Techno-Economic aspects of Flexible Operation
The Indian Experience

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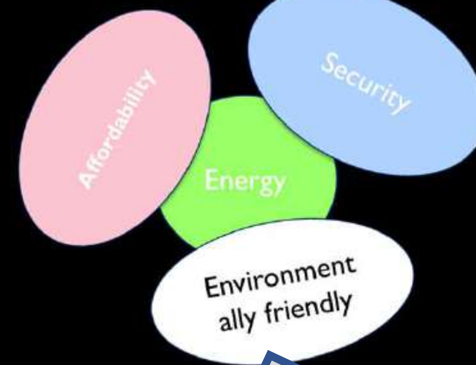
Ahmedabad

Evolution and Transition of the Indian Electricity market

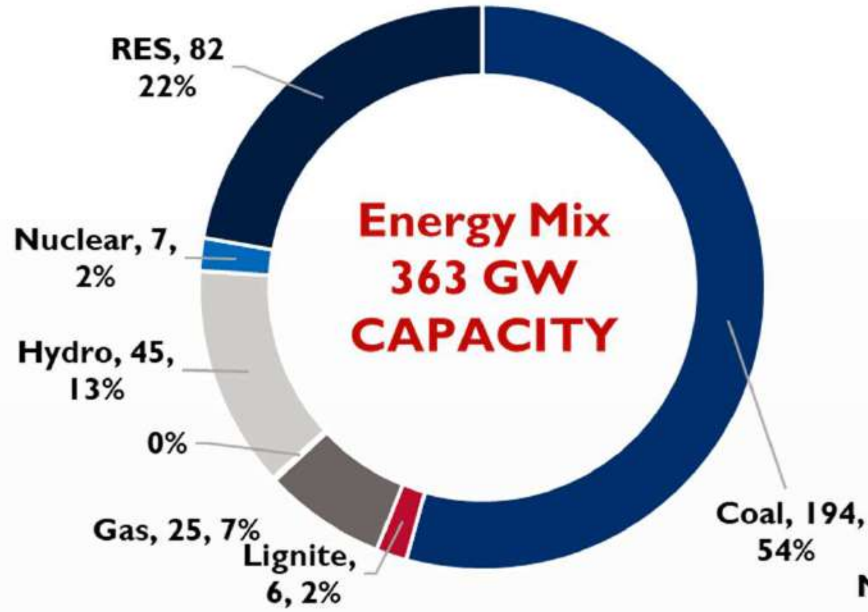


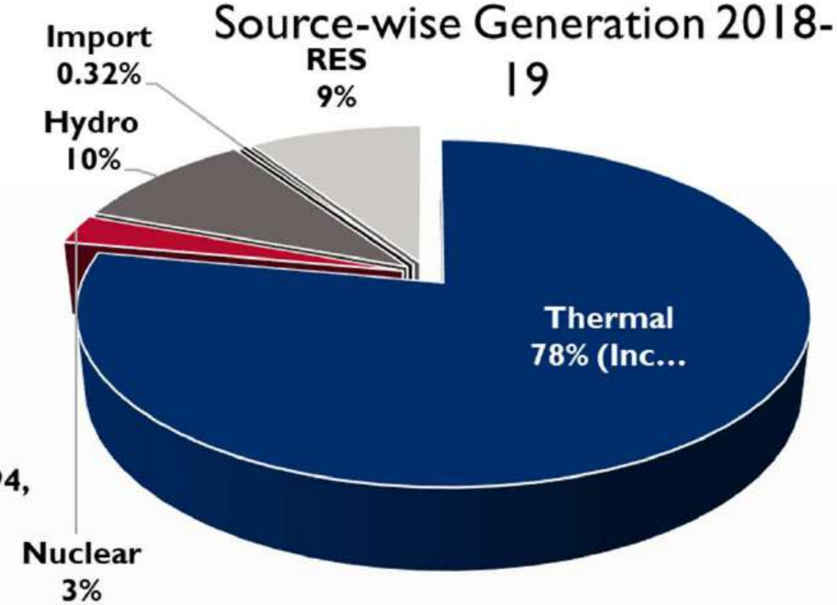
The first demonstration of an electric light in Calcutta was conducted in1879 by P.W. Fleury & Co. In 1897, Kilburn & Co secured the Calcutta electric lighting license as agents of the Indian Electric Co, which was registered in London on 15 January 1897. A month later, the company was renamed the Calcutta Electric Supply Corporation. The control of the company was transferred from London to Calcutta only in 1970.

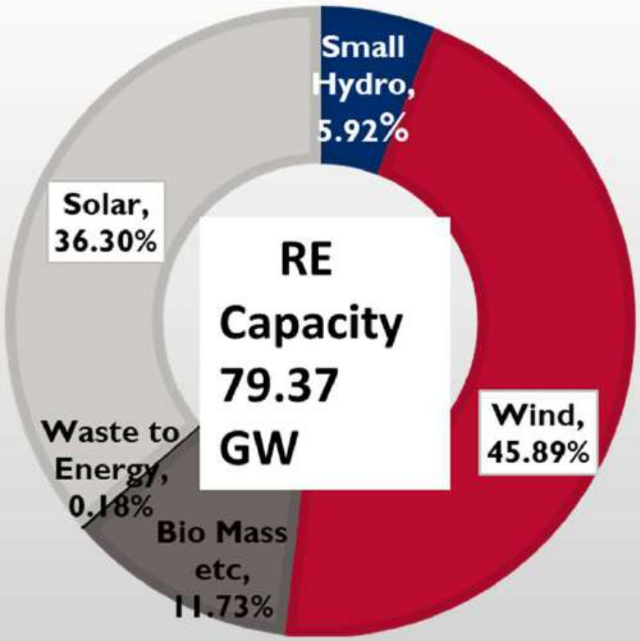
Today's Regulated Market

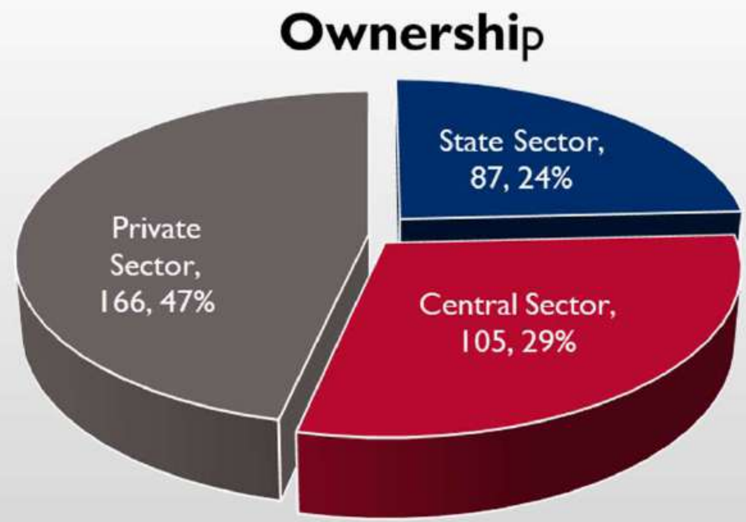
Real Time Market ..In 1st April'20

The journey till today has been primarily towards ensuring Energy security. But the next journey will be towards addressing the **Energy Trilemma** (Security, Affordability and sustainability)-It will be disruptive in nature & Scale both technology & economic



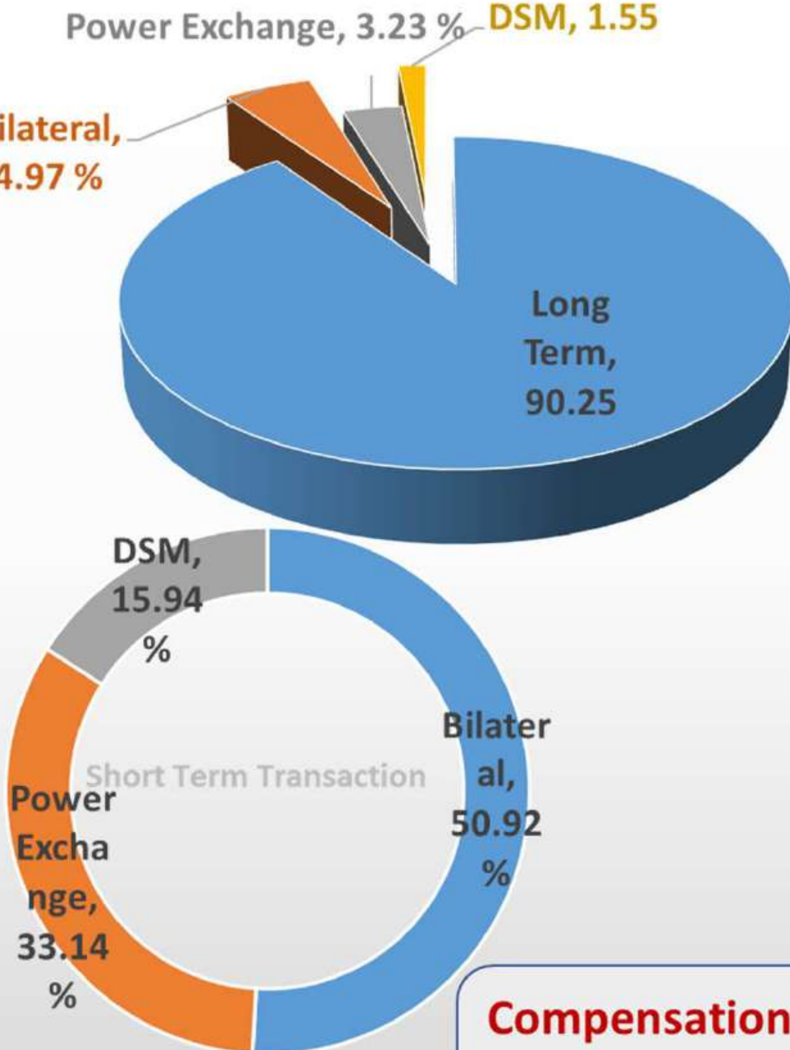






Source: MOP,CEA

Volume of Electricity Transaction-May,2019



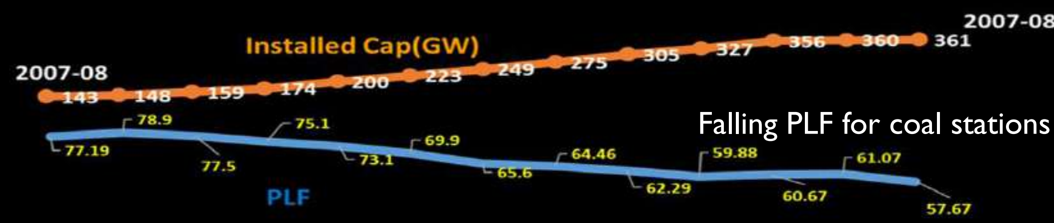
The Indian Power Market

- Mostly Long term physical contracts and on a day-ahead basis PPAs with two part tariff based on capacity charges and Variable Costs
- **DSM**(Deviation settlement Mechanism) and **Anciallary Services** (RRAS) to address intra-day energy requirement as well as system imbalances
- **AGC** introduced in few coal stations
- **SCED**
- Flexibility in generation and scheduling

Compensation mechanism for part load operation which partly compensates the generators for the extra cost incurred on account of efficiency deterioration and extra oil consumption.

Emerging Scenario & Need for Flexibility

Flexibilisation: Why Bother?
Or Why should I get ready?
...What to do?

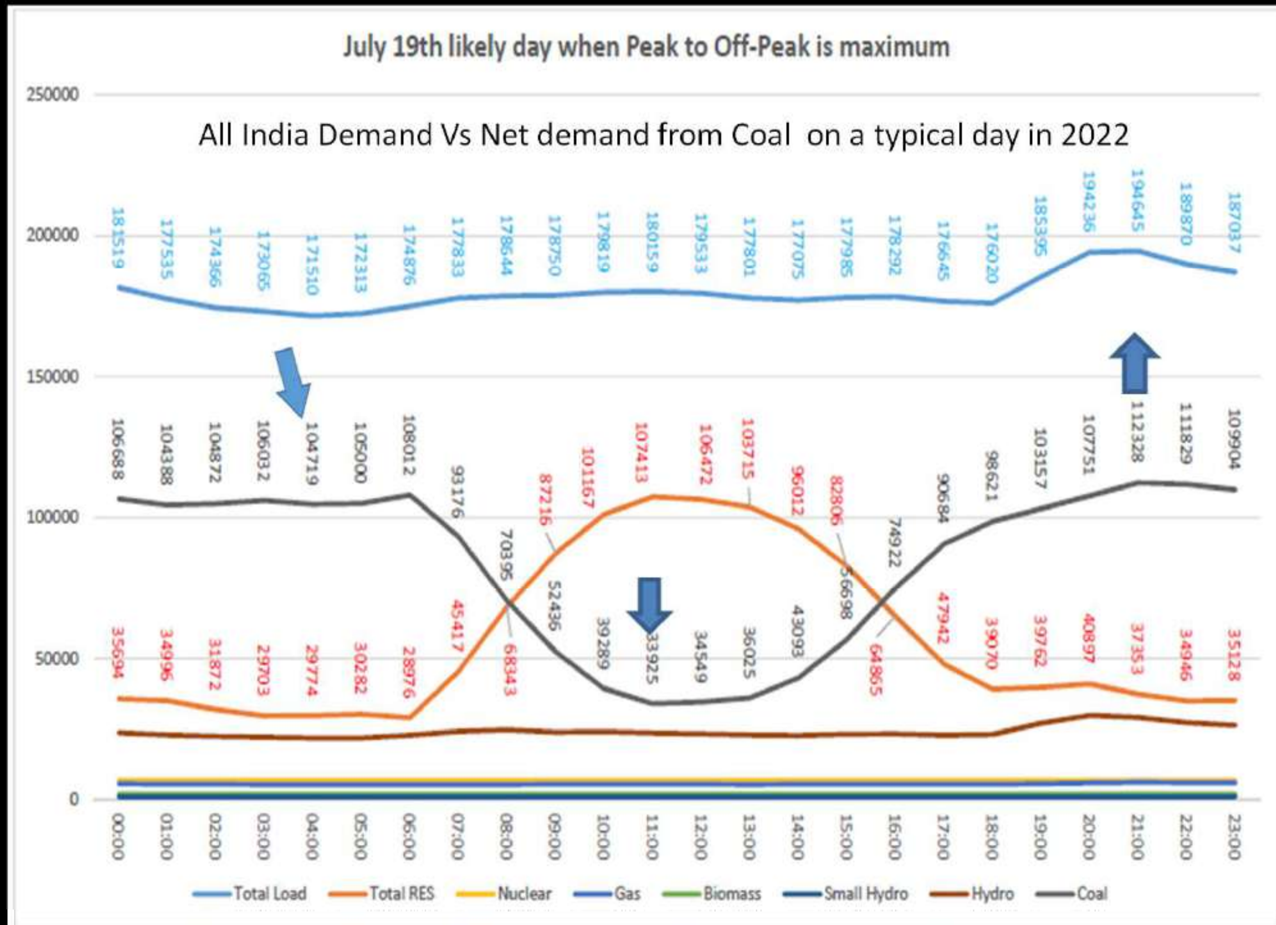


Thermal under increased VRE
Baseload ➡ Cycling

Impacts of Plant Cycling on Damage Rates and the ultimate Costs of providing power

Critical risks of process safety, increased costs, higher probability of equipment failure and reduction in unit life associated with cycling will need effective management

Building a Business Case for Flexibilisation



Impact of Variable Renewable power

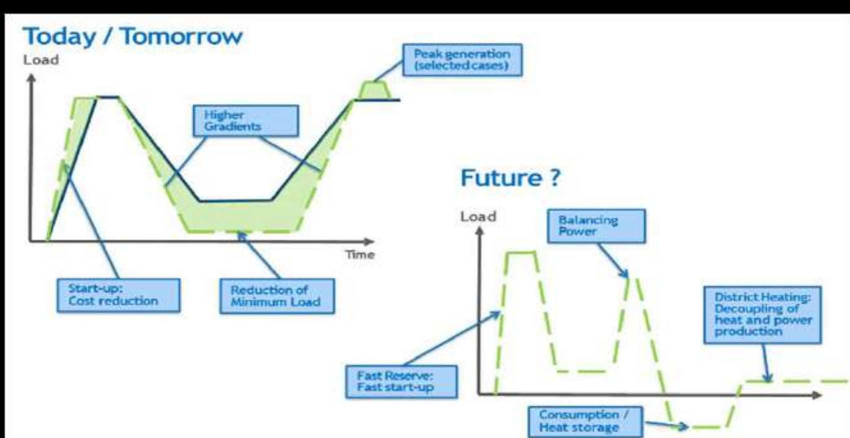
The Variability, Uncertainity,and the Geographically Confined VRE will be challenging for the grid operators as well as generators.

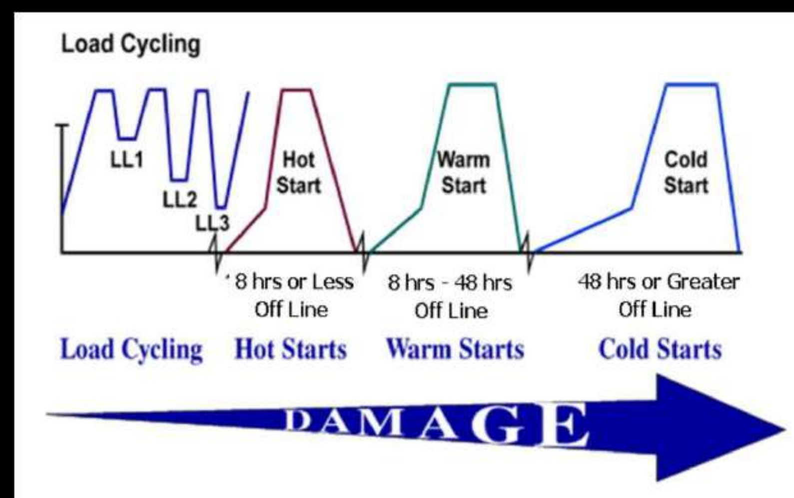
Impact on System

- Difficulty in load frequency control
- Difficulty in scheduling of tertiary reserves
- Requirement of enhanced transmission network and its under utilisation
- Increase in requirement of ancillary services and hence increased system operation cost
- Increase in transmission cost due to all above factors

Impact on existing Plant

- Lower PLF due to ducking of load curve
- High ramping requirement
- Two shifting and cycling of plants
- Increased forced outage and O&M cost
- Equipments life time reduction
- Poor heat rate and high Aux. Power

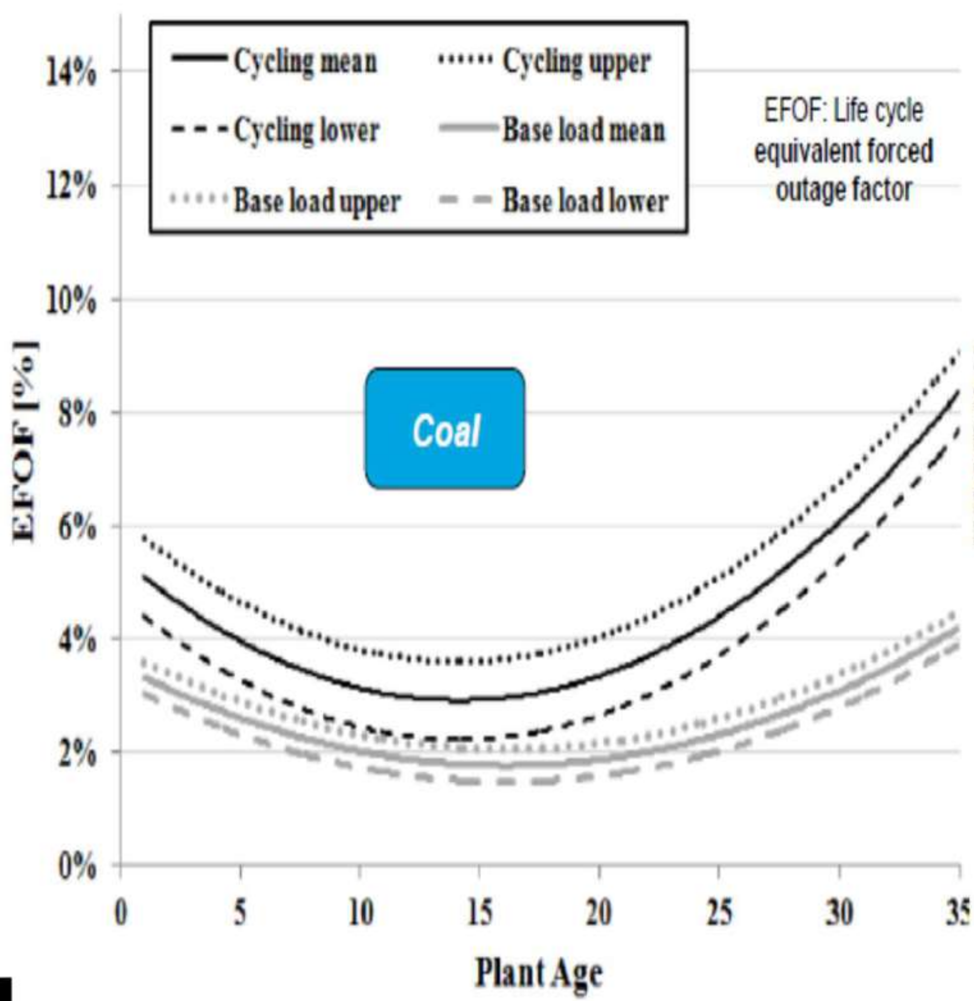




Part Load EFOR

Fossil Steam (Coal - >100MW)

- **Baseloaded (<10 starts per year):**
  - 2000-2017- EFOR: 5-6%
- **Extended Shutdown (>2000h Reserved Shutdown per year):**
  - 2000-2017- EFOR: 7.16%
- **Load Following (Service Factor >70%, Capacity Factor <60%):**
  - 2000-2017- EFOR: 7.06%
- **Minimum Load (Capacity Factor <50%, Unit Starts <20):**
  - 2000-2017- EFOR: 7.19%
- **Two Shifting (>50 Starts per year):**
  - 2000-2017- EFOR: 11-12%



Source: EPRI

Flexible operation impact on life – evolving manitenance

Impact of daily cycling on life

Critical Components likely to be affected by fatigue	Typical design Starts #No.
Economizer Inlet Header	1000
Turbine steam chest (Throttle valves)	1000
Economizer NRVs	1500
Economizer Inlet Header stubs	1500
Drum furniture cracking	1500
Primary SH outlet header	1500
Boiler stop valves	1500
Down comer attachment welds	2000
Circulating pump bodies	2000
Final SH outlet headers (2Cr)	2000
Final RH stubs	2000
Intermediate SH headers	3500
Drum shell (welds)	4000
Final SH outlet headers (P-91)	5000
Final RH outlet header	5000

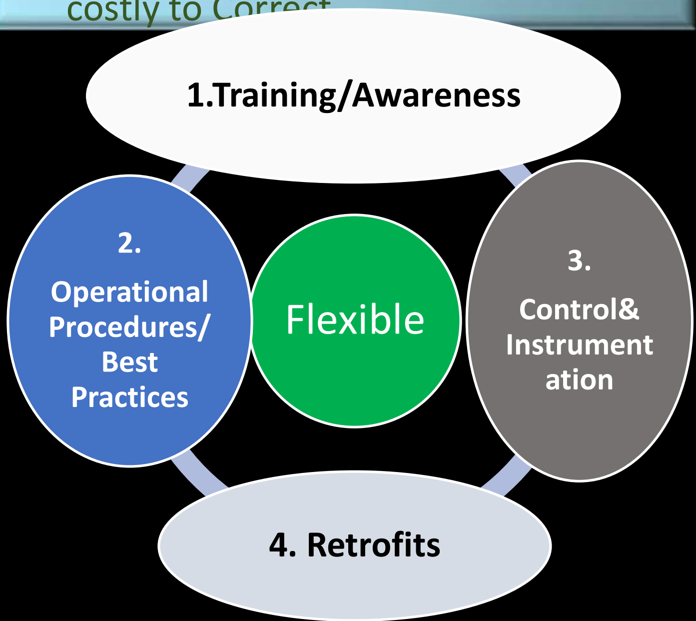
Critical Components likely to be affected by creep	Typical design Hrs.
Primary SH outlet header	180000
Final SH elements (parts)	180000
Final SH outlet header	250000
Intermediate RH outlet header	180000
RH cross over pipes	180000
Final RH outlet header	180000
Steam pipework	250000

Average @40%/ year reduction in Fatigue life is expected

Source:GE

Harsh Realities of Cyclic Operation

- Flexing with lack of **awareness**, can be disastrous
- Well known that cycling causes damage and when equipment degrades, performance degrades.
- Damage not immediate but accumulated and not easy to quantify
- By the time symptoms of damage is visible it may have become very costly to Correct



- The biggest obstacle to achieving Unit Flexibility is the Culture.
  - The entire organization needs to be invested in meeting the new market demands and keeping the coal units viable.
- **Flexible operation is a difficult mode of operation** and even the most conservative approach will increase plant O&M costs along with per MW variable costs
- However those plants that can operate flexibly to meet market conditions while minimizing the financial impact of operating in this environment, **will continue to be dispatched**, at least for the near future.
- Operations for Flexible Operations requires a **holistic perspective of the entire plant** to avoid unintended consequences.
- Revisiting the operational procedures, Training of O&M manpower can enhance flexibilization
- Plant operators need to be **trained for an in-depth knowledge** of every plant system, with broad understanding of combustion, heat transfer, plant control methodology, damage mechanisms such as creep and FAC, steam turbine operating limits, and emissions equipment.

Barriers to Flexiblisation

Varying Coal Quality posed a major challenge to flexibilisation

	GCV (KCal/Kg)	VM	ASH
A	4000	18%	36%
A	3400	14%	40%
B	4600	21%	34%
B	3700	18%	37%
C	6000	22%	30%
C	3300	15%	40%

Min. Load - 55%-30%

Coal Quality

Most of the state Utilities yet to reduce minimum load levels

Geographical Concentration of Renewable

Transmission constraints

Curtailment of RE

Limited participation

Flexibilisation for Integration of 175 GW RE

Capacity building & Investment

Operating Expertise to be created

Simulators for flexible operation

New Analytical Tools required

Increased Digitilisation

One time investment for making units flex ready.

Country-wide cost estimated at **14,000 crores for 82** GW capacity.

Policy support / Regulatory Framework

In India ,Market participation is limited. (Net Traded Energy is <

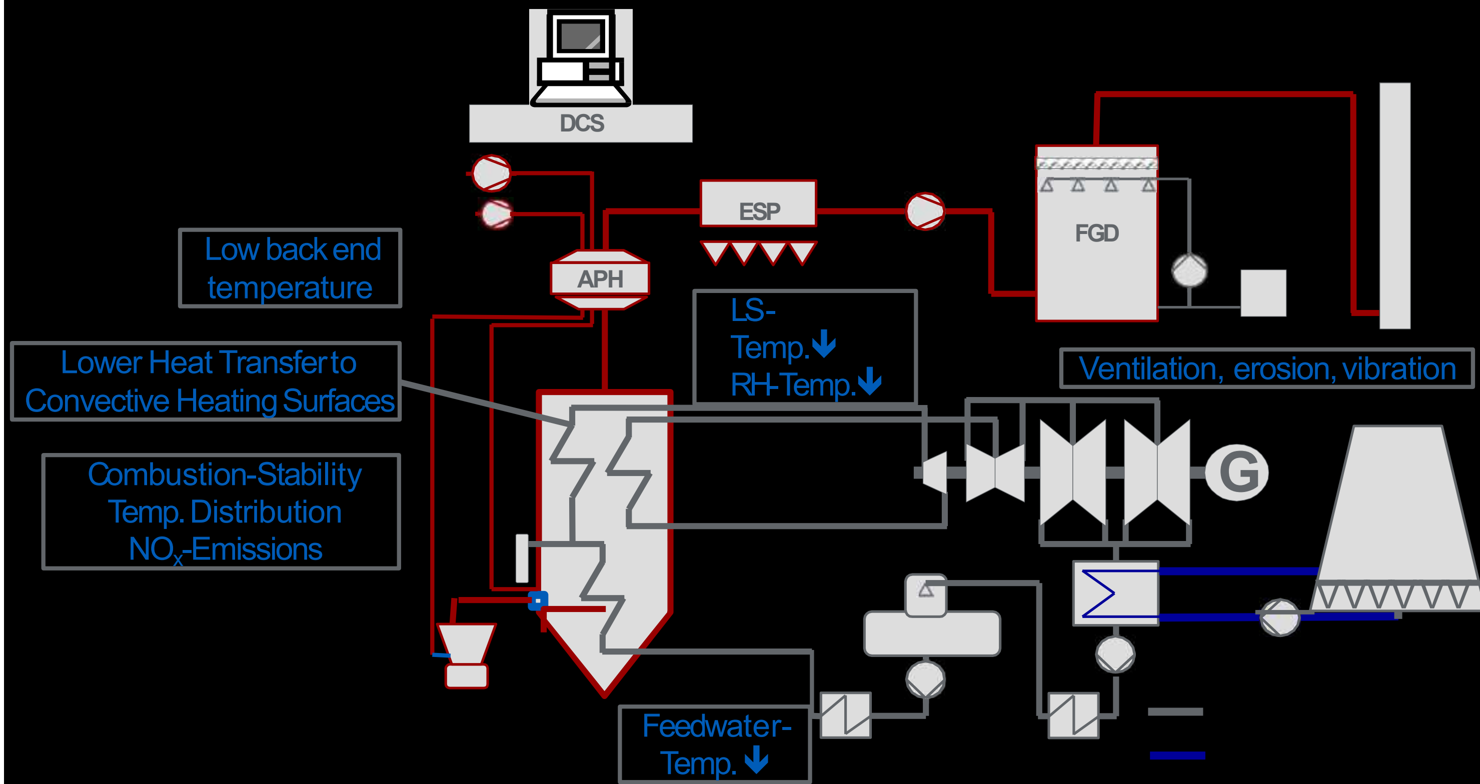
Largely under Long Term Contract arrangements(PPA),which have limited flexibility.

Incentivization through regulation or market needed.

Grid codes..

AGC,Anciliary services

Limitations to be addressed



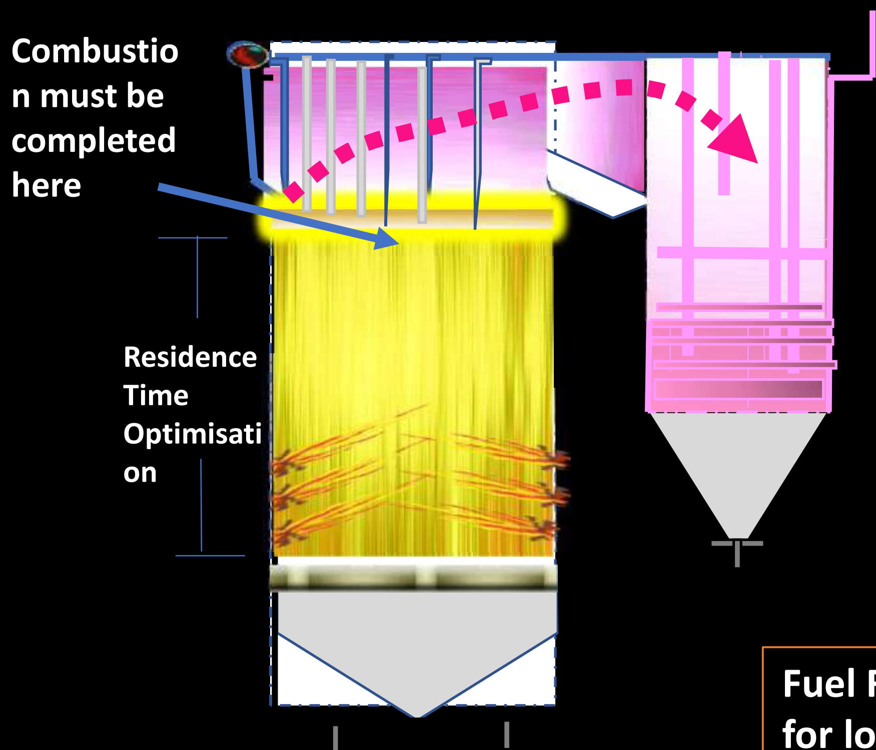
Ramp Rates-Limitations

- Stresses in thick walled components
- Fuel quality
- Controls and time lag between coal milling and turbine response

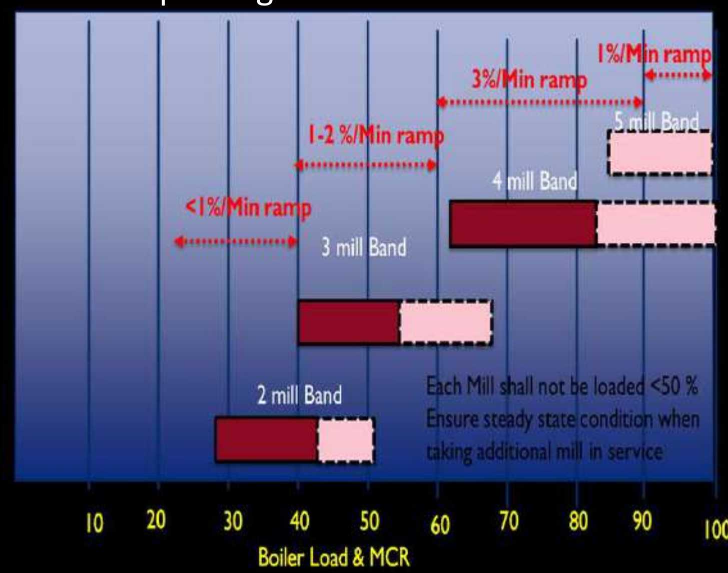
Minimum load limitations

- Combustion stability
- Boiler circulation
- DNB
- Minimum feed water flow & BFP
- Last stage blade flutter
- FG Exit Temp./Acid due point
- Vibration issues

COMBUSTION OPTIMISATION



Improving Mill Turndown



Fuel Firing System Optimization Package for low load oprn:

- **Air/Fuel ratio**
- **Coal pipes dynamic balancing**
- **Auto mill start**
- **Coal analyser**

Auto Coal Sampler

Flame scanners modifications
Burner modification

Best Operational Practices for flexible operation

- Judicious use of HP/LP bypass, oil guns
- Sliding pressure
- Deaerator heating and charging of HP heaters
- Reliable Temperature measurement for thick walled components-
- Accurate and well-placed temperature measurements of thick-walled
- components (inner wall and middle wall) are inevitable for evaluating the
- thermal stress (temperature difference) during power plant start-up and
- shut-down and the corresponding lifetime consumption

- Accurate and reliable control of start-up fuel
- Optimisation of control loops(tuning for low load operation)
    - Spray water control
    - Feed-water control
    - Drum level control
    - O_2 / air control
    - Circulation control

Best Operational Practices for flexible operation

- **I&C optimization is the most cost-effective way to enhance power plant flexibility**
- Use of SCAPH- This will ensure faster PA temp. and guarantee a sufficient drying of coal
- An online pulverized coal and air distribution management system is capable of measuring the air-fuel ratio to coal burners in each PC pipe to coal burners in real time which can be optimized automatically based on the received coal quality
- Reducing the number of mills in service at part load to ensure Minimum load of each mill and proper air-fuel ratio
- To get faster heat output the storage capabilities of mills can be exploited by purposely adapting the classifier's rotational speed
- Use of heating blankets to keep turbine warm during stand-stills by balancing the upper and lower casing and thus avoiding the bending of the shell- for start-up optimisation

Retrofits for flexible operation (As suggested by Siemens/BHEI) based on Test Runs

Automated start-up – One button start-up

Advanced unit control particularly comprises feed-forward model-based approaches that have proven to be an appropriate measure for improving the dynamic behavior of power plants

Indirect and direct throttling of extraction steam – Advanced frequency control

- Condensate throttling (indirect)
- Throttling of extraction steam to LP preheaters and feed-water tank (direct)
- Throttling of extraction steam to HP pre-heater (direct)

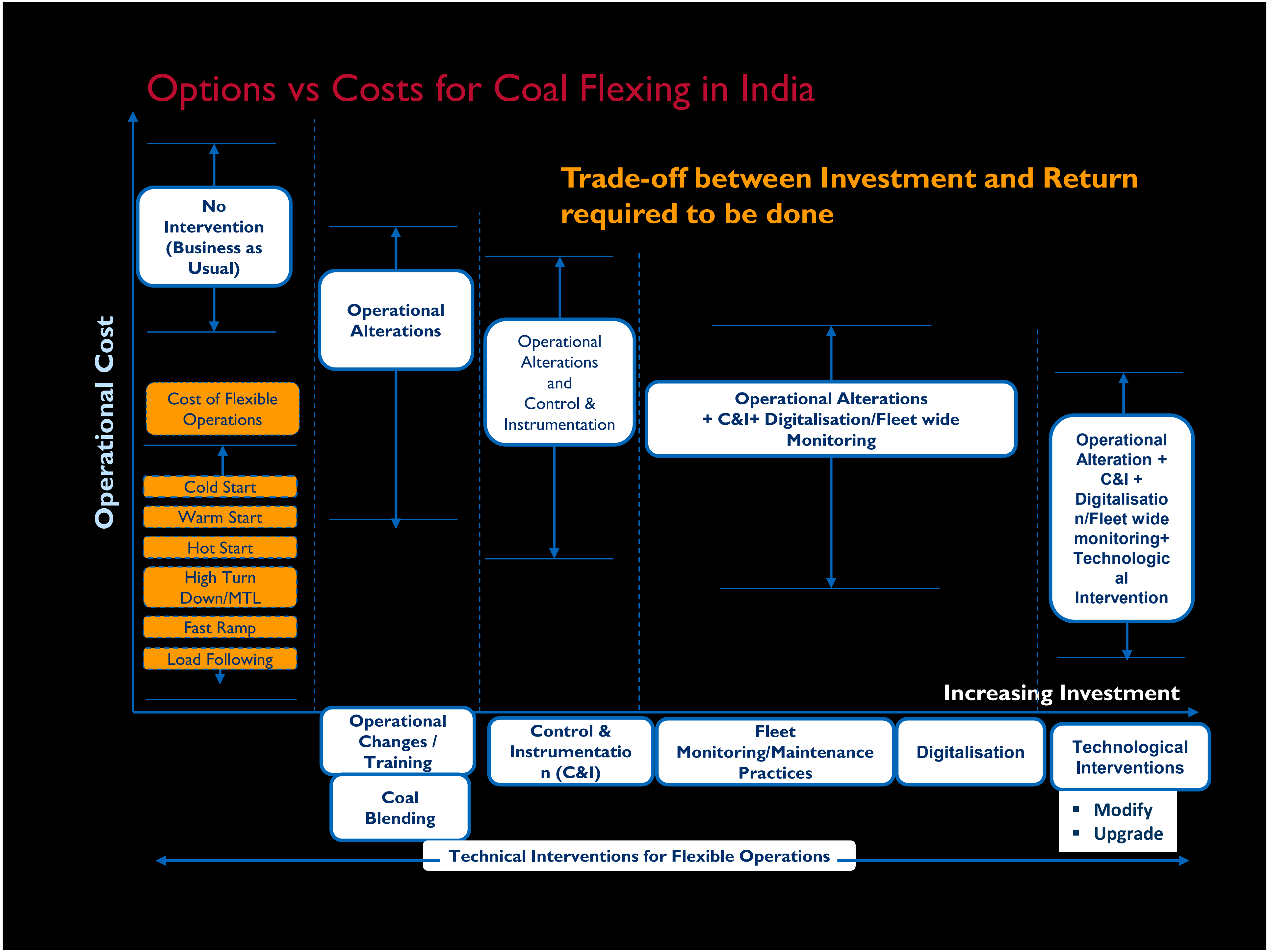
Condition monitoring systems should monitor highly loaded boiler and piping components against creep and fatigue

Coal sampler

Coal analyser

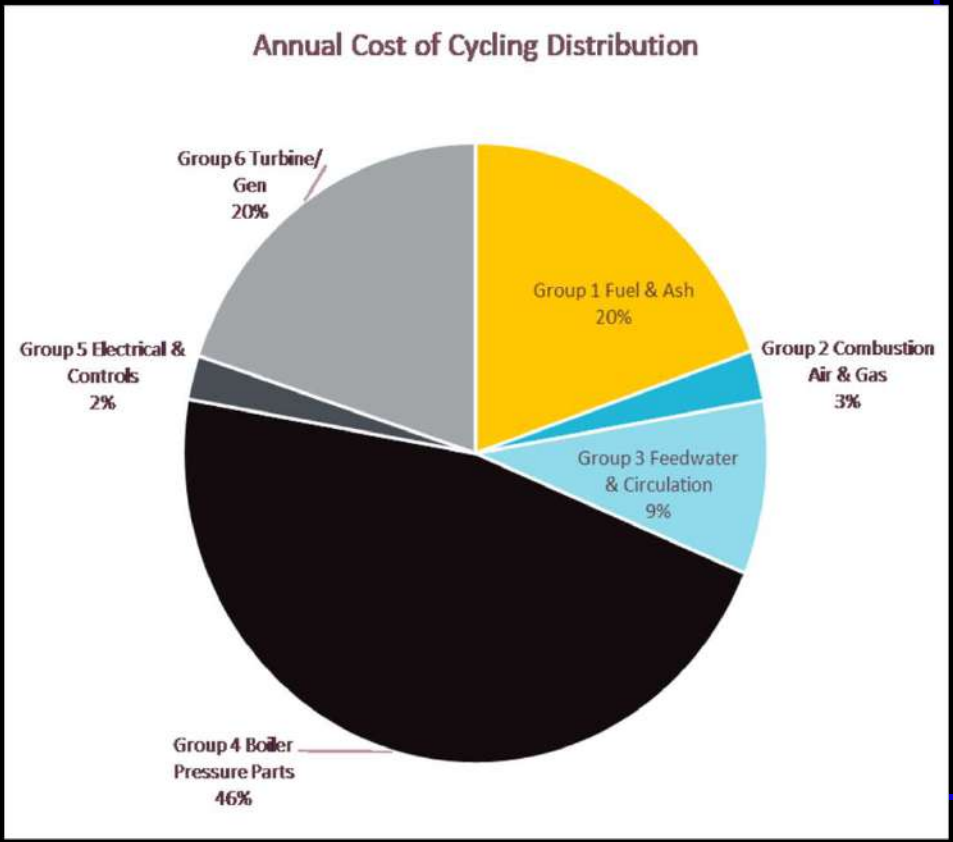
BFP Recirculation valve

Scanners



Options vs Costs for Coal Flexing in India
Trade-off between Investment and Return required to be done
Operational Cost
No Intervention (Business as Usual)
Cost of Flexible Operations
Cold Start
Warm Start
Hot Start
High Turn Down/MTL
Fast Ramp
Load Following
Operational Alterations
Operational Alterations and Control & Instrumentation
Operational Alterations + C&I+ Digitalisation/Fleet wide Monitoring
Operational Alteration + C&I + Digitalisation/Fleet wide monitoring+ Technological Intervention
Increasing Investment
Operational Changes / Training
Coal Blending
Control & Instrumentation (C&I)
Fleet Monitoring/Maintenance Practices
Digitalisation
Technological Interventions
Modify
Upgrade
Technical Interventions for Flexible Operations

Understanding the Total Costs distribution



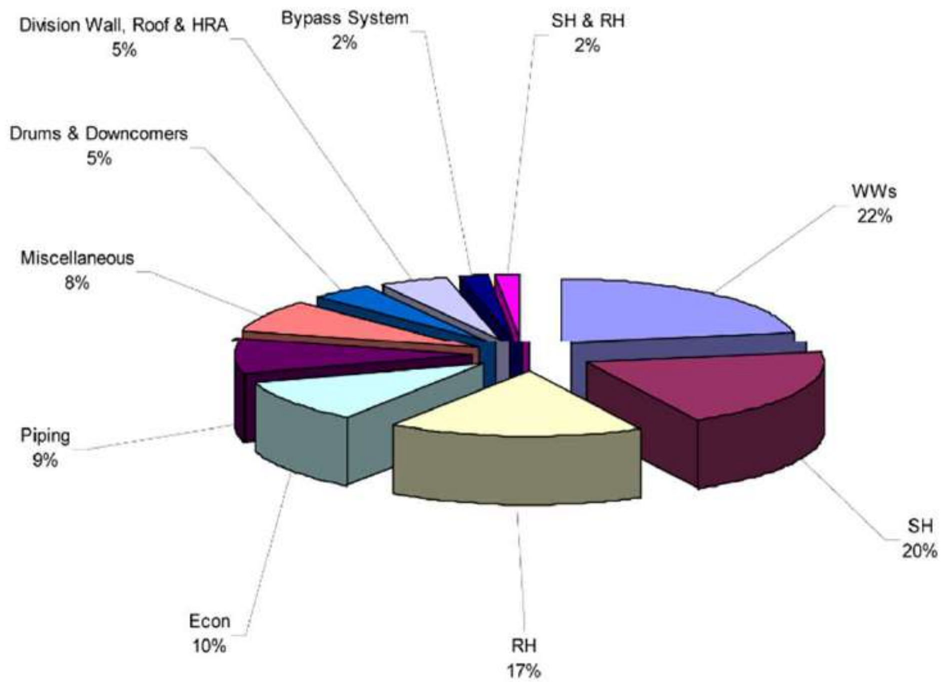
- Systematic records of all components
- Optimise maintenance expenditure
- Overhauling duration, timing and scope-Greater OH frequency in later years of life and cycling
- Failure statistics
- **Failure faults-independent of operation**
  - Due to construction, design, operating errors etc.
- **Predictable faults and dependent on service time**
  - Wear and tear of ageing component
  - Corrosion, erosion and distortion
  - Creep and fatigue damage
  - Cycling

Predictive Tools: Estimated weekly damages, EFOR,Life management actions

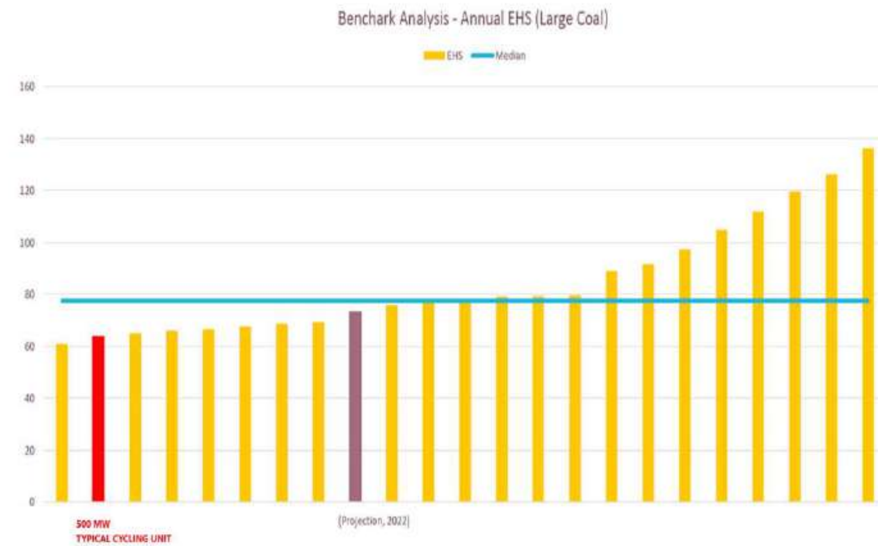
It is necessary to tailor the overhauling and maintenance intervals for the particular unit on the basis of data available.The analysis of component-wise cost data is important

Metrics of equivalent operating hours, EHS is helpful.

Cycling Damages in boiler components-Global Benchmark



BENCHMARK ANALYSIS (LARGE COAL)



In the Indian condition, we have limited data. Benchmarking for other units will be done.

Future maintenance strategy to address the increasing cycling damages will be based on:

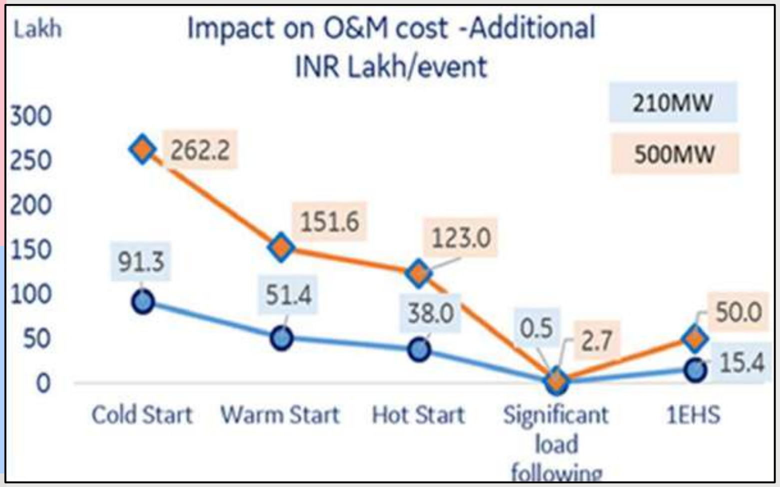
- **Cycling frequency and age of unit**
- **Boiler Component/Damage ranked on most affected by cycling**
- **Inspections schedules/Corrective Actions(**anticipated repairs, and Replacements)
- **Cost benefit analysis**

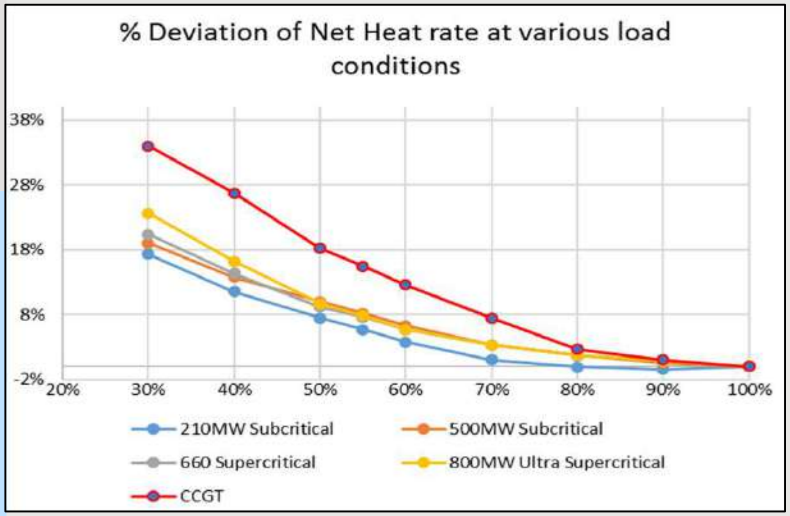
Identification of the damage mechanism by examination and monitoring.
The state of knowledge of the underlying mechanism and root cause
Self-calibrating incremental damage models that can be used to forecast the effect of frequency and severity of cycling, including failure rates

Typical Costs of Flexible Operations

Cost of Flexible Operations

Factors	Parameters
Energy Charges	• Start-up cost increases due to increase in ➢ Heat Rate ➢ APC ➢ Oil support
O&M Cost	• Increased EFOR • Accelerated life consumption due to ➢ Start-ups ➢ Load Following
Fixed Cost	• Accelerated life consumption will have impact over unit availability in ling-term • EFOR can impact unit availability in short-term
Environmental Impact	• Specific (Kg/MWh) NOx, SOx & CO emissions will be somewhat higher at unit level while flexing • Overall emissions would reduce for flexible units due to reduced coal usage. • Significant adverse impacts are very unlikely due to installation of emission control devices.





IMPACT ON TARIFF(FC+ ECR)		ECR-200P/Kwh			
		Typical 200/210MW Unit			
		Due to HR	Add. O&M*	Start up oil	Total Impact(FC+VC)
	Unit loading %	Addl. Paisa/ Kwh			
Minimum load with significant load following	90%	0	0	0	**0**
	80%	0	0	0	**0**
	70%	2.1	3.31	0	**5.4**
	60%	7.5	3.31	0	**10.8**
	50%	15	3.31	2.5	**21.3**
	40%	23.2	3.31	2.5	**29**
	30%	34.6	3.31	2.5	**40.5**
Weekly start		23.2	60.22	14.8	**98.2**
Daily start		7.5	257.39	65.2	**330.1**
		Typical 500 MW Unit			
	Unit loading %	Addl. Paisa/ Kwh			
Minimum load with significant load following	90%	1.1	0	0	**1.1**
	80%	3.4	0	0	**3.4**
	70%	6.7	7.15	0	**13.8**
	60%	12.6	7.15	0	**19.7**
	50%	20	7.15	0	**27.2**
	40%	27.6	7.15	0	**34.8**
	30%	38	7.15	0	**45.2**
Weekly start		27.6	69.18	10.7	**107.5**
Daily start		12.6	307.74	43.5	**363.8**

Compensation proposed in Report of Expert Group of review of IEGC

Against Heat Rate Loss

S. No.	Unit loading as a % of installed capacity of the unit	Increase in SHR (for supercritical units) (%)	Increase in SHR (for sub-critical units) (%)
1	85 and above	Nil	Nil
2	80	0.66	0.76
3	75	1.19	1.45
4	70	1.96	2.40
5	65	2.84	3.56
6	60	3.67	4.79
7	55	4.92	6.59
8	50	6.15	8.60
9	45	7.40	10.21
10	40	8.81	12.14

Against APC Loss

Sl. No	Unit loading (% of MCR)	% degradation in AEC admissible
1	85 and above	Nil
2	80	0.10
3	75	0.25
4	70	0.40
5	65	0.55
6	60	0.75
7	55	0.95
8	50	1.20
9	45	1.55
10	40	2.10

Minimum Turndown 55% mandatory. Below 55% optional, with provisions for compensation

Oil Compensation for every start(over and above 7th start/Year)

Unit Size (MW)	Oil Consumption per start-up(kl)		
	Hot	Warm	Cold
200/210/250 MW	20	30	50
500 MW	30	50	90
660 MW and above	40	60	110

Compensation for Load Following:

Proviso (iii) to regulation 30(2) of Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2019 states that

"in case of thermal generating stations with effect from 1.4.2020:

a) Rate of return on equity shall be reduced by 0.25% in case of failure to achieve the ramp rate of 1% per minute;

b) An additional rate of return in equity of 0.25% shall be allowed for every incremental ramp rate of 1% per minute achieved over and above the ramp rate of 1% per minute, subject to ceiling of additional rate of return on equity of 1.00%

- Further….
- Load following is also being compensated through AGC as markup of 50P/KwH.
- Ramping as an Ancillary product ?

In Summary….

- The transition of India Electricity is difficult and complex innovative and proactive policy and regulatory interventions are needed.
- Market and operational rules would be the key enabler for efficient energy system transformation
- Holistic interventions required
- A change in mindset of conservative technical experts
- We are in transitional phase, which a mix of market and regulatory mechanisms
- It is important to understand the value and economic cost of each services and compensation mechanisms must be devised
- New market and Ancillary products
- Ramping as an Ancillary Product
- The Stakeholders engagement including International cooperation is critical at every step

Thank You …
Questions??

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