source: Cost-Benefit Analysis of Flexibility Retrofits for Coal and Gas-Fuelled Power Plants (NREL)

RETROFITS OPTIONS	PLANT AREA IMPACTED THROUGH RETROFITS		SEGREGATION OF IMPACT ON DIFFERENT FLEXIBLE SERVICES THROUGH RETROFIT (%)			COST TO INSTALL IN MILLIONS (US $)		
			IMPACT ON RAMP RATE	IMPACT ON TURNDOWN	IMPACT ON START-UP / SHUT DOWN	SMALL SUB CRITICAL (200 MW)	LARGE SUBCRITICAL COAL (500 MW)	SUPERCRITICAL COAL (750 MW)
Heated precipitator hoppers	Emission Control		-	50%	50%	0.5	1	1.8
New dry fly ash transport	Emission Control		-	50%	50%	2	3	4
Small package boiler, electric boiler with air modeling and permit	Balance of Plant		-	50%	50%	3.2	4	6
Motor driven boiler feed pump with startup to min load capability	Balance of Plant			50%	50%	4	6	8
Improved vibration sensing and monitoring of all rotating equipment	Balance of Plant		33%	33%	33%	1.5	2.5	3.5
Speed Controlled motors on ID and FD fans using variable frequency drives	Balance of Plant		33%	33%	33%	5	7.5	7.5
Transformer monitoring gas analysis and temperature and emergency oil removal if arching occurs	Balance of Plant		33%	33%	33%	0.57	1.5	2.25
Turbine electric heating blankets	Turbine		-	-	100%	1	2	2.5
Convert 3 rpm to 40 rpm turning gear motor to prevent blade attachment wear and generator loose parts	Turbine		33%	33%	33%	0.75	1.5	2
New valve operators Full arc emission/sliding pressure	Turbine		33%	33%	33%	1	1.8	4
Turbine drains to the condenser hot well including main steam drains and before seat warmup drains should be routed to the hotwell with a sparger discharge below the normal water level	Turbine		-	-	100%	0.25	0.5	0.75
Turbine water Induction prevention Upgrades including MOVs on extractions and inspection of heater drains and extraction piping and bellows in con-denser	Turbine		33%	33%	33%	0.5	0.75	1
Condenser tube shielding	Turbine		-	50%	50%	0.5	0.75	1
Nitrogen Blanketing of condensate storage tank, Boiler, turbine	Chemistry Related Improvement		-	-	100%	1	2	3
Condensate polishing system for rapid water chemistry cleanup when cycling	Chemistry Related Improvement		-	-	-	1.25	2	3
Larger condensate storage tanks	Chemistry Related Improvement		-	-	100%	1.5	3	4
Add steam cooled enclosure min flow protection for balanced flow with blow down or dump to LP turbine	Chemistry Related Improvement		-	50%	50%	0.3	0.5	-