Plant Management, Engineering & Operations Conference, Roundtable and Mine Tour

August 1-2, 2018
San Juan College
Farmington, NM

Instructed by:
Tom Reid, Manager of Engineering, TG Advisers
Gary Ruhl, Manager, Fuels & Technical Services, Omaha Public Power District
Jake Schmitter, Sr. Manager, Training & Exercises, Electricity Information Sharing and Analysis Center
Ryan Walter, Compliance Analyst, Tri-State Generation & Transmission Association
Thomas Livingston, Plant Manager, Four Corners Power Plant, Arizona Public Service
Bill Paiz, Power Production Engineer V, PNM Resources
Saul Macias, Power Production Engineer, PNM Resources
Phil Duran, Sr. Director, Business Operations, Tyr Energy, Inc.
Brad Buecker, Sr. Technical Publicist, ChemTreat
and actions being pursued will be summarized. The evolving energy markets are driving these changes in an effort for sustained viability of core generating assets.

10:00 a.m. - 10:15 a.m. Networking Break

10:15 a.m. - 11:00 a.m. GridEx IV After Action Report and Lessons Learned
Jake Schmitter, Senior Manager, Training & Exercises, Electricity Information Sharing and Analysis Center

The presentation will go over the GridEx IV background information: scenario, participation metrics and exercise construct. The lessons learned portion will highlight known issues, incident response gaps identified within the Electricity Industry and ways forward for GridEx V.

11:00 a.m. - 11:45 a.m. Low Impact Generation CIP Compliance
Ryan Walter, Compliance Analyst, Tri-State Generation & Transmission Association

This presentation will cover NERC Low impact compliance in its entirety for Generation facilities. Mr. Walter will discuss the evolution of the CIP standards through the years and the introduction of the High, Medium, and Low classifications. He will cover what specifically is required by the regulation CIP-003-7 for Low impact assets. Finally, he will discuss and show what Tri-State has done or will be doing to comply with the requirements.

1:00 p.m. - 1:45 p.m. Physical Security (Suspicious Package Handling)
Thomas Livingston, Plant Manager, Four Corners Power Plant, Arizona Public Service

1:45 p.m. - 2:30 p.m. NERC BAL-003 – Frequency Response Impacts on Plants
Bill Paiz, Power Production Engineer V, and Saul Macias, Power Production Engineer, PNM Resources

Frequency response has been a WECC requirement for generators for several years. Over the last two years, the issue has become more critical because of the transition of conventional boiler-fired generating units to renewables (wind and solar) so a NERC standard was developed to address this issue. The new standard defined the required frequency response required for each control area. The renewables do not have the stored energy required to support the frequency excursions. All older generator control systems have been installed with automatic drop control which provides for frequency stability. With the addition of state-of-the-art control systems, this has become a challenge because these new control systems were designed for set point control. During a frequency excursion, the new control system would override the drop control thus driving the unit back to set point. In our presentation, we will demonstrate how PNM overcame those control issues.

2:30 p.m. - 2:45 p.m. Networking Break

2:45 p.m. - 3:00 p.m. Attendee Announcements
Any registered attendee is invited to make a short announcement on their company, new products, technologies or informational updates. Announcements may include showing a product sample but not videos and power point slides. Please limit announcement to 5 minutes.

3:00 p.m. - 3:30 p.m. Four Corners Plant Overview
Thomas Livingston, Plant Manager, Four Corners Power Plant, Arizona Public Service

3:30 p.m. - 4:30 p.m. Generation Vital Issues Roundtable
Bring roundtable topics for discussion and/or send topics ahead of time to jamessakamoto@rmel.org.

Roundtables offer a unique forum for peer-to-peer sharing of experiences, critical issues and expertise. The roundtable is a discussion group, open only to RMEL members. Discussion is based on topics brought by attendees. Roundtables are focused on the open discussion period and provide each attendee the opportunity for participation and dialogue on their particular issue. Roundtables are held in conjunction with a conference and many topics presented at the conference are discussed further in the roundtable setting. The roundtable is a good opportunity to share experiences, troubleshoot problems and network with peers in a smaller, informal setting. Each participant is offered a chance to pose questions and share information. All attendees are encouraged to bring issues for discussion and materials for sharing.
Combustion Turbine Trends and Technology Advancements
Luke Buntz, Market Research Analyst, Mitsubishi Hitachi
Combustion turbines have evolved significantly since the “bubble” era of the early 2000s. Turbine technologies have been shaped by fuel prices, regulation and OEM competition for market share. This presentation will discuss the evolution of the combustion turbine (D/E class to modern-day Advanced class), recent historical market trends, market outlook and the technical advancements that have made current performance levels possible.

Reciprocating Engines - Flexibility for Peaking Operations and Black Start
Phil Duran, Sr. Director - Business Operations, Tyr Energy, Inc.
Certain engines provide great flexibility for generators given the small (~9MW) increments with which power generation can be brought online. Such flexibility is particularly helpful in a black start scenario when small incremental loads and generation need to be sequenced while recovering stably from a black grid.

Networking Break

Steam Generation and Water Treatment Chemistry - Lessons Learned and Emerging Technologies
Brad Buecker, Senior Technical Publicist, ChemTreat
Water/steam chemistry control and monitoring are critical issues with regard to steam generating plant reliability, availability, and most importantly, employee safety. But many experienced power plant personnel are retiring, and are taking valuable information with them. Furthermore, new combined cycle plants are often minimally staffed, where plant personnel have little knowledge and time to deal with critical chemistry issues. This presentation discusses a number of the most important aspects of steam generation chemistry control, including the severe difficulties that may be encountered from operation with condenser tube leaks, eliminating oxygen scavenger use in any unit that does not have copper alloys in the feedwater system (virtually all heat recovery steam generators), the criticality of high-purity steam, and the importance of corrosion prevention during layups. The paper also highlights some other evolving issues in the power industry, including a major shift in cooling tower treatment chemistry, and the increasingly common selection, and challenges posed thereby, of alternatives to fresh water as the plant makeup supply.

Generation Vital Issues Roundtable

Meeting the Challenges of Market Transition
Thank You RMEL Generation Committee

CHAIR
Jeff Karloff
Division Manager, Production Engineering & Fuels
Omaha Public Power District

VICE CHAIR
Curt Brown
Associate Vice President, Retrofit and Plant Betterment, Power Generation Services
Black & Veatch Corp.

David Aranda
Plant Manager - Rio Grande
El Paso Electric Company

Matt Ferguson
VP, Client Development Leader
HDR, Inc.

Jeff Kruse
Sr. Director, Coal Generation Operations
CPS Energy

Ed Seal
Director, Design Engineer & Projects
Arizona Public Service

Richard Threet
Director, Power Generation PNM Resources

Kellen Walters
Regional Sales Director
Mitsubishi Hitachi Power Systems Americas, Inc.

Ed Seal
Director, Design Engineer & Projects
Arizona Public Service

John Wester
Director, Power Plant Operations
Austin Energy

Tom Wos
Regulatory Program Administrator
Tri-State Generation and Transmission Assn.

The RMEL Generation Committee plans all RMEL Generation events. If you’d like to send information to the committee, email James Sakamoto at jamessakamoto@rmel.org.
Turbine Troubleshooting and Repair Methods

Tom Reid
Manager of Engineering
TG Advisers
Flexible Operations Impact on Steam Turbine Failure Modes and Best Practices

August 1st, 2018

Thomas R. Reid, P.E.
Manager of Engineering
Tom.Reid@TGAdvisers.com
(302) 691 - 3330

Farmington, NM
Industry Trends

Steam Turbine

– More cycling
  • Two-shifting
– Reduced minimum loads
– Fast Starts
– Re-powering of vintage coal assets
– Higher inlet temperatures
– Combined cycle application

Generator

– Along for the ride!
US Coal Fired Unit
Ultra Minimum Load Operation
# Flexible Operations Impact on Steam Turbine Failure Modes

<table>
<thead>
<tr>
<th>Flexible Operations</th>
<th>Solid Particle</th>
<th>Low Cycle Fatigue Cracking</th>
<th>High Cycle Fatigue Cracking</th>
<th>Rotor Vibration</th>
<th>Stress Corrosion</th>
<th>Water Droplet Erosion</th>
<th>Differential Expansion Rates</th>
<th>Turbine Water Induction</th>
<th>Rotor Bow</th>
<th>Turbine Overgauge</th>
</tr>
</thead>
</table>

## Impacted Components
- HP and LP Early Stage Rotating and Stationary Shading
- Valve Components
- Inner casing
- Rotor blade attachments
- Rotor peripheral surfaces
- Blade Roots
- HP, LP, and Generator Rotors
- Bearings, Potentials, Foundations
- LP Rotor Blade Attachments
- LP Blasting
- LP Seat Grooves
- LP Rotor Disc Faces
- Turbine Rotor and Blades
- Gaing

## Best Practices
- SPE coatings on early stages
- Operate in sliding pressure mode to reduce throttling
- Upgrade blade with components to reduce impingement angles
- Hardface valve components
- Minimize steam to initial mismatch to reduce thermal stresses
- Ensure detailed NOE plan to inspect for cracking
- Optimize hold speeds and times based on rotor NOE findings and crack growth analysis
- Utilize advanced life assessment on cold starts
- Audit operational data to ensure compliance with load and speed limits
- Correct warmup and cooldown
- Vacuum is broken at correct RPM during cooldown
- Set appropriate seal clearances for the mode of operation
- Ensure complete casing insulation on cover and base
- Factor in cold vs. hot alignment differences
- High speed, balance, flexible
- NDE Impact all wet rows for 300 no blade attachments
- Circumferential Gage UTR
- Axial Entry MT of End face
- Pin Frog: Partial blade removal
- Frequency line load vs. load due to expansion
- Complete eddy current inspection of stressed areas
- Smooth out erosion damage and re-tighten the bolt
- High speed, balance, flexible
- Ensure differential expansion instrumentation is calibrated
- Audit existing TIRP protection system and compare to ASME standards
- Upgrade system based on mode of operation
- Overhaul turning gear at each major outage
- Take TIR at major outages and load

## Significant Impact
- Red
## Moderate Impact
- Yellow
## Minor or No Impact
- Green

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STEAM TURBINE FAILURE MECHANISMS
Key Steam Turbine Mechanisms

- **High Cycle Fatigue** – Vibration
- Creep - Steady stress at elevated temperatures
- **Environmental** - Stress Corrosion Cracking (SCC)
- **Low Cycle Fatigue** – Thermal and mechanical Cycling
- **Foreign Object Damage** - Flow path liberation
- Embittlement – Time and temperature exposure
- **Erosion** – Water droplet and solid particle
- **Rubbing** – Axial and Radial
- **Event Driven** – Water Induction, Overspeed

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Minimum Load Considerations

• Primary Failure Mechanisms
  – High cycle fatigue (stall flutter)
  – Solid particle and water droplet erosion

• Secondary Failure Mechanisms
  – Stress corrosion cracking

• Operational Concerns:
  – Turbine differential expansion
  – Increased vibration levels
  – Turbine water induction
  – Boiler issues
  – Overheating at LP exhaust

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Cycling Considerations

• Primary Failure Mechanisms
  – Low cycle fatigue cracking of rotor, blades, casing, generator
  – Rotor bow and rubbing
  – Solid particle erosion

• Secondary Failure Mechanisms
  – High cycle fatigue cracking
  – Water droplet erosion

• Operational Concerns:
  – Vibration
  – Turbine water induction
  – Differential expansion
  – Boiler issues
  – Overspeed
Partial Arc Admission - HP inlet

- Control Stage Blading Issue
- Shock Loading
  - Increased steady loading
  - Impact entering the arc excites blade modes (usually first mode)
- Nozzle Passing Frequency Concerns
  - Impulse blading
  - High nozzle exit velocities
- Operation and/or design changes may be required to correct this issue
Campbell Diagram – Hold Speeds
Stall Flutter – LP Blading

- Flow separation produces vibrations
- Occurs in last stage of LP under low load and high back-pressure conditions
- Conditions of concern:
  - Longer blade designs with lower first blade mode frequencies
  - High air in-leakage
  - Summer periods where backpressure control is challenged
  - Potential for increase in failure mode with shift towards load cycling
EROSION – SPE AND WATER DROPLET
Solid Particle Erosion

• First few stages of HP and IP blading
• Damage caused by high velocity rust particles striking blading
• Surface roughness deteriorates fatigue strength and performance
• Low load operation leads to valve throttling
• Operator Awareness
  – Minimize startups/load swings - dislodge particles
  – Operate in sliding pressure mode - reduces throttle pressure which keeps velocities down
Nozzle Plate and Block SPE
SPE Coatings

- Tungsten Carbide
- Chromium Carbide
- Titanium Nitride
LP Water Droplet Erosion

- Surface roughness caused by droplets reduces fatigue properties
- Reduces mass of tuned blades
- Repair Considerations
  - Blade frequency testing and trending
  - Stellite repair and/or stellite solid nose bar
  - Flag stellite
  - Blade replacement
- Operator Awareness
  - Keep reheat temperatures at design level
  - Low load operation - boiler droop lowers reheat and throttle temperatures
  - Operational trends to reduce minimum loads
Erosion Rates are Non-Linear
LOW CYCLE FATIGUE
Low Cycle Fatigue

• Primarily driven by On/Off Cycles – areas with stress concentrations are of highest concern
  – Startup/shutdown cycles
    – Thermal stresses \( \Rightarrow \Delta T; \) HP & IP vs LP
    – Mechanical stresses \( \Rightarrow \sigma = mr\omega^2 \)
• Can be exacerbated by specific startup/shutdown practices
  – Improper or inadequate soak times
Rotor Peripheral Cracks

• Operational
  • Increasing vibration levels over weeks
  • 1X and 2X components increasing with time
  • Shifts in critical speeds
  • Higher critical speed amplitudes
  • Inconsistent phase and vector change in static unbalance

• Outage
  • MT of “J” hook areas
  • Eddy Current (ET)
  • Ultrasonic's

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IP Rotor Inlet Cracking
Low Pressure Rotor Shaft End Cracking
Casing Cracking

• High steam to metal temperature differential (~600F)
Nonuniform Steam Inlet Design

- First Major Inspection
- Crack 17” length x 1” depth
- 40,000 hours
- 1,000 on/off cycles
Clearances

• Trade off between performance and operability for radial clearances
• Set seal clearances appropriate for mode of operation
• Hard seal rubs can lead to blade looseness, rotor bowing, and bearing babbitt fatigue
• Axial clearances must be maintained to avoid differential expansion limitations
Simple Shaft System Critical Speeds

- 304.8 mm Diameter
- 50.8 mm Thick
- Centered, Rigid Disk

660.4 mm

50.8 mm

First Mode (i=1)  Second Mode (i=2)  Third Mode (i=3)

Isotropic Bearing

Isotropic Bearing

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Integral Shrouded Blades (Looseness)
Babbitt Fatigue
Inadequate Axial Clearances

Check critical clearances prior to the tops being placed on!
Rotor Bow

THE EXTENT OF DAMAGE WHEN RUBS OCCUR

There are several factors that influence the extent of any damage resulting from a rub event. Depending on the severity, these factors can lead to metallurgical changes in addition to dimensional deviations. The majority of the rub damage is caused by high intensity heating due to friction. The heating is not uniform around the circumference of the rotor or stator, resulting in non-uniform heat penetration. The rotor cross section in Figure 1 below shows an example of the variation that can be seen in shaft heating around the circumference at a specific axial location. The width of the orange bar corresponds to depth of heating, with section cuts taken at 3 locations.

Figure 1 – Example Variation of Heating Depth in Rotor Cross Section
Rotor Straightening Options

- Hot Spot Rotor diametrically opposite the bow
- Machine plastically deformed material at the bow and weld repair
- Re-machine journals and critical rotor diameters to new centerline
- Re-heat treat deformed areas – limited success
Rotor Bow Repairs
EVENT DRIVEN – WATER INDUCTION, OVERSPEED
Water Induction Common Causes

• Extraction Sources
  – Leaking Feedwater Heater Tubes
  – Level Control Failures
  – Poor design – heater drains
  – Obstructed extraction line drains

• Main Steam Sources
  – Inadequate drains or not at low point
  – Fast start after boiler trip
  – Attemperator spray malfunctions

• Steam Seal Systems
  – Auxiliary source issues
  – Clogged gland seal header or inadequate drains
  – Operational
Turbine Trip Protection

• Worst case is overspeed event with severe damage
• Potential problem indications:
  – Slow or sticky steam valve operation
  – Delays in rolling down to turning gear due to valve leakage
  – Delays in valve closure
• Mitigation?
  – Valve testing
  – Routine overspeed testing
  – Routine maintenance
  – Sampling and analysis of hydraulic oil
  – Thorough testing to any newly installed turbine trip system
  – Trip on Reverse Power
Thank you – Questions?
Steam Power Plant Cycling Symposium Update

Gary Ruhl
Manager, Fuels & Technical Services
Omaha Public Power District
Steam Power Plant Cycling Symposium Update

Gary Ruhl, P.E.
Manager of Fuels and Technical Services
Omaha Public Power District

- Coal is increasingly pinched between strong wind and solar generation in the West and Midwest, which primarily hurts Powder River Basin (PRB) dispatch—grievously for some units—and gas, which reduces overall coal demand. This outcome also hurts the ability of generators that run for thin or negative margins overnight to make that up in higher power price times.

From IHS Markit, US Steam Coal Market Update, June 2018
Energy Market Volatility and Cycling

Planning and anticipated reserve margins in select NERC regions, summer 2018

Anticipated margin reference margin

Western Electricity Coordinating Council
Midcontinent ISO
Southwest Power Pool
Electric Reliability Council of Texas
Florida Reliability Coordinating Council
New York ISO
PJM Interconnection
SERC Reliability Corporation
ISO New England
National Wind/Solar Potential

Map of the United States showing regions with high wind, high solar, and high wind/solar potential. The map highlights the WI-El Seam and ERCOT Seam. The colors represent:
- High wind potential: blue
- High solar potential: yellow
- High wind/solar potential: green

Source: SPP
SPP Installed Wind Capacity

- SPP currently has 17,700 MW of wind generation.
SPP Price Variability

7:15AM 11/10/16 ~$15
9:30AM 11/10/16 ~$80

Prices can change rapidly

Congested areas can change rapidly
SPP Wind Impact
Cycling Symposium Highlights

- SOLDOUT - THANK YOU!
- Morning covered operational environment
- Afternoon covered consequences
- Roundtable discussions morning/afternoon
Plant Movements = Generation Changes In Absolute Terms!

- 3 Observed Negative Generation Changes = +300 MWh Movement
- 2 Observed Positive Generation Changes = +300 MWH Movement
- Total Plant Movement Over 9 Hours = +600 MWh Movement
- Total Plant Generation Over 9 Hours = +3,450 MWh Generation
- Movement Is Often a Much Smaller Value Than Generation
### The CAISO BA Cycling Research Project

#### Cycling Causality Results

<table>
<thead>
<tr>
<th>CYCLING CAUSALITY of CAISO DRIVERS</th>
<th>SYSTEM LOAD</th>
<th>THERMAL PLANTS</th>
<th>RENEWABLES</th>
<th>IMPORTS</th>
<th>SPECIFIC REACTOR</th>
<th>NUCLEAR PLANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>55.4%</td>
<td>13.4%</td>
<td>13.8%</td>
<td>12.3%</td>
<td>4.8%</td>
<td>0.3%</td>
</tr>
<tr>
<td>2013</td>
<td>53.1%</td>
<td>11.4%</td>
<td>20.9%</td>
<td>10.2%</td>
<td>4.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>CHANGE</td>
<td>-2.3%</td>
<td>-2.0%</td>
<td>7.1%</td>
<td>-2.1%</td>
<td>-0.6%</td>
<td>-0.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CYCLING CAUSALITY of CAISO RENEWABLES</th>
<th>VMND</th>
<th>SOLAR</th>
<th>LG HYDRO</th>
<th>SIM HYDRO</th>
<th>BIOMASS</th>
<th>GEO THERMAL</th>
<th>BIO GASP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>6.0%</td>
<td>1.5%</td>
<td>5.5%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
<tr>
<td>2013</td>
<td>6.0%</td>
<td>7.6%</td>
<td>4.6%</td>
<td>0.3%</td>
<td>0.2%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>CHANGE</td>
<td>2.0%</td>
<td>6.1%</td>
<td>-0.9%</td>
<td>0.1%</td>
<td>0.0%</td>
<td>-0.1%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Impact to coal utilities

- Market drives cycling of coal plants
- Utilities pay RTO/ISO to run in negative market
- Price volatility can cause significant DART spreads for utilities
- Price volatility can cause significant unit swings to follow market prices
- Markets will get worse before they get better
Focus on Key Parameters

- Min-Max output - stretching
- Start up costs (hot, intermediate, cold)
- Start up times (hot, intermediate, cold)
- Minimum Run Time, Minimum Down Time
- Sync to Minimum Time
- Ramp rates
- Unit Heat Rates Performance
- Maintenance Costs
- Unit commitment status - Costs of Cycling
- Fuel and Transportation pricing
# Unit Decision Matrix

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Common Inputs</th>
<th>Unit 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas price</td>
<td>$3.48 per MMBtu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel oil price</td>
<td>$2.09 per Gallon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shutdown fuel (select from dropdown)</td>
<td>Gas</td>
<td>200</td>
<td>335</td>
</tr>
<tr>
<td>Energy Price - On Peak (06:00-22:00)</td>
<td>$1.00 per MWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Price - Off Peak (00:00-06:00, 22:00-24:00)</td>
<td>$(10.00) per MWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min load (coal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated outage start</td>
<td>4/28/2017 3:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated outage end</td>
<td>4/29/2017 6:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total duration (maximum = 100 hours)</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Unit 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit (loss) staying online at min load (coal)</td>
<td>$(111,916)</td>
<td>$(115,535)</td>
</tr>
<tr>
<td>Profit (loss) at reserve shutdown</td>
<td>$(111,356)</td>
<td>$(121,394)</td>
</tr>
<tr>
<td>Best option</td>
<td>shut down</td>
<td>stay on</td>
</tr>
<tr>
<td>Better by</td>
<td>$560</td>
<td>$5,859</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensitivity Analysis</th>
<th>Unit 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy prices needed to stay ON (for expected duration)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average needed ($/MW)</td>
<td>$(3.38)</td>
<td>$(2.45)</td>
</tr>
<tr>
<td>Current average ($/MW)</td>
<td>$(3.48)</td>
<td>$(1.62)</td>
</tr>
<tr>
<td>Date and time at which Reserve Shutdown becomes the right decision (if outage lasts past this time, shut down)</td>
<td>4/29/2017 7:00</td>
<td>4/2/2017 3:00</td>
</tr>
</tbody>
</table>
Value Potential of Flexibility

Southeastern US Power Plant
Hourly Operating Profile for January 3rd, 2016

Value Potential
- Peak Power
- Ramp Rate
- Cool Down Rate
- Low Load Limits
- Startup Efficiency
Enhanced Flexibility for Steam Plants

- **Power Increase**: Up to +10% output, additional fuel
- **Peak Load**: Up to +5% output for short term, no additional fuel
- **Frequency Response**: 
- **Part Load Efficiency**: Up to 3% reduction in heat rate losses
- **Fast Start-up**: Up to 50% time reduction, <8hrs cold start-up time
- **Increased Ramp Rates**: Up to 5% / min, Efficiency transients to reduce life consumption
- **Enhanced Low Load Operation**: 
  - Down to 10% min load (gas)
  - <30% min load (coal)
  - Minimize losses during off-peak hours of generation
- **Soft Shutdown**: Reduced lifetime impact
- **Hot Standby**: Shorter start-up time, in warm/hot conditions

**Two Main Areas of Interest**
Generation Supply Curve

Units 2,1,3,4

Variable O&M Costs ($/MWh)

Cumulative Summer Capacity (MW)
Closed-loop control – Classic feedback loop

R = Set-point
E = Error or Deviation between set-point and process
Y = Process or “controlled” variable
U = Output or “manipulated” variable
D = process upset or deviation not caused by controller action
Model based control schematic

Model-based Control

- Process model encapsulated within controller
- Controller output ‘U’ feeds both actual process and model
- Disturbance (Y-Y)’ consists of actual disturbance and modeling offsets
- Parameters
  - Y = actual process variable
  - Y’ = modeled process
  - D = Y-Y’ = disturbance
Performance of Model Based Steam Temperature Controls

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>N*</th>
<th>Mean</th>
<th>SE Mean</th>
<th>StDev</th>
<th>Minimum</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEB5_OFF</td>
<td>2000</td>
<td>0</td>
<td>1004.3</td>
<td>0.104</td>
<td>4.63</td>
<td>969.0</td>
<td>1002.5</td>
<td>1004.6</td>
<td>1006.6</td>
<td>1024.6</td>
</tr>
<tr>
<td>FEB8_OFF</td>
<td>2000</td>
<td>0</td>
<td>1004.7</td>
<td>0.120</td>
<td>5.36</td>
<td>981.3</td>
<td>1002.4</td>
<td>1004.8</td>
<td>1007.2</td>
<td>1026.7</td>
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</table>
Model Based Load Control

Ramp Rate Improvements Enabled with Model Based Load Controls
Mindsets and Behaviors Shift

- **Fixed**
  - Avoid challenges
  - Give up easily
  - See effort as pointless
  - Ignore useful negative feedback
  - Feel threatened by the success of others

- **Growth**
  - Embrace challenges
  - Persist in the face of setbacks
  - See efforts as a path to mastery
  - Learn from criticism
  - Feel lessons and inspiration in the successes of others.

Consider where you would place yourself currently. Now think about what you can do to release your growth mindset.
“If you talk to a man in a language he understands, that goes to his head. If you talk to him in his language, that goes to his heart.”

Nelson Mandela
## Mindsets Intervention Examples

### Mindset today

<table>
<thead>
<tr>
<th>Input oriented</th>
<th>What we heard in interviews</th>
<th>Future mindset</th>
<th>Proposed intervention</th>
</tr>
</thead>
</table>
| ▪ A good job is putting in a lot of effort | ▪ “We come to work every day to put in our best effort.”
| ▪ Good work is completing any task well | ▪ “I do my best at whatever I’m told.”
| | ▪ “There are no specific targets, how should they know what good is?”
| | ▪ “I don’t have a direction on what I’m supposed to work for, so I just try hard.” | ▪ Results oriented
| | ▪ A good job is achieving the target |
| | ▪ Good work is completing the most important tasks well |

<table>
<thead>
<tr>
<th>Risk averse</th>
<th>Continuous improvement</th>
<th>Create no-blame culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Short term stability over long term solutions</td>
<td>▪ Take reasonable risks to improve plant performance</td>
<td></td>
</tr>
<tr>
<td>▪ Micromanagement</td>
<td>▪ Cost-benefit analysis for expensive projects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Trusted autonomy in employees to execute independently</td>
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</tr>
<tr>
<td></td>
<td>▪ Define what success looks like for each level</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Incorporate metrics into feedback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Publicly track key metrics</td>
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</table>

### Lean leadership and coaching skills

- Work with managers to set up boundaries for independent problem-solving. Create step-up opportunities for frontline to take the lead.

---

Source: Interviews, team analysis
Answering the Whys....

• Learning Series
  – We began to teach about why the units were cycling more.
    • Energy Marketing
    • Renewables
    • Integrated Resource Plan
• Leadership Communication - Targets
• IGS and PSS Training
Morning Roundtable
HTD coal nozzle assemblies produce the required conditions for unsupported stable coal flames at lower unit loads.

Coal nozzle and inlet elbow design concentrates coal, reducing A/C ratio and adjusts for discharge velocity.

Special corrugated V-shaped diffuser with shear bars produces local turbulence & recirculation.
Wall-fired burner upgrades that can improve low load unsupported flame stability

**Air Registers**
- Stronger air register swirl generation & stronger recirculation zone and better air flow control at lower load.

**Stability Nozzles**
- Mechanical **flame stability** coal nozzle. Courtesy: Doosan
- Aerodynamic **flame stability** coal nozzle. Courtesy: R-V

**Fuel Concentration Nozzles**
- Fuel Concentrating coal nozzle assemblies.

COMBUSTION SOLUTIONS AND EQUIPMENT • R.V. INDUSTRIES, INC.
RMEL CONFERENCE - 2018
**Cycling Damage**

**Creep**
- Creep is a time dependent change in the size or shape of a material due to (near) constant loading.
- In power plants, creep is caused by continuous stress from constant high temperature and pressure in a pipe or tube occurring during steady-state base load operation.

**Fatigue**
- Fatigue is a phenomenon which leads to crack initiation, crack growth, and fracture (failure) when a material is under repeated, fluctuating loads, temperatures, and their resulting stresses.
- In a power plant, such fluctuating stresses result from large transients in both pressures and temperatures. The worst of these transients typically occur during cyclic operation.

![Creep Fatigue Graph](image-url)
EFFECTS OF CYCLING – RELIABILITY

Actual Plant Data Reflects Creep Fatigue Interaction Design Curve

EFFECTS OF CYCLING – EFFICIENCY

1-5% Reasonably Attributable to Cycling


Intertek Engineering Consulting
Engineering | Failure Analysis | Technology
Impacts of Changes in Operations

- Increased number of start/stops
  - Thermal transients
  - Low cycle fatigue cycles
- **Damage is CUMULATIVE**
- Static inspection intervals may no longer accurately reflect unit needs
  - Often based on *years* rather than today’s operating profile
  - May not account for age and accumulated service on unit
Analysis Drivers

**Stress Corrosion Cracking**
- Operating Hours
- Yield Strength
- Temperature
- Location of Wilson Line

**Low Cycle Fatigue**
- Frequency of Cycling
- Stresses
- Fracture Toughness
DRIVING FORCES OF DAMAGE

Many different factors play into the increased costs for operation and maintenance due to cycling. However, for purposes of this discussion, let's take a look at a few of the most significant damage mechanisms driving the increased maintenance cost and premature failure of critical pressure components of a traditional baseload power generating unit.

Thermal Fatigue – a progressive degradation of a material due to cyclic fluctuations in temperature.

Mechanical Fatigue – resulting from fluctuating stresses that have a maximum value less than the tensile strength of the material creating progressive fractures.

Corrosion – resulting from fluctuating water chemistry which can lead to increased corrosion and accelerated component failure.

Creep Fatigue – effects of thermal and mechanical fatigue working in conjunction with one another.
Cycling Impacts on Water Chemistry

- The major impacts of cycling operation without any modifications:
  - Corrosion of feedwater heaters and interconnecting piping due to potential increases in air in-leakage.
  - Increased iron transport potential
  - Boiler tube failures and outages
  - Heat transfer and efficiency losses

- Startup and startup fuel consumption due to time required to meet quality.
- Steam Turbine Fouling
- Boiler Deposition
- Other corrosion mechanisms; FAC, SCC, pitting, corrosion fatigue, etc
Changing the Operating Mode

Component
- Cycle Chemical Feed
- Condensate Polishing
- Sampling and Analysis

Base Load / Conventional
- AVT-O w/ Aqua Ammonia
- Not Typically Required
- Cation Conductivity

Cycling / Fast Start
- AVT-O w/ Filming Amine & TSP
- Deep Bed or Pre-coat Polisher
- Degassed Cation Conductivity
Afternoon Roundtable
Summary

• Cycling = Hot Topic
• Market volatility will get worse
• Costs, impacts, best approach??
• Efforts stave off plant closures
Low Impact Generation CIP
Compliance

Ryan Walter
Compliance Analyst
Tri-State Generation & Transmission Association
Low Impact Generation CIP Compliance

Ryan Walter
Agenda

- Entity Overview
- NERC CIP Introduction
- CIP-002-5.1, Asset Classification
- What Should Already be Done
- CIP-003-7, Low Impact Requirements
- Tri-State’s Approach
- Removable Media and Transient Cyber Assets
Who is Tri-State?

- Member-owned, not-for-profit wholesale power supplier to 43 co-ops and public power districts
- Founded in 1952
- 1,500+ employees
- Peak load: 3,342 MW (WECC) 294 MW (MRO)
- Serves more than a million cooperative members and consumers, and collectively have a 200,000 sq. mile service territory across Colorado, Nebraska, New Mexico and Wyoming
- Owns and Operates 9 Generation Facilities
  - 3 Coal
  - 6 Natural Gas
- Purchase Power Agreements
  - Solar, Wind, Hydro, etc.
  - No Compliance Responsibility for these facilities.
Who is NERC?

- **FERC- Federal Energy Regulatory Commission**
  - Following the Northeast blackout in 2003, was charged to appoint an entity to develop, monitor, and enforce Reliability Standards
  - Entity that gives final approval of all NERC Standards

- **NERC was established as the regulating entity in 2006**
  - 2007 First Reliability Standards become Mandatory and Enforceable, FERC Order 693
  - The first CIP (Critical Infrastructure Protection) standards were approved in 2008. FERC Order 706

- **The Regional Entities:**
  - Charged with enforcing the standards in 7 smaller sections of the US and Canada
  - Western Electric Coordinating Council (WECC), Midwest Reliability Organization (MRO), Florida Reliability Coordinating Council (FRCC), Northeast Power Coordinating Council (NPCC), ReliabilityFirst Corporation (RFC), SERC Reliability Corporation (SERC), Texas Regional Entity (TRE)
What is CIP?

- Standards are primarily directed towards Cyber Security, but also includes Physical Security

- Current version of the CIP Standards went into effect in 2016
  - This version established High, Medium, Low asset rating criteria

- Upcoming Standards and Requirements
  - Supply Chain Management
  - Low Impact Transient Cyber Assets and Removable Media Requirements
  - Also in development: Virtualization and cloud storage, computing, etc.
CIP-002-5.1 for Generation – Plant Impact Rating

- **Medium Impact Rating for Plant**
  - 1500 MW Net Real Power Capability in a single interconnection for a single unit or group of units
  - Generation Station that the Reliability Coordinator, Planning Coordinator, or Transmission Planner deem critical to the BES
  - Only cyber assets or systems that could within 15 minutes adversely impact the reliable operation of the plant are subject to the CIP Standards
    - Potential assets and systems: DCS devices, Microprocessor Relays, RTU’s, etc.

- **Low Impact Rating for Plants**
  - All BES Generating Stations/Units not included in the Medium Criteria
  - Only cyber assets that could within 15 minutes adversely impact the reliable operation of the plant are subject to the Low Impact Requirements
Step 1: Evaluate all systems at our BES plants to determine if they could impact operations or availability of the plant within 15 minutes
   - Examples: DCS, Chiller System, Vibration Monitoring, CEMS, etc.

Step 2: For systems identified in Step 2, label as a BES Cyber System, and inventory all associated Cyber Assets.
   - Potential assets: DCS Servers, Microprocessor Relays, Battery Chargers, RTU’s, switches, PLCs, Operator Consoles, Chiller Controllers, etc.

Step 3: Identify all routable and dialup connectivity

Step 4: Document and have CIP Senior Manager approve a list of Assets with one or more BES Cyber Systems
   - Annually verify your list is still correct.
Determining Cyber Systems and Assets

Cyber System Analysis

| Asset ID (Generating Station) | Asset Type | List of systems or standalone devices that are used in the operation of the power plant to be considered for BES Cyber Systems | Number of BES Cyber Assets associated with the BES Cyber System | Impact Assessment - identify whether the system can trip the plant or a unit within 15 minutes or less (without the intervention of a person) if destroyed, degraded, misused or rendered unavailable? | Programmable Electronic Device Assessment - Does the system have microprocessor or field updatable firmware? Management port, web interface, socketed chipset, or any external interface that would allow firmware, software or logic update. (In case is applicable) | BES Reliability Operating Service (BROS) Assessment - Does the system perform one of the BROS? | Identify BES Cyber Systems (Yes to columns I & G, and if BROS= BES Cyber System) | Comments |
|-------------------------------|------------|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RW Gen. Station               | Generating Station | Distributed Control System | 52 | Yes | Yes | Monitoring and Control | Yes | Comments |

Cyber Asset Analysis

<table>
<thead>
<tr>
<th>Cyber Asset Classification</th>
<th>Asset ID</th>
<th>Unit/Location ID</th>
<th>Cyber Asset ID</th>
<th>Description</th>
<th>Associated BES Cyber System</th>
<th>Physical Location</th>
<th>Physical Security Controls</th>
<th>Low Impact External Reliability (LERC) Assessment - Identify if the system is accessible from outside of the plant or controls room</th>
<th>Low Impact Electronic Access Point (LEAP) Assessment - If there is LERC there must be LEAP - Identify if LEAP exists for the system</th>
<th>Identify whether remote access is ever attempted even on a temporary basis</th>
<th>Identity: whether the asset can trip the plant or a unit within 15 minutes or less (without the intervention of a person) if destroyed, degraded, misused or rendered unavailable?</th>
<th>Comments</th>
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<tr>
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<td>RW Gen. Station</td>
<td>Station</td>
<td>OPSC01</td>
<td>Operator Control</td>
<td>Distributed Control System</td>
<td>Control Room</td>
<td>Card Reader</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Ethernet</td>
<td>Yes</td>
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</table>
What should already be done

- All entities with Low Impact assets had to write a Cyber Security Plan for Physical and Electronic Security Controls, Cyber Security Awareness and Cyber Security Incident Response by 04/01/17.

- Entities had to reinforce cyber security awareness at all low facilities by 04/01/17 and every 15 months thereafter.

- All entities with Low Impact assets had to write and test their Cyber Security Incident response plan by 04/01/17.

Document all of your compliance efforts.
CIP-003-7 for Low Impact

- **Cyber Security Awareness (April 1, 2017)**
  - Every 15 Months you must reinforce cyber security practices (example: training, poster changes, etc.)

- **Physical Security Controls (January 1, 2020, Originally July 1, 2018)**
  - Control physical access to the plant itself or the locations where BES Cyber Systems (BCS) reside, and
  - The Cyber Assets that provide electronic access controls below

- **Electronic Access Controls (January 1, 2020, Originally July 1, 2018)**
  - Should only permit necessary inbound and outbound electronic access for communications that are:
    - Between a Low Impact BCS at the plant and a Cyber Asset outside the plant
    - Using routable protocol when entering or leaving the plant
    - Not used for time-sensitive protection or controls functions
  - Authenticate all Dial-up Connectivity
Cyber Security Incident Response (April 1, 2017)
- Entities must create and test a plan to Identify, Classify and respond to Cyber Security Incidents

The New Ones:

Transient Cyber Asset Malicious code Mitigation (January 1, 2020)
- Transient Cyber Asset (TCA) - is an asset that is capable of transmitting or transferring code and is connected to the station’s network or BES Cyber Assets for 30 days or less.
  - Ex: Company Laptops, Vendor Laptops, or testing devices
- Entity owned TCAs must have at least one of the following: antivirus, application whitelisting or other methods to prevent the introduction of malicious code to the network.
- 3rd Party TCAs- must perform a review of vendor’s methods for malicious code mitigation*

Removable Media (January 1, 2020)
- Storage devices capable of transferring executable code and is connected to the station’s network or BES Cyber Assets for 30 days or less
  - Ex: USB Flash Drives, External Hard Drives, CD’s, etc.
- Method to detect Malicious Code on Removable Media, and
- Mitigating any Malicious Code found on that Removable Media prior to use.
Tri-State’s Implementation Details

- Cyber Security Awareness posters or media at all Low impact sites.
- Determined a list of BES Cyber Systems.
- Walkthroughs of all of our generating facilities:
  - One walkthrough was to examine Physical Security.
  - Second walkthrough was to gather a list of all Cyber Assets and all external routable connections to the plants.
- Once we had our cyber asset list, assets were put into different BES Cyber Systems and given an impact assessment.
Plant Physical Security

- 6 of Tri-State’s plants are using the fenced perimeter as their primary means of Physical Security.
  - Gates are all locked; if not card controlled, with keys to those locks being tracked and managed.

- The other 3 are utilizing a variety of physical security measures:
  - One is using Electronic Card Readers, to secure areas within the plant
  - Another is using a defense in depth approach
  - The final plant is using brass key lock to secure the Generation Plant Building

- Tri-State rekeyed all locks, and implemented key management.
Electronic Security

- All Stations have 2 separate networks. The plant network (where the DCS resides) and the corporate network.

- The networks are segregated by an IT managed firewall.
  - Does not have to be a firewall, could be a switch, Communication Processor, etc. as long as you can control or “manage” inbound and outbound traffic.
Transient Cyber Asset

- **Internal Computers**
  - All of Tri-State’s computers will have Symantec antivirus software, and endpoint privilege management.

- **What are we going to do for 3rd party contractors???**
  - Still working on that, we have some options.

- **Possibilities:**
  - Web-based scanning software
  - Portable Scanning Device that sends data to a central server
  - Log in and Review from Corporate IT
  - Requiring Procedure review of 3rd parties documentation prior to allowing them onsite.
  - Not allowing 3rd party laptops
Removable Media

- How to deal with those handy USB drives.
  - Scanning Kiosks
  - Do not allow the use of thumb drives
  - Disable USB Ports (logically or with port locks)
  - Use a laptop with antivirus to scan all thumb drives prior to only allowing access.
    - Requires third party to allow you to scan prior to use at facility
Takeaways

- Don’t procrastinate
  - Will help you work out the issues before you have to be compliant

- Document your Efforts

- Work with your vendors
  - Make sure your strategies will work with your systems and won’t hinder plant operations.
Questions?

Ryan Walter
Tri-State G&T
rwalter@tristategt.org
303-254-3722
Physical Security (Suspicious Package Handling)

Thomas Livingston
Plant Manager, Four Corners Power Plant
Arizona Public Service
Four Corners Power Plant

Suspicious Device Discussion

August 1st, 2018
08/04/2015: Suspicious devices found inside of Plant

- Technician walking to assigned work area noticed suspicious devices in separate locations on the same elevation on the boiler adjacent to the turbine building
- Technician immediately notified Supervisor
- Management reviewed photos of the devices
- Reduced load on units
- First stage evacuation to reporting areas
- Notified authorities
- Set up Emergency Command
- Second stage evacuation of non-essential personnel
- Devices removed by authorities
What Did We Do Right?

- Evacuation
- Communication
- Emergency Command
- Control Situation
What Did We Do Wrong

- Preparation
- Food & Water Available
- Notification
- Work Area Inspections
- Media
Is Your Plant or Facility Prepared

- Drills
- Command Center Readiness
- Notification
- Area Control
- EAPs
- Local, State, and Federal Officials Familiar
- Emergency Assignments
- Food & Water
- Media
NERC BAL-003 – Frequency Response Impacts on Plants

Bill Paiz
Power Production Engineer V
PNM Resources

Saul Macias
Power Production Engineer
PNM Resources
NERC BAL 003-1.1
IMPACT ON POWER PLANTS
RMEL, August 2, 2018
Frequency Response for Generators

Outline

– Purpose
– Grid Stability
– Generator Governor
Frequency Response for Generators

Purpose

- To provide sufficient Frequency Response from the plants within predefined bounds by arresting frequency deviations and supporting frequency until the frequency is restored to its scheduled value.
NERC issued advisory specifying the method to improve grid stability by setting:

- Dead band of +/-36mHz,
- Droop settings of 3%-5% (1% droop setting translated to 20% governor valve movement)
- Depending on turbine type continuous, proportional (non step) implementation of the response
- Appropriate operating modes to provide frequency response
- Appropriate outer loop controls (distributed controls) settings to avoid primary frequency response withdrawal
Frequency Response for Generators

Frequency Response

– Pre-event measurement period = 14 seconds from T-16 to T-2
– Post-event measurement period = 32 second period from T20 to T52
– Average values calculated for both frequency and generation output for both pre and post event periods

Frequency Response (MW/0.1 Hz) = \frac{\text{Gen output (post-event)} - \text{Gen output (pre-event)}}{\{\text{Frequency (post-event)} - \text{Frequency (pre-event)}\}} \times 10
• Advisory issued February 5, 2015
• Initiated by NERC Resource Subcommittee
  ▪ Interconnections frequency response has declined
  ▪ Eastern Interconnection Lazy L profile
  ▪ 2010 and 2013 Generator Survey Data

**Generator Governor Frequency Response Advisory**
The characteristics found in that study were:

- Only 30% of the units on-line provide primary frequency response.
- Two-thirds of the units that did respond exhibit withdrawal of primary frequency response.
- Only 10% of units on-line sustain primary frequency response.

Figure 24: Comparison of Legacy and Generic Simulations to August 4 Event
Frequency Algorithm

No Frequency Algorithm in DCS

Frequency Algorithm in Plant DCS

3-175 MW GETFA Gas Mark Vle Turbine
3/3/2015

PNM®
2016-17 Compliance Year

- December 1, 2016 – October 30, 2017
- PNM BA FRO = -13.9 MW/0.1 Hz
- PNM BA Median FRM = -28.6 MW/0.1 Hz
- Q1 PNM BA Median FRM = -16.1 MW/0.1 Hz
- Q2 PNM BA Median FRM = -28.5 MW/0.1 Hz
- Q3 PNM BA Median FRM = -35.5 MW/0.1 Hz
## NATURAL GAS UNIT PERFORMANCE

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<th>Events</th>
<th>Gen</th>
<th>% time online</th>
<th>% good</th>
<th>Best</th>
<th>Worst</th>
<th>Median</th>
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<table>
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<th>Events</th>
<th>Gen</th>
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<th>Best</th>
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<td>14%</td>
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<td>-1.76</td>
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<td>RVS2</td>
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<td>0%</td>
<td>0%</td>
<td>0.00</td>
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<td>0.00</td>
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<tr>
<td>LORDS 1</td>
<td>1</td>
<td>5%</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>0.00</td>
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<tr>
<td>LORDS NET</td>
<td>1</td>
<td>5%</td>
<td>0%</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td></td>
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<tr>
<td>LA LUZ</td>
<td>1</td>
<td>5%</td>
<td>0%</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
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## 2015 vs 2016 Compliance Year Generator FRM Comparison

### Coal Units

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<td>SJ1</td>
<td>48</td>
<td>44</td>
<td>50</td>
<td>66</td>
<td>-0.02</td>
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<tr>
<td>SJ2</td>
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<td>37</td>
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<td>SJ4</td>
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<tr>
<td>FC4</td>
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<td>FC5</td>
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<td>38</td>
<td>35</td>
<td>1.73</td>
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### Natural Gas units

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<tr>
<td>LUNA CT1</td>
<td>46</td>
<td>46</td>
<td>83</td>
<td>93</td>
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<td>LUNA CT2</td>
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<td>49</td>
<td>85</td>
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<td>AFTON CT</td>
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<td>21</td>
<td>56</td>
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<td>16</td>
<td>37</td>
<td>50</td>
<td>0.04</td>
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<td>90</td>
<td>57</td>
<td>-4.64</td>
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<td>VALENCIA</td>
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<td>5</td>
<td>80</td>
<td>80</td>
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<td>REEVES 1</td>
<td>11</td>
<td>7</td>
<td>73</td>
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<td>REEVES 2</td>
<td>9</td>
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<td>78</td>
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<td>REEVES 3</td>
<td>16</td>
<td>7</td>
<td>94</td>
<td>100</td>
<td>-0.63</td>
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<td>LORDS 1</td>
<td>4</td>
<td>3</td>
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<td>25</td>
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<td>0</td>
<td>-</td>
</tr>
<tr>
<td>LORDS NET</td>
<td>6</td>
<td>4</td>
<td>50</td>
<td>25</td>
<td>0.01</td>
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<tr>
<td>LA LUZ</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>33</td>
<td>0.19</td>
<td>-</td>
</tr>
</tbody>
</table>
BW230 Converter

- PNM contracted a 3rd party to implement control system improvements to allow the converter to provide bi-directional frequency response
- Completion of work posted on OASIS 8/18/17
- Appears to provide 15 MWs of response regardless of level of frequency decay and holds response for 2+ min
- FRM will vary from -15 MWs/.1 Hz for 100 mHz event to -30 MWs/.1 Hz for 50 mHz event
Plant Control System Frequency ISSUES

• Reeves
  – During a frequency excursion unit’s did not sustain support.
  – Frequency response dead band too large

• Rio Bravo (Combustion Turbine)
  – During a frequency excursion unit’s did not sustain support.
  – Frequency response dead band too large
  – Emission's Issues
Control System Resolutions
Reeves

• Control System Program Modifications
  – Reconfigured software to suspend MW control to allow unit to ramp up or down depending on required frequency response.
  – Set frequency dead band to 3 RPM
## Frequency for Reeves Dead Band

<table>
<thead>
<tr>
<th>Reeves Generating Station</th>
<th>Date of Setting</th>
<th>Droop Setpoint</th>
<th>Governor Response Characteristic</th>
<th>Upper Gap Deadband RPM Setpoint</th>
<th>Upper Deadband Frequency</th>
<th>Lower GAP Deadband RPM Setpoint</th>
<th>Lower Deadband Frequency</th>
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</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>7/7/2015</td>
<td>5%</td>
<td>Proportional/Continuous</td>
<td>+3.0 RPM</td>
<td>+50.0 mHz</td>
<td>-3.0 RPM</td>
<td>-50.0 mHz</td>
</tr>
<tr>
<td>Unit 2</td>
<td>7/8/2015</td>
<td>5%</td>
<td>Proportional/Continuous</td>
<td>+3.0 RPM</td>
<td>+50.0 mHz</td>
<td>-3.0 RPM</td>
<td>-50.0 mHz</td>
</tr>
<tr>
<td>Unit 3</td>
<td>7/9/2015</td>
<td>5%</td>
<td>Proportional/Continuous</td>
<td>+3.0 RPM</td>
<td>+50.0 mHz</td>
<td>-3.0 RPM</td>
<td>-50.0 mHz</td>
</tr>
</tbody>
</table>
MW Control Hold Algorithm
Dead Band Algorithm
WECC Testing Frequency Results

Figure 5.2.2 – STG 2 Frequency Step Test Response (+15.5 RPM)
Control Resolution For Rio Bravo

• Control System Program Modifications
  – Reconfigured software to suspend MW control to allow unit to ramp up or down depending on required frequency response.
  – Set frequency dead band to 3 RPM.
  – Limited frequency excursions response to Mode 6 to minimize emissions.
Rio Bravo Frequency Response Test

Control Constants sets:

TEST1: (a test of slow grid conditions), just within the TNKPFR setting.
- TNKNGCSTEP1 = -0.35 (This defines Frequency error)
- TNKNGCSTEP2 = 0.00 (This defines Frequency error on step completion)
- TNKNGCHILIM = 0.00 (This defines Frequency error Hi Limit)
- TNKNGCLOLIM = -0.30 (This defines Frequency error Lo Limit)
- KNGCRMPOFF = 90.0 (This defines length of frequency event)
- KNGCRATEON = 0.1 (This defines the Rate of start of speed step)
- KNGCRATEOFF = 0.1 (This defines the Rate of removal of speed step)

TEST2: (a test of fast grid conditions), just within the TNKPFR setting.
- TNKNGCSTEP1 = +0.35
- TNKNGCSTEP2 = 0.00
5.3) Perceived Speed Step Test

An increase/decrease was added to the governor's perceived speed and the dynamic response was recorded. The test was repeated at a load point where the increase in MW output activated temperature control. The described responses can be seen in Figures 5.3.1 through 5.3.2. The figures include the following three signals:

- \( P \): Gross Real Power Generator Output (MW). The real power output of the generator reacts proportionately to the FSR-initiated fuel flow change.

- \( FSR \): Fuel Stroke Reference (%). The fuel demand signal that reacts to the change in TNR. FSR is a combination of two signals – FSRN (speed control FSR) and FSRT (temperature control FSR), whichever is lower. FSR is determined by FSRN during the first step and by FSRT during the second step, where the requested load change exceeds the unit's temperature-limited capability.

- \( TNHSTEP \) (%): The perceived unit frequency down-stream of the dead-band. This signal is manipulated during the test to elicit a governor response.
Rio Bravo Speed Up Test

Figure 5.3.1 – Rio Bravo GT Perceived Speed Positive Step Test
Rio Bravo Speed Down Test

Figure 5.3.2 - Rio Bravo GT Perceived Speed Negative Step Test
Questions?

Thanks!
Four Corners Plant Overview

Thomas Livingston
Plant Manager, Four Corners Plant
Arizona Public Service
• APS operates the 1,540MW Four Corners Power Plant located in the Shiprock Agency of the Navajo Nation (located in Fruitland, New Mexico)
  • APS shares ownership of Units 4 and 5
    – Arizona Public Service, Public Service New Mexico, Salt River Project, Tucson Electric Power, and Navajo Transitional Energy Company
    – APS’s current share of the plant’s total production is 970 megawatts
• The units are fueled by low-sulfur coal from the nearby the Navajo mine
• Water is supplied by San Juan River to Morgan Lake
Plant Facts Units 4 & 5

- Commercial Operation: Unit 4 = 1969, Unit 5 = 1970
- Boiler: Babcock & Wilcox Supercritical
  - 5,500 Klb/hr, 3500 psi, 1000 F
- Turbine: General Electric Cross Compound
  - 22KV, HP @ 3600rpm, LP @ 1800rpm
- Heat Rate: 9,687 BTU/KWh
- Morgan Lake: 1260 surface acres, 39,000 acre ft.
- Baghouse and Scrubbers added in late ‘80s
Plant Facts Units 4 & 5

- SCRs added in 2017 and 2018
  - 95 day outages
  - Turbine Majors
  - Boiler Tube Replacements
  - Air Heater Removals
  - CEMS Additions
  - Construction with Operating Plant
  - Operational Challenges
Questions?
Reciprocating Engines – Flexibility for Peaking Operations and Black Start

Phil Duran
Sr. Director, Business Operations
Tyr Energy, Inc.
RECIPROCATING ENGINES

Flexibility for Peaking Operations and Black Start

Phil Duran
Sr Director – Business Operations

TYR ENERGY
EXAMPLE RECIP ENGINE
• Provide Reactive and Peaking Power
• Compensate Fluctuations from Wind, Solar and Other Non-dispatchables
• Ensure Quick and Stable Black Start Generation
ADVANTAGE – FASTER START TIMES

Energy Advantage of Gas Engines
ADVANTAGE – HIGH ALTITUDE PERFORMANCE

![Graph showing relative output vs altitude for Gas Engine Power and Gas Turbine Power](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ISO Engine</th>
<th>ISO Turbine</th>
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</thead>
<tbody>
<tr>
<td>Ambient Temp.</td>
<td>25 °C</td>
<td>15 °C</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>30 %</td>
<td>60 %</td>
</tr>
<tr>
<td>Pressure</td>
<td>1000 mbar</td>
<td>1013 mbar</td>
</tr>
<tr>
<td>Altitude</td>
<td>111 m</td>
<td>0 m</td>
</tr>
</tbody>
</table>

Source: MDT, General Electric
DISADVANTAGES

• Fuel Cost/Efficiency in Base Load Operation at Continuous Full Load

• Power Plant Civil Works (“Foot Print”)  

• Higher Total Installed Mass – Challenging in Remote Areas
Emergency Diesel Generator Provides Station Power and Cranking Power to Recip Engines

Legend:
- Red indicates breaker closed ("hot" – power flowing)
- Green indicates breaker open (no power flow)
Recip Engines Run Stably at Max Turndown Under Load from Load Banks

Legend:
- Red indicates breaker closed ("hot" – power flowing)
- Green indicates breaker open (no power flow)
Main Breaker Open – Grid Power Slowly Restored as Additional Recip Engines Started

Legend:
- Red indicates breaker closed ("hot" – power flowing)
- Green indicates breaker open (no power flow)
OPERATOR’S PERSPECTIVE – ADVANTAGES

1. Flexible Maintenance Scheduling – One Engine at a Time, No Plant Outage Required

2. Maintenance Cost Spread Over Entire Year as Opposed to One or Two Large Plant Outages

3. High Plant Availability – Very Few Single Point Failures that Affect Entire Plant
1. Higher Maintenance Cost – More Rotating Equipment and Other Moving Parts

2. OEM Support – Improving but Still Lags Behind More Established Technologies

3. Fewer Alternatives to OEM for Parts and Service than for Established Technologies
OFFTAKER’S PERSPECTIVE – ADVANTAGES

1. Supplemental Reserves – Quick and Reliable Starts

2. Black Start Resource – Quick Small Load Start and Stable Controlled Ramp Up

3. Fast Ramping Capability – Remote Control of Many Engines with Quick Start and High Turn-down Capability
OFFTAKER’S PERSPECTIVE – DISADVANTAGES

1. Higher Cost Power – GT More Efficient (Base Load)

2. Capital Cost per MW for High Capacity

3. None
Q & A
Steam Generation and Water Treatment Chemistry – Lessons Learned and Emerging Technologies

Brad Buecker
Sr. Technical Publicist
ChemTreat
Steam Generation and Water Treatment Chemistry – Lessons Learned and Emerging Technologies

RMEL Plant Management, Engineering and Operations Conference

Brad Buecker
Senior Technical Publicist
ChemTreat
Introduction

- Many experienced power plant personnel are retiring, leaving a big gap in knowledge.

- Many of the new combined cycle plants that have been or are being constructed are minimally staffed.

- A dearth of knowledge (both lessons learned and emerging technologies) exists at many plants regarding critical aspects of steam generation and water treatment chemistry control.
Agenda

- Overview of five topics
  - Steam Generation Chemistry
    - #1 – Don’t operate with impurity ingress
    - #2 – Ditch the oxygen scavenger (unless copper alloys are present)
    - #3 – The importance of layup chemistry
  - Emerging Cooling Water and Makeup Water Issues
    - #4 – An evolution in cooling water treatment
    - #5 – Makeup water isn’t what it used to be
#1 – Don’t Operate with Impurity Ingress (Condenser Tube Leaks or Otherwise)
Case History – 1250 psig utility boiler

- Operators ran the unit for three weeks with a significant condenser leak because the utility was selling the extra power.
- Chlorides in the condensate when reaching the boiler induced the following reaction:
  - \[ \text{MgCl}_2 + 2\text{H}_2\text{O} + \text{heat} \rightarrow \text{Mg(OH)}_2\downarrow + 2\text{HCl} \]
Plant chemists kept the boiler water steadily dosed with phosphate, but hydrogen damage occurred underneath waterwall tube deposits.

- \[ 4H + Fe_3C \rightarrow 3Fe + CH_4 \uparrow \]
- Formation of voluminous \( CH_4 \) causes metal cracking. Failures can occur with relatively small metal loss.
#1

- The leak was corrected, but within two months boiler tubes began failing regularly due to hydrogen damage.
- The unit had to be shut down, and all waterwall tubes replaced.
- Very negative return-on-investment for the three weeks of power sales.
#1

- Impurities can also induce other corrosion mechanisms such as corrosion fatigue (CF) and stress corrosion cracking (SCC).
- Also critical is prevention of impurity carryover to steam.
  - Sodium, chloride, and sulfate limits are at 2 ppb due to the damage these impurities can cause in the steam system and turbine.
  - Pitting, CF, and SCC of turbine blades, especially in the LP section
  - Blade failure may be the end result.
#2 – The Continuing Crusade Against Oxygen Scavengers
For years, EPRI and IAPWS have strongly recommended against oxygen scavenger (reducing agent) treatment in steam generator feedwater systems containing no copper alloys.

- Applies to virtually all HRSGs

Yet, many combined-cycle specifications still contain language for oxygen scavenger feed.

- Oxygen scavenger combined with ammonia (or amine) feed for pH control is known as all-volatile treatment reducing [AVT(R)].
• The combination of a reducing environment, pH, temperature, and flow disturbances influences single-phase flow-accelerated corrosion (FAC).

The recommended program for drum units is all-volatile treatment oxidizing [AVT(O)].

- No reducing agent feed, only ammonia for pH conditioning
  - Allow oxygen that enters through condenser air in-leakage to carry through the system.
- Recommended feedwater D.O. concentration of 5 to 10 ppb.
  - For plants with deaerators, may have to close the vents.
  - Supplemental pure oxygen injection may be required.
    - Condensate pump discharge and LP evaporator discharge
#2

- Gray-black magnetite ($\text{Fe}_3\text{O}_4$) layer becomes interspersed and overlaid with “rugged red” FeOOH.

Split tube showing the gray-black magnetite layer.

“Rugged red” FeOOH. Photo courtesy of Dan Dixon, Lincoln Electric System.
#2

- Condensate/feedwater must be very pure (cation conductivity less than 0.2 µS/cm).
- Maintain pH in the proper alkaline range.
  - 9.2-9.8 or 9.6-10.0 depending upon boiler configuration
  - Higher range is recommended in some units to minimize two-phase FAC.
- Operating at high pH range can require a significant amount of ammonia.
  - Blending in some neutralizing amine may help, but decomposition products are of concern.
#2

- Film-forming substances (FFS); a potential game changer.
- Most well known are film-forming amines (FFA)
  - Long organic chain of 18 carbon atoms or more, with amine functional groups.
  - Amine groups attach to base metal, carbon chains form a shield.
  - Protects steel from FAC during normal operation.
  - Protects metal during layup.
#2

- Products used in years past were problematic.
  - Did not provide complete coverage.
  - Had a tendency to form “gunk balls.”
- New products appear to be much more effective, but:
  - Monitoring techniques are still evolving.
  - Overfeed can potentially still form gunk balls.
  - Ingredients are closely guarded.
  - Often blended with neutralizing amines that break down in high-temperature steam to form small-chain organic acids.
#3 – Layup Protection
Corrosion in poorly-protected units during downtimes can be extremely severe.

- Air ingress is the primary culprit.
- Steam generators and turbines need protection.

Good layup practices are followed by RMEL member Lincoln Electric System for the two HRSGs at the LES Terry Bundy plant.

#3

- Layup Guiding Principles

1. Maintain same oxidation/reduction potential (ORP) for wet layup as for operation

2. Keep air away from water & avoid stagnant conditions

3. Keep moisture away from components meant or intended to be kept dry
#3

- Actions to meet steady ORP
  - Normal Operation: AVT(O) chemistry with ammonia feed to maintain pH at 10. **No reducing agent**
  - Into Shutdown: Ensure pH remains at 10. **No reducing agent**
    - A uniform protective oxide would be unable to form if the environment was switched from an oxidized state during operation to a reduced state during layup.
  - Nitrogen capping helps to maintain steady ORP.
Plant is equipped with a pressure-swing adsorption nitrogen generator

- *Blankets* HRSGs during wet layups
- *Bottles* HRSGs during dry layups
- *Blankets/Bottles* auxiliary boiler and its deaerator, and glycol heat exchangers
- Provides sweep gas for the gas transfer membrane (GTM) system that de-oxygenates HRSG makeup water

<table>
<thead>
<tr>
<th>SCFH</th>
<th>% N₂ Purity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>99.5</td>
</tr>
<tr>
<td>619*</td>
<td>99.9*</td>
</tr>
<tr>
<td>248</td>
<td>99.99</td>
</tr>
</tbody>
</table>

*Design point
#3

- Makeup Water D.O. Control
  - Gas Transfer Membrane
    - Deaerates hotwell makeup to <10 ppb.
    - Deaerates HRSG shutdown makeup.
  - Continually recirculates condensate storage tank water for deaeration.
  - Deaerates auxiliary boiler makeup.
#3

- **LP Turbine Protection**
  - If vacuum is broken on a condenser, the LP turbine is exposed to humid, atmospheric conditions, especially if water remains standing in the hotwell.
  - In this humid air, salt deposits on the last stages can initiate pitting of blades and rotors.
  - Pitting can lead to corrosion fatigue, stress corrosion cracking, and potentially blade failure.
  - At Terry Bundy, dehumidified air (DHA) is applied to the condenser and LP turbine during such periods.
#3

- Rotary Desiccant Wheel Dehumidifier Skid
  - Applies warm, DHA into the LP steam turbine injection line to dry the turbine to prevent:
    - Pitting
    - Corrosion fatigue
    - Stress corrosion cracking
  - Secondary objective is to dry the hotwell to minimize general corrosion
#3

- Film-forming products can potentially provide excellent layup protection.

- Would still advise using the layup techniques outlined previously for added security.
#4 – Evolution of Cooling Water Scale/Corrosion And Microbiological Control Methods
After over four decades of phosphate/phosphonate treatment for cooling tower-based systems, an evolution is taking place. A primary driver is a growing restriction on phosphorus discharge to natural bodies of water. Movement towards non-phosphorus (non-P) polymer chemistry, which actually appears to provide better scale and corrosion control.
Polymers containing the carboxylate functional group in various configurations have been used for years to control calcium carbonate scaling.

\[
\text{[CH}_2\text{C}=-\text{O} \text{ O]}_n
\]

But, many other deposits are possible, including calcium sulfate, calcium and magnesium silicates, manganese dioxide, iron oxides, and so on.

Co- and ter-polymers have been developed for these scale formers.
#4

- Generally, carboxylic acid functionality performs best on carbonates and sulfates.
- Generally, sulfonic acid functionality performs best on phosphates, zinc, Mn, iron.
Polymers inhibit scale by two primary mechanisms.
- Crystal modification (crystals may form, but lack rigid structure and wash away)
- Ion sequestration
- Typically, a relatively low parts-per-million (ppm) concentration is needed.
But what about corrosion protection?

- Phosphate/phosphonate programs inhibit corrosion by precipitation of reactants at anodes and cathodes on the metal.
  - Calcium phosphate and polyphosphate
  - Iron phosphate
  - Zinc hydroxide
- This chemistry can be rather complex.
  - Under-dosing – Potential for corrosion and deposition
  - Over-dosing – Potential for heavy calcium phosphate deposition
A corrosion control supplement to polymer chemistry is a formulation known as reactive polyhydroxy starch inhibitor (RPSI).

Active groups on the material bind to metal surfaces to form a protective coating. Functions include:

- General corrosion protection of carbon steel
- Passivation of rusted steel surfaces
- Improved protection of stainless steels from chloride-induced crevice and pitting corrosion
- Doesn’t rely on deposition chemistry like the phosphate/phosphonate programs
As contrasted to phosphate/phosphonate programs, RPSI does not rely on deposition products to inhibit anodic and cathodic reactions.

The next slide shows the results of the chemistry in the cleaning solution (and subsequent standard treatment) of a wet-surface air cooler (WSAC®) at a natural gas liquid (NGL) fractionation plant on the U.S. Gulf Coast.

Data from another full-scale application showed a corrosion rate reduction of nearly two orders of magnitude.
Many plant personnel still seem to underestimate issues due to microbiological fouling.

- Cooling systems provide an ideal environment (warm and wet) for microbiological growth.
- Any lapses or weaknesses in treatment can allow for explosive development of microbial colonies.
The core of any treatment program is an oxidizing biocide.

Gaseous chlorine was the preferred choice for years.

- \( \text{Cl}_2 + \text{H}_2\text{O} \Leftrightarrow \text{HOCl} + \text{HCl} \)
- Hypochlorous acid (HOCl) is the killing agent.
- Least expensive method

General shift to bleach (sodium hypochlorite, NaOCl) due to safety concerns

Successful applications of on-site bleach generation
The slight basicity of many makeup waters (pH near or slightly above 8) makes chlorine somewhat ineffective due to dissociation of hypochlorous acid.

- \( \text{HOCl} \Leftrightarrow \text{H}^+ + \text{OCl}^- \)
- \( \text{OCl}^- \) much less potent killing agent

Chlorine also reacts irreversibly with ammonia, and it will produce halogenated organic compounds that may be of concern.

- Modified or alternative oxidizing programs are common.
One common modification is bleach-activated bromine.

Bleach and sodium bromide are blended in a side stream and fed to the cooling water.

Produces the hypobromous (HOBr) analog of HOCl.

- HOBr dissociates at a higher pH

Rumors are circulating that bromide ion may become part of discharge regulations
% Hypohalous Acid, HOCl or HOBr

\% Hypohalite Ion, OCl⁻ or OBr⁻

\(\text{pH}\)

\(0\) \(10\) \(20\) \(30\) \(40\) \(50\) \(60\) \(70\) \(80\) \(90\) \(100\)

\[\text{HOCl}\]
\[1.49\text{V ORP}\]

\[\text{HOBr}\]
\[1.33\text{V ORP}\]

\[\text{OCl}⁻\]
\[0.90\text{V ORP}\]

\[\text{OBr}⁻\]
\[0.70\text{V ORP}\]
Another alternative is chlorine dioxide ($\text{ClO}_2$)
  - Must be produced on-site.
  - Not affected by pH.
  - Does not react with ammonia.
  - More expensive than other methods

Others include specially-prepared monochloramine ($\text{NH}_2\text{Cl}$) and monobromamine ($\text{NH}_2\text{Br}$).
  - Not as powerful oxidizers, but appear to better penetrate the protective slime layer formed by bacteria.

Also, solid products like the hydantoins
Non-oxidizing biocides can deliver a “one-two punch” to microorganisms.
- Feed perhaps once per week for one hour, or some similar schedule.
- Non-oxidizers are basically divided into two classes:
  - Metabolic inhibitors
  - Surface active agents
- Selection influenced by the need to control bacteria, algae, or fungi, or a combination.
- Safety and discharge permitting are important issues.
Some common non-oxidizers are:

- Isothiazoline
- Di-Bromo-Nitrilo-Propionamide (DBNPA)
- Quaternary amines $\left[ R_1 - N^+ - R_2 \right] - R_3 - Cl^-$
#5 – Increasing Complexity of Makeup Water Treatment
Fresh water is becoming more scarce.

By choice or mandate, personnel at new plants are selecting alternative supplies.

One rapidly emerging alternative is effluent from a publicly owned treatment works (POTW), i.e., municipal wastewater treatment plant.
#5

- POTW effluent often contains significant concentrations of ammonia, nitrate/nitrite, organics, and phosphate.
- These are nutrients and food for microorganisms.
  - Can cause intense growth in cooling systems.
  - Without pretreatment, only splash fill may be allowed in the cooling tower.
  - Ammonia and organics, typically in fluctuating concentrations, can play havoc with biocide feed.
Two technologies becoming popular for pre-treatment are membrane bioreactors (MBR) and moving-bed bioreactors (MBBR).

Both use beneficial microorganisms to consume nutrients and food, producing a clean effluent.

Advanced technology over the old trickling bed filters and conventional activated sludge processes.
Basic process is return activated sludge, but with microfiltration rather than clarification to screen suspended solids from the effluent.
#5 – MBBR

- MBBR has floating media to which the beneficial microorganisms attach. Sort of a trickling filter on steroids. Requires external filtration.
The basic MBR and MBBR systems shown in the previous slides will consume organics and phosphorus.

- But most of the ammonia is only converted to nitrite/nitrate.
- Inclusion of anoxic or anaerobic reaction vessels in the design will convert nitrogen species to elemental nitrogen.
  - Consider early in the design phase whether complete nitrogen conversion is needed.
#5

- There is reluctance in the power industry to operate such seemingly sophisticated pre-treatment systems. Potential solutions include:
  - If the POTW is nearby, place the system at that site and have the POTW personnel operate it.
  - Reputable vendors will supply equipment on a build-own-operate-maintain (BOOM) basis.
Conclusion

- Examples above outlined a number of the most important issues/trends in the power industry.
- These concepts often are not recognized at new plants due to minimal staffing and loss of experienced personnel to retirement.
- Lack of understanding can cause operating problems, induce very expensive failures, and, in some cases, lead to safety issues.
Thank you!

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