EEC workshop on " Flexible Thermal Power Plants: Bridge to a Decarbonized Energy System" 24th November

Digital Solutions for Flexibilization Operation–

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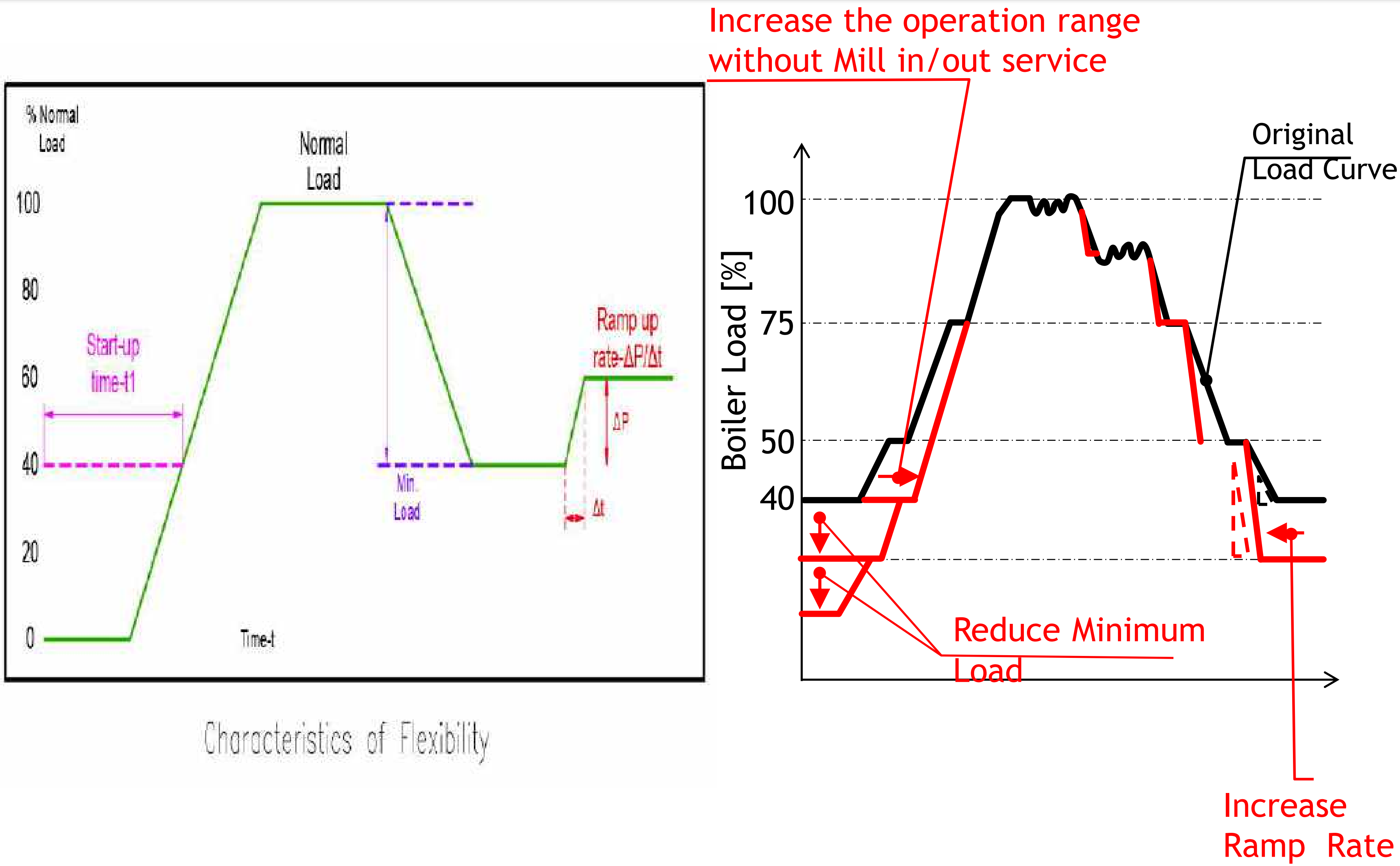
Presentation Flow

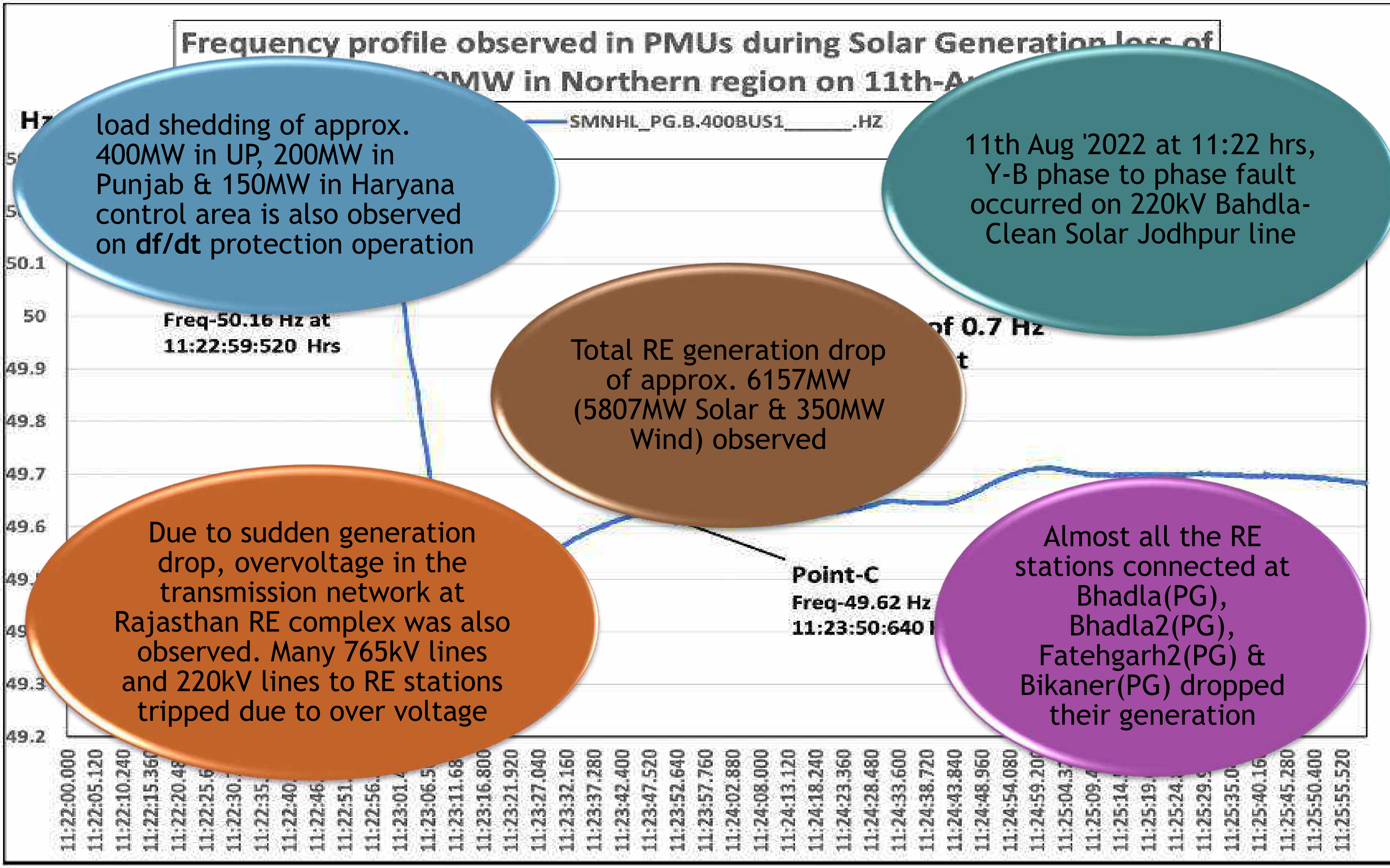
1. Concerns of Flexible Operation in Thermal Power Plant.
2. Solutions Towards Flexibilization of Coal Based Thermal Power Plants.
3. Digital Twin & Flexibilization of Coal Based Thermal Power Plants
4. Way Forward.

Characteristics of Flexible Operation



Characteristics of Flexibility

Frequency Response Characteristics



load shedding of approx. 400MW in UP, 200MW in Punjab & 150MW in Haryana control area is also observed on **df/dt** protection operation

11th Aug '2022 at 11:22 hrs, Y-B phase to phase fault occurred on 220kV Bahdla-Clean Solar Jodhpur line

Total RE generation drop of approx. 6157MW (5807MW Solar & 350MW Wind) observed

Due to sudden generation drop, overvoltage in the transmission network at Rajasthan RE complex was also observed. Many 765kV lines and 220kV lines to RE stations tripped due to over voltage

Almost all the RE stations connected at Bhadla(PG), Bhadla2(PG), Fatehgarh2(PG) & Bikaner(PG) dropped their generation

Concerns of Flexible Operation in Thermal Power Plant

Concerns for Flexible Operation in Coal Fired **Thermal Power**

- Upgradation, Retrofit and Modernization of existing generating units involves CAPEX / OPEX allocation
- Faster load ramps leads to Increased Fuel costs
- More Start ups & Load Cycling leads to increased number of thermal cycles and Creep / Fatigue life of pressure parts, piping, hanger etc is consumed at a faster rate
- Increase in furnace header stub and outlet metal temperature.
- Frequent load changes leads to increase in heat rate / Aux power and reduced Plant Efficiency
- Frequent minimum load operation has negative impact on Cycle Chemistry & increase in Scaling / Corrosion

Concerns for Flexible Operation in Coal Fired Thermal Power

- Minimum load without oil support and without compromising flame quality up to the MPL of 40% with Stable ignition and combustion of coal burner

- Quantum / Net change in MW load with defined ramp rate within scheduled time period

- Acceptable deviation of MS/RH steam temperature and rise in Metal temperature during wide net change in load with fast ramp up /down period

- Volatile Matter content & High moisture in coal being fired

- Non-availability of design range of coal (Varying from 2400 to 5000 Kcal /kg) leading to parametric deviation in flexibilization

Concerns for Flexible Operation in Coal Fired Thermal Power

- Minimum loading of Mill for stable ignition of coal burner
- Mill Turn down & Mill Capacity increase requirement
- Avoiding Mill in/out service during Ramp up/down
- Need of dynamic classifier on mills
- Maintaining Mill outlet temperature at low load by continuous SCAPH charging
- Coordinated Control of coal mills
- Flame Scanner Tuning for various coal type & mill combination.

Concerns for Flexible Operation in Coal Fired Thermal Power

- Monitoring ash fusion temperature at low load
- Monitoring hopper temperatures
- Lower flue gas velocity at low load operations
- Frequent ash evacuation from Economizer hoppers, APH hoppers and Flue Gas ducts & ESP
- Maintaining higher Air flow than stipulated
- Frequent APH soot blowing to avoid baskets choking

Concerns for Flexible Operation in Coal Fired Thermal Power

- Maintaining APH flue gas outlet temperature higher than acid dew point to prevent Cold end corrosion at low load
- Improper Soot Blowing Frequency
- Low Load operation with only one stream of APH, Fans and ESP
- Running Unit in continuous Coordinated Control Mode
- Minimizing Cycle losses
- Maintaining performance parameters within limit at steady state condition as per boiler predicted performance and HMBD conditions

Concerns for Flexible Operation in Coal Fired Thermal Power

- Frequent or continuous operation of HP-LP Bypass to ensure bump-less operation at low load and during load changeover periods

- Limitation to achieve ramp rate of 3%/min and 5%/min in the load change from 40%TMCR to 100%TMCR due to mill in & out service requirement and fluctuation of boiler parameters by mill in & out.

- Adherence to turbine metal temperature for cold / hot start up as per OEM design instead of defining below approximately 40% / 80% of their full load values

Concerns for Flexible Operation in Coal Fired Thermal Power

- Monitoring the metal temperature distribution, requirement of replacing furnace inlet orifice and subsequent combustion tuning

- Controlling LP exhaust conditions within recommended limits during minimum technical load operations as per OEM

- Vibration monitoring system of turbine last stage blade

- Online Creep & Fatigue Stress Monitoring System in Boiler and Turbine components for suitability in higher ramp rates and continuous operation at MPL.

- Opportunity of combustion tuning at 100%TMCR load and all partial load with load change at short range (ex. 75% => 90%, 100%=>75%).

  (Mill in & out service is excluded during dynamic load change tuning)

Concerns for Flexible Operation in Coal Fired Thermal Power

- Study of allowable variation in turbine inlet temperatures (Main steam and Reheat Steam) during load cycling i.e. ramping up and down from MPL to rated load and vice versa

- Defining the adequate Main steam and Reheat steam parameters for continuous low load operation (55% rated load and 40% rated load) in turbine side.

- Additional measurement requirements in boiler & turbine for better monitoring of the boiler & turbine components and its feasibility check.

Solutions Towards Flexibilization of Coal Based Thermal Power Plants

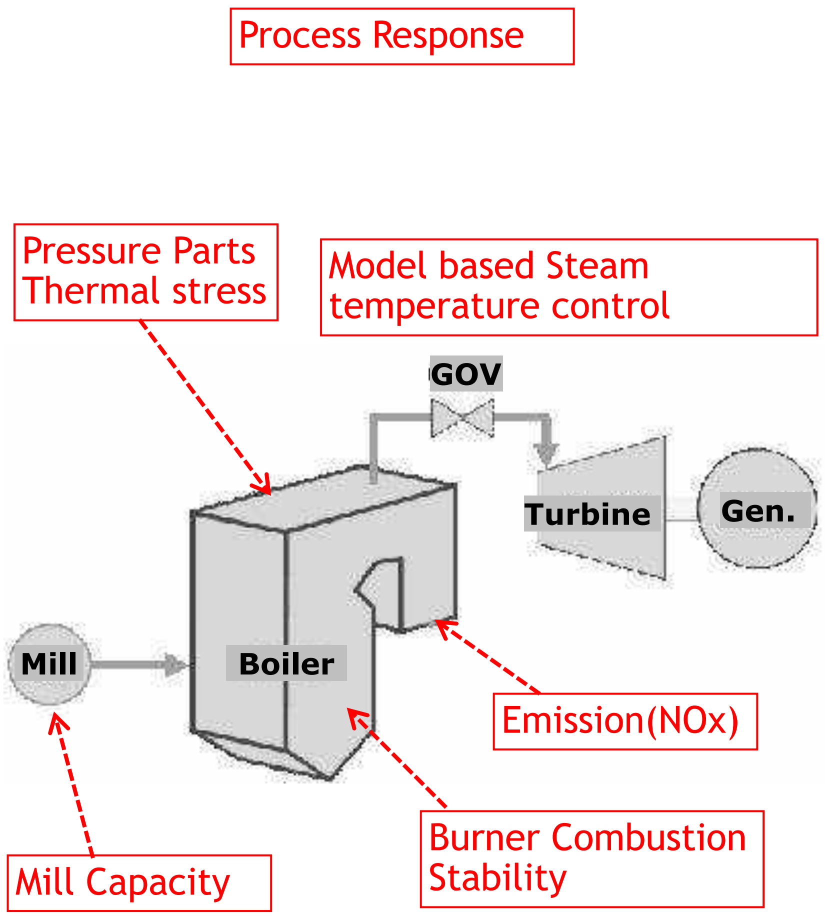
(1) Mechanical Solution- Modification of Design Features & Equipment

(2) Digital Solutions- Application of Immersive 3D Digital Twin & Advanced Control

Need Of Equipment Upgradation / Modification

- Combustion Modification
- Mill Modifications
- Pressure Control Mode Modification - Modified sliding pressure control
- Introducing Online coal analyser for Coal selection (Design/ Best / Worst)
- Introducing Online Boiler Stress Monitoring System (CFOMS)
- Improvement in process response of auxiliary equipment e.g. ID/FD/PA Fans, TDBFP etc.
- Throttling of the condensate flow through LPH to Deaerator by main De -Aerator level CV reducing LPT extraction steam limited to the increase in hotwell level & decrease in the D/A level

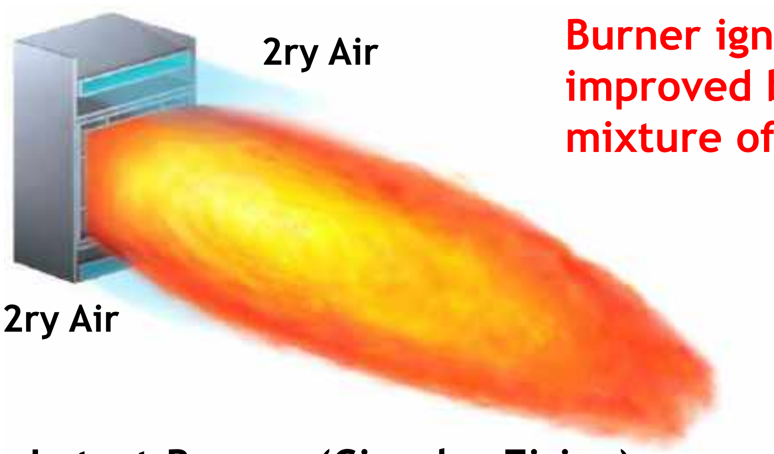
Need Of Equipment Upgradation / Modification



Major Technical Items for increase ramp rate	Major changes required in Boiler
Burner combustion stability during load change	▪ Burner Modification
Mill Capacity	▪ VVVFD modification of mill motor ▪ Mill capacity/Turn down ratio increase
Pressure parts thermal stress	▪ Reinforcement of pressure part ▪ Structure modification ▪ Replacement to high-grade material
Application of Advanced Control Strategy & Steam temperature control	▪ Improvement of control method ▪ Parameter tuning ▪ **Coordinate the plant heat balance with Turbine**

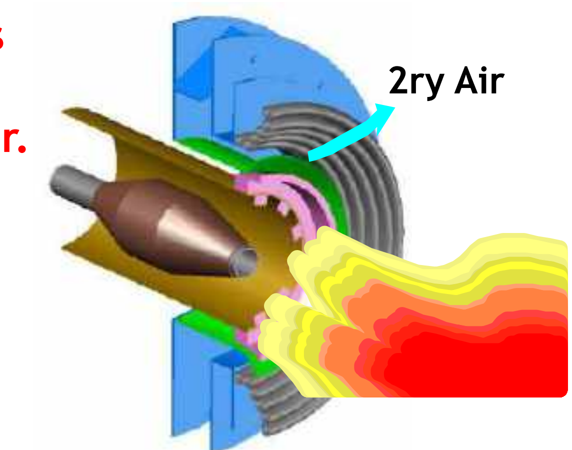
Burner Modification

The latest burner design is capable of stable ignition at low load, allowing for lower minimum boiler load operation.

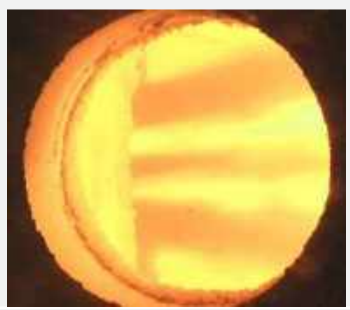
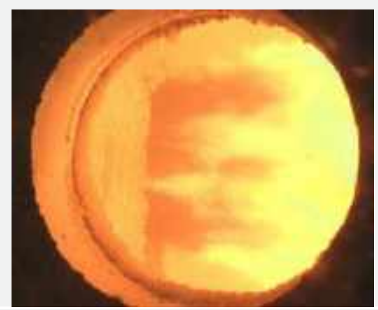
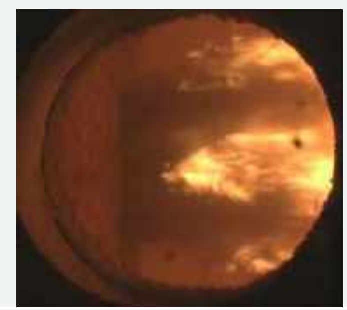


Latest Burner (Circular Firing)

Burner ignition stability is improved by enhancing mixture of fuel and 2ry air.

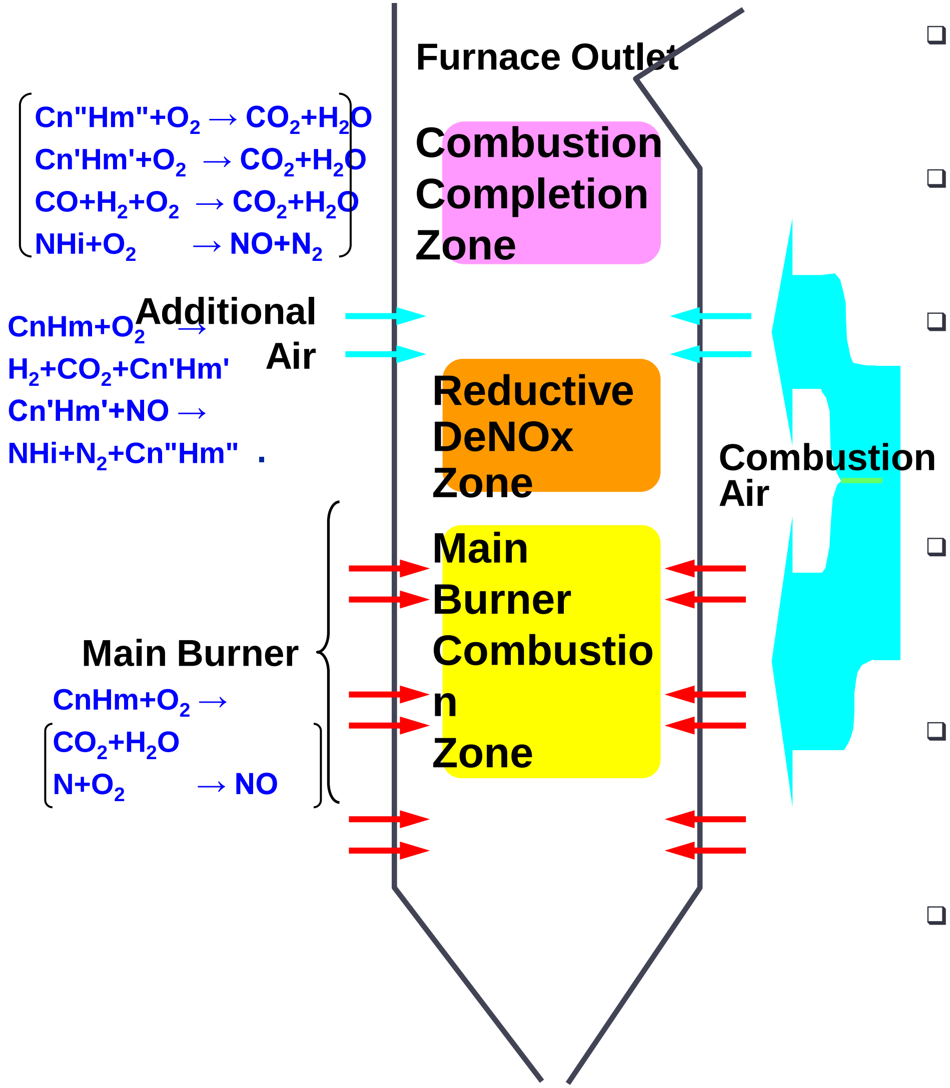


Latest Burner (Opposed Firing)

Ignition condition			
Burner Load	100%	50%	20%
Boiler Load	100%	30%	8%

Stable ignition can be maintained at 20% burner load with the latest burner.

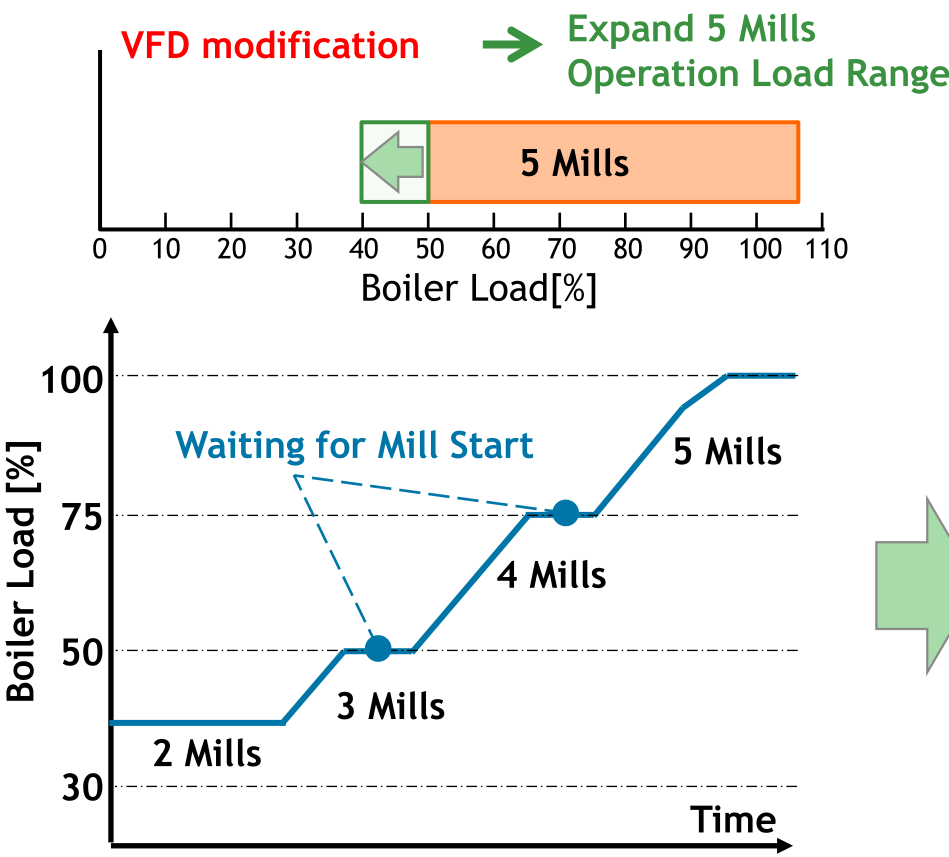
Burner Modification

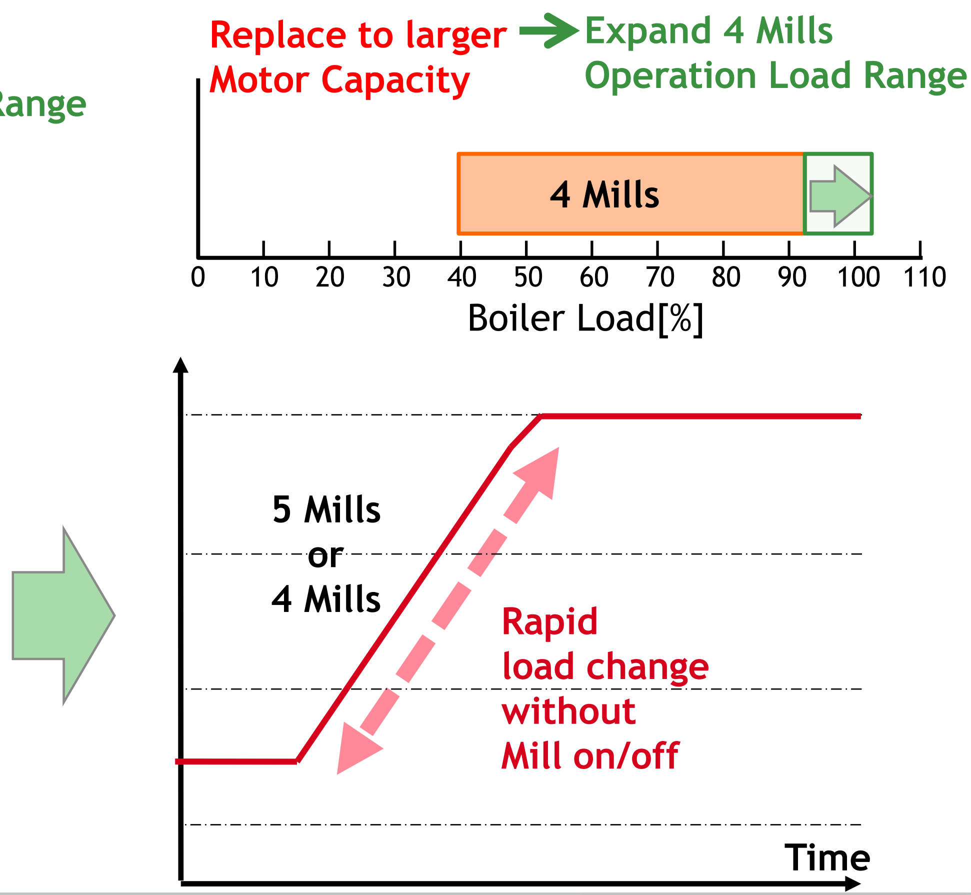


- Used for low-low NOx applications.
- Applicable to all fossil fuels, gas, oil, coal, etc.
- No additional operating cost. No need of ammonia injection or use of catalyst.
- No emission of undesirable substance to environment.
- Boiler efficiency and flue gas flow unchanged.
- Combustion in furnace is good and stable, and safety is secured.

Need for Mill Modification

- Mill table rotation speed is decreased by VFD and mill minimum load is lowered.
- 5 mills operation load range is expanded to 40% load and rapid load change at 40%~100% load is achieved.
- Mill motor is replaced to large capacity motor and Mill capacity is increased.
- 4 mills operation load range is expanded to 100% load and rapid load change at 40%~100% load is achieved.





Applying Immersive 3D Digital Twin

Digital twin is a 3D Interactive virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

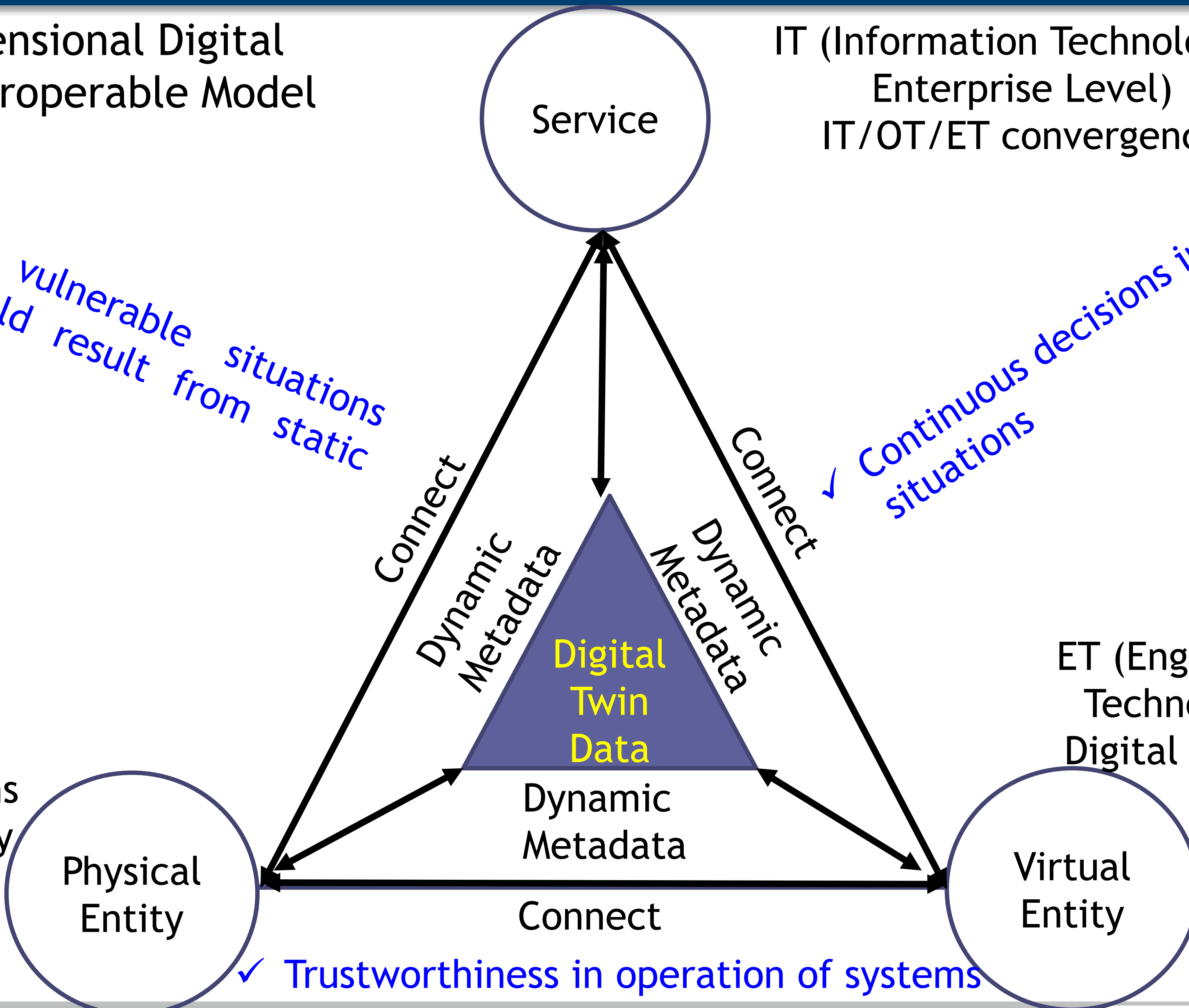
Digital Automation and Interconnectivity

Five Dimensional Digital Twin Interoperable Model

IT (Information Technology – Enterprise Level)
IT/OT/ET convergence

✓ Prevent vulnerable situations that would result from static measures

✓ Continuous decisions in changing situations



OT (Operations Technology –Plant Level)

ET (Engineering Technology – Digital Models)

✓ Trustworthiness in operation of systems

3D Rich Digital Twin Solutions Environment

Mathematical & Thermal Process Modelling & Data Historian

Asset management & Reliability

Plant Maintenance

Document Management

Planning & Scheduling

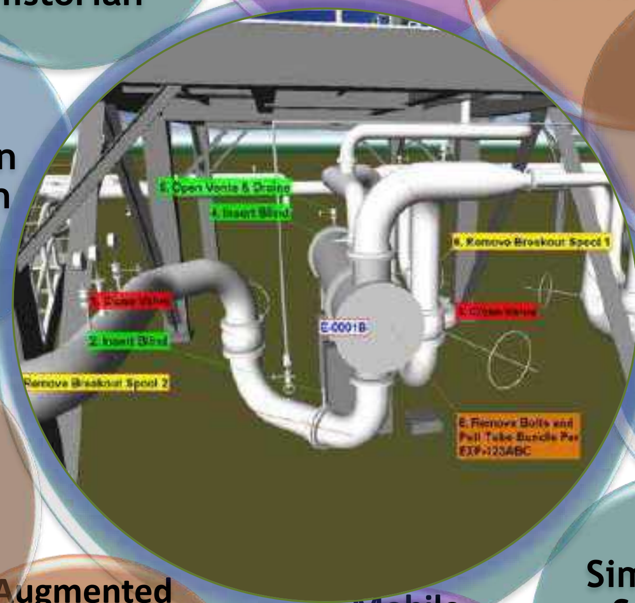
Simulation, Safety & Risk Assessment

Mobile Role Based Work Packages for Engineering, Safety, Operations & Maintenance

Augmented Reality Perform critical tasks with efficiency and certainty while mobilized.

Virtual Reality Collaborate and remotely gain understanding of planned activities.

Boiler Control Optimisation & Operation Assistance Systems



Digital Twin for Flexible Operation in Thermal Power Plant

- Mathematical & Thermodynamic Resilient Dynamic Process Modelling & Estimation with iterative and finite horizon optimization

  Using White Box/ Black Box/Grey Box modelling, simulation utilizing AI/ML, optimum settings suggestion based on combustion optimization, soot blower optimization, predictive analytics, thermal efficiency, merit order based economic dispatch, emissions prediction & compliance of all of parameters that can affect all thermal cycles

- Data driven AIML based boiler predictive heat transfer model

  Allows for convective and radiative heat transfer from the boiler combustion process to the economiser sections, waterwalls, superheater stages and reheater stages, reduce the parameter deviation

Digital Twin for Flexible Operation in Thermal Power Plant

- Deployment of AIML ,ANN,IMC,MPC,DMC advanced control algorithm
  (Feedforward mode with the classical P/PI/PID controllers)

  - Load Frequency Control
  - Load prediction & forecasting
  - Large load changing range
  - Multi-coal firing & Automatic correction of Calorific value fluctuations
  - AGC for conventional & renewables generation
  - Unit Response Optimization with Unit Fast Response
  - Steam Temperature Optimization
  - Combustion control Optimizer
  - Control in Reduction of minimum load
  - FW, WFR, Fuel/FW & Fuel Air Cross Limit
  - Improvement in the dynamic characteristics of the boiler

Digital Twin for Flexible Operation in Thermal Power Plant

- **Assets Management**

IIOT sensors , drone-based LiDAR, photogrammetry, historian database, digital tracking & traceability, integration, analysis, asset risk & criticality assessment, asset strategy development & optimization, condition monitoring, planning, scheduling, monitoring & improvement

- **Process Mining and Operation Assistance Systems**

Integration of 3D Virtual Plant with Plant DCS/SCADA, simulator, What-If analysis, Predictive analysis, avoid miss operation under normal & emergency operations, increase in plant productivity and efficiency, Energy monitoring, optimization, DSM in Live System

Digital Twin for Power Monitoring System

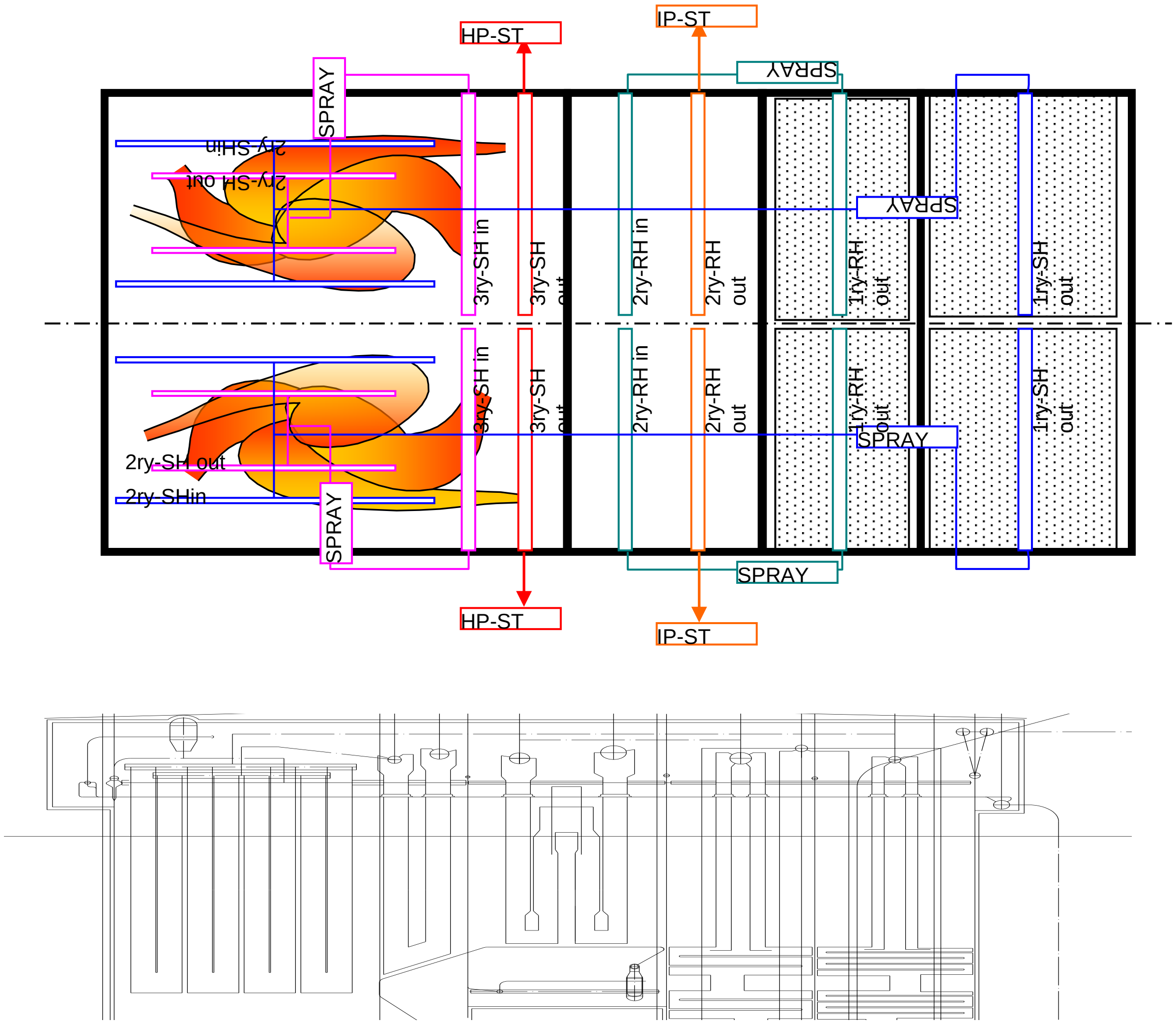
Energy Optimization & Management

- Energy Accounting & Monitoring in Live System
- Opportunity Generation & Evaluation in Live System

Transmission network model management across operations and planning

- Protection data management
- Streamlined renewable integration analysis using GIS data
- Data management for integrated T&D analysis
- Distribution planning model creation and synchronization with GIS,DMS and MDM data
- Fault prediction and detection method based on DT
- Enables operators to predict the possible future state and provide solutions in time before the power system's failure or emergency occurs
- Dynamic Digital Mirroring (DDM) that reflects the system status in real-time
- Data of Remote Terminal Unit (RTU) and Phasor Measurement Unit (PMU) sensor are input into the DT database, and then used for real-time simulation, fast system analysis and control feedback in DDM modeling instance

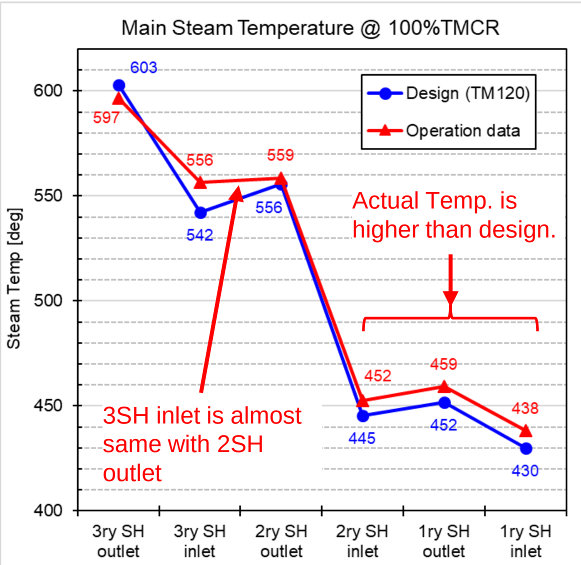
Classical Control of MS & RH Steam Temperature Variation

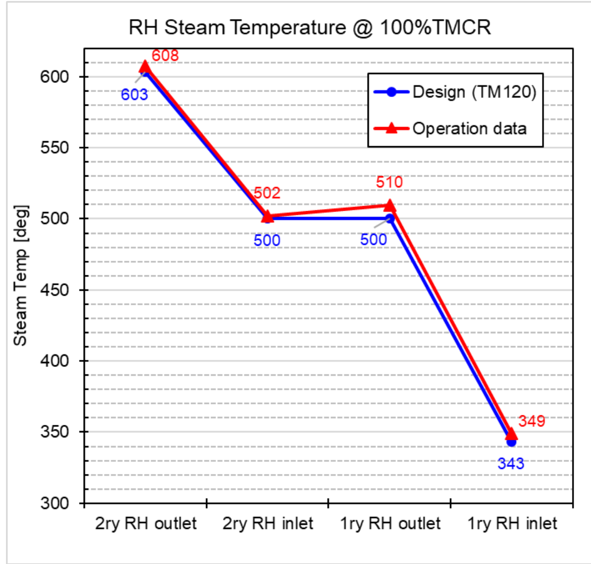


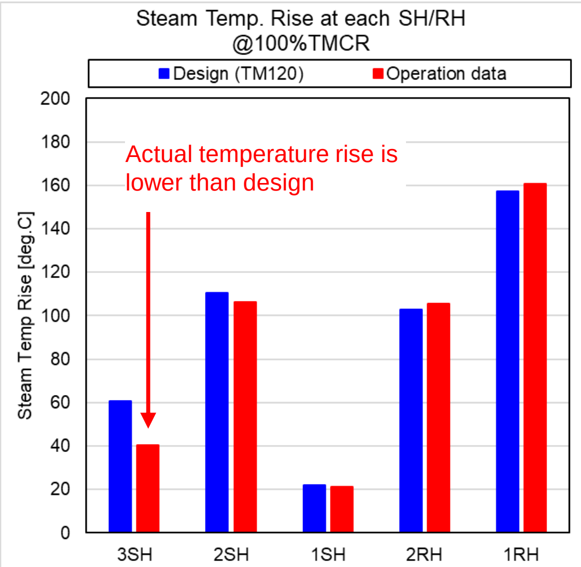
- One SH steam pipe per one fire vortex
- No crisscross arrangement is necessary for reducing left and right temperature imbalance
- Final SH outlet temperature imbalance will be very minimum due to individual SH spray flow

Classical Control of MS & RH Steam Temperature Variation

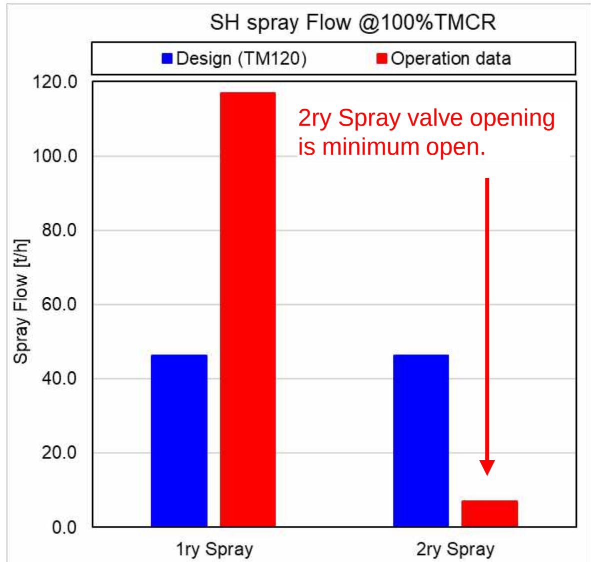
<Steam Temperature @ 100%TMCR stable condition>







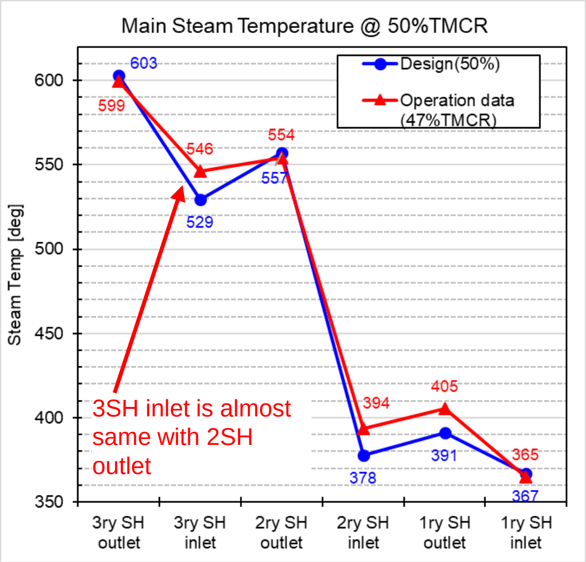
Notes; Stem temperature rise is Outlet – Inlet.

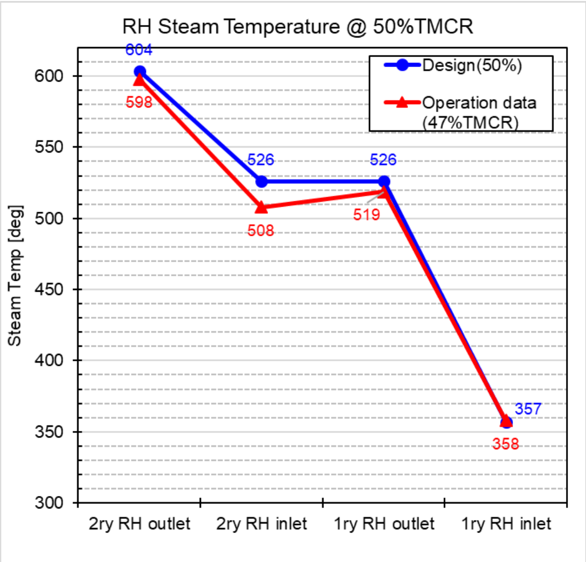


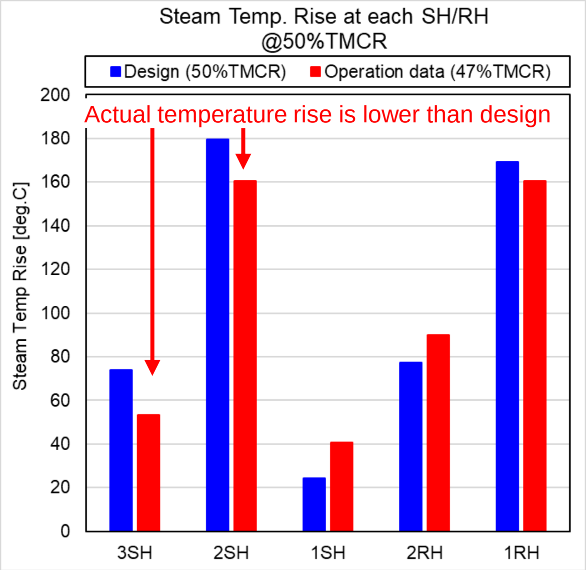
Parts	Observation
3SH	• Actual temp. rise (outlet – inlet) is lower than design. • 3SH inlet temp. is almost same with 2SH outlet.
2SH	• Actual temp. rise is almost same with design. • Actual 2SH outlet temperature is same with design, but actual inlet temperature is 7deg.C higher than design.
1SH	• Actual temp. rise is almost same with design. • Actual 1SH inlet/outlet temperature is 7deg.C higher than design.
2RH	• Actual temp. rise is almost same with design. • Actual 2RH inlet/outlet temperature is almost same with design. • 2ry RH inlet temperature is lower than 1ry RH outlet, but RH spray is not injected.
1RH	• Actual temp. rise is almost same with design. • Actual 1RH inlet temperature is 6deg.C higher than design, and Outlet is 10deg.C higher than design.
1ry Spray	1ry Spray flow is more than design.
2ry Spray	2ry Spray valve position is minimum opening.

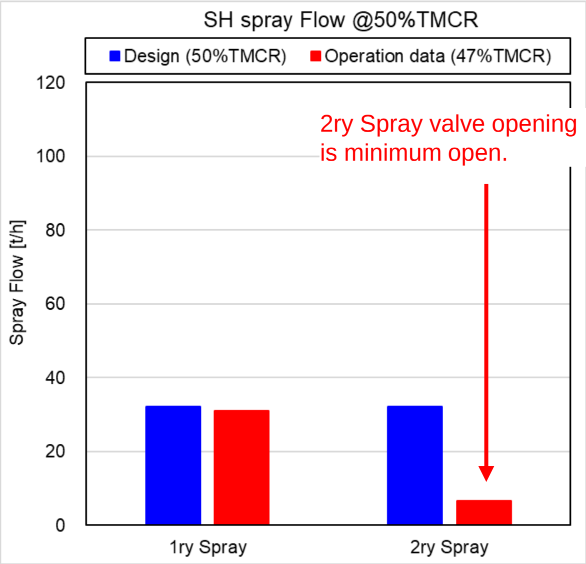
Classical Control of MS & RH Steam Temperature Variation

<Steam Temperature @ 50%TMCR stable condition>









Parts	Observation
3SH	• Actual temp. rise (outlet – inlet) is lower than design. • 3SH inlet temp. is almost same with 2SH outlet.
2SH	• Actual temp. rise (outlet – inlet) is lower than design. • Actual 2SH outlet temperature is almost same with design, but actual inlet temperature is 16deg.C higher than design.
1SH	• Actual temp. rise (outlet – inlet) is higher than design. • Actual 1SH outlet temperature is 14deg.C higher than design.
2RH	• Actual temp. rise (outlet – inlet) is higher than design. • 2ry RH inlet temperature is lower than 1ry RH outlet, but RH spray is not injected.
1RH	• Actual temp. rise (outlet – inlet) is lower than design. • Actual 1RH inlet temperature is almost same with design, but Outlet is 7deg.C lower than design.
1ry Spray	1ry Spray flow is almost same with design.
2ry Spray	2ry Spray valve position is minimum opening.

Notes; Stem temperature rise is Outlet – Inlet.

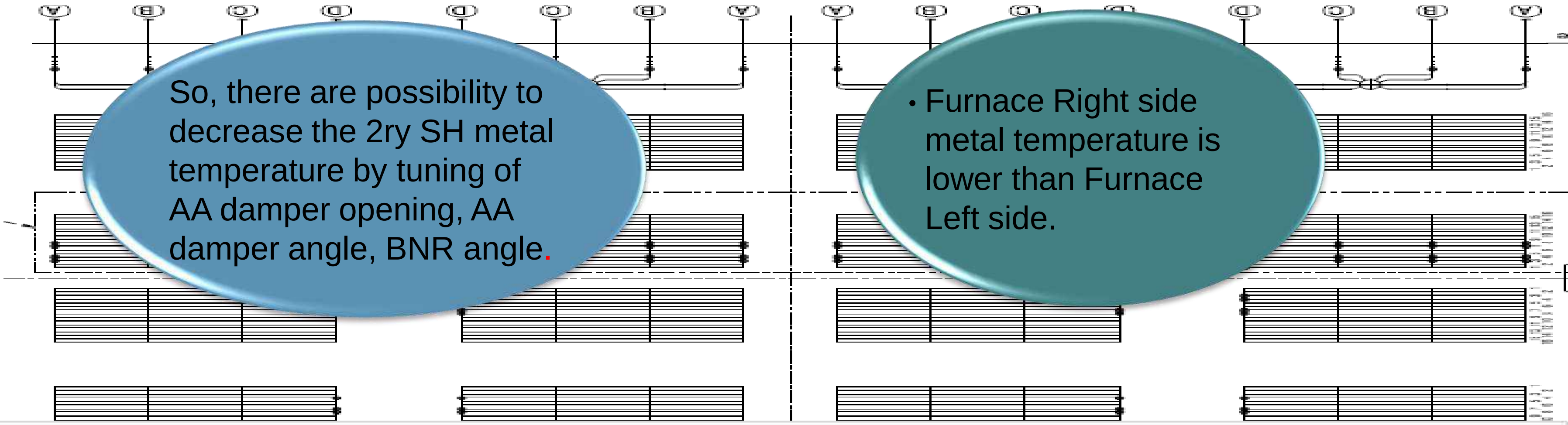
Classical Control of MS & RH Steam Temperature Variation

Parts	Observation for operation data @100%TMCR	Observation for operation data @50%TMCR
3SH	• Actual temp. rise (outlet – inlet) is lower than design. • 3SH inlet temp. is almost same with 2SH outlet.	• Actual temp. rise (outlet – inlet) is lower than design. • 3SH inlet temp. is almost same with 2SH outlet.
2SH	• Actual temp. rise is almost same with design. • Actual 2SH outlet temperature is same with design, but actual inlet temperature is 7deg.C higher than design.	• Actual temp. rise (outlet – inlet) is lower than design. • Actual 2SH outlet temperature is same with design, but actual inlet temperature is 16deg.C higher than design.
1SH	• Actual temp. rise is almost same with design. • Actual 1SH inlet/outlet temperature is 7deg.C higher than design.	• Actual temp. rise (outlet – inlet) is higher than design. • Actual 1SH outlet temperature is 14deg.C higher than design.
2RH	• Actual temp. rise is almost same with design. • Actual 2RH inlet/outlet temperature is almost same with design. • 2ry RH inlet temperature is lower than 1ry RH outlet, but RH spray is not injected.	• Actual temp. rise (outlet – inlet) is higher than design. • 2ry RH inlet temperature is lower than 1ry RH outlet, but RH spray is not injected.
1RH	• Actual temp. rise is almost same with design. • Actual 1RH inlet temperature is 6deg.C higher than design, and Outlet is 10deg.C higher than design.	• Actual temp. rise (outlet – inlet) is higher than design. • Actual 1RH inlet temperature is almost same with design, but Outlet is 7deg.C lower than design.
1ry Spray	1ry Spray flow is more than design.	1ry Spray flow is almost same with design.
2ry Spray	2ry Spray valve position is minimum opening.	2ry Spray valve position is minimum opening.

2ry spray flow shall be increased because Final SH outlet steam temperature is controlled by 2ry spray flow mainly in advanced control Logic.

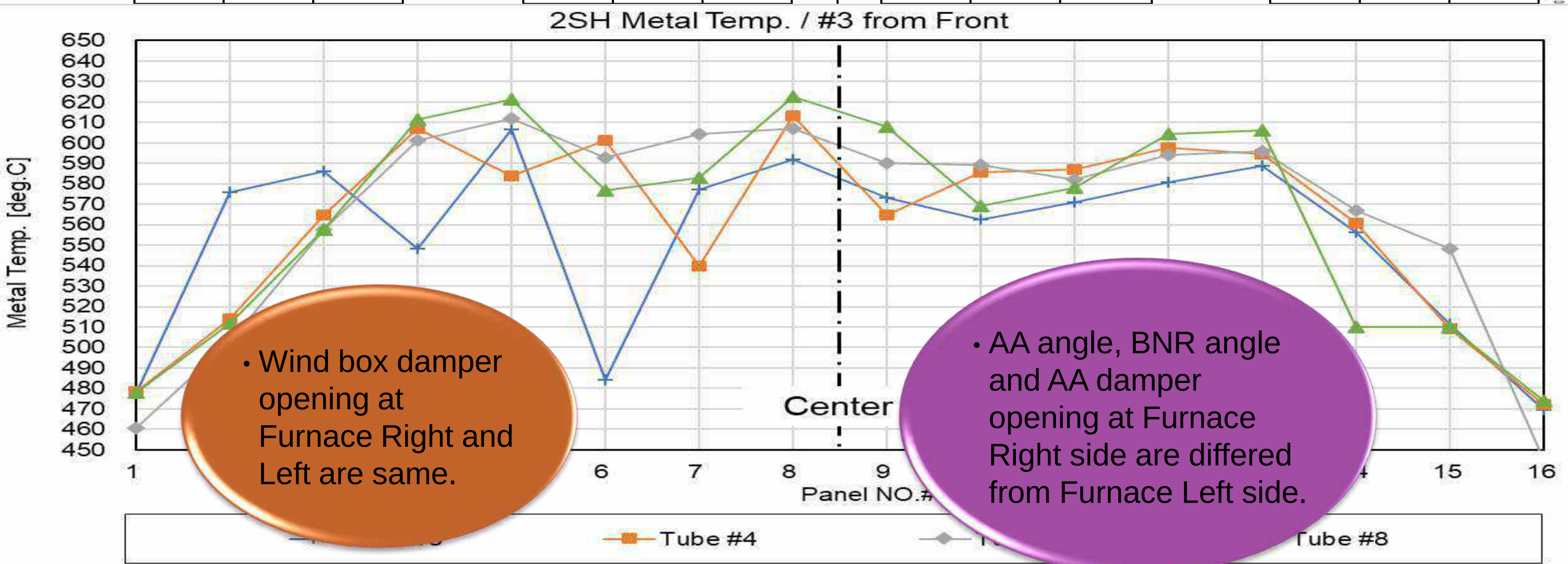
- To increase 3ry SH heat absorption for increasing 2ry spray flow at 100%TMCR and 50%TMCR.
- To increase 2ry SH heat absorption for increasing 2ry spray flow at 50%TMCR.
  It is assumed that if 2ry SH heat absorption is increased, gas temperature at 2RH inlet is decreased and 2ry RH ,1ry RH and 1ry SH heat absorption approaches close to design condition.

Classical Control of MS & RH Steam Temperature Variation



So, there are possibility to decrease the 2ry SH metal temperature by tuning of AA damper opening, AA damper angle, BNR angle.

- Furnace Right side metal temperature is lower than Furnace Left side.



- Wind box damper opening at Furnace Right and Left are same.

- AA angle, BNR angle and AA damper opening at Furnace Right side are differed from Furnace Left side.

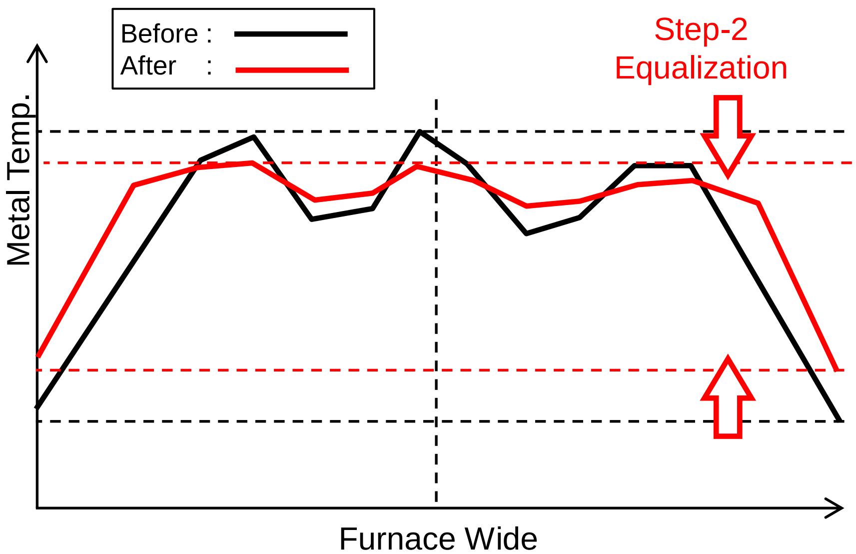
Recommended Combustion Tuning

Combustion tuning is recommended to be conducted in following step because 2ry SH outlet metal temperature may be risen by tuning for increasing 3ry SH heat absorption

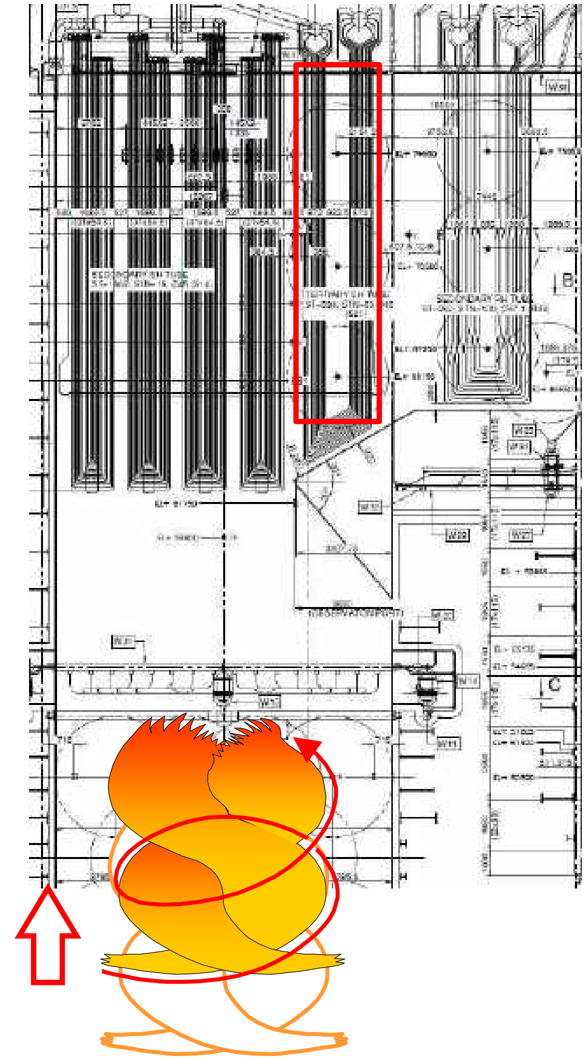
Step-1 : Operating 3ry SH sootblower

Step-2 : Equalization of 2ry SH outlet metal temperature distribution

Step-3 : Increasing 3ry SH heat absorption



Step-1: Increasing 3ry SH heat absorption by 3ry SH soot blower operation

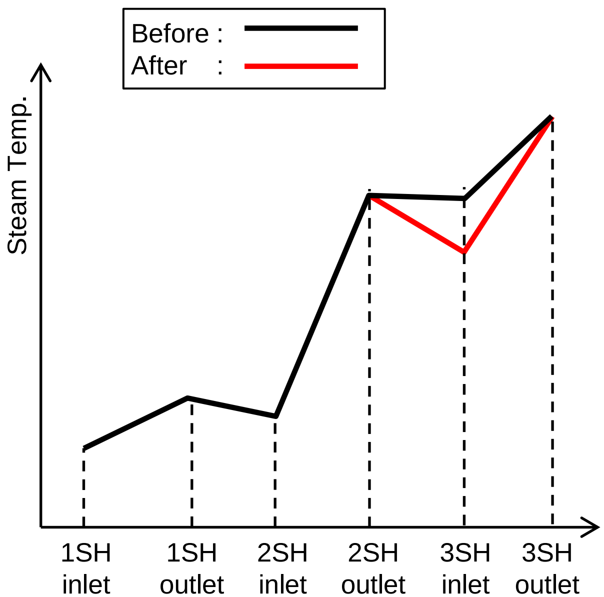


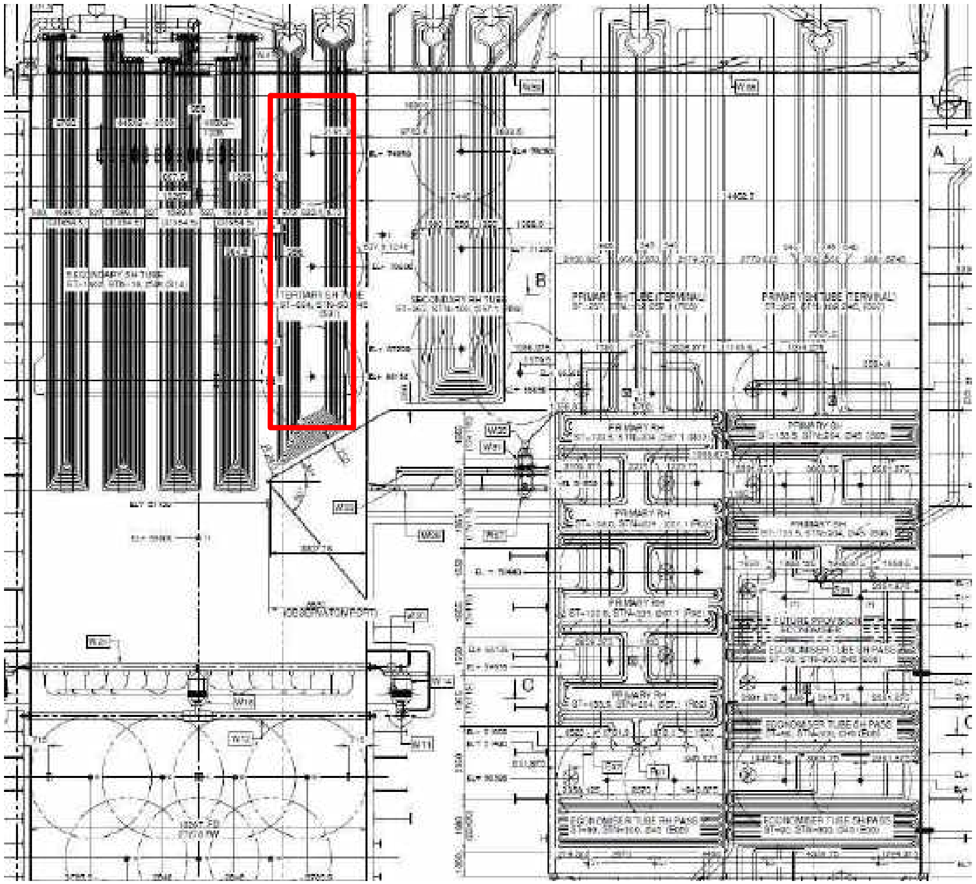
Step-3: Increasing 3ry SH heat absorption by changing fireball position (with spray flow adjustment if any)

Controlling 2ry SH Metal Temperature

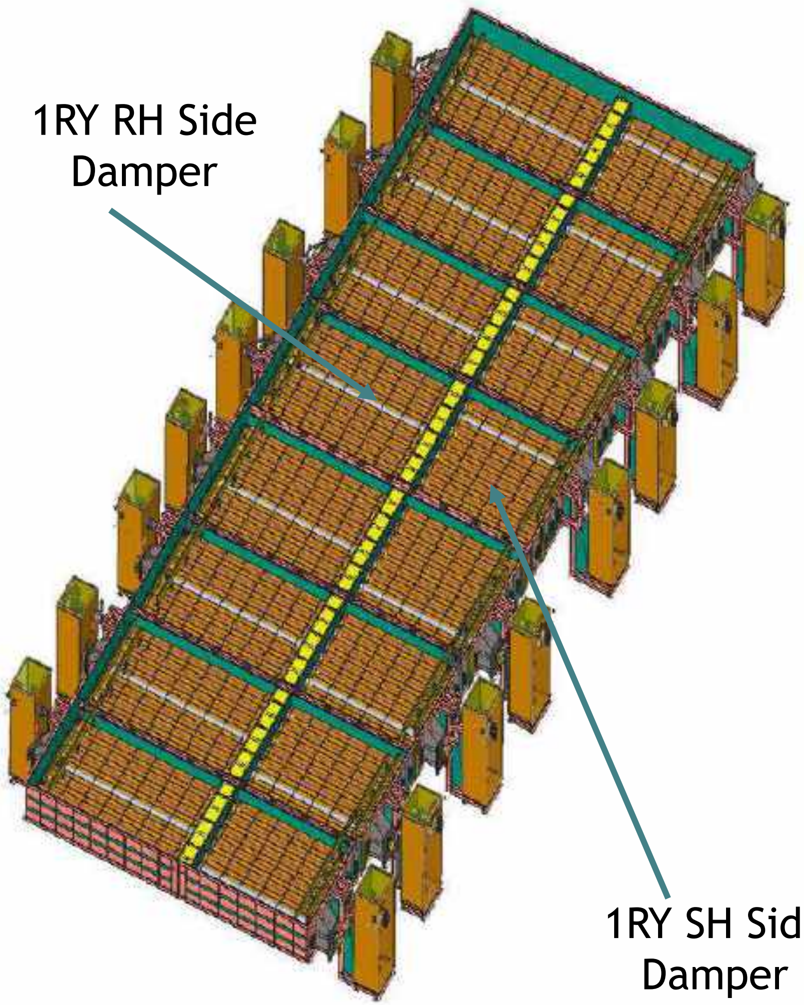
3ry Soot Blower Operation

All 3ry SH soot blowers are operated at each stage,and confirm whether 3ry SH heat absorption is increased or not (3ry SH inlet steam temperature is decreased or not).





Controlling RH Temperature



- Second pass Gas biasing damper is used as a primary control for RH temperature.
- Burner Tilt and RH spray are the secondary and tertiary measures for RH temperature control.
- Final RH outlet temperature at each side can be controlled by each side RH pass damper & imbalance will be very minimum due to controlling each side damper.
- Damper control system can keep RH temperature from 50% to 100%BMCR.

Overview of Boiler Digital Twin features

- AI include rule-based control systems, deductive systems, machine learning and deep learning
- Applied technologies include question answering systems, search engines, image recognition, natural language processing and voice recognition.
- conventional control systems have an automatic control feature mainly “based on strict rules and operable under certain conditions
- Machine learning is roughly classified into supervised learning, unsupervised learning and reinforcement learning
- Digital Twin for boilers adopts the kind of machine learning which would be classified as supervised learning to replicate measurement data such as pressure, temperature ,flow rate etc.

Overview of Boiler Digital Twin features

- Monitoring feature in Interactive 3D AI Driven Platform

Main parameters of the boiler, operational data are indicated in the system 3D diagram rather than in a table, for the purpose of achieving a more user-friendly interface.

The data consist of the measurements of the water/steam system, air/gas system, instruments around the mill and burner etc.

- Prediction feature

Real-time prediction of process values is available utilizing a pre-trained AIML model.

- Optimization feature

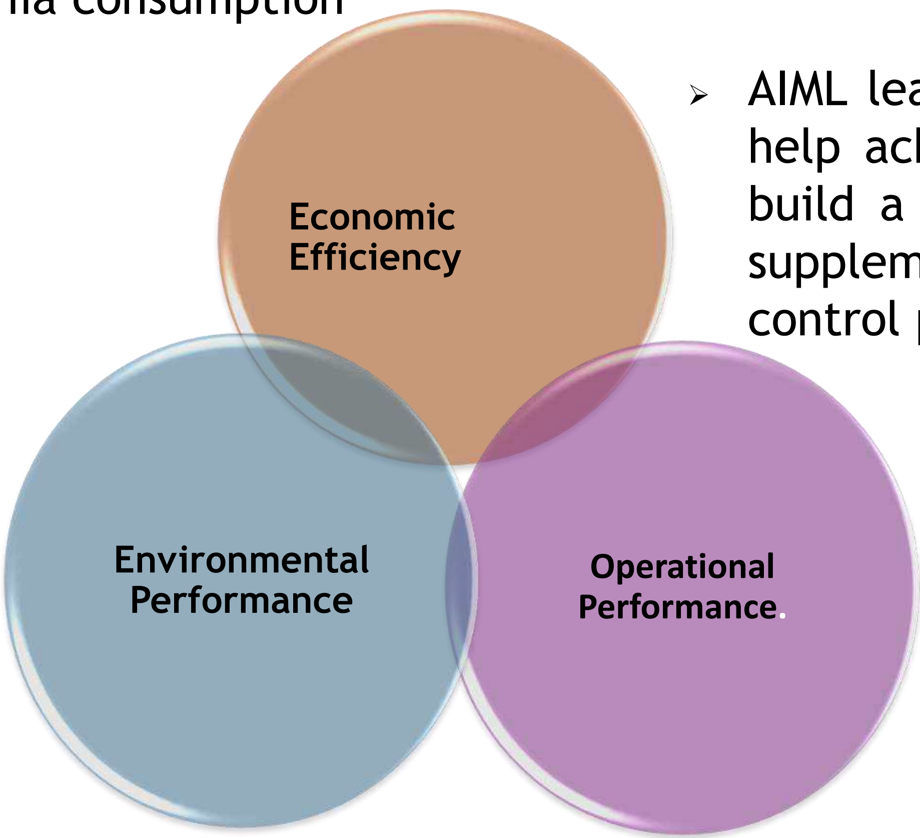
Target values are set for major parameters which experienced engineers would consider in combustion tuning.

- Digital Twin suggests the optimum settings that are economically efficient (i.e., reducing fuel consumption, ammonium consumption and auxiliary power) satisfying the target values

Overview of Boiler Digital Twin features

Fuel consumption,
Auxiliary power,
Ammonia consumption

- In contrast to classical maintenance, the digital twin provides insight into the behavior of the entire system.
- AIML learn from plant operation data and help achieve better operating conditions, build a more flexible operation of plant, supplementing the conventional-style control process.



Enhancement of control margin & response e.g.
SH spray,
Gas damper opening
FW, Fuel, Airflow etc

Properties of flue gas eg Nox,CO,unburnt C

Overview of Boiler Digital Twin features

Intelligent Solution

- Cloud Computing
  (Device connection, big data storage, etc.)
- Technical Supporting HUB
- Anomaly Detection System
- Analysis of Event Log
- Water Quality Assurance
- Boiler Smart Inspection
- Boiler Smart Search

- Boiler Tube leak Detector
- Boiler AI Combustion tuning
- Boiler Control Optimization System (BCOPS)
- Boiler Creep & Fatigue Monitoring System (CFOMS)

Anomaly Detection System

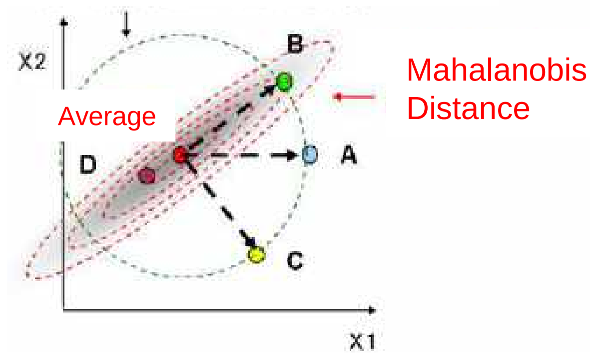
- ✓ **MT method is applied to detect anomaly.**
- ✓ **Contributing to improvement of availability by shortening and avoiding plant outage.**

What is the MT method (Mahalanobis Taguchi method)?

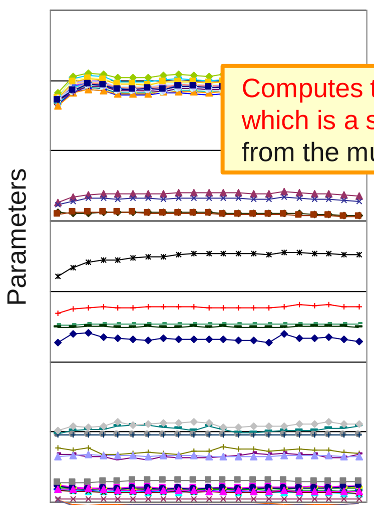
〇A normal data from multivariate data is defined as “unit space”, and determine whether object data belongs to the group by Mahalanobis distance (MD).

〇In order to determine normal/abnormal based on the distance from the normal space, it is early to detect, comparred with the conventional method using upper and lower limit values for each parameter.

〇Orthogonal table analysis ranks parameters contributing to MD values by signal-to-noise(SN) ratio, which identifies cause.



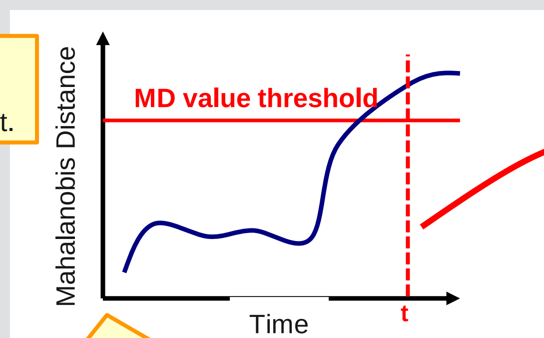
<Conventional Method>



Computes the MD value which is a single indicator from the multivariate data set.

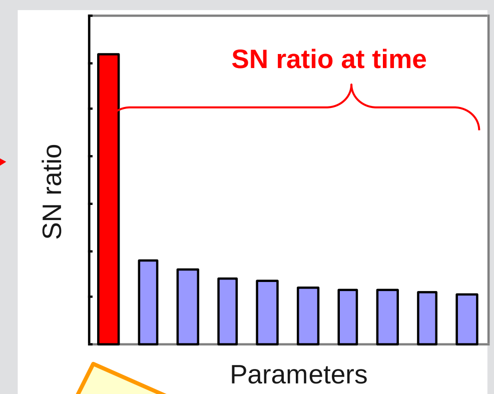
<Anomaly detection by MT method>

MD value calculation



The MD value (distance from normal space) based on the multivariate data can detect the anomaly early.

Factor identification by SN ratio



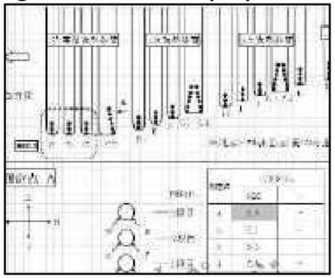
The cause can be identified by ranking the SN ratio at the time when the anomaly is detected.

Boiler smart inspection

The tool support the planning of maintenance and repair work.
And, everybody search and check the inspection record early.

- Investigation records are assembled and converted into digital data.
- Damage tendency is analyzed and visualized based on digitalized data.
- The digitalized data supports the decision of inspection and repair work items.

Original Data as paper



Digitalized

Visualization

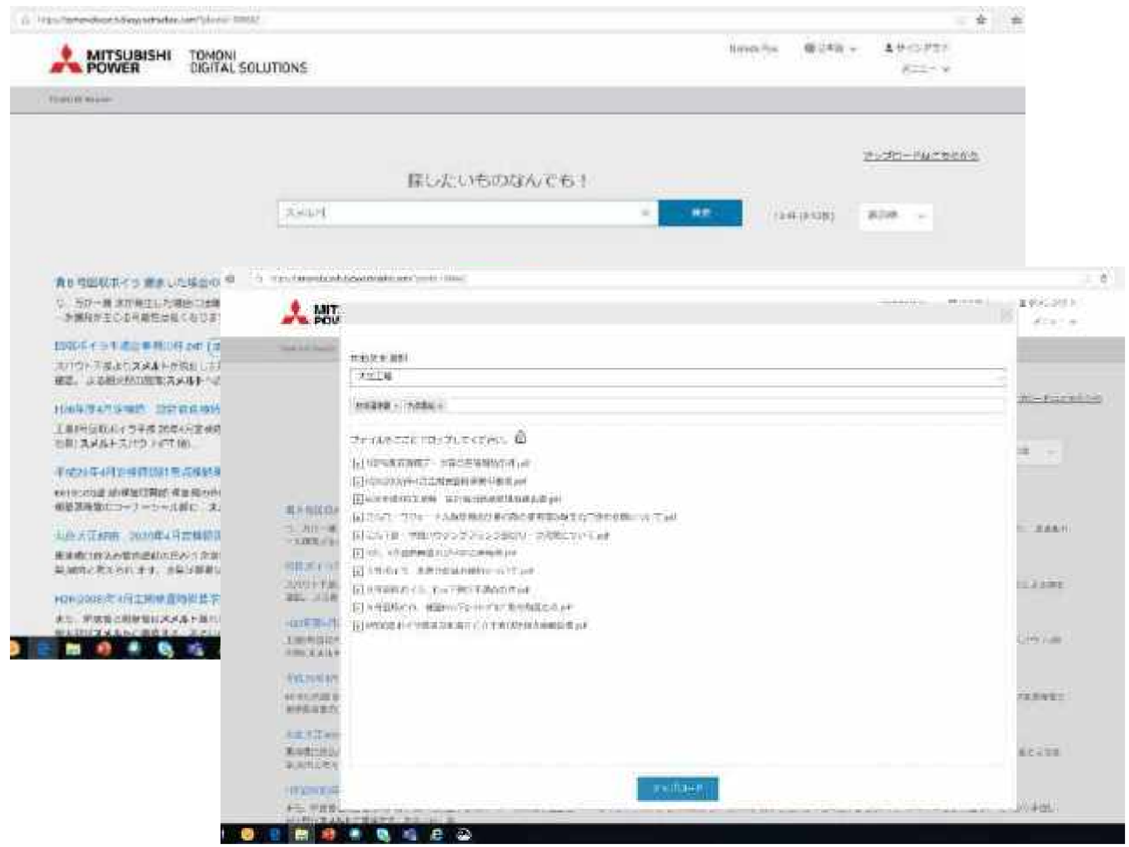
- The system supports planning of inspection items based on MPW failure experience.
- The inspection items are classified by Boiler type, kind of fuel, operation hours, and frequency of start up/shut down.

Boiler Smart Search

- All document such as Drawings, O&M are converted into searchable digital data.
- The system reduces searching time of documents, and sharing of past failure record is easily.

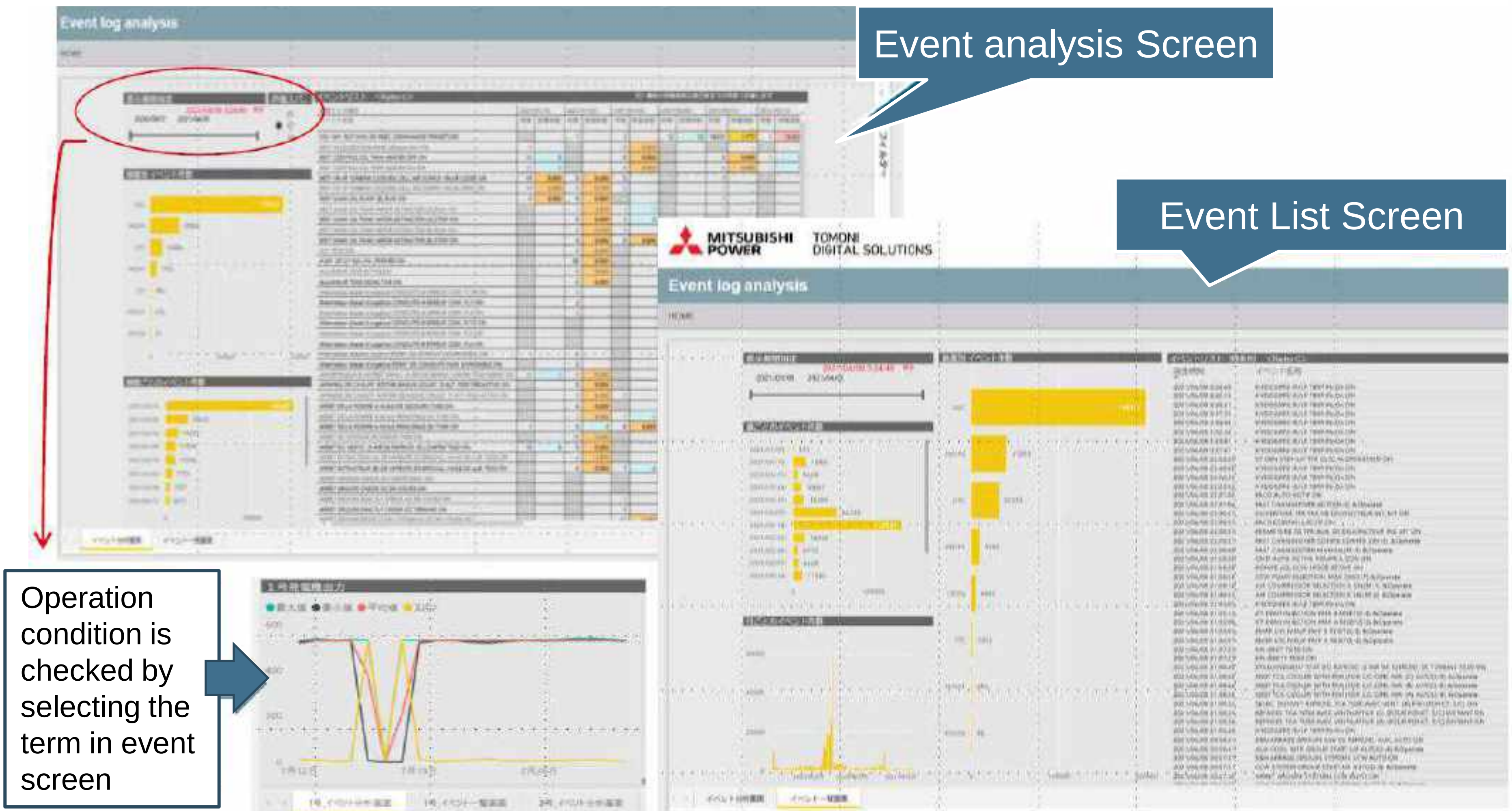
<Before>

<After>



Analysis of Event Log

The finding of abnormal condition through event log is tough for operator.
So, the system inform the unit operation condition by analysis of event log, and event frequency and interval.



Water Quality assurance

- Water quality data is analyzed continuously, and the tendency of water quality with guidance and evaluation result is displayed.
- The system reduces the damage risk of equipment.

Evaluation & Guidance

Operation data trend (Unit output, water quality data, etc.)

Boiler Tube Leak Detector

Early Recovery

Boiler tube leak detection at early stage by continuous vibration monitoring

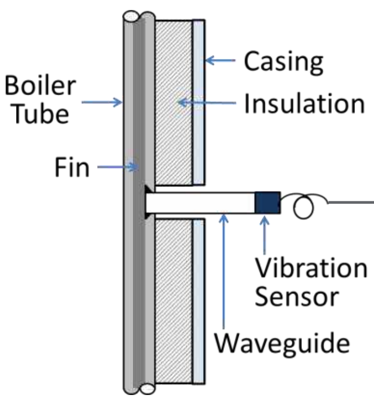
1. Advantages

By detecting tube leak at an early stage,

- To adjust operation load and shutdown schedule
- To prepare material/resource for repair before shutdown.
- To minimize secondary damage and unexpected shutdown period.

2. System Overview

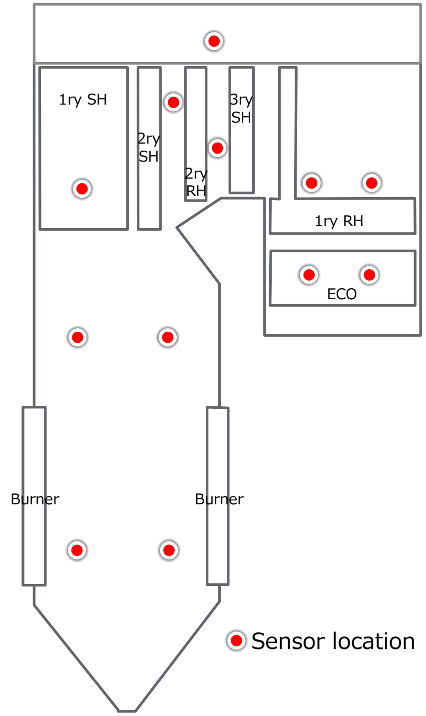
- When high-pressure water/steam is discharged from raptured tube, leak sound is generated.
- Leak sound vibrates the water wall through combustion gas.
- The system can identify the vibration by tube leak which is different from that of boiler normal operating condition.



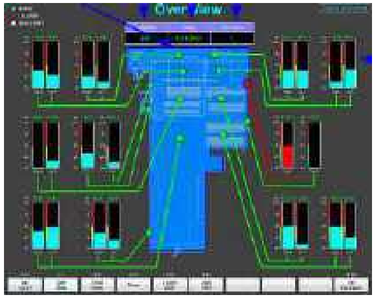
3. Applicable Parts

- ✓ Furnace/2ry Pass Water Wall
- ✓ Superheater, Reheater
- ✓ Evaporator, Economizer

4. Application Case



Example for Sensor Arrangement



Red part : tube leak detected sensor

Screen for indication of tube leak detection

Installation condition of sensor

Boiler AI Combustion Tuning

- Customer's needs for plant operation are changing and diversifying, e.g. co-firing with carbon-free fuel and high-efficiency operation to reduce CO_2 emissions.
- To optimize operation settings in response to customer's changing and diversifying needs, it is unrealistic to dispatch skilled engineer each time to perform the combustion tuning.

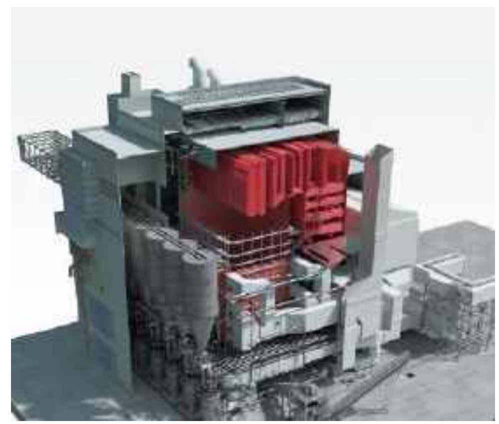
Digital Twin

Digital twin is generated from operation data to represent the actual boiler for the combustion tuning using artificial intelligence (AI) technique.

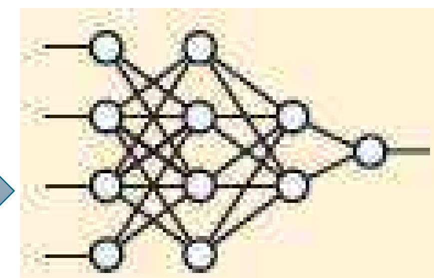
Optimization program

Optimization program is utilized with evaluating operating conditions quantitatively for findding the optimum setting point among vast amounts of setting combinations using this digital twin.

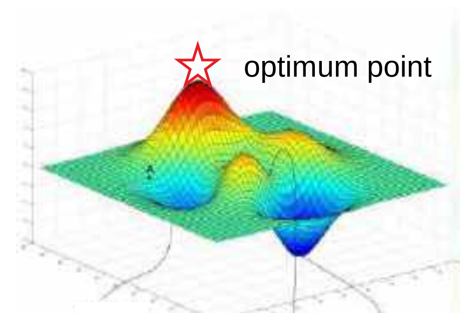
Actual boiler



Digital Twin



Optimization program



*an example of the number of setting combinations

Operating device: 20 sets

Parameters: 5 levels

Approx. 100 trillion cases (5 ^ 20)

Boiler AI Combustion Tuning

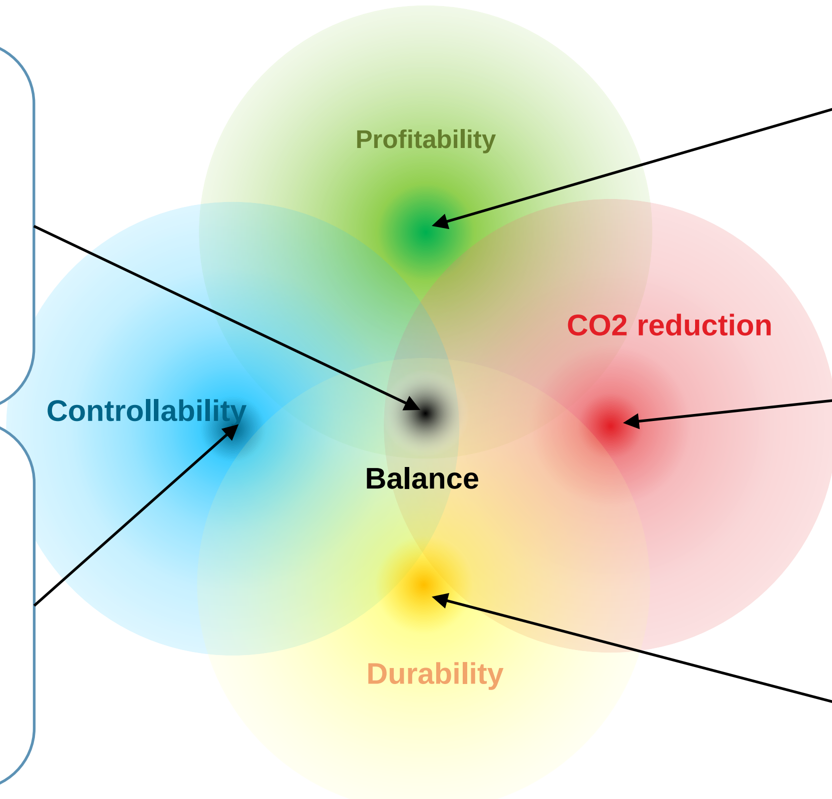
- Optimum setting can be obtained with simple operation according to coal type and/or variation due to furnace heating surface dirtiness, etc.
- Combustion tuning mode can be changed to any mode to suit your needs by the selecting switch.
- Furthermore, optimum mode according to your specific need is also applicable by changing the evaluation of each process value.

Balance mode

Balance setting that takes into account the effects of operation condition, coal type, and dirt condition, etc., like skilled engineer's practice

Controllability mode

Setting to prepare for load change and/or change of coal type by ensuring appropriate margin of control device like gas damper, spray valve, etc.



Profitability mode

Setting to save operating cost

CO2 reduction mode

Setting to place top priority on plant gross thermal efficiency and therefore to improve boiler efficiency

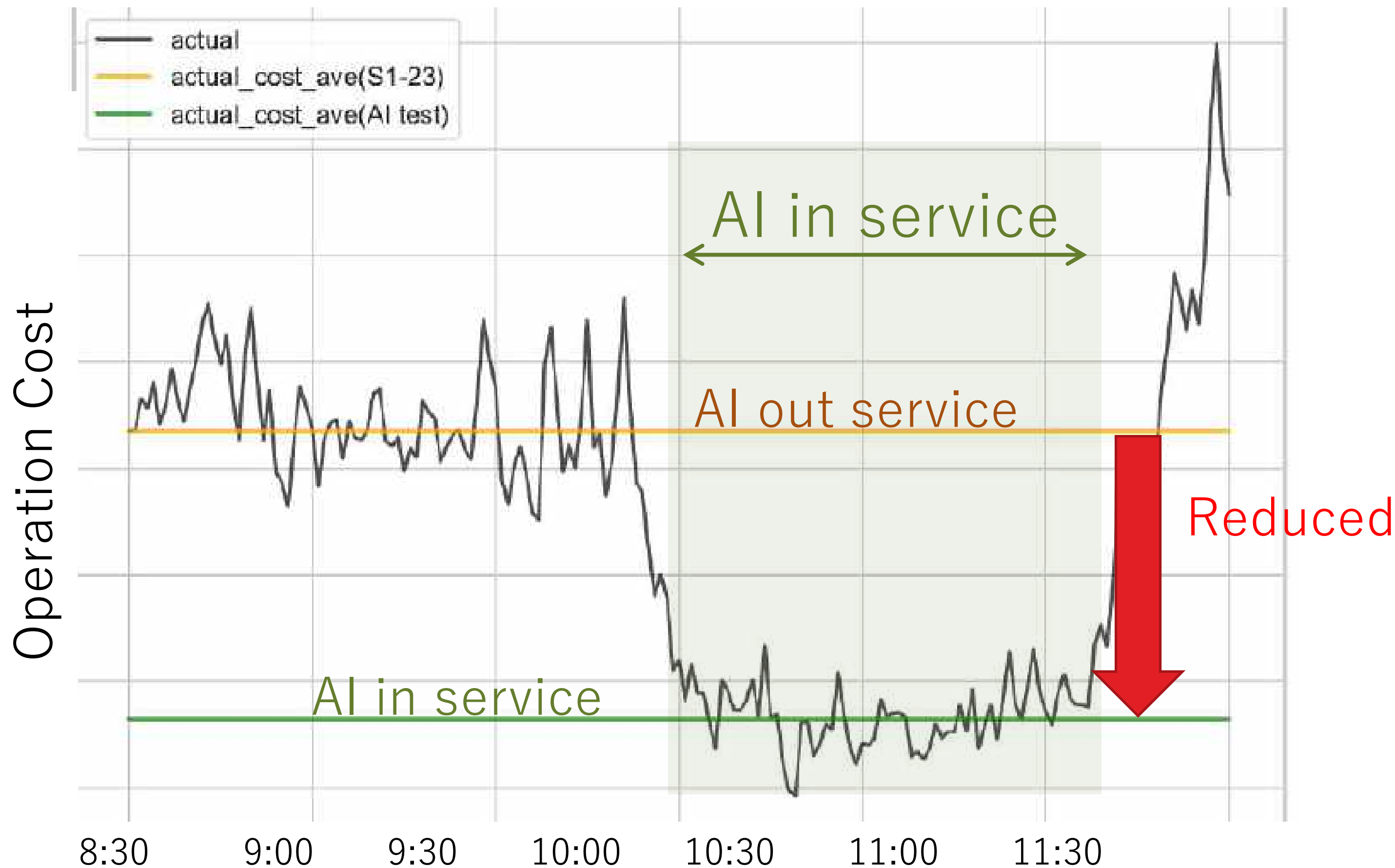
Durability mode

Metal temperature, etc. are maintained within the proper range

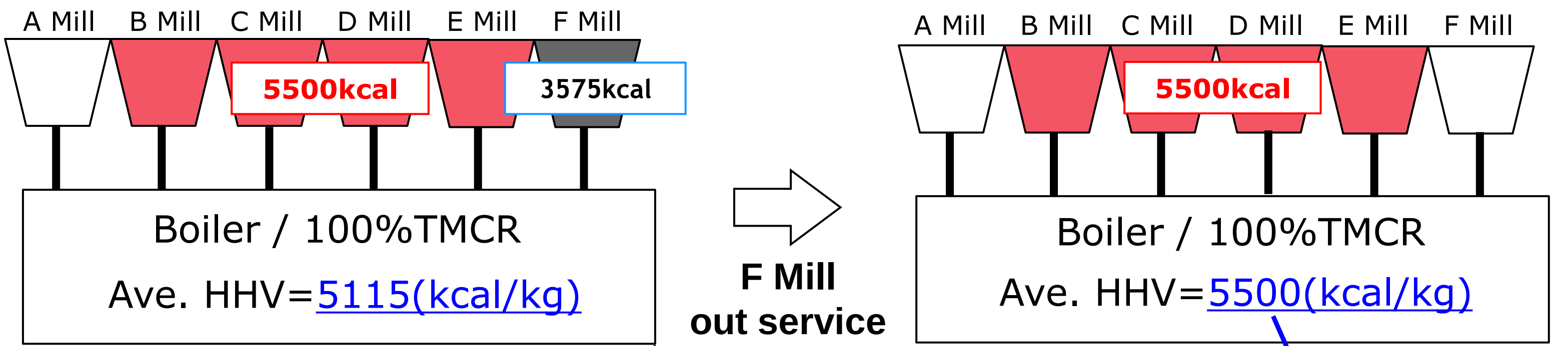
Boiler AI Combustion Tuning

Example of Boiler AI Combustion Tuning

Operation cost is reduced by Profitability mode.
(NH3 consumption and FDF/IDF power consumption are reduced by tuned of O2 set point and AA damper opening/angle)



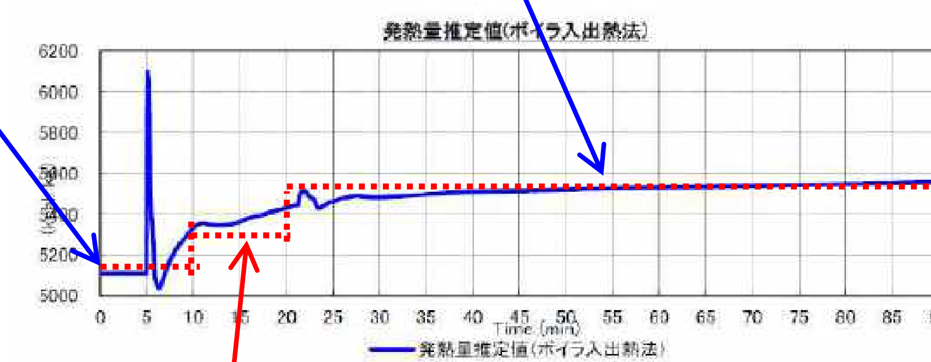
Philosophy of HHV Correction Logic



Response or original HHV correction is very slow because the step is deviation of steam temperature → Water/Fuel ratio → HHV correction.
So, HHV is predicted by Boiler heat input output calculation.

$$\eta_B = \frac{Output}{Input} \times 100 = \frac{Q_1 - Q_0}{W_f \times H_h} \times 100$$

η_B : Boiler Efficiency (assumed as 90%)
Q_1 : Boiler heat output of steam (calculable)
Q_0 : Boiler heat input of water/steam (calculable)
W_f : Coal Flow (measured vale)
H_f : HHV

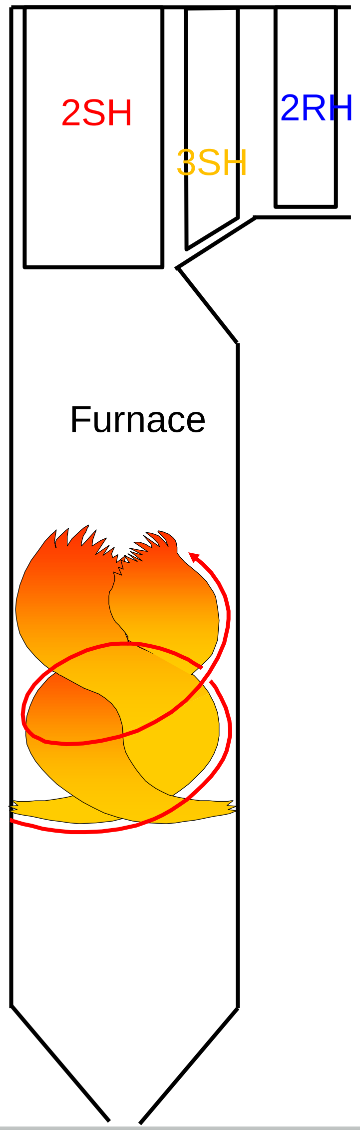


*HHV correction time
Original : few hours
↓
Latest : 30 min

(1) Predicted HHV is average value.
(2) Deviation of HHV few min. ago is monitored.
(3) HHV is corrected when the deviation is over criteria.
And, correction is done step by step.

Fuel HHV Correction

Philosophy of Multi coal firing control logic (response to changing Fuel ratio)

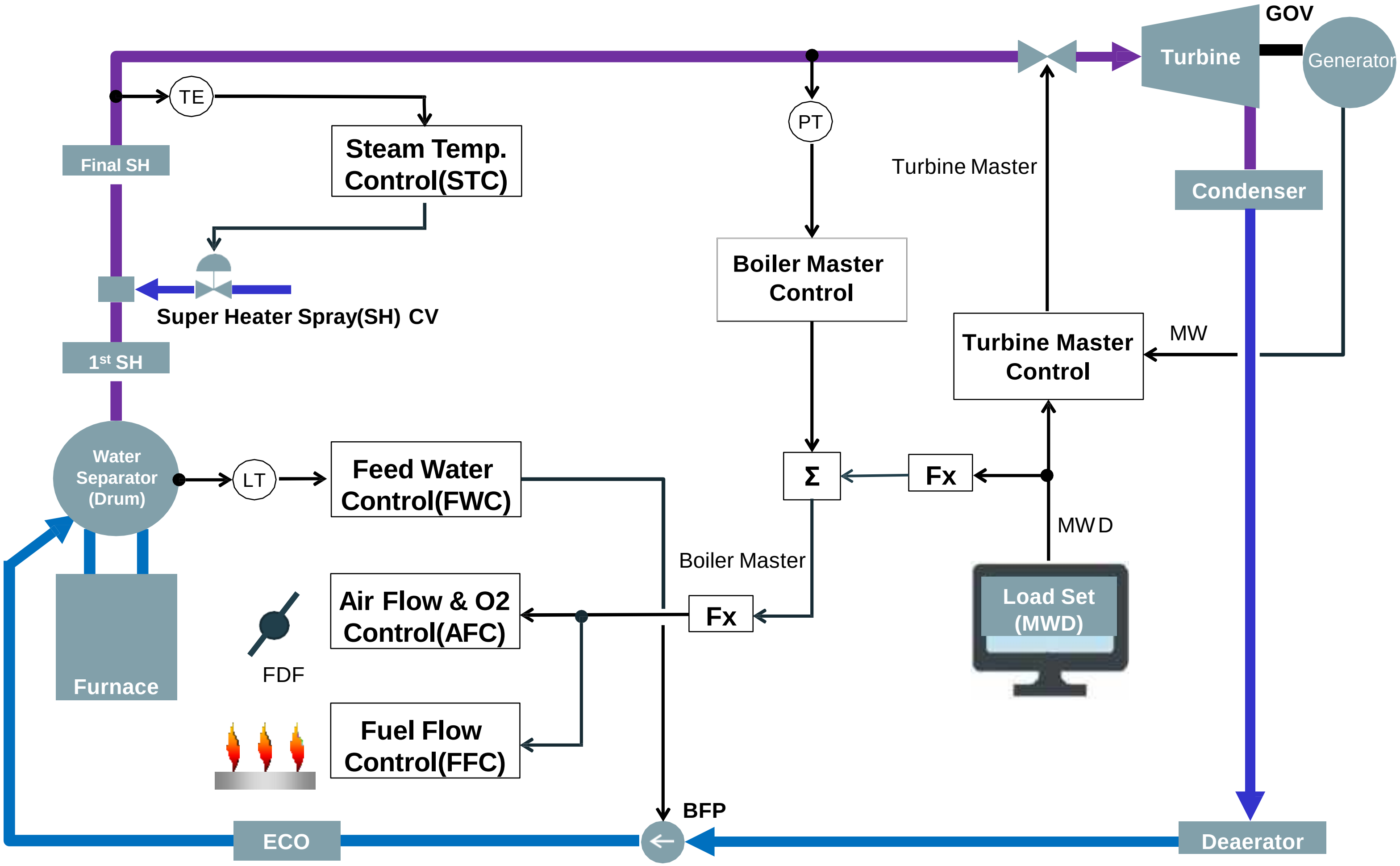


- Combustion characteristics is difference among High/Middle/Low fuel ratio coal. So, Heat absorption ratio between Furnace and 2ry RH is also difference.
- Each set points are set for High/Middle/Low fuel ratio coal individually in logic.
- Heat absorption ratio is predicted by operation data, and set point is changed automatically based on the heat absorption ratio.

		High Fuel Ratio	Middle Fuel Ratio	Low Fuel Ratio
Coal Property	Fixed Carbon	Much	Base	Less
	Volatile Matter	Less	Base	Much
Fuel Ratio (Fixed Carbon/Volatile matter)		1.8≧	1.8～1.3	1.3<
Heat Absorption	Furnace	Decrease	⟷	Increase
	2ry RH	Increase	⟷	Decrease

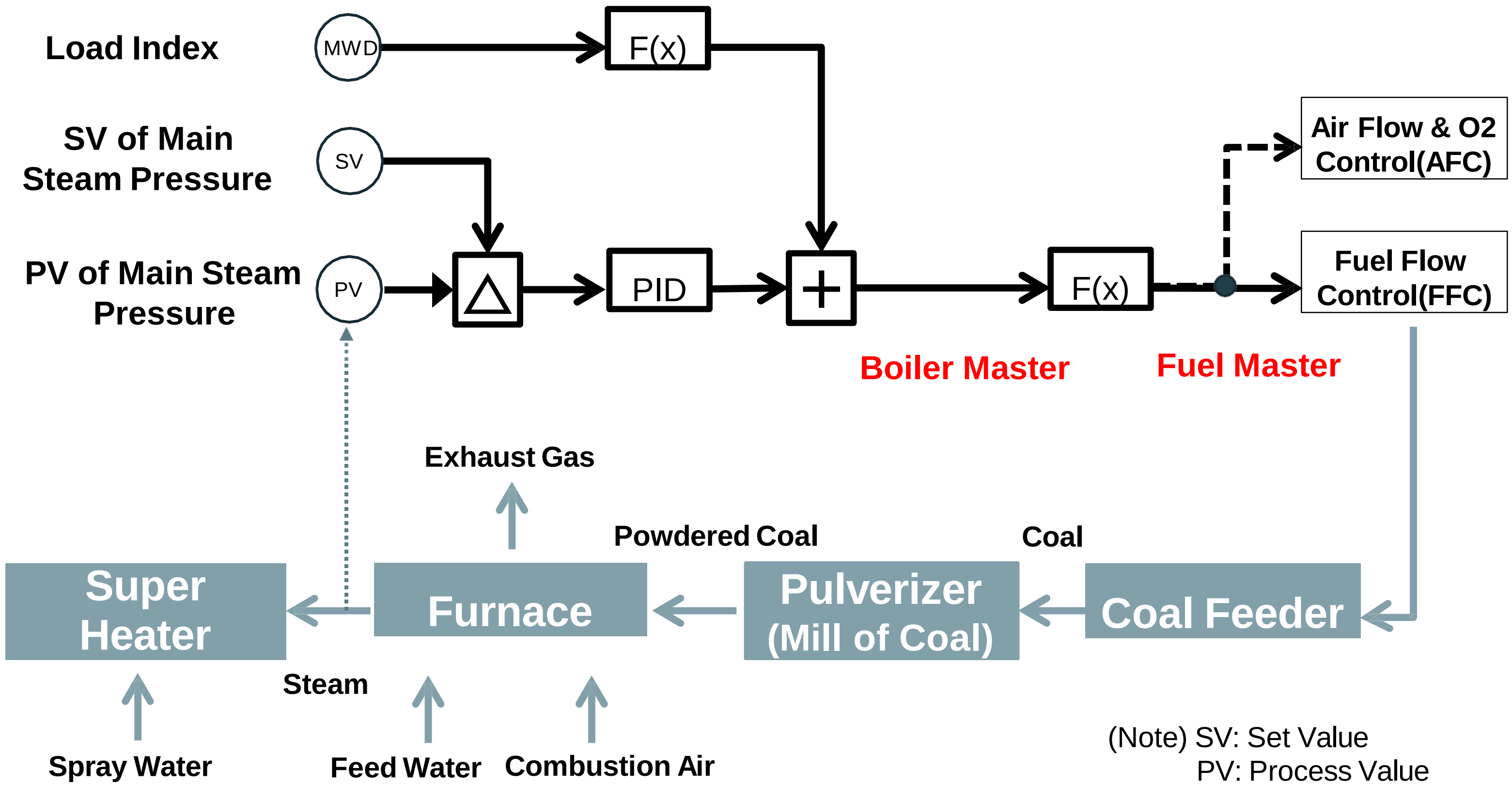
Classical Unit Control

Automatic Boiler Control(ABC) consists of six main control parts, and we need to optimize them to be able to output expected performance of boiler.
The current method is the manual tuning related parameters by ABC specialist.



Classical Boiler Master Control

This logic consists of PID controller to maintain Main Steam Pressure at setting constant values and the advance control based on MWD like the below logic.



(Note) SV: Set Value
PV: Process Value
MWD: Megawatt Demand

Main Boiler Master Problems

It is hard for us to keep the best performance of any boilers due to their aging or unexpected disturbances from other processes, even if the specialists have finely tuned parameters of ABC based on initial characteristic of boilers.

Experiencing problems:

1. Changing heat absorption or balance from design values due to aging.

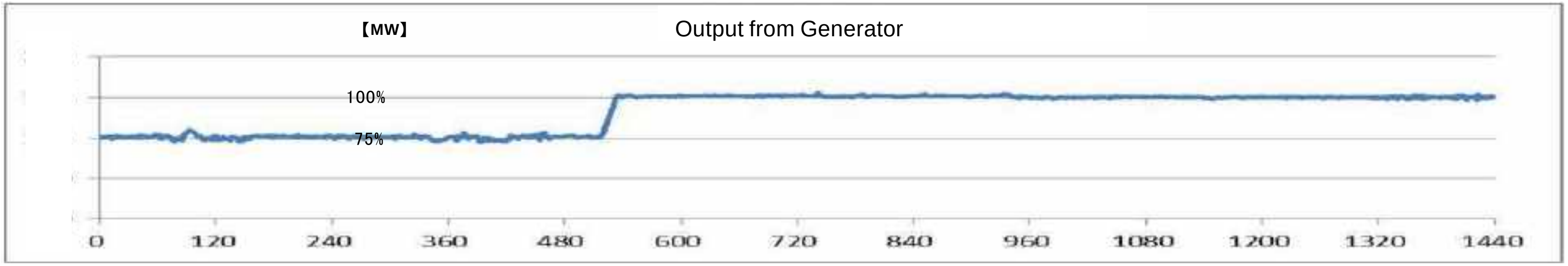
2. Changing combustion characteristic with unexpected mixing fuels or the fuels of which properties differ from our recommendation.

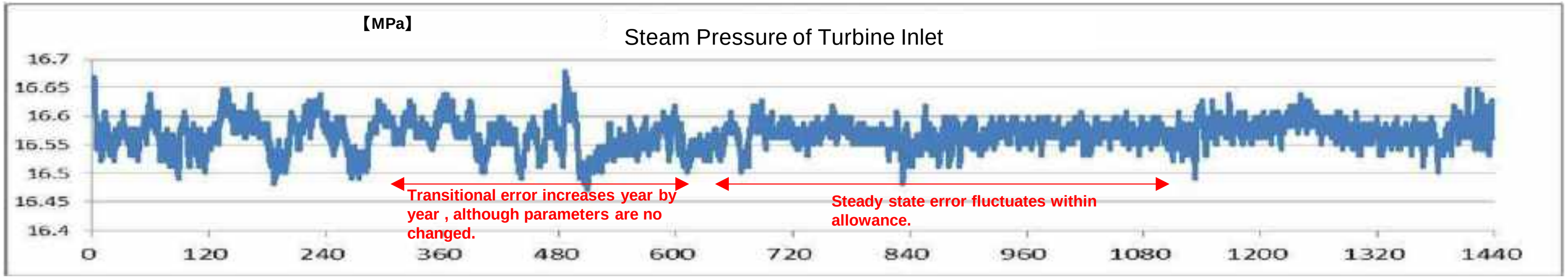
3. Changing heat absorption or heat balance form design values due to disturbance from other processes like blowing soot blowers.

Influence of Slagging or Fouling

- The transitional response of boiler delays year by year, because the efficient of heat transfer shifts to the worse characteristic due to slagging or fouling.
- The boiler master could not reduce fluctuation of main steam pressure in this case after the generator load achieves to MWD.
- Consequently, we need to tune parameters of Boiler Master Control again to reduce steady state error.

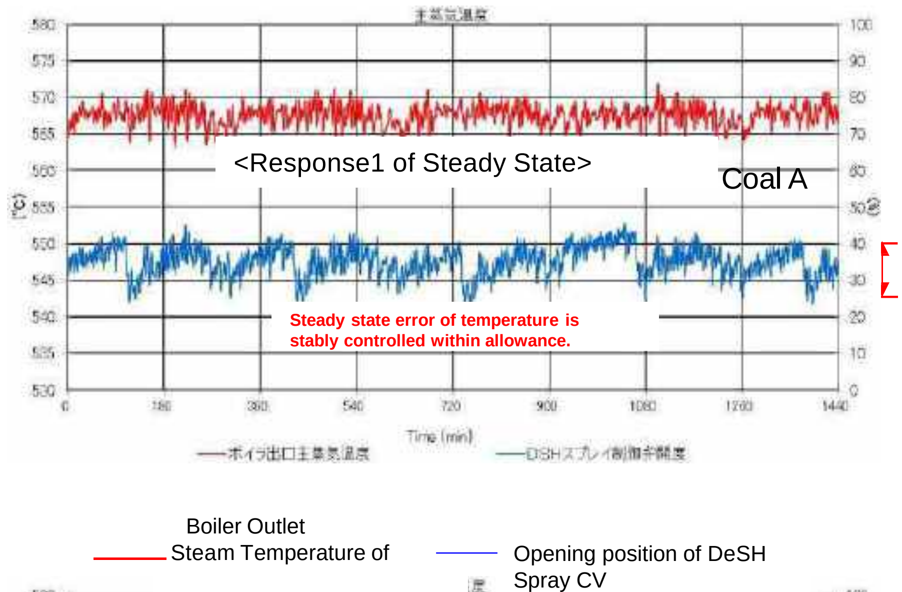
<Sample of Transitional Response>

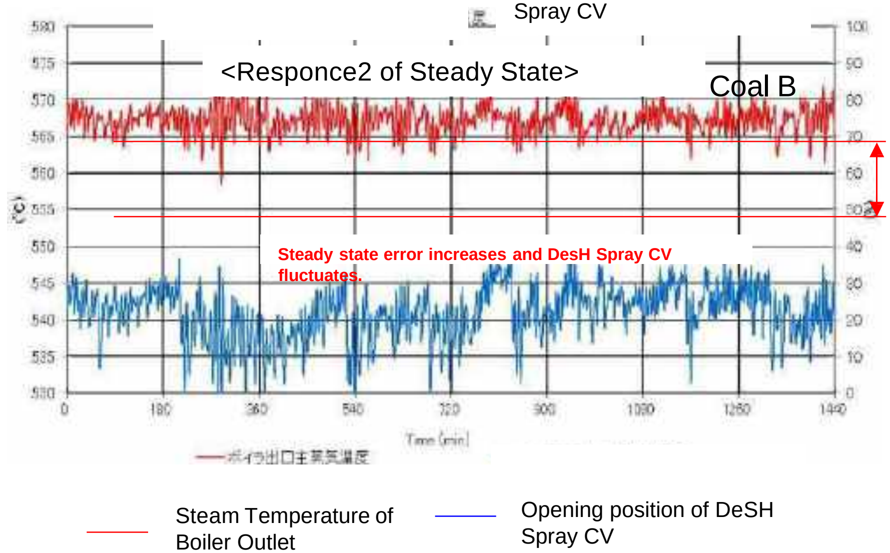




Influence of fuel properties

- The heat value and combustion of boiler could be changed due to changing properties or mixing rate of fuels.
- The performance of boiler could change, although fuel master from ABC is same setting value in these cases.
- The change of fuel control could finally affect to steam temperature control like trend data at right side.
- Consequently, we need to tune parameters of Fuel Flow Control and Steam Temperature Control again.





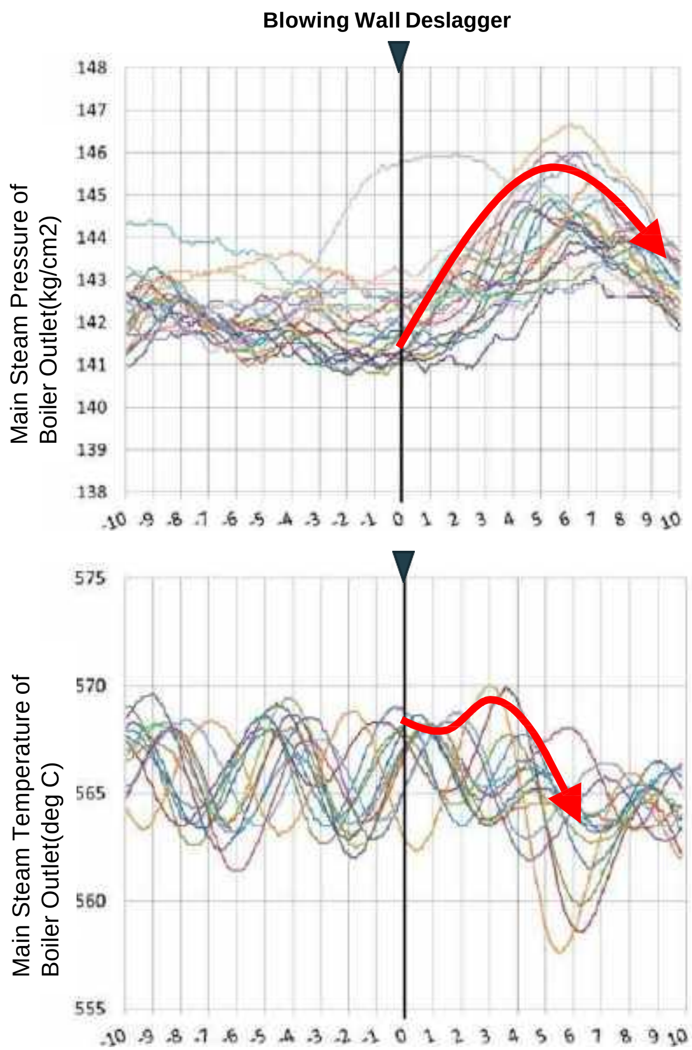
Influence of disturbances

The efficient of heat transfer and the balance of heat absorption could change due to blowing soot-blowers.
And they could give disturbance to Boiler Master Control and Steam Temperature Control.

We've experienced "In/Out-service of Burners" as a similar case.

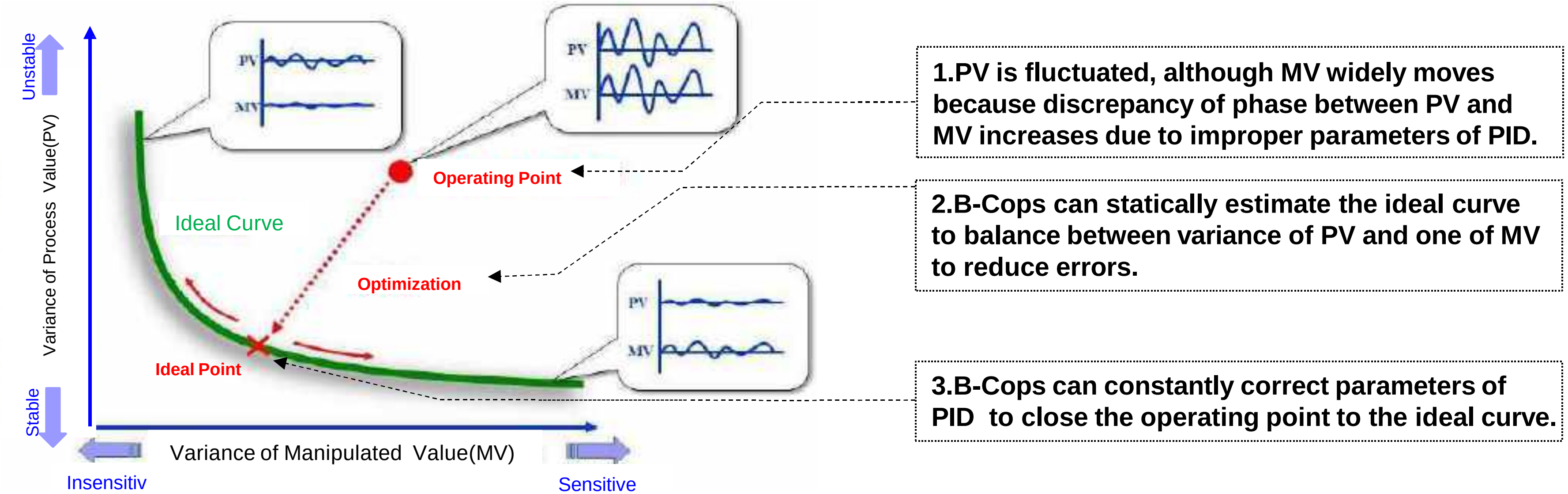
If main process values are fluctuated to close alarm levels like trend at right side, operators always need to decrease their targets far from the rated values.

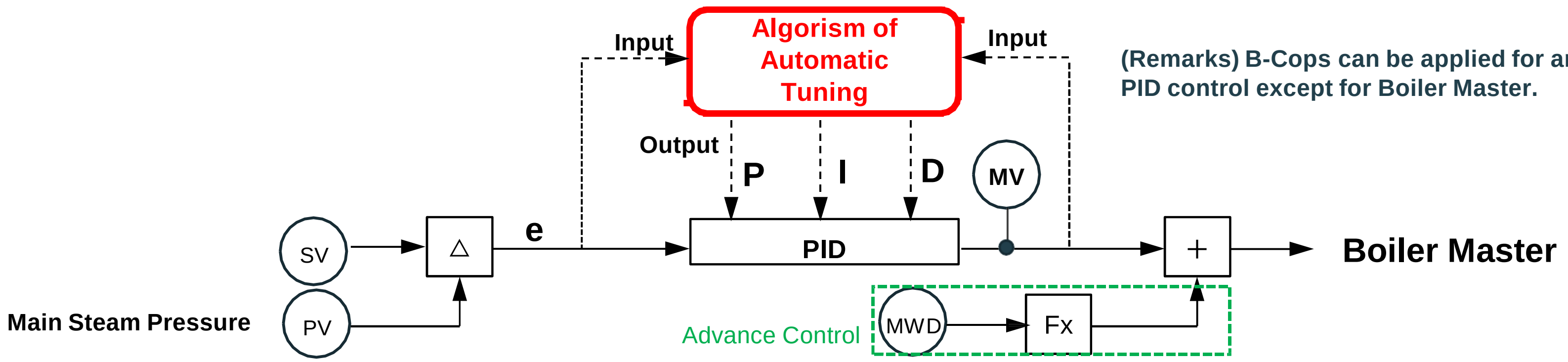
It means that boilers could not supply expected powerful steam to the turbines, because operators need to keep lower set values than rated ones not to set off alarm or interlock.



Function of Auto Tuning

B-Cops could constantly correct PID parameters to balance valiance of PV and MV instead of ABC specialists.
It can correct PID to reduce steady state error after generator load achieves MWD, however it can't correct the advance control to reduce transitional error while generator load is changing.

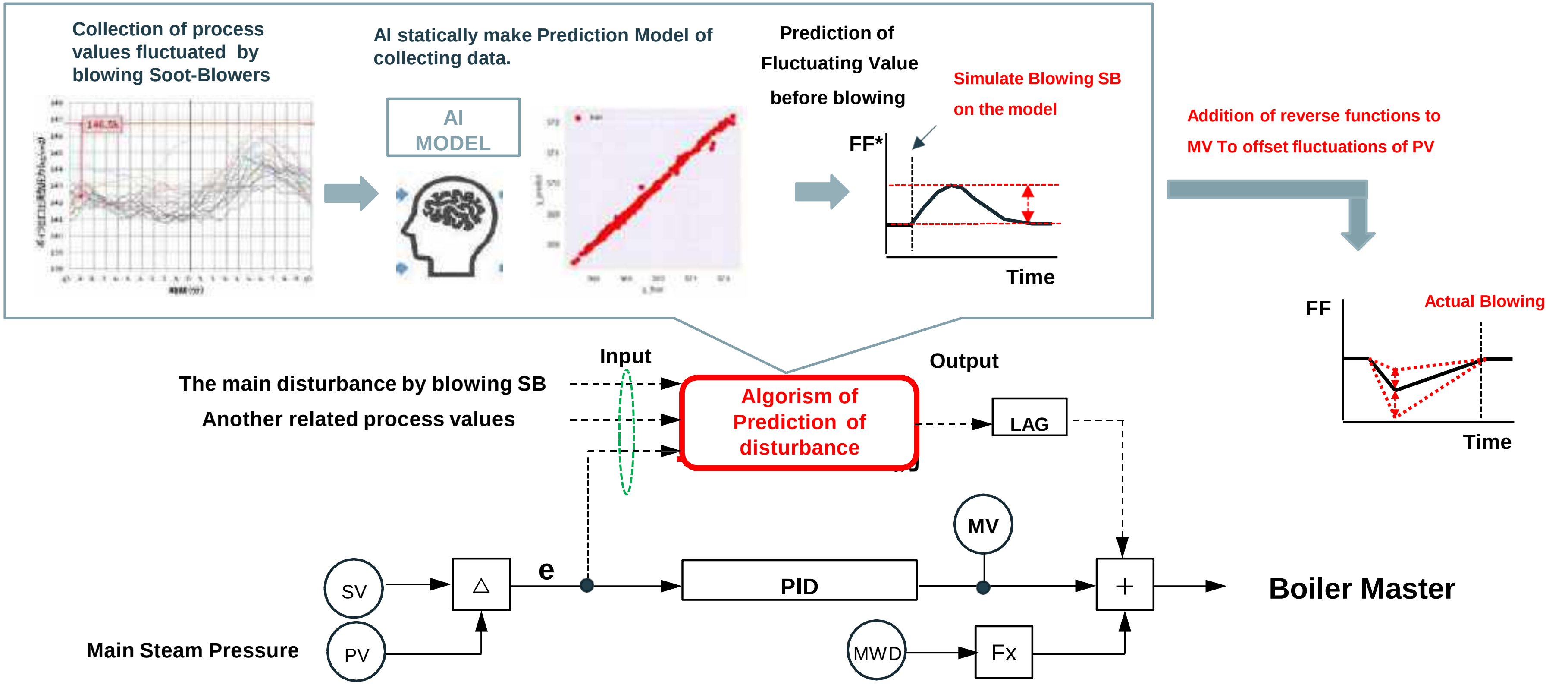




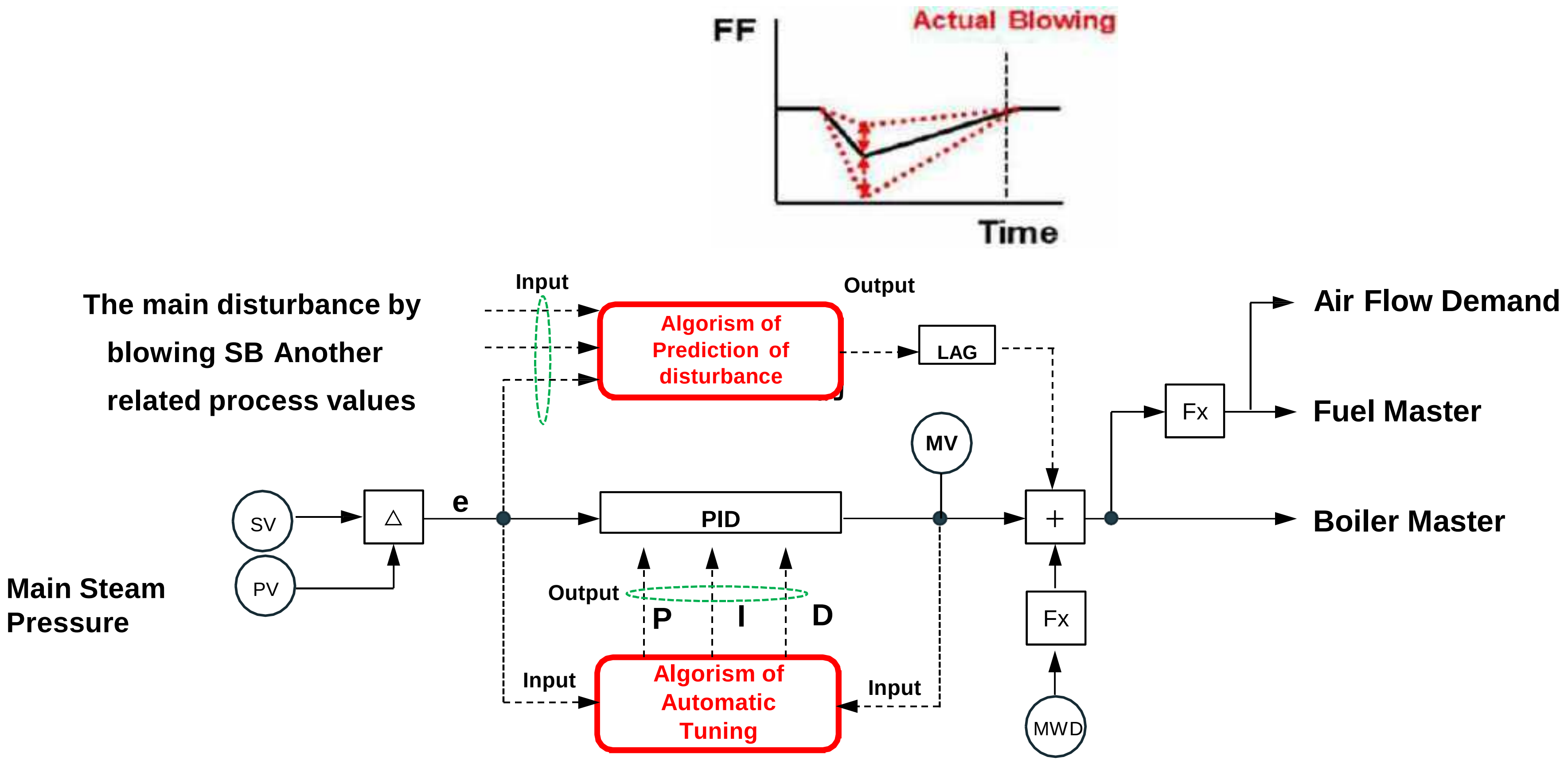
(Remarks) B-Cops can be applied for any PID control except for Boiler Master.

Function of reduction of Influence from disturbance

B-Cops could predict fluctuation of PV by various disturbances from simulated models.
This AI model is made of the collecting data from actual process.
B-Cops could add the reverse functions to MV to offset fluctuation of PV by disturbances beforehand.



Application of B-Cops for Boiler Master

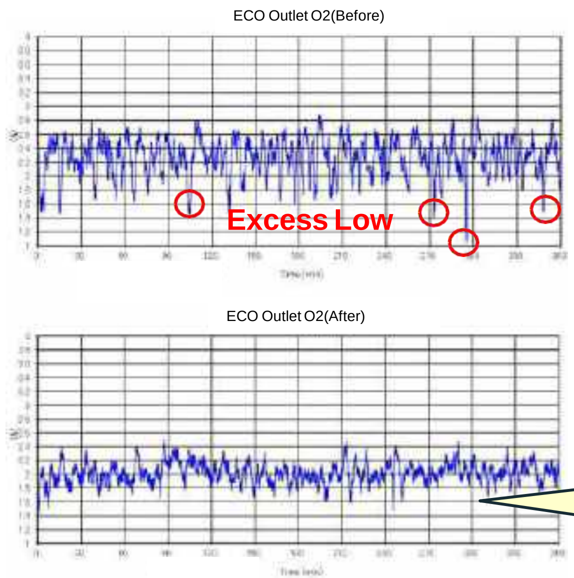


Function of Phase Correction

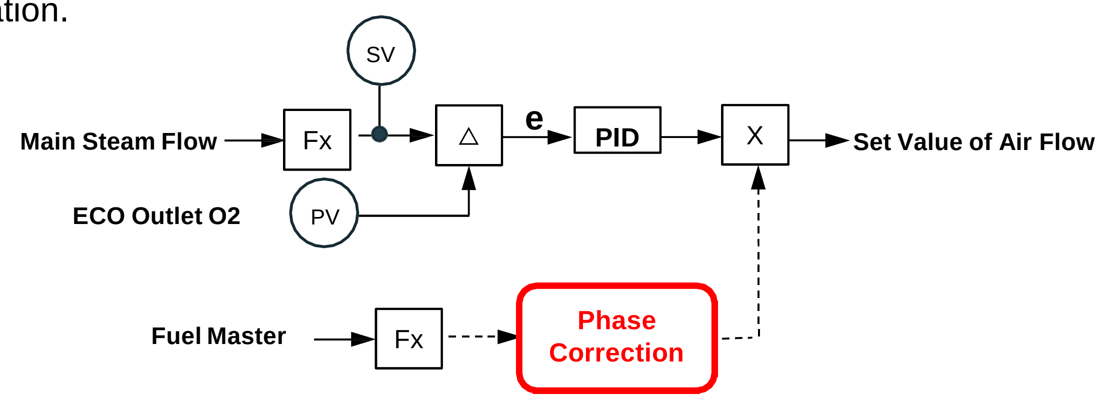
It is not enough to correct BM control to optimize whole ABC, we often need to tune control of sub-loop in many cases such as AFC,FFC,FWC and so on.
B-Cops could be applied for the correction of sub-loops, especially phase correction could synchronize cycles between PV and MV to reduce discrepancy of them.
We can successfully apply phase correction to Air Flow Control(O_2 Control) as follow.

【Application of O2 Control】

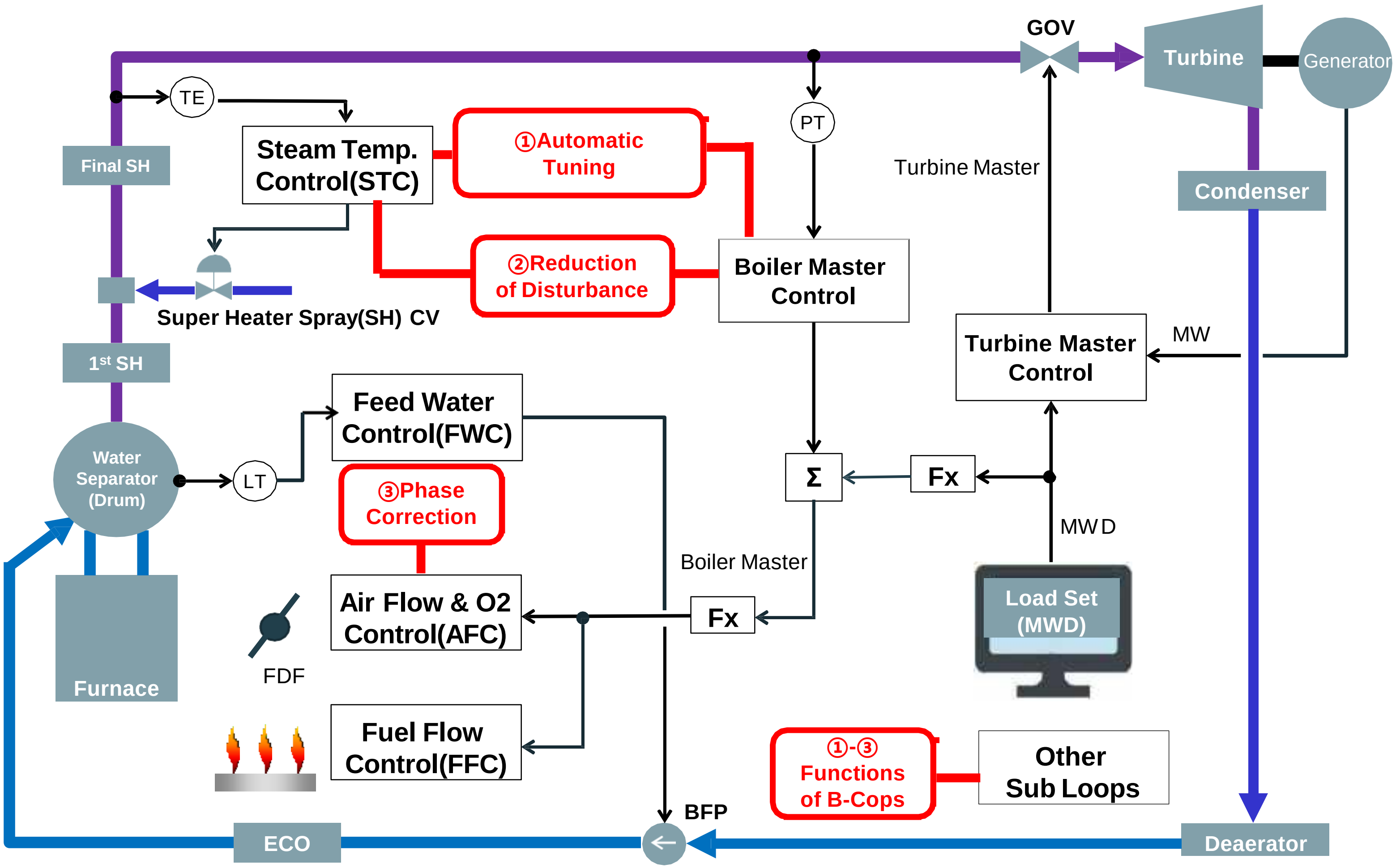
The cycling discrepancy occurs between actual fuel and air flow because actual fuel follows more slowly for fuel master.
Therefore, phase of O_2 based on fuel master leads for actual fuel.
Phase correction could improve such a situation.



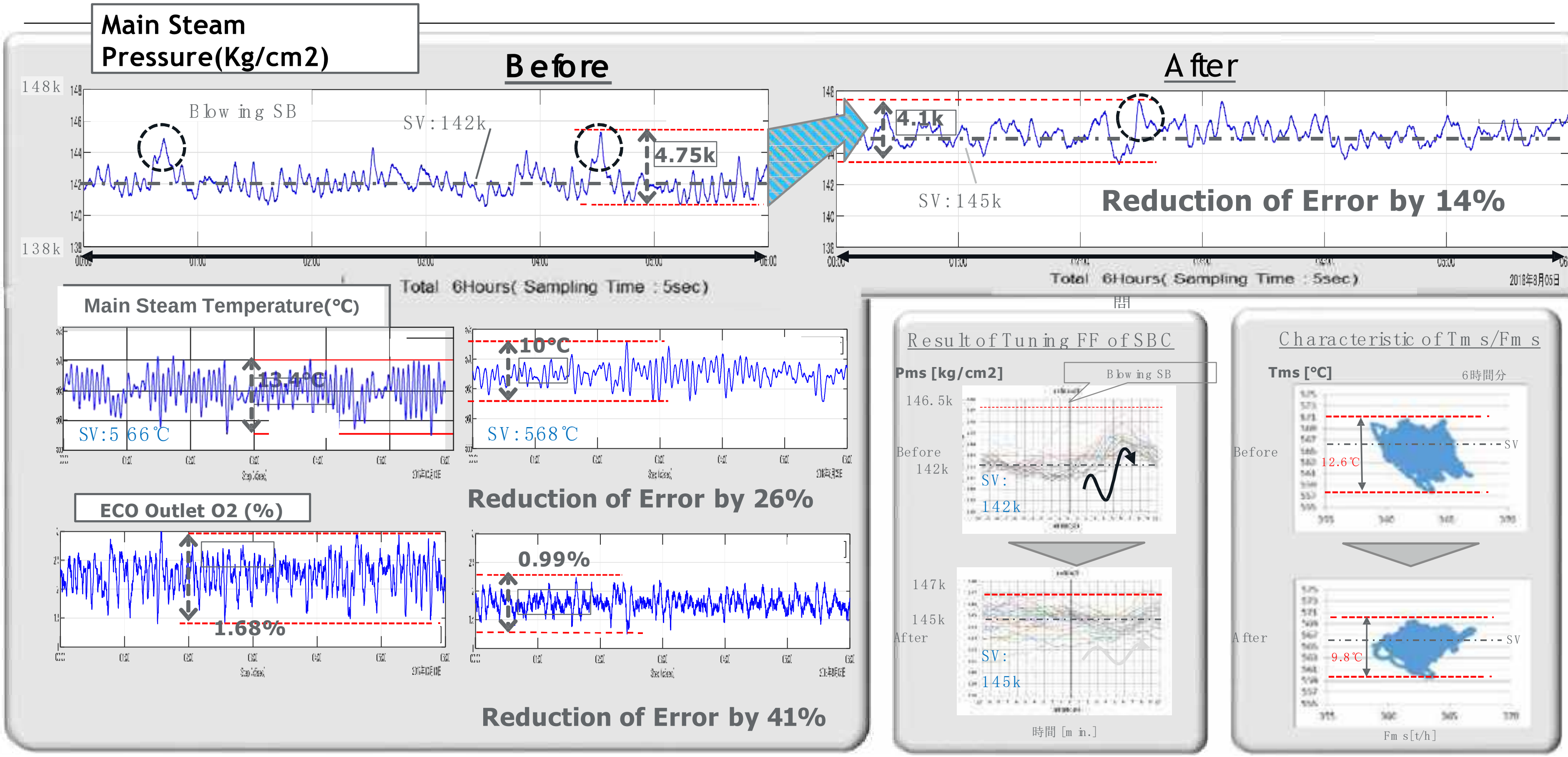
Reduction of excess low points during steady state



BCOPS Applied for Boiler Control



Improved Case for Coal Firing Boiler



Reduction of fluctuation of Pms after SB Blowing in case 100% ECS Load

(Remarks)
Pms: Main Steam Pressure
Tms: Main Steam Temperature
Fms : Main Steam Flow
SB : Soot Blower
SV: Set Value

SV of Main Steam Pressure : +3 k
SV of Main Steam Temperature : +2 deg C
SV of ECO outlet O2 : -0.2%

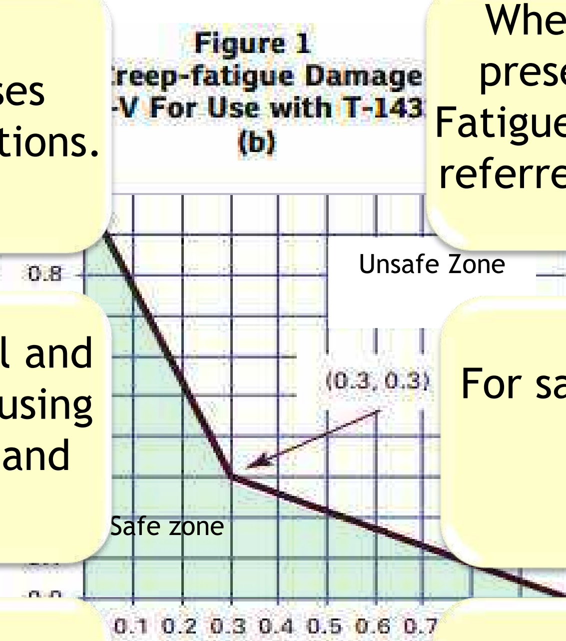
BCOPS successfully reduce fluctuations of steady state error of process values related combustion to Improve Boiler Efficiency.

Boiler Creep & Fatigue Monitoring System for Cyclic Loading

Cyclic loading operation causes temperature & pressure fluctuations.

Fluctuations generates thermal and circumferential stress, thus causing deterioration in the material and reduction in life.

For materials operating at high temperatures for long time, life is reduced due to creep stress.



Fatigue damage ratio

ASME BPVC.CC.NC-2015 Case N-

All Co-ordinate must lie v
safe zone to avoid failure

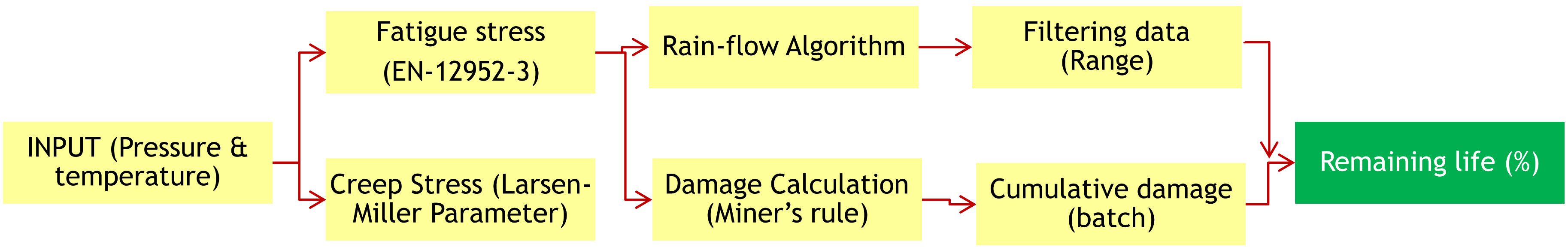
When fatigue & creep stress are present combinedly, then Creep-Fatigue Interaction curve is generally referred for assessment of remaining life.

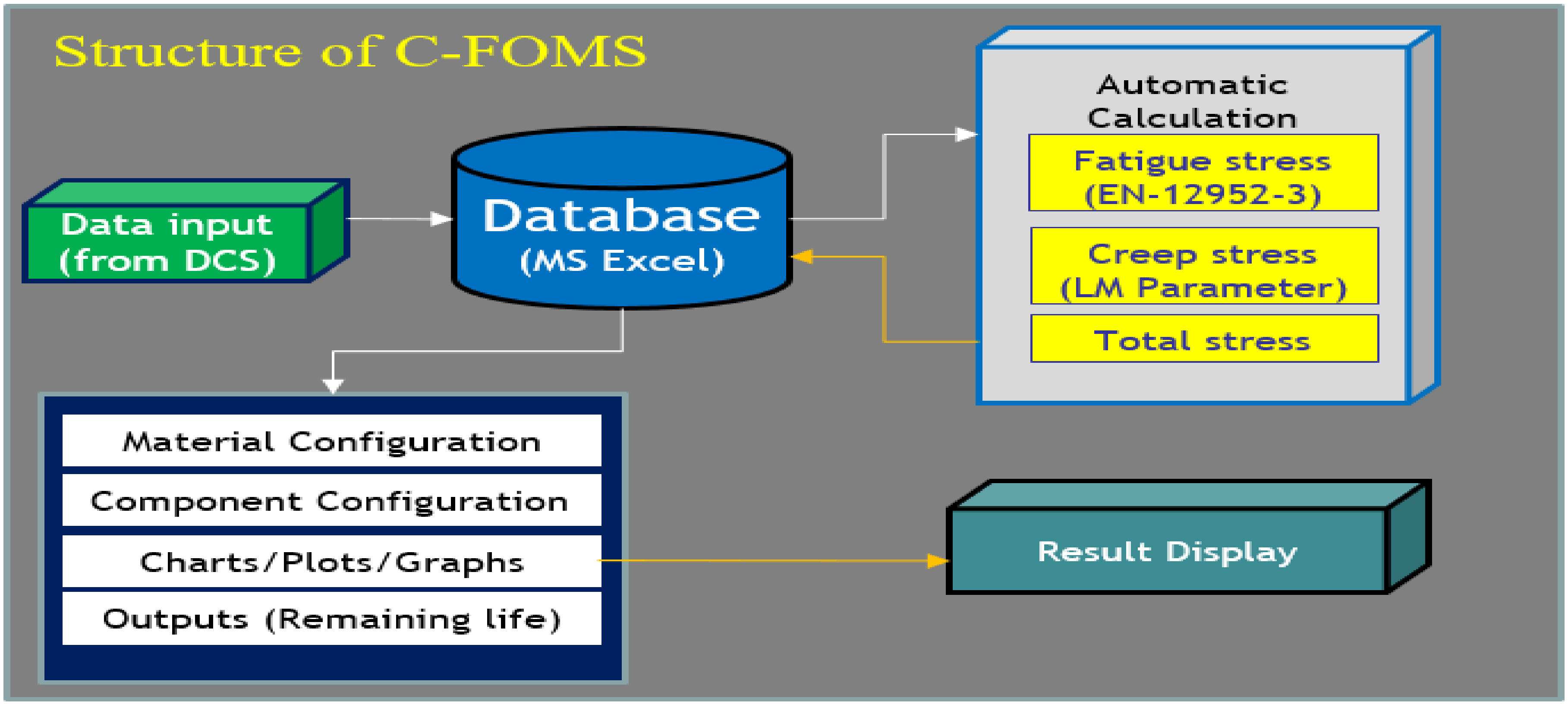
For safe operation,
Fatigue damage ratio <1
Creep damage <1

Fatigue damage ratio & creep damage ratio are determined to assess the damage / remaining life.

Assessment of damage/remaining life becomes important for such materials which operate under fluctuating loads and are exposed to high temperature altogether.

Boiler Creep & Fatigue Monitoring System CFOMS

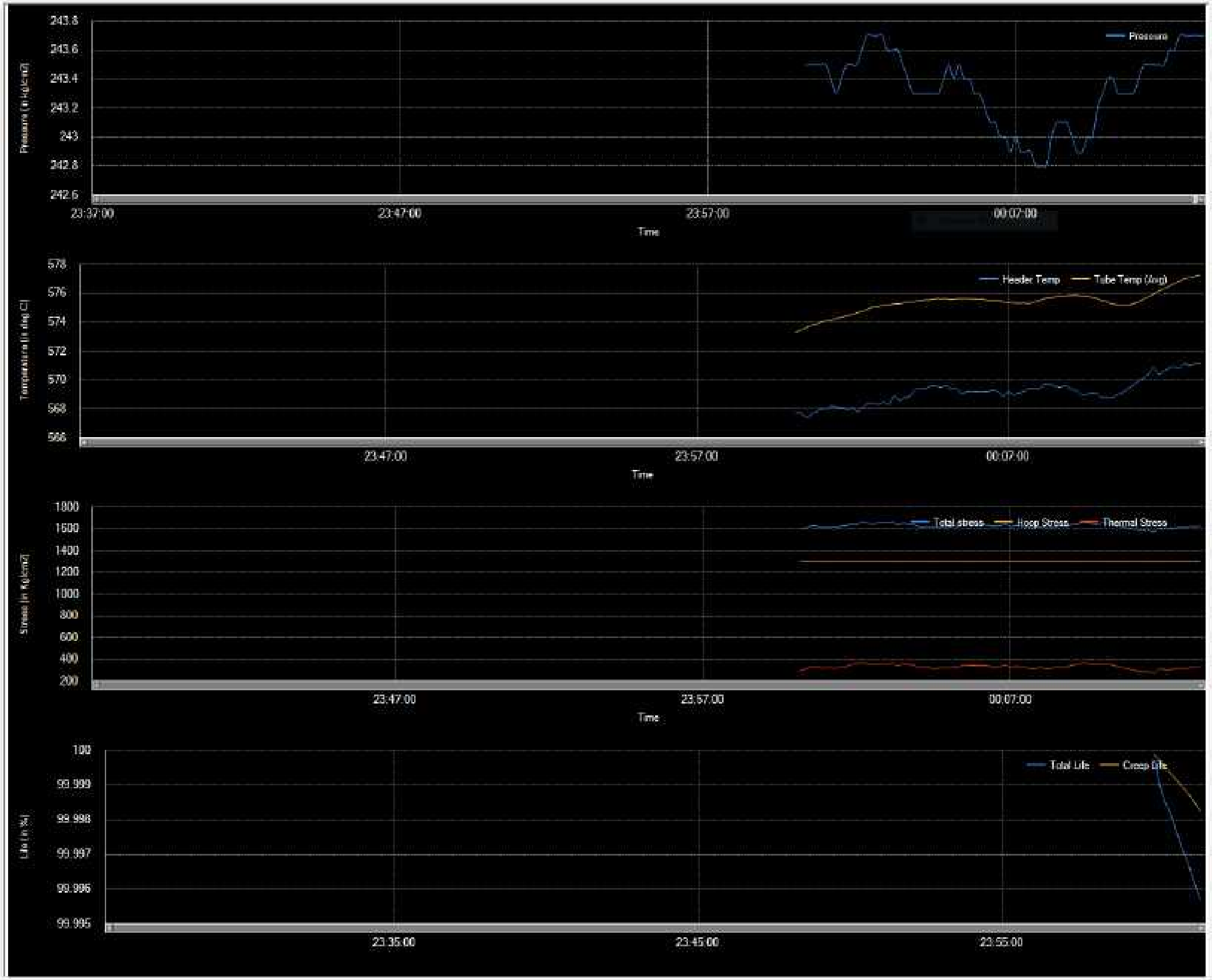




Boiler Creep & Fatigue Monitoring System CFOMS

CREEP-FATIGUE ONLINE MONITORING SYSTEM

BOILER | 2RH | 2SH | 3SH | WS | CRH HDR | HRH BEND | MS BEND | CREEP-FATIGUE GRAPH



User - Admin

20 March 2020 000 00:07:57

PLANT OPERATING STATUS

COMPONENTS	STRESS [kg/cm2]	REMAINING LIFE [%]	[Years]
2RY RE-HEATER	-	-	-
2RY SUPER HEATER	1722	99.9961326	24.999
3RY SUPER HEATER	2009	100	25
WATER SEPERATOR	1623	99.9735	24.993
CRH HEADER	-	-	-
HRH BEND	-	-	-
MS BEND	-	-	-

Plot Graph | Pause | Resume

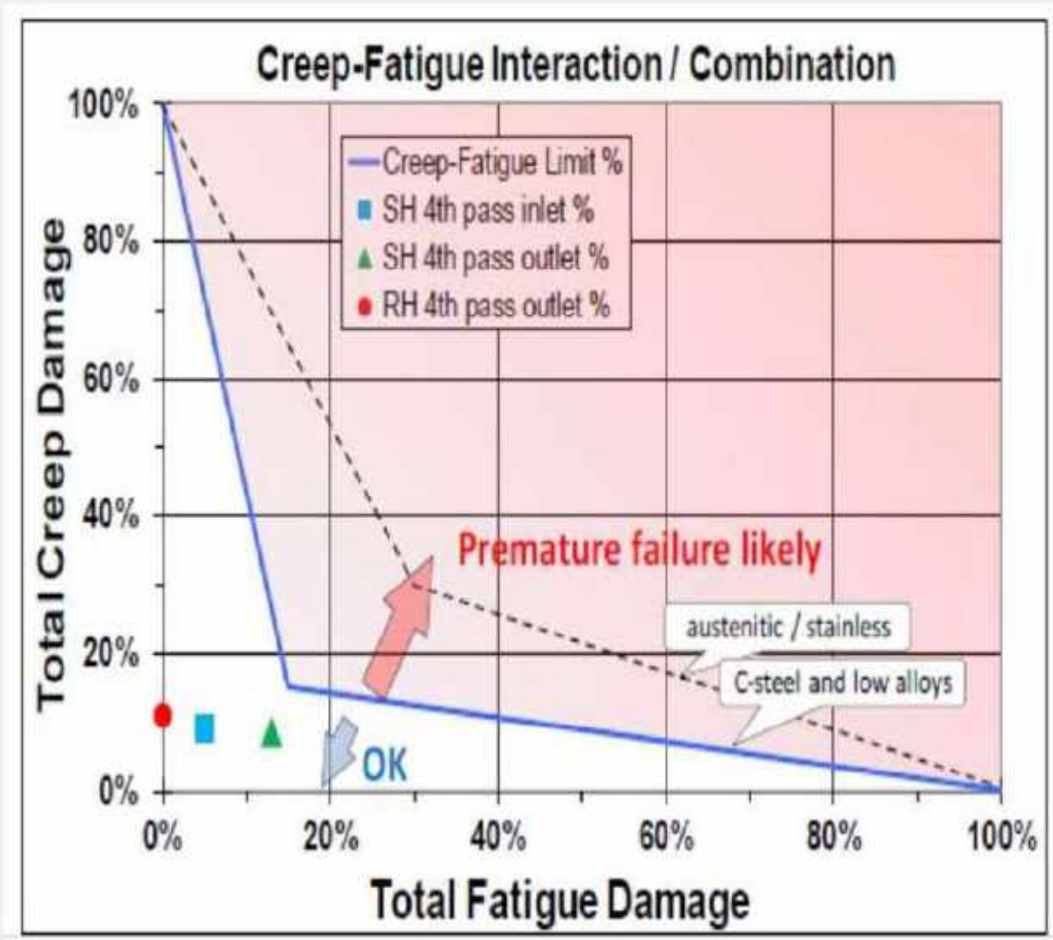
Plotting is in Progress

2RY RE-HEATER :- Not Added
2RY SUPER HEATER :- OK
3RY SUPER HEATER :- OK
WATER SEPARATOR :- OK
CRH HEADER :- Not Added
HRH BEND :- Not Added
MS BEND :- Not Added

Features of Boiler CFOMS

CREEP-FATIGUE ONLINE MONITORING SYSTEM

BOILER | 2RH | 2SH | 3SH | WS | CRH HDR | HRH BEND | MS BEND | CREEP-FATIGUE GRAPH



User - Admin
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PLANT OPERATING STATUS

COMPONENTS	STRESS [kg/cm2]	REMAINING LIFE [%]	REMAINING LIFE [Years]
2RY RE-HEATER	-	-	-
2RY SUPER HEATER	1722	99.9961326	24.999
3RY SUPER HEATER	2009	100	25
WATER SEPERATOR	1623	99.9735	24.993
CRH HEADER	-	-	-
HRH BEND	-	-	-
MS BEND	-	-	-

Plot Graph | Pause | Resume

Plotting is in Progress

2RY RE-HEATER :- Not Added
2RY SUPER HEATER :- OK
3RY SUPER HEATER :- OK
WATER SEPARATOR :- OK
CRH HEADER :- Not Added
HRH BEND :- Not Added
MS BEND :- Not Added

Features of Boiler CFOMS

Real time calculation
Fatigue stress, creep stress, total stress & continuous monitoring of remaining life of components.

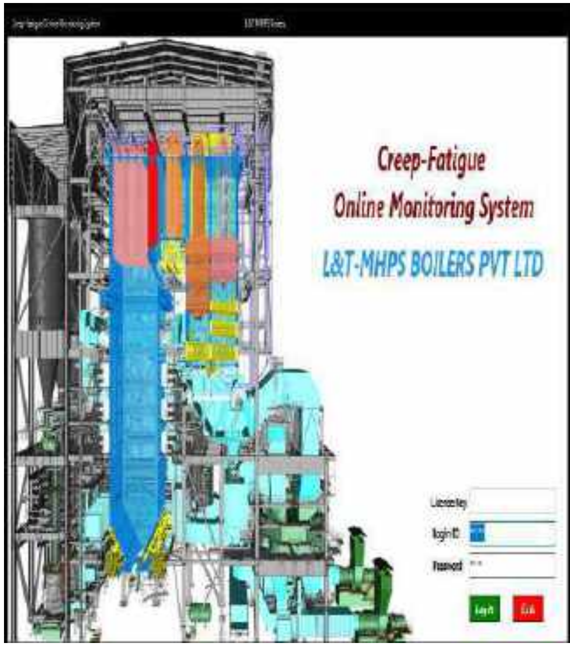
Alert/warning signal
When load fluctuation is beyond design data, a pop-up exhibits.

Error handling
In case input values are beyond design values, the program exhibit error signal.

Graphs
Data displayed in graphs in real-time.

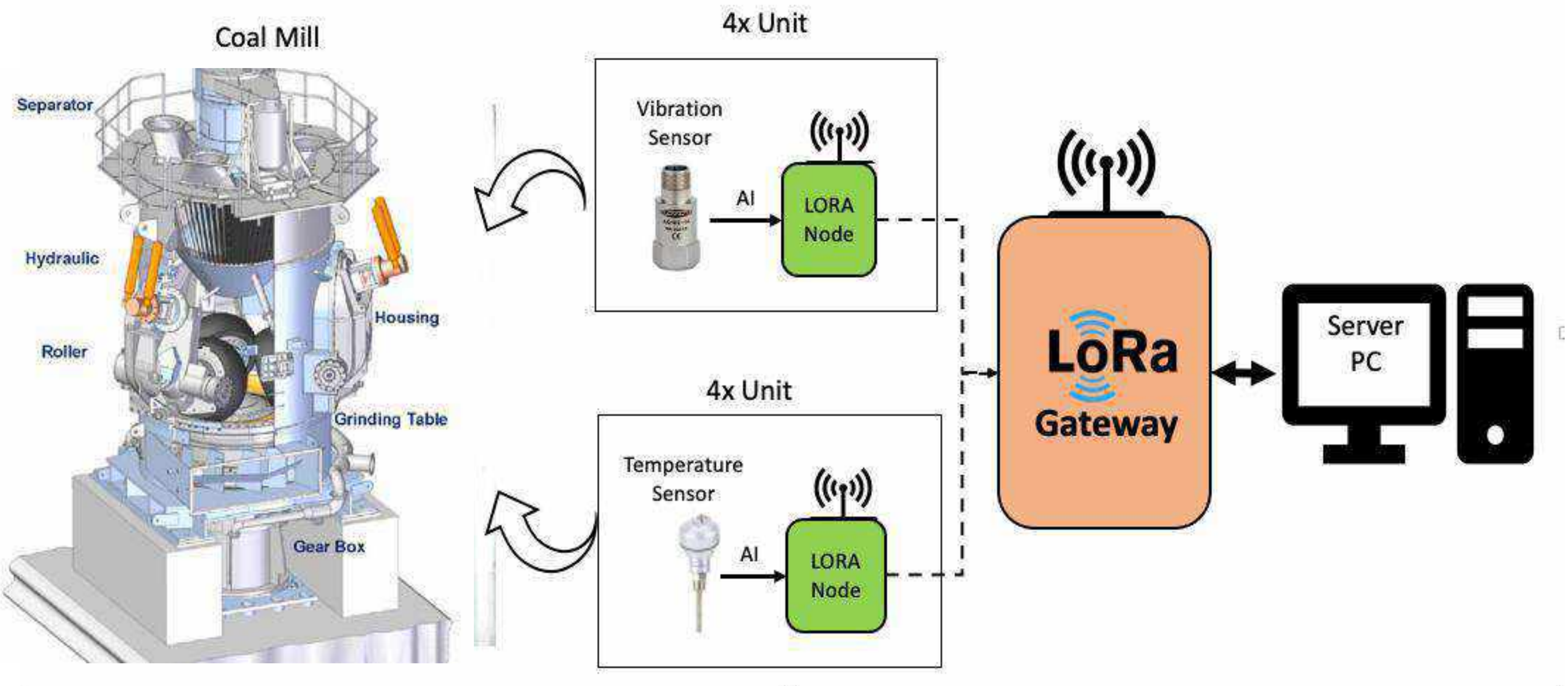
Restarting the program:
In case desktop is shutdown or plant is shut down, C-FOMS program will start from the previous value of remaining life.

Creep-Fatigue interaction:
Creep-fatigue interaction curve will be implemented for each component from ASME Section III-Div. 5



Overview of Digital Twin of Coal Mill

- Ability in developing Generic Mathematical Model using AI & ML for prediction of mill response under varying coal flow/coal characteristic/operating parameters with an objective of keeping minimum differential pressure across it maintaining mill outlet temperature so that the boiler response can be improved under flexible operation



Digital Twin of Steam Trap Management

Problems with Steam Traps

- •High Failure Rate:15-20% fail each year (US department of energy)
- •Cost of Leakage Failure: Most fail open and leak dry steam which cost 1600/ton. Industries having 1000 traps can have estimated steam loss worth up-to 2 Cr annually
- •Cumbersome Manual Methods: No real-time awareness of trap condition and manual measurement are done quarterly or bi-annually
- •Safety and Efficiency Concerns caused by Condensate Blocking: If condensate is allowed to collect in the pipelines, it reduces the flow capacity of steam lines and lead to “water hammer "with potentially dangerous and destructive results
- •Boiler Down times: Loss of money caused due to boiler downtimes that may be caused due to water hammering

Overview of Digital Twin of Steam Trap Management

LoRaWAN865-867 MHz (Free ISM Band)

Range Upto2 km in free line of sight

Battery operated ~ 3-4 years

Data every 4 hours

Way Forward

Digital Solutions- Application of Immersive 3D Digital Twin & Advanced Control

Era of Digital transformation and Digital Twins are key enabling technologies which is accelerating in Energy industries and are pursuing opportunities for transforming plant operations to

- Increase efficiency, productivity, and profitability
- Reduce downtime,
- O&M costs and emissions
- R&D in advanced process control and optimal sensor network design
- Improved plant operational flexibility

Way Forward

- Two Shift Operation of supercritical plants (5hrs on bar) may not be required, as the units can operate on house load with HP bypass operation without any oil support(around 30%-40% load)
- Variable Pressure Operation with Pure Sliding / Modified Sliding Mode (Preferred)
- Load Ramp up or Ramp down rate of 3%-5% per Minute from 50% to 100% load range
- Ramping down from 100% to 50% load with 100% per Minute during Runback condition
- Ramping down from 100% to House load with 200% per Minute under load rejection

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