Power Plant Thermodynamic Performance Monitoring

National Energy Efficiency Conference
September 2012
Agenda

• Performance Monitoring Objective
• Performance Monitoring Methodology
• Examples of Issues Identified
• Case Studies
• Experience Establishing a PM Program
• Alignment to ISO 50001 EMS
Introduction of Tuas Power

- 2 x 600 MW oil fired steam plants, Unit 1 & 2
  - Mar & Dec 99

- 2 x 367.5 MW gas fired combined cycle plants, CCP 1 & 2
  - Nov 01 & Jan 02

- 2 x 367.5 MW gas fired combined cycle plants, CCP 3 & 4
  - Jul 05 & Sep 05

Installed capacity - 2,670 MW
Performance Monitoring Objective

- Facilitate Operational Adjustments and Corrective Maintenance to ensure plant operates at optimum thermal efficiency.
- As fuel is a substantial part of power generation cost, small gains in thermal efficiency could achieve significant fuel savings.
- Enable advance maintenance planning to restore degraded performance of plant components.
Performance Monitoring Objective

Singapore 2009 Primary Fuel and Electricity Consumption

Kilo Tons Oil Equivalent

- Primary HC Fuel
- Others
- Domestic
- Commerce
- Industry
- Transport
- Industry, Commerce, Households
- Power Plants
Performance Monitoring Objective

- Proactively identifying the plant sections that have degraded performance
- Quantifying the degradations in terms of effect on overall plant efficiency
- Enabling a condition based predictive maintenance program to set and prioritize maintenance activities that will minimize degradation and hence maximize efficiency
Performance Monitoring Objective

<table>
<thead>
<tr>
<th></th>
<th>Nov 06</th>
<th>Dec 06</th>
<th>Jan 07</th>
<th>Feb 07</th>
<th>Mar 07</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT Compressor Fouling</td>
<td>0.051%</td>
<td>0.150%</td>
<td>0.320%</td>
<td>0.423%</td>
<td>0.030%</td>
</tr>
<tr>
<td>BFP Inefficiency</td>
<td>0.012%</td>
<td>0.020%</td>
<td>0.025%</td>
<td>0.026%</td>
<td>0.026%</td>
</tr>
<tr>
<td>LP Bypass</td>
<td>0.300%</td>
<td>0.320%</td>
<td>0.288%</td>
<td>0.310%</td>
<td>0.310%</td>
</tr>
<tr>
<td>HP Bypass</td>
<td>0.150%</td>
<td>0.150%</td>
<td>0.150%</td>
<td>0.150%</td>
<td>0.150%</td>
</tr>
<tr>
<td>Condenser Fouling</td>
<td>0.085%</td>
<td>0.092%</td>
<td>0.224%</td>
<td>0.225%</td>
<td>0.225%</td>
</tr>
<tr>
<td>IAF Pressure Drop</td>
<td>0.005%</td>
<td>0.022%</td>
<td>0.033%</td>
<td>0.054%</td>
<td>0.054%</td>
</tr>
<tr>
<td>Actual Efficiency</td>
<td>50.300%</td>
<td>50.100%</td>
<td>49.800%</td>
<td>49.700%</td>
<td>50.040%</td>
</tr>
</tbody>
</table>

Note: Figures in this chart are fictitious to maintain data confidentiality.
To make a Complete Heat and Mass Balance

Establishing current performance level of individual components and total system

Establishing the benchmark for the individual component and for total system

Set targets for improvement/maintenance
Performance Monitoring Methodology

**GT**
- GT Power Generation
- GT Comp Eff.
- GT Turbine Eff
- GT Heat rate
- IAF performance

**HRSG**
- HRSG Effectiveness
- Duty of individual heat transfer components

**Steam Turbine**
- HP Turbine Power
- IP Turbine Power
- LP Turbine Power
- HP/IP/LP Turbine Eff

**Condenser**
- Condenser Water Flow
- Condenser Duty
- Condenser effectiveness

**Auxiliaries**
- CWP Performance
- BFP Performance
- CEP Performance

**Distribution**
- Valve passing
- Line Loss

**CCP Power Station**
Performance Monitoring Methodology
Performance Monitoring Methodology

- Complete quantification of all streams in a power plant eg flue gas, cooling water, steam and fuel flows
- Establish the present performance level of the individual equipment eg efficiency, heat transfer coefficients, leakages
- Enables data validation
  - Measured values can be compared against the heat balance output for validating the accuracy of measurement.
Performance Monitoring Methodology

Modeling Application

- To make a Complete Heat and Mass Balance
- Establishing current performance level of individual components and total system
- Establishing the benchmark for the individual component and for total system
- Set targets for improvement/maintenance
Performance Monitoring Methodology

Each piece of equipment modeled **separately** to match **guaranteed** data, then read by overall model.

- **GT** uses curves or spreadsheet data
- **ST model** matches ST vendor
- **HRSG** matches HRSG vendor
- **COND** matches HEI/condenser

Diagram:
- GT
- ST model
- HRSG
- COND
Performance Monitoring Methodology

- Construct software models of the plant components tuned to design performance
- New & Clean performance is the benchmark

<table>
<thead>
<tr>
<th>Component</th>
<th>Inputs</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Turbine</td>
<td>Ambient Temp, Press, Load</td>
<td>Heatrate</td>
</tr>
<tr>
<td>HRSG</td>
<td>GT Exh Flow, Temp</td>
<td>HP, IP, LP steam Stack Temp</td>
</tr>
<tr>
<td>Condenser</td>
<td>LPST Exh Flow, Enthalpy, Cooling Water Flow, Temp</td>
<td>Vacuum</td>
</tr>
</tbody>
</table>
Examples of Issues Identified

- Lost of efficiency after MI due to IGV reprogramming
- Boiler Feed Pump minimum flow recycle valve passing
- Identification of Passing HPST Bypass Valve
- FW Preheater Bypass Valve passing
- Selection of Optimum Inlet Air Filter
- Condenser Cooling Water Optimization
- Condenser Cooling Water Debris Filter Choke
- HPST Bypass Spray Valve Passing
- HRSG HP and RH Spray Valve Passing
- Condenser Air Ingress
- Condenser Tube Fouling
Case Study : FW Preheater Bypass

Condensate Extraction Pump
Flue Gas Inlet
Feed water Preheater
Preheated Water To Deaerator
Bypass Valve
Flue Gas to Stack
Passing Valve
V-1
Case Study: FW Preheater Bypass

Stack temp Vs Feedwater Preheater Temperature

(Actual) / (New and Clean Performance)

Valve Repaired
Case Study: Cond Debris Filter Choke

- Condenser cooling water flow dropped in June 2011 and it is because B side water path was choked.
- Transmission shaft gear of debris filter was replaced with a new one during July 2011 shutdown. Condenser cooling water flow resumed back.
Case Study: Condenser Air Ingress

- Condenser performance was very poor in Q1 and Q2 2007 (Condenser Pressure ACT/NC is very high). It was then found out that the vacuum pump sealing strainer was clogged and the pump was running with less sealing water. After it is rectified, the Condenser performance has improved significantly.

Condenser Press ACT/NC

Condenser Air Ingress Solved
Experience Establishing a PM Program

- 2003 engaged ACTSYS for thermodynamic analysis of MHI GT performance
- 2004 – Present, annual Performance Monitoring contract with ACTSYS on all CCPs
- Quarterly reporting and presentations, review performance gaps and required corrective actions
- Involvement of Maintenance, Equipment specialists, Instrumentation, Operations
- Close working relationship where ACTSYS engineers track plant performance and correlates findings to operational and maintenance events
Experience Establishing a PM Program

- Operations & Maintenance
- Plant Data
- Plant Info System
- Data Reconciliation
  - Heat Balances
  - Performance Models
- Theoretical Analysis & Interpretation
- Reports
- Presentation & Discussion of Results
- Discussion Points
- Decision Support
Alignment to ISO 50001 EMS

ISO 50001 EMS

- Energy policy
- Planning
- Implementation and operation
- Checking
- Monitoring and measurement
- Corrective and preventive action
- Continual improvement
- Management review
- Internal audit

Implemented PM System

- TP Mgmt provides the framework for setting and reviewing energy objectives and targets
- Allocating resources and setting up of a methodology for analyzing energy usage
- Operating and maintaining systems and equipment, in accordance with operational criteria
- For all Energy Performance Indicators review non-conformities => check Actual versus “New & Clean”
- Quarterly Performance Review Meetings
- Determining and implementing the appropriate action needed
GT SHAFT POWER (34.23%)
INLET AIR (1.45%)
HP STEAM (34.39%)
HP TURB POWER (2.18%)
LP TURB POWER (10.87%)
CONDENSER LOSS (33.53%)
HP TURB POWER (6.68%)
LP TURB POWER (10.87%)
RADIATION LOSS (0.06%)
RADIATION LOSS (0.09%)
RADIATION LOSS (0.04%)

COMBUSTOR LOSS (0.49%)
SHAFT POWER

COMPRESSION WORK (97.32%)
FOUR-VALVE LEAKAGES (1.00%)
CHEMICAL ENERGY (97.32%)
SHAFT POWER 

RADIATION LOSS (0.06%)
RADIATION LOSS (0.09%)
RADIATION LOSS (0.04%)

COMPRESSOR WORK (97.32%)

ROTOR COOLING LOSS (2.09%)

CHEMICAL ENERGY (97.32%)

FUEL SENSIBLE HEAT (100%)

Thank you