Experiences with flexible operation in India – field tests and recommendations for plant operators

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IGEF- Task Force on Flexibilization

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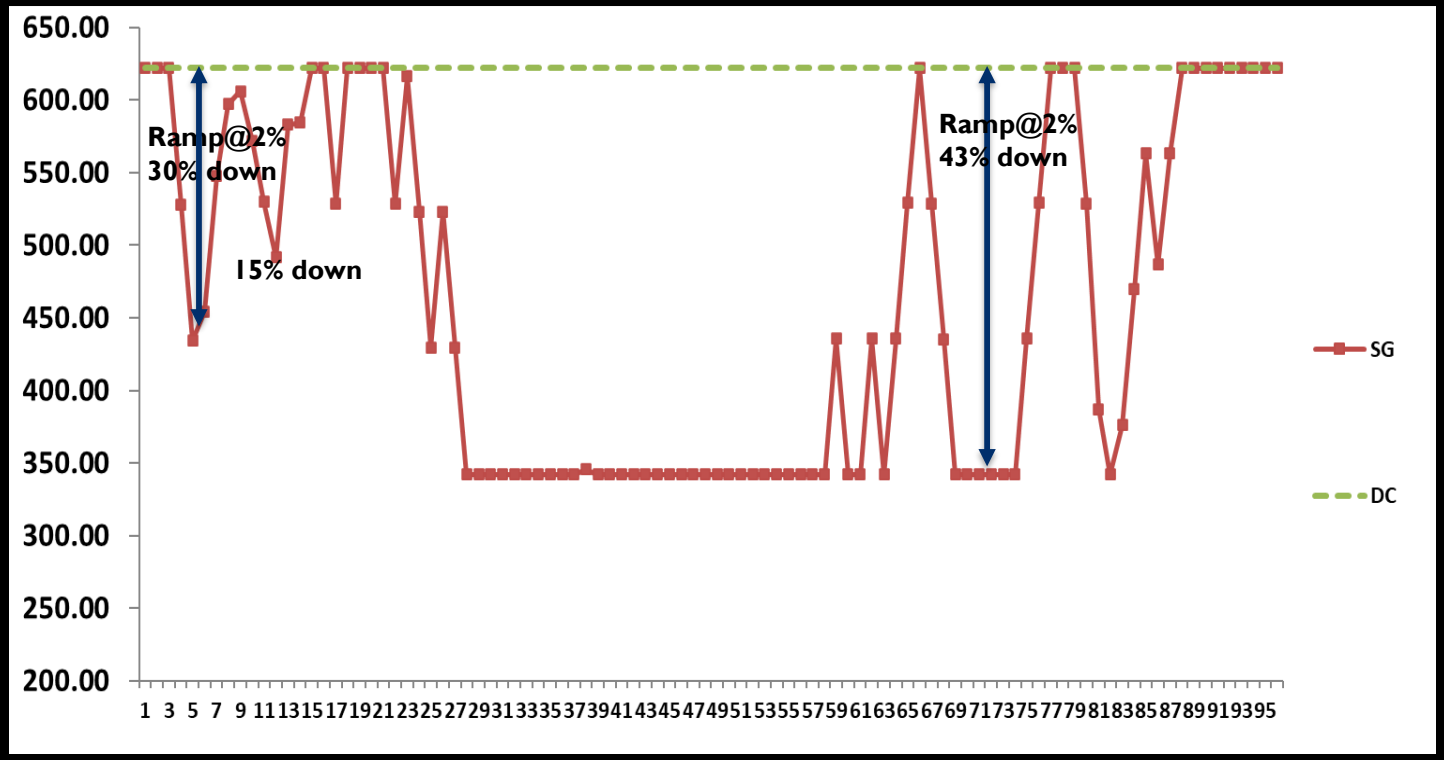
Content

- Emerging Scenarios and Flexibility requirements
- Harsh Realities of Cyclic Operation
- Options vs Costs for Coal Flexing in India
- Criteria and Selection of units for Flexibilization
- Damages due to flexibilisation
- How to proceed with Preparation for flexibility-
  ..... first step is test run Key Takeaways from the field Tests
- Operational Procedures for flexible operation
- Combustion Optimization
- Recommendations for Dadri
- Best Practices

Scheduling of ISGS Stations –One example(April 20th)



- Safety Issues
- O&M cost – under recovery
- Need for investments in retrofits

If we consider a significant load following of ramp size>15%,then we have at least 7 significant load followings

Each of this event costing >2lakhs for the generator, which the generator has no way to recover from the present regulatory mechanism.

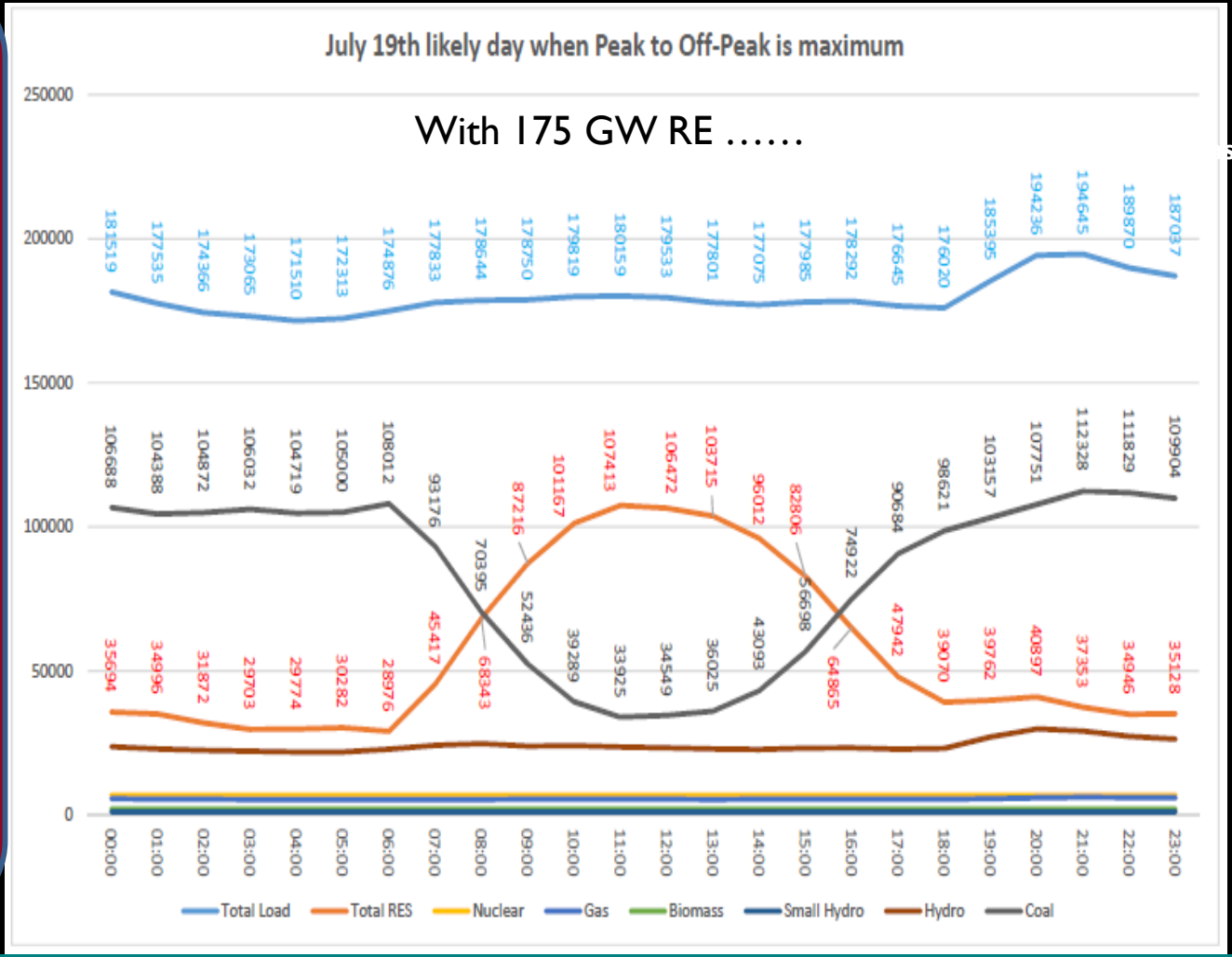
Emerging Scenario & Need for Flexibility

With SCED mechanism in place-already, the low merit order Stations have started facing the heat of frequent changes in schedule

Units are typically facing around 15 or more significant load-followingg in a day. Units which are unable to reduce their minimum load are asked to start-stop

There is no compensation for recovery of O&M costs incurred due to increased cycling on the units

It is important for the station to know what value of flexibilization it can best deliver



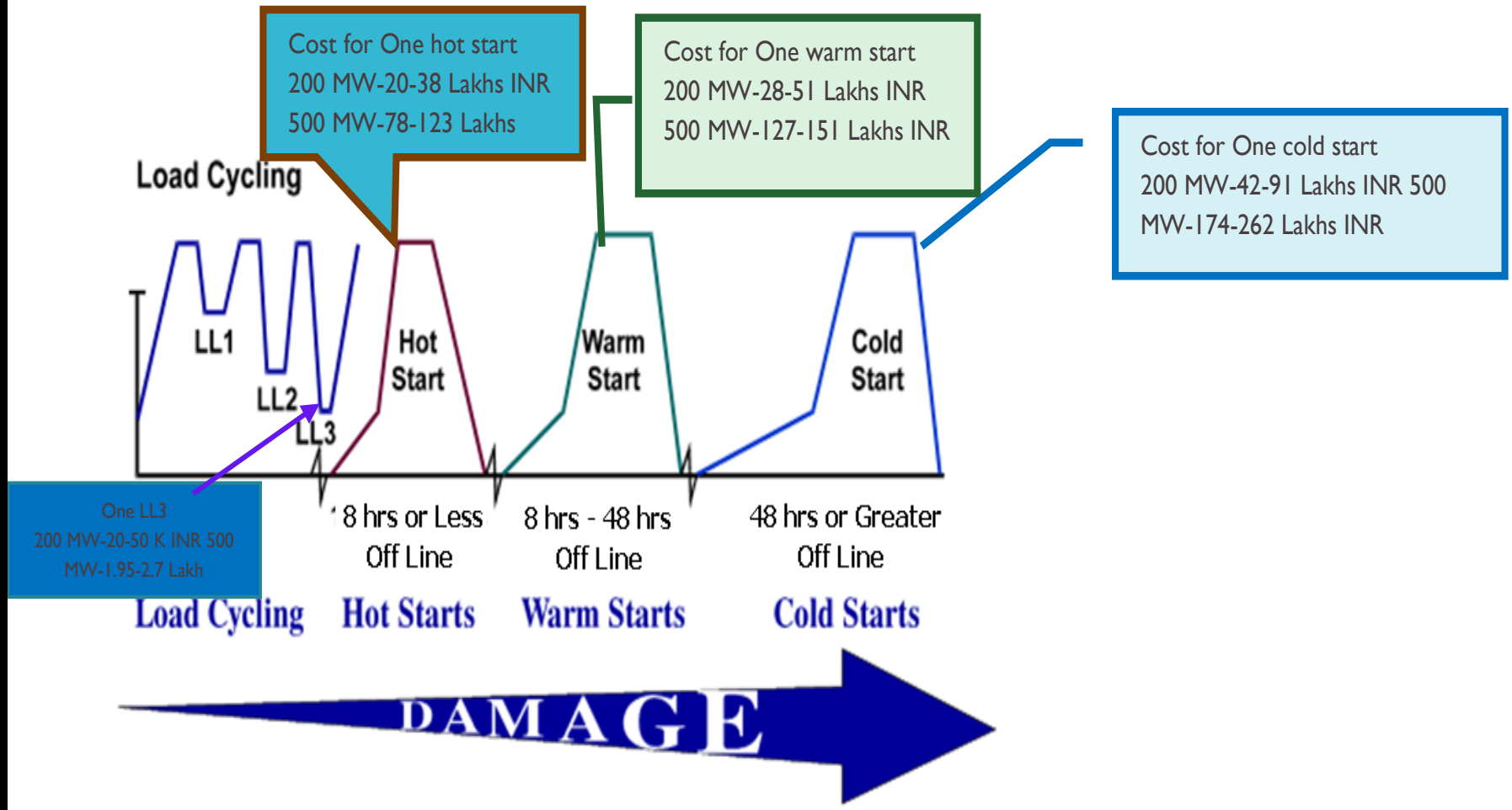
Coal units will have to compete with other resources for delivery of balancing power

Harsh Realities of Cyclic Operation

- 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.
- Investments in retrofits can enhance the flexibility to a large extent
- Revisiting the operational procedures, Training of O&M manpower can enhance flexibilization
- Proactive participation of stakeholders in enhancing latent system flexibility can be driven by Policy and regulatory interventions

- 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

Why do you need to prepare for reducing the level of minimum load ?



Damages due to flexible operation

Consequences of Improper cycling

Cracking of Thick Wall Components

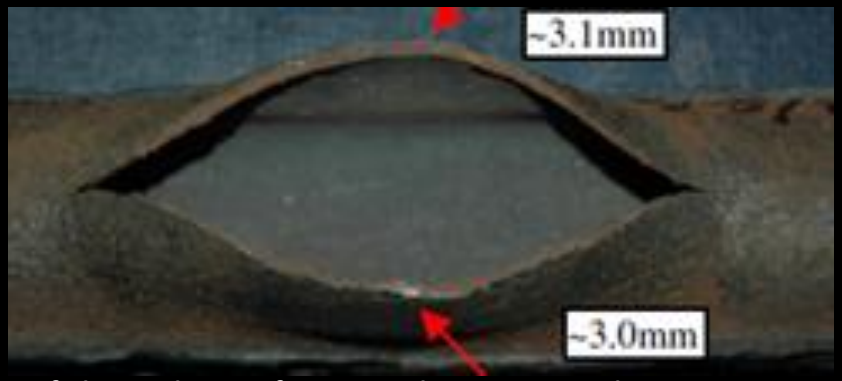
Pipe cracking

Cracking of ligament between stubs

Rapid temperature transients during starts/shutdown and ramping operation

Typically shutdown operation is critical. …and also during hot start-up
When cold water is fed ,it leads to quenching

Failures due to temperature transients



WW failure ,3 hours of start-up-Short term overheating

SH LT overheating

- Ensure adequate steam flow
- Drainage is critical (operation in auto)
- Ensure adequate flow in RH

KNOW THE LIMITS

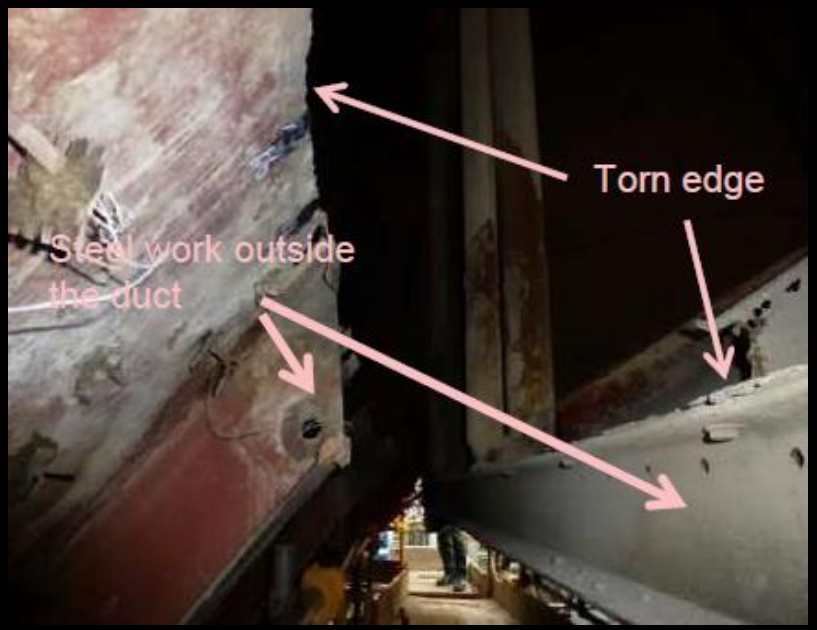
- Secondary superheater temperatures increase no more than **78°C/h.**
- Reheaters limit of **90 to 100 °C/hr** for steam tubes or surfaces
- Boiler tube metal temperature increase: no more **than 83.3°C/h. & no more than 9.4°C/5-min period**
- Maximum differential temperature between individual furnace riser and the risers average of **44°C**.

Turbine temperature raising Limits:

- Steam turbine metal temperature increase of no more than **28°C/h.**
- Steam turbine throttle steam temperature increase of no more than **1.6°C/min.**
- Feed Water heaters- **40°C/h**r

Acid dew point corrosion

FG temperature below -Acid dew point

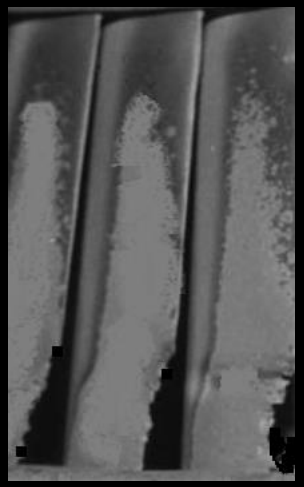


ESP Collapse- Continuous operation with FG temp close to acid dew point

ESP Internals-corroded

Areas prone to ADP corrosion include- APH, ducts

Damages to turbine blades –Exfoliation/pitting



Exfoliation

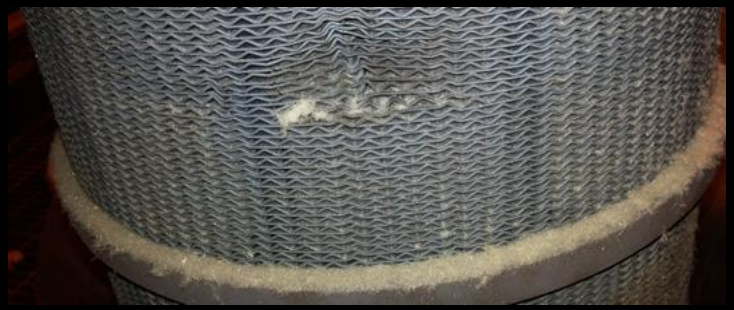
Pitting

Damage to seals

Other areas include:
Turbine valves
Damages due to uneven expansion
Hammering in pipelines

Common reasons for damages apart from temp transients are…
Excessive use of spray & water carry over
Chemistry
O2 ingress

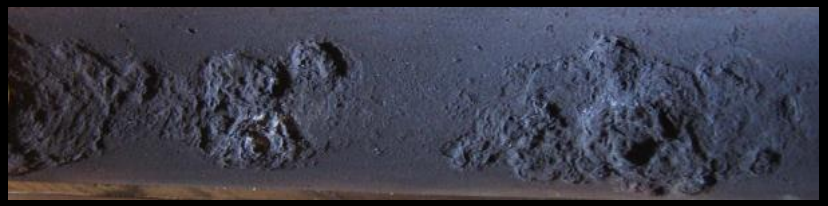
Chemistry related damages



Turbine side strainers damage

Scale Deposits

Pitting



PA Fan Stalling

Damaged PA fan blade during stalling

- Typically, with a configuration where units have two PA fans.
- At minimum load operation, the PA flow gets reduced, while the PA header pressure is maintained at a certain level.
- In this situation, stalling of PA fans is a common phenomenon.

Flexible operation impact on TPPs life

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

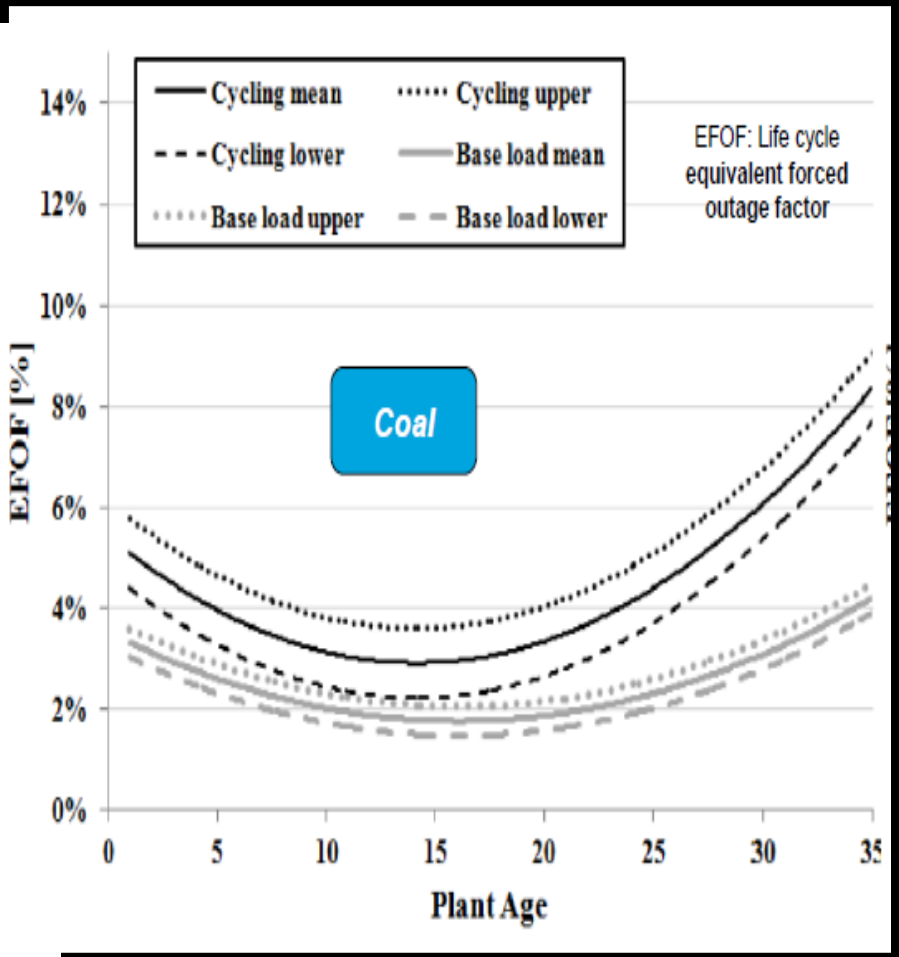
Source:GE

Part Load EFOR

Key factors:

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

Plant equipment with most significant impacts	Primary damage mechanism
Boiler water-walls	Fatigue corrosion, corrosion due to oxygen and chemical deposits (depending on water quality)
Boiler super-heaters	High temperature differential and hot spots from low steam flows during start-up, long-term overheating failures
Boiler re-heaters	High temperature differential and hot spots from low steam flows during start-up, long-term overheating failures, tube exfoliation damages IP turbines
Boiler economizer	Temperature transient during start-ups
Boiler headers	Fatigue due to temperature ranges and rates, thermal differentials tube to headers; cracking in dissimilar metal welds, headers and valves
Drum	Thermo-mechanical stress at drum walls
LP turbine	Blade erosion
Turbine shell and rotor clearances	Non-uniform temperatures result in rotor bow and loss of desired clearance and possible rotor rubs with resulting steam seal damages
Feedwater heaters	High ramp rates during starts; not designed for rapid thermal changes
Air heaters	Cold end basket corrosion when at low loads and start up, acid and water dew point
Fuel system / pulverizers	Cycling of the mills occurs from even load following operation as iron wear rates increase from low coal flow during turn down to minimum
Generator	Thermo-mechanical stress on generator components especially at windings and insulation
Water chemistry / Water treatment	Cycling results in peak demands on condensate supply and Oxygen controls

Plant equipment with most significant impacts	Primary damage mechanism
Piping	Water ingress,thermal shock,improper drainage Thermocouple monitoring and automated drains can help

How to proceed with Preparation for flexibility- ..... first step is test run

Interventions for Flexibilisation

Interventions with International support

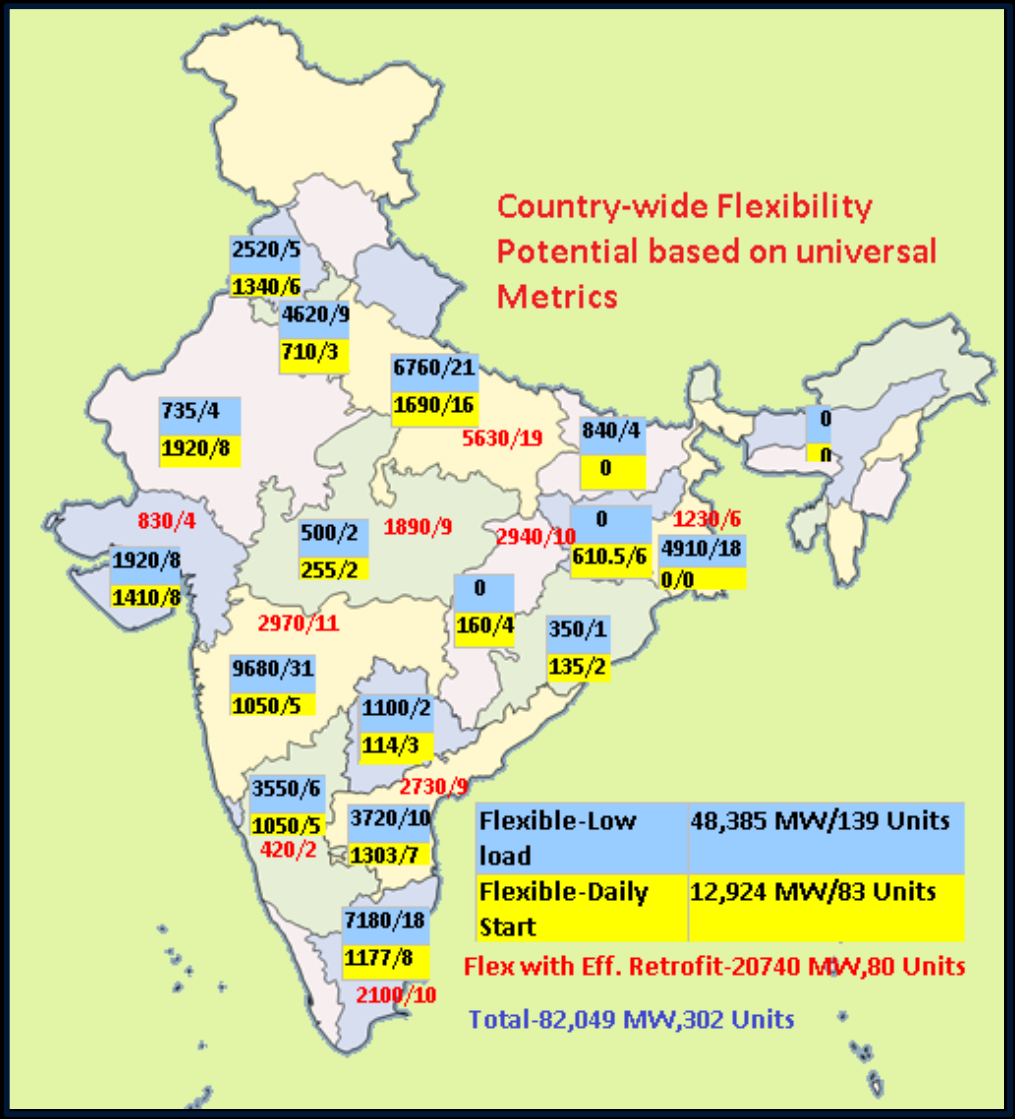
- IGEF-Task Force on Flexibilisation(supported by EEC/VGB)
  - Study at NTPC Dadri & Simhadri
  - Test run at Dadri(with Siemens)
  - Flexibility Tool Box
  - Training
- USAID-GTG-RISE
  - Study at NTPC Ramagundam & Jhajjar and 2 units of GSECL(cost of cycling)
  - Test run at NTPC Mouda & GSECL Ukai(with BHEL)
  - Regulatory interventions
- Engie Lab
  - Study at NTPC Dadri & Farakka
- Jcoal- study at NTPC Vindhayachal

Interventions by Indian stakeholders

- Study by GE at NTPC Talcher(K)
- Test runs by NTPC & GSECL
- Test runs carried by BHEL at State GENCOs
- Policy roadmap by CEA
- Condensate throttling
- APC at Simhadri
- AGC
- Regulatory Interventions –compensation, ramp rates, scheduling, RTM

Identification of Units for different modes of operation

Category	Metrics
Base Load 140GW/299Units	ECR<< State M.O. GCV < 2800,VM<15% Supercr. (except 14 Units)
Flexible-Low Load	ECR=> State M.O.(>Rs.2.5/KWH) GCV >2800,VM > 15%
Flex with Efficiency Retrofit	Units>25 Years Unit size-200 and above HR> 2500
Flexible Daily Start	ECR>> State M.O. (unlikely to get schedule in 2022) HR>2500, GCV>3400
Retire/replace	>25Years HR>2600 Unit sizes<200 MW



Test run at Dadri Unit (500 MW)

- Evaluate the Unit's response to:
  - Ramp up/ Ramp down characteristics
  - Response to minimum stable load (Target: 40% minimum load without any changes in plant configuration)
- Identifying of the process limitations/ restrictions (thermal, mechanical, aerodynamically, operation) during the new/ old minimum load
- Check of control system
- Identification of Operational procedures
- Identification of retrofits for this plant - Required and Possible

- Dadri unit achieved 40 % minimum load with 3 mills in service
- Achieved 3% ramp rate at defined load range
- Minimum parameters deviation

- The minimum load and ramp rates were achieved in a controlled condition with some operation on manual.
- For sustained minimum load operation and high ramping, interventions are necessary.

Operational Procedures for flexible operation

Options vs Costs for Coal Flexing in India

Does It Matter How Unit Flexibility is achieved?
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

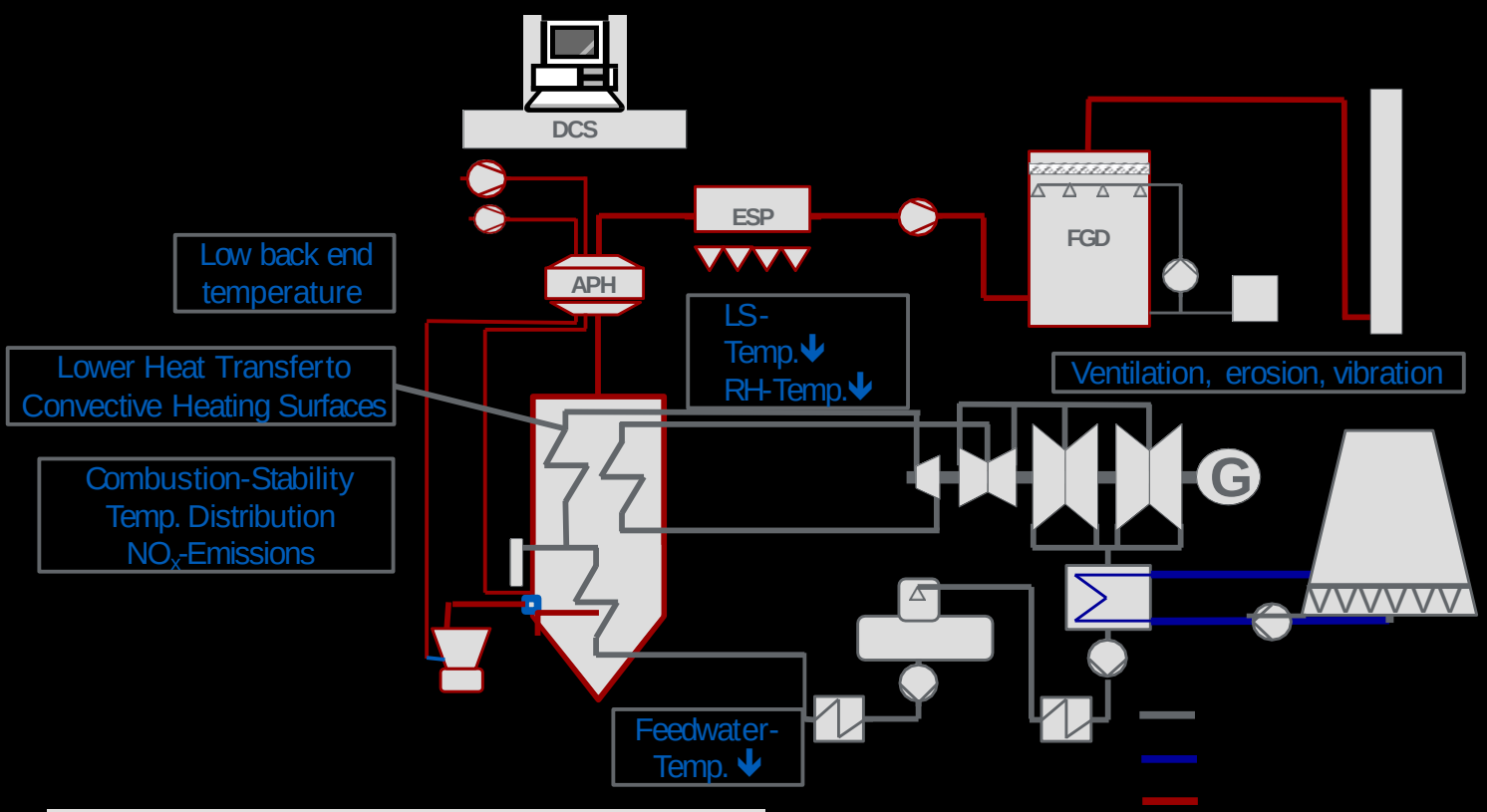
Digitalisation

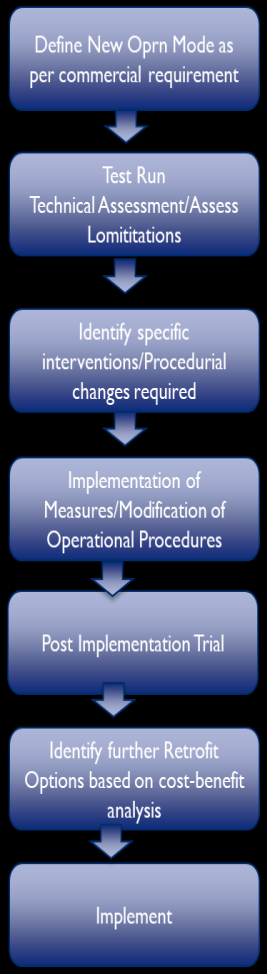
Technological Interventions

- Modify
- Upgrade

Technical Interventions for Flexible Operations

Limitations to be addressed





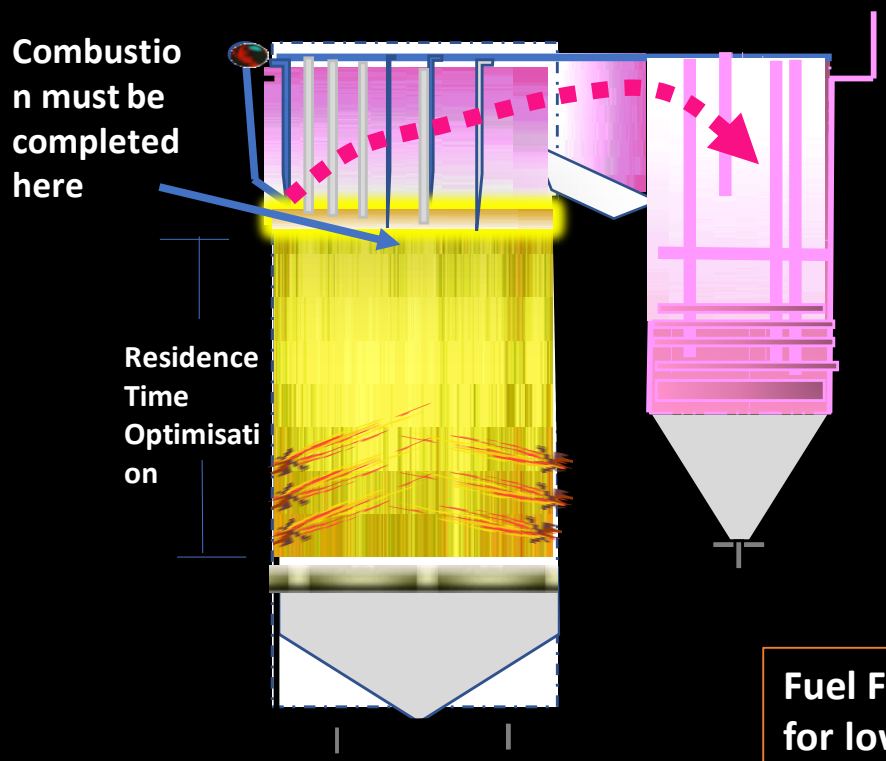
Ramp Rates-Limitations

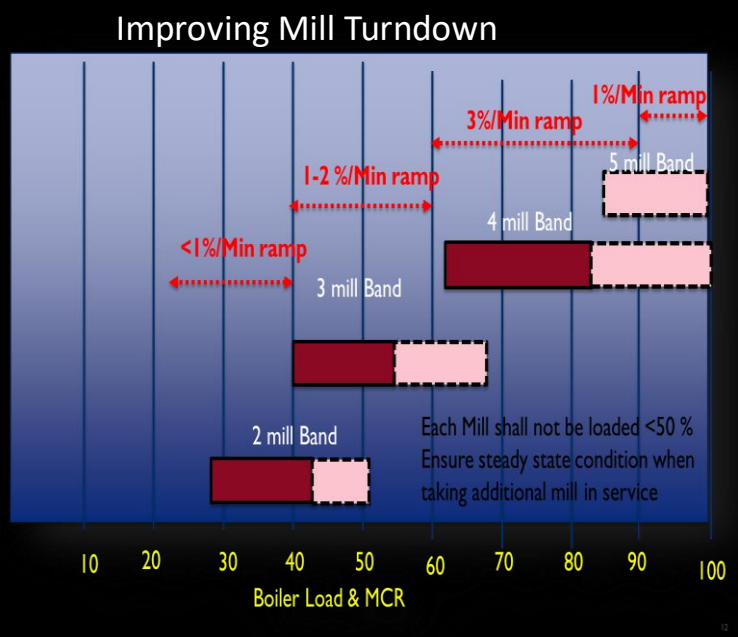
- Stresses in thick walled components
- Fuel quality
- Controls and time lag between coal milling and turbine response

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





Fuel Firing System Optimization Package for low load oprn:

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

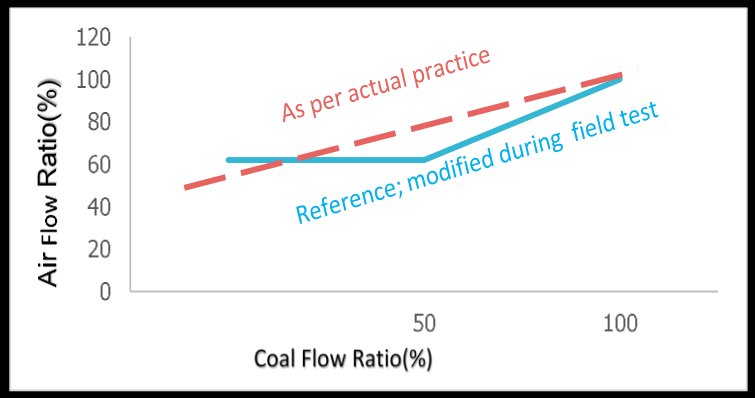
Auto Coal Sampler

Flame scanners modifications
Burner modification

Combustion Optimisation to attain Minimum load reduction potential

- Balancing of Coal flow across the coal pipes
- Fuel/Air ratio, Combustion air
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air stratification
- Flue gas oxygen /Excess air level
- Coal mill inlet/outlet temperature
- **Primary Air header pressure**
- Mill outlet temperature
- Pulverized coal flow velocity /Temperature of coal pipes
- Windbox pressure
- Burner Tilt
- Flame scanners
- Coal fineness
- Selection of burner

Review of PA flow curve



- The velocity in the coal pipes must be high enough to prevent settlement of coal particles in the coal pipes (not less than 20m/sec)
- The velocity at the burner nozzle must be more than the speed of flame propagation to avoid backfire within the coal pipes (not less than 15m/sec)
- The velocity at the burner nozzle should not exceed the blow-out velocity of the flame.

Individual Secondary air flow measurement

Combustion Optimisation to attain Minimum load reduction potential

- **Balancing of Coal flow across the coal pipes**
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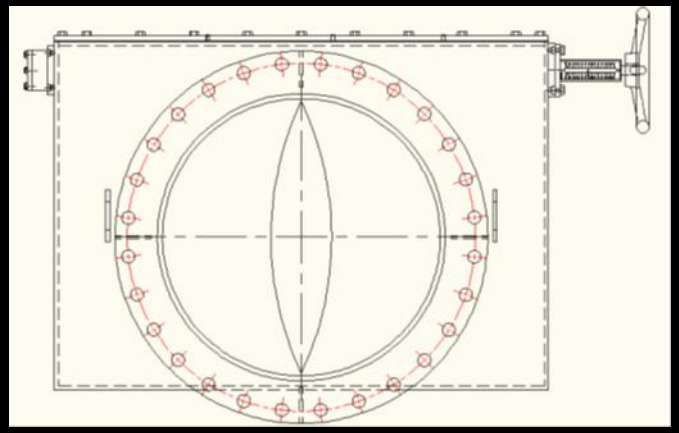

Variable orifices

Combustion Optimisation to attain Minimum load reduction potential

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Compliance to the NFPA (National Fire Protection Association) guidelines.
The standards of NFPA 8502 which requires that the airflow is maintained at or above the purge rate (not less than 25% of the full load mass airflow) during all operations must never be violated.

Never add air to a dark smoky furnace. It is advisable to trip the unit & remove all ignition sources, then purge thoroughly before restarting.

Improve Mill turndown- Minimum load on a mill – 50%

Combustion Optimisation to attain Minimum load reduction potential

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In coal with VM below 30%, the mill outlet temperature of 75-80^{0}C is recommended by BHEL. With higher VM, 55-65^{0}C is recommended (BHEL). However, International literature suggests a temperature in the range of 70-93^{0}C **with low VM coal (15-30%) and a range of 60-80^{0}C.**

Maintaining a slightly higher mill outlet temperature at low loads will help faster stabilization of the flame. Another consideration for mill inlet temperature w.r.t. the moisture in coal. A general thumb rule can be used – 10-15% moisture-mill i/l temperature of around 270^{0}C, 10-8% moisture-250^{0}C, <8-6%-230^{0}C, <6%-210^{0}C,>15%-290^{0}C. The mill outlet temperature should be the final check point.

Combustion Optimisation to attain Minimum load reduction potential

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- Use SCAPH
- Increase the PA temperature by throttling the dampers of SAPH during initial lightup
- Check passing of CAD/CAD

- Installation of upper furnace thermal mapping by zones to identify problems with specific burners before the problem escalates and results in poor combustion or loss of stable flames.

Combustion Optimisation to attain Minimum load reduction potential

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Retrofit Solutions under implementation at Dadri

Mandatory Measures: - Ensure safe and smooth operation within the new load range
- Manage the consequences of flexible power plant operation

- **Automatic Mill Scheduler**
  - Determining when to start or stop a burner/mill and
  - Determining which burner/mill has to be started/stopped where necessary
  - Fully automatic operation of all burners/mills without manual intervention between a load of 0 and 100 %
  - Automatic switching of burners/mills on/off
  - On burner failure automatic selection of the best alternative burner
  - Automatic adaptation to changed load requirements
  - Plant operators can remove individual burners from the regime of the burner and mill scheduler while the remaining burners continue to be controlled optimally
  - The furnace fireball can be shifted vertically where required by boiler temperature
- **Optimization of Control Loops (MS,RH,FG Temperatures)**
- **BFP R/c Valve replacement by control valve type**
- SCAPH

Retrofit Solutions recommended for Dadri

Optional Measures

- ❑Advanced Unit Control
- ❑Condition Monitoring
- ❑FEM analysis
- ❑Thermal feasibility modelling study
  - – Thermal and mechanical models of the plant will be constructed, calibrated with test measurement data and applied. Since other Indian power plants are built with the same setup, these models can be used for the rollout into the 500 MW fleet.

Best Operational Practices for flexible operation

- Judicious use of HP/LP bypass, oil guns
- Sliding pressure operation (modified)
- 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

- **C&I 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

Need for preservation or lay-up procedures

- Preservation or lay-up procedures are another important aspect. Boiler tube failures and other corrosion fatigue effects can be reduced by defining lay-up procedures, depending on the duration of the plant being off-line. For implementing suitable preservation procedures to protect equipment, the VGB Standard "Preservation of Power Plants" and "Preservation of Steam Turbo-Generator Set" could serve as a guideline

Examples of Best Practices in Flexibilisation

- Condensate throttling
- Advanced process control
- Online Combustion Optimisation
- Automatic Mill Scheduler
- Hot gas generator for coal drying
- Automatic plant startup and guide
- Plasma Ignition System
- Exploiting the storage capabilities of mills
- Use of Film Forming Amines (FFA)
- Modifications for hot filling of boiler
- Nitrogen Blanketing of Demineralized water storage tanks
- Fleet optimized operation method for group/s of power units for securing economic rationality
- Advanced sealings in the turbine (smart seals
- Cycling Advisor / COSTCOM

Thank You for Your Time

Stay Safe. Maintain social distancing

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Task Force on Flexibilisation