A Presentation on

EIDM: REAL TIME PERFORMANCE IMPROVEMENT FOR A THERMAL POWER PLANT USING ARTIFICIAL INTELLIGENCE TECHNIQUES

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**NEED:** Power Plant process Dynamics is complex Nonlinear relationship of multiple variables continuously changing

...... and greatly Impact combustion and HR.

### Controllable
- Excess O2
- WB DP
- Mill Biasing

### Disturbances
- Different Operators
- Coal Quality
- Instrument drift / Failure
- Equipment conditions
- Ambient condition
- Weather, humidity

For δ improvement in existing good performing NTPC units, require above complexity / nonlinearity to be understood and resolved in real time and provide a standard solution for unit operation

**AI is the answer to this**
System Overview

- Artificial Intelligence based real time optimizer

- Real time generation of operator advisory for controllable parameters for optimized Boiler efficiency while maintaining steam temperatures and other constraints and thereby effecting overall unit heat rate

- Incorporates ANN based plant models and genetic algorithm (GA) based optimizer ensuring global optima

- Self learning feature for models to be in sync with current plant operating regime

- Artificial Intelligence based power plant data rectification and reproduction system using advance pattern recognition technique

- Provides boiler efficiency and TG heat rate in real time without any coal and ash sample

- Can be customized according to specific plant needs
“Artificial Intelligence is an area of computer science concerned with designing intelligent computer systems, that exhibit the characteristics we associate with intelligence in human behavior. AI is a science that is concerned with automation of intelligent behavior.”

- Inspired by nature
- An alternative way to tackle complex, nonlinear and dynamic problems
- Learn from examples (data), and once trained can perform prediction and generalization at high speed
- Robust and tolerance to uncertainty and imprecision
- Inherently Parallel in nature hence fast and reliable
- Adaptability to changing conditions
- Faster, Low Cost and reliable solutions

Artificial Intelligence is an alternative, robust and cost effective way to tackle complex, highly nonlinear modeling and optimization problems which either is way to costly or simply not possible by traditional means
Energy Intensification and Diagnostics Model (EIDM)

AI

Artificial Neural Network
Intelligence from Data

Fuzzy Logic
Intelligence from human experience

Metaheuristic Search
Intelligence from Nature

Hybrid
Intelligence from combination

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**Neural Networks**, which are simplified models of the biological neuron system that have the ability to learn and thereby acquire knowledge and make it available for use.

**Features:**
- Can map input patterns to their associated output patterns.
- Can predict new outcomes from past trends.
- Can recall full patterns from incomplete, partial or noisy patterns.
- Parallel, high speed and distributed processing.
- Stability vs. Plasticity Dilemma

**Artificial Neuronal Networks (ANN)**

![Biological Neuron](image1)

![Feed-forward Artificial Neural Net](image2)
ANN: Self Organizing Maps

- An unsupervised means of learning ANN primarily used for pattern recognition.
- The basic Self-Organizing Map (SOM) can be visualized as a sheet-like neural-network array in which neurons are loosely coupled with a neighbourhood function.
- The cells (or nodes) are specifically tuned to various input signal patterns or classes of patterns in an orderly fashion.
- SOM can be used as a powerful visualization tool as it clusters the multidimensional input space into well defined regions by projecting into two dimensional space.
- SOM has been used in development of data validation system.
**Soft Sensor by Function approximation**
Supervised learning can be used to build alternative solution for various hard sensor. Applied mainly for Nox measurement, Unburned carbon in ash, FEGT measurement, TIT measurement etc.

**Modeling**
ANN models for objective function or constraint can be build in MIMO or MISO form which can be used for controller design or optimization.

**Pattern recognition for classification**
ANN can be used for recognizing sound, image or video even without prior information using unsupervised learning. This can also be used validation of data and gross error removal. Important application, real time data validation, flame image processing, sound or vibration recognition.

**Optimization**
ANN can directly be applied to carry out real time online optimization mainly by reinforcement learning in which process learn from environment and approach to most optimal solution.
Genetic Algorithms

- Developed in the early 1970 by John Holland is a random, unorthodox search and optimization algorithms. Inspired from the Darwin’s principle “Survival of the fittest”.
- It follows two simple principles of nature:
  1. If by genetic processing an above average offspring is created, chances of its survival are higher than an average individual and thus have more opportunities to produce children having some of its traits.
  2. If, on the other hand, a below average offspring is created, it does not survive longer and thus gets eliminated from the population.

Features:
- Search and optimization process where
  1. Search space is large with many dimensions or
  2. Obj. fun is discontinuous or
  3. Where gradient calculation is not possible or
  4. Obj. fun. Is not known in mathematical form
- Massively parallel in nature
- Provides a robust, efficient and global optimum solution for complex, ill-defined real world problems
- Genetic algorithms need design space to be converted into genetic space, hence particularly suited for computer implementation
EIDM: Problem formulation

- The power plant process complexity and scope of improvement can be identified by defining various disturbances, manipulating variables, and optimization targets.
- ANN learns from these data and once trained, perform prediction for optimization & control.

**Manipulated Variables**
- O2 % Controller
- WB Press (Aux air damp)

**Models Inputs and Outputs**

**Measured Disturbance**
- Boiler Load
- Mill Combination

**Unmeasured Disturbance**
- Coal Quality

**Boiler Model**

**Optimization Targets**
- Boiler Efficiency
- SH and RH Temp
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**Inputs**
- Load
- Frequency
- FW Flow
- Fur-WB DP
- PA Hdr Press
- HP Ctrl vlv pos
- HRH O/L Temp
- CW I/L Temp
- MU Flow

**NN Inputs** (Controllable & Uncontrollable)

**Real time Data set** For self learning

**GA Optimizer**

**Controllable set point**

**Constraints**

**Real time Operator Advisory**

**Outputs**
- SH O/L Temp-L/R
- RH O/L Temp-L/R

**EIDM: System Architecture**

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1. Identification of Test parameters and range

2. Instruments relocation, addition and validation

3. Finalization of Test matrix

4. Conduct of test

5. Online and offline data collection and calculation

6. Model Building

7. Model optimizer, and data validation module building

8. GUI development and packaging
EIDM: Testing and data collection

• Base Line Testing

• Testing with varying controllable parameters to their extremes for given operating conditions. e.g. O2% is varied from 2.5% to 4.5% in different mill combinations for full load and part load

• Base line conditions + Mill Biasing

• Total 79 tests were conducted.

• Data was collected covering all seasonal variations

• For upgrading models in the face of changing plant conditions data is continuously collected in Backend for building database

• Periodic Retraining of models is done to ensure models are up-to-date according to plant conditions
**EIDM: Model Building**

**Model Info**

- **No. of Neural Net Models:** 8 (outputs and constraints) MISO Type with 62 inputs
- **Total Data Set:** 1510 data points (1200 after outlier removal using statistical filtering mechanism)
- **ANN Topology:** Multi-layer feed-forward networks with multiple hidden layers
- **Training Method:** Back-propagation Training with advance complex training procedure

**Training Results**

<table>
<thead>
<tr>
<th></th>
<th>Boiler Eff.</th>
<th>Model1</th>
<th>Model2</th>
<th>Model3</th>
<th>Model4</th>
<th>Model5</th>
<th>Model6</th>
<th>Model7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Train</td>
<td>99.6%</td>
<td>98.2%</td>
<td>97.9%</td>
<td>96%</td>
<td>98.4%</td>
<td>98%</td>
<td>96.3%</td>
<td>98.9%</td>
</tr>
<tr>
<td>Test</td>
<td>99.3%</td>
<td>97.1%</td>
<td>97.2%</td>
<td>95%</td>
<td>97.2%</td>
<td>97.1%</td>
<td>95.1%</td>
<td>97.8%</td>
</tr>
</tbody>
</table>

**Actual Vs Predicted Boiler Eff. for Test Data**

![Graph showing Actual Vs Predicted Boiler Efficiency for Test Data](image)
EIDM: Data Validation Module

“A user friendly package, detect and rectifies sensor failure and allows continuous operation of any real time modeling and optimization software “

Data Validation Package
- Intelligent data detection and rectification using advance pattern recognition technique.
- Validation on PI Server / DCS in real time
- Detection of corrupt / biased data and its rectification into plausible value
- Reconcile the data by mass and energy balance around any equipment
- Able to retrained online as per current plant operating regime

- Such modular package is not commercially available for utility.
- Can be connected with PI Server or DCS for any application and NTPC wide can be deployed.

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### EIDM: Data Validation Module Results

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>Biased Value</th>
<th>Actual Value</th>
<th>Rectified Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feed Water Temperature (°C)</td>
<td>218.45, 235.72, 235.24, 235.79</td>
<td>238.45, 255.72, 255.24, 255.79</td>
<td>238.5, 255.7, 255.4, 255.8</td>
</tr>
<tr>
<td>2</td>
<td>Total Coal Flow (TPH)</td>
<td>256.20, 345.87, 350.35, 360.35</td>
<td>226.20, 315.87, 320.45, 330.35</td>
<td>224.17, 321.89, 325.10, 333.70</td>
</tr>
<tr>
<td>3</td>
<td>Total Secondary Air Flow (TPH)</td>
<td>1417.66, 1223.08, 1240.7</td>
<td>1377.66, 1183.08, 1200.78</td>
<td>1376.7, 1190.1, 1194.8</td>
</tr>
</tbody>
</table>
EIDM: Data Validation Module Screenshot
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## EIDM: Testing & Validation

<table>
<thead>
<tr>
<th>S. NO.</th>
<th>Date/Time</th>
<th>Present Con.</th>
<th>Recomm. Followed</th>
<th>Obtained Cond.</th>
<th>Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>05/03/2011 10:15 AM</td>
<td>Boiler Eff: 86.6 TGHR: 2052 UHR:2367</td>
<td>WB Pr: 85(\rightarrow) 91.1 mmwc</td>
<td>Boiler Eff: 86.68 TGHR: 2048 UHR:2362.6</td>
<td>Improvement in boiler efficiency and GTCHR was observed, further investigations and validations are in progress to correlate the results</td>
</tr>
<tr>
<td>2*</td>
<td>25/08/2011 04:55 PM</td>
<td>Boiler Eff: 86.8 TGHR: 2086 UHR:2380</td>
<td>O2 %: 3.85(\rightarrow) 3.4</td>
<td>Boiler Eff: 87.8 TGHR: 2074 UHR:2362</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10/01/2012 3:30:51 PM</td>
<td>Boiler Eff: 86.29 TGHR: 1994 UHR:2310.8</td>
<td>WB Pr: 87(\rightarrow) 78 mmwc Burner Tilt 60(\rightarrow)64</td>
<td>Boiler Eff: 86.37 TGHR: 1984 UHR:2297</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>24/01/2012 5:00 PM</td>
<td>Boiler Eff:86.986 TGHR: 1989.5 UHR:2287</td>
<td>WB Pr: 75.6(\rightarrow) 72 mmwc Burner Tilt 50(\rightarrow)55 FAD 25(\rightarrow)35</td>
<td>Boiler Eff: 87.1 TGHR: 1979 UHR:2273</td>
<td></td>
</tr>
</tbody>
</table>

* Part Load
Conclusions

• The system developed can be used as an effective tool for plant operation for optimizing the combustion process for real-time Unit HR improvement.

• The System can be customized to meet specific plant needs such as imbalance in left right temperatures, large sprays, large variation in GCV etc.

• In the era of strict environment norms, Coal scarcity, and advent of PAT regime such systems can benefit NTPC and other utilities.

• Having golden data of plant process, huge experience in O&M practices and competency in developing Intelligent systems, development and maturing of such system is no longer an issue.

• The Most important aspect of data driven approach is good quality data for model building which is specific to a particular station, hence quality data and reliable availability is to be ensured.
Thank you