Worldwide Pollution Control Association

WPCA-Duke Energy
Is Your Precipitator Ready for MATS?
Aug. 28, 2012 – Plainfield
Sept. 11, 2012 - Charlotte

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IMPROVING ESP PERFORMANCE WITH VOLTAGE AND RAPPER CONTROL SETTINGS

DIAGNOSING PROBLEMS USING VOLTAGE CONTROL METERS

PRESENTED AT WPCA/DUKE ENERGY SEMINAR
IS YOUR PRECIPITATOR READY FOR MATS?

AUG. 28, 2012
PLAINFIELD, IN
SEPT. 11, 2012
CHARLOTTE, NC

CHRISTOPHER ROGLIERI
KC COTTRELL INC.
LODGE COTTRELL INC.
Today’s Discussion

- Introduction
- Safety
- Transformer Rectifier Controls
  - Operation
  - Troubleshooting
  - Common Upgrades
- Rapper Controls
  - Operation
  - Troubleshooting
  - Common Upgrades
Introduction

- Understanding controls operation
- Determine when a problem exists
- Improving precipitator performance by optimizing control settings
- General Troubleshooting practices
Safety

• Safety Key Interlock System
• Lock Out Tag Out (LOTO)
• Training
• Permits
• JHA’s, JSA’s
• Wear proper PPE
• Most utilities now require flash protection at voltages >120VAC
• Troubleshooting should be performed by a qualified electrician or properly trained technician.
• Follow plant guidelines for troubleshooting energized equipment, LOTO and key interlock system.
Precipitator Transformer

Rectifiers

Mechanical Rectifiers

1883 Lodge first demonstrates the use of electrostatic precipitation for the collection of dust particles.

1886 Lodge makes first attempt on a commercial scale to precipitate dust and fume from gases at Deeside Lead Works

1907 US patent issued to Frederick Cottrell for precipitation process

1908 Cottrell installs first precipitator in US at smelter in California to collect acid mist fumes

Vacuum Tube Rectifiers

Solid State Rectifiers and Semi Conductor Diodes
Precipitator Transformer
Rectifiers

Vacuum Tubes later replaced by Solid State Diodes and Semi-Conductor Rectifier Stacks
Diodes configured as a fullwave bridge Pos(+) to Ground Neg(-) to ESP

External Solid State Rectifiers Replaced Obsolete Vacuum Tube diodes
Precipitator Transformer Rectifiers

- Nearly all ESPs updated with microprocessor based automatic high voltage controls
Control Operation

- Maintain highest power levels in electrostatic precipitator to maximize charging strength and efficiency
- Modify/adjust power levels for upset conditions, sparks/arcs
- Ramps power to operator programmed limits/set points of voltage and current, or
- Reduces power if an upset condition (spark) occurs
- Continuously ramps to limits/set points (especially after a spark) to maintain maximum precipitation rate
- Most problems are identified by an alarm
- All alarms should be proven and addressed
Primary Voltage $V_p$

- Primary Voltage -RMS volts measured after SCR and CLR used for metering and undervoltage trip alarm
  - SCR and snubber circuit varies conduction angle (voltage regulator) driven by AVC microprocessor
  - Control relies on feedback of $V_p$, $I_p$ and $I_s$ (typ.)
  - Voltage drop over CLR and field cable
  - Line Voltage typ. (480VAC)
  - Control Voltage (120VAC)
  - Primary Voltage $V_p$ (actual T-R input voltage)

- Use TRMS meter to check or calibrate
Primary Voltage $V_p$

- Precipitator Primary Voltage between 0-100 typically a result of a short circuit condition.
- ex) 600/20 PT 0-20VAC input represents 0-600VAC
Primary Voltage $V_p$

0 Volts?
- Control will trip on Undervoltage if minimum current limit is not met.
- Primary voltage signal is typ. reduced prior to AVC board or analog volt-meter using step-down transformer.
- Locate CLR (typ. inside control cabinet, external, or inside T-R oil tank)
- Primary volt signal wiring typically located at Transformer Tap (LV junction box) or at CLR
Primary Voltage $V_p$

0 Volts? (cont’d)

- Measure actual T-R volts after CLR and check ratio.
- Check fuses (typ. in series with CT primary, located in Control Cabinet, TR LV J-box or CLR enclosure
- Check for proper voltages at PT primary and secondary
Primary Current $I_p$

- Primary Current - RMS amps measured on L1 or L2 inline with T-R using Current Transformer (CT). Used to drive analog meters.
- Feedback allows control to limit primary current.
- Converted to voltage signal by adding a shunt (load) resistor. Shunt resistor value determined by control OEM (set feedback scale to primary current nameplate rating of Transformer).
- Use TRMS clamp ammeter to check or calibrate.
Primary Current $I_p$

- Primary Current Signal
- Schematic shows CT with load resistor for voltage feedback to AVC
Primary Current $I_p$

0 Amps?
- Open Circuit?
- Always verify with External TRMS Clamp meter
- Check connections
- If applicable, check CT load resistor (disconnect one end)
Primary Current $I_p$

Overcurrent Trip alarm
- SCR1 or SCR2 short or misfiring
- Remove and tape leads, energize control
- When disconnected, $V_p$ and $I_p$ should be 0
- Otherwise one or both SCRs are shorted or leaking
- Confirm SCR gate leads connected properly and not switched
- Replace control board
Primary Current $I_p$

Breaker Trip
- SCR1 or SCR2 short or misfiring
- Short between SCR and breaker
- Light bulbs can be connected across outputs to check for short
- Control board firing circuit
- Replace Breaker
Secondary Voltage ($V_s$)

- Precipitator secondary kV typ. not a required input to operate HV controls (reference only)
- Older installations used divider after ACR to create current source to drive meters for display. ($50\,\Omega$ creates 0-1mA current source scale representing 0-50kV)
- Most installations use additional signal resistors to create a voltage divider circuit for input to the microprocessor control
- Mean voltage is measured by a resistance type voltage divider circuit.
Secondary Voltage ($V_s$)

- kV divider circuit scales down T-R operating voltage for input to microprocessor control.
- Analog meter can be used in parallel with signal to microprocessor.
- Voltage divider typically installed inside T-R oil tank (newer installations.)
- On older installations the divider is typically retro-fitted inside the ground switch enclosure or pipe & guard.
- Surge protector prevents lethal voltage outside of T-R junction box or ground switch enclosure.
Voltage Dividers

Voltage Divider retrofit on GE Pitts. T-R.

[R₁] Voltage Divider (typ. sizes 50, 80, 120, 400 MΩ)

[R₂] Signal Resistor
typ. installed in LV J-box or AVC cabinet
(sized by control vendor to scale input)
Secondary Voltage Vs

- Secondary Voltage feedback
- Basic kV divider circuit for microprocessor controls
- kV dividers designed to dissipate heat
Secondary Voltage

0 kV?

- Determine kV divider and sec. signal resistor values (T-R nameplate, schematic, or inspect voltage divider)
- Check control vendor manual for input scale
- Voltage divider can be Meg-Ohm tested to confirm value (follow LOTO and key interlock procedure)
- Secondary resistor is sometimes adjustable (slide resistor) this value can be checked when disconnected from the circuit.
- Meg-Ohm field cable
- Check surge protectors (Meg-ohm check)
Secondary Voltage

Ex: Nameplate Data
Double Half-Wave GE
480 Tap T-R (H1/H2)
• 400MΩ kV dividers
• 1MΩ sec. resistors
• 45kVDC [Nameplate]
Secondary Voltage (con’t)

- Modern controls typ. use 0-5V or 0-10V scaling for kV feedback and spark detection

- Signal conditioning boards may be used combining mA and kV metering circuits.
Secondary Current

- Shunt resistor used to scale secondary mA signal.
- Precipitator load current passes through resistor (connected between ground and low side of rectifier bridge)
- Shunt resistor provides feedback volt signal to microprocessor based on T-R secondary current rating.
- Surge protector prevents lethal voltage outside of T-R junction box or ground switch enclosure.
Secondary Current

- Secondary Current Feedback
- Warning! High voltage potential exists
Secondary Current

- **0 mA?**
  - If primary and secondary amps are 0, try short circuit testing TR
    - Current present => Open Circuit inside ESP
    - 0 Current => Open circuit between control and TR
  - Meg-Ohm field cable
  - Check surge protectors (Meg-ohm check)
  - Meg-Ohm TR primary and secondary
    - Open primary => Repair TR
    - Open secondary => check diode stack
Normal Operation

– Precipitator voltage should be above about 30 kilovolts D.C. and 100 volts A.C. in all fields.
– Precipitator current (milliamps D.C. and amps A.C.) should increase from inlet to outlet fields, usually approaching nameplate ratings in the outlet fields.
– Precipitator sparking should diminish from inlet to outlet fields, seldom exceeding about 50 sparks per minute on any one control.
Low Power
High Spark Rate

Low power and/or excessive sparking:

• Ash build up/ high hopper level
• Tracking or cracked insulator
• Rappers not working (causing excessive build up)
Precipitator kW

Reaching kV limit?
TR Nos. 1 & 2 Spark limited
Focus on TR Nos. 3 & 4 (limited at 55kV avg)
- Primary Voltage at 65-70% Rating
- High capacitance, slow discharge
Slight increase to kV limit => Increased Power Density
$V_p$ increased to 75% of nameplate rating

Increased Power
TR#3  100%
TR#4  30%

* Power limited by plant operators to “protect” electrical equipment from failure.
Power Density

Typical ESP Power vs Performance

ESP Collection Efficiency %

Low | Medium | High

ESP Power Density
Power Density

\[
\frac{[kVDC \times mADC]}{FT^2 \text{ COLLECTING AREA}} = \frac{WATTS}{FT^2}
\]

- \textbf{CE AREA} = \# GP \times 2 \times CE \text{ HEIGHT} \times CE \text{ LENGTH}

- \textbf{CALCULATE INSTALLED vs OPERATING}
Dust Loading

- Higher dust load => Increase in Voltage
  Current path restricted
Dust Loading

- High dust loading combined with non-aggressive electrodes on inlet field

<table>
<thead>
<tr>
<th>TR No.</th>
<th>Primary Volts</th>
<th>Primary Amps</th>
<th>Secondary Current (mA)</th>
<th>Secondary Voltage (KV1)</th>
<th>Power (KW)</th>
<th>Power Density (Watts/FT2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>260</td>
<td>5</td>
<td>80</td>
<td>62</td>
<td>5</td>
<td>0.20</td>
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<tr>
<td>2</td>
<td>390</td>
<td>110</td>
<td>600</td>
<td>60</td>
<td>36</td>
<td>1.48</td>
</tr>
<tr>
<td>3</td>
<td>340</td>
<td>120</td>
<td>700</td>
<td>50</td>
<td>35</td>
<td>1.43</td>
</tr>
</tbody>
</table>
Dust Resistivity

Fly ash resistivity curve
V/I Curve Low-Med Resistivity

Precipitators used for range of $10^4$ to $10^{14}$ ohm-cm

Preferable resistivity in the range of $10^8$ to $10^{11}$ ohm-cm

Basic VI curve for 9-in spacing
Low to Medium Resistivity Particulate
High Resistivity Dust

High resistivity dust layer on collecting plates can neutralize current and reduce voltage.

Particles do not conduct charge to ground.

Also known as “Back Corona”

Plot a V/I curve.
V/I Curve High Resistivity

High resistivity effects on Voltage and Current

Typ. VI curve for 9-in spacing
High Resistivity Particulate
Back Corona

• Back corona and Intermittent Energization modes have been used to find and operate at the “knee” in the V/I curve during back corona conditions and maintains the power at that point.

• Power is increased when the back corona condition is no longer present
Common Upgrades

• Rebuild Options
  – Rebuild Weighted Wire ESPs [9” to 12” spacing]
    • Existing T-Rs can be re-used with more aggressive electrodes
    • Lower corona onset or “starting voltage”
    • Increase power density
Common Upgrades

• Rebuild Options
  – Upgrade to more aggressive electrodes on inlet field
  – Common upgrade for high inlet dust loading
  – Increase electrical sectionalization by adding TRs or Switch Mode Power Supplies
    • Reduces amount of collecting area affected by spark or upset condition.
Common Upgrades

• HF SMPS (High-Freq.)
  – Replace existing conventional 60Hz Transformer Rectifiers (T-Rs) with High Frequency Switch Mode Power Supplies (HF SMPS), ranging up to 25kHz
  – Typically requires 3-phase to precipitator roof

• MF SMPS (Mid-Freq.)
  – T-Rs can be replaced with MF SMPS or
  – Controls can be upgraded while re-using the existing T-Rs.
SMPS (cont’d)

- Reduces ripple, average kV approaches peak kV
- Increases kV can be attained on inlet and middle fields that are often spark constrained.
- Small kV increase often results in significant increase in current
- 5-10% kV increase can result in total power level increase >20%

Courtesy of Redkoh Industries
Impact on Performance

- Precipitator OEM’s are claiming sizing credits between 10-20%
- Average kV approaches Peak kV.
- Significant increase in precipitator current with small increase in operating kV.
- Fast recovery following spark/arc condition
- Recent interest in precipitator studies and upgrades due to MACT PM limit and DSI opportunities.
Rapping Systems

- Top rapping systems typically grouped by row or field
- Most common mode of operation is Round Trip using cycle clocks
- RT time is assigned to each group of rappers
- Rappers fire in sequence at frequency of RT Time/# Rappers
Rapper Controls

- Top rapped ESPs have been updated with microprocessor based controls. European style rapping systems use tumbling hammer type systems
- Objective to maintain collecting efficiency by forming nominal dust layer and removing with impact force to collecting surface
- Excessive ash buildup on plates reduces the inter-electrode clearances and causes high spark rates and electrical degradation of the precipitator field
# Rapping

<table>
<thead>
<tr>
<th>Dust Build-up</th>
<th>DE</th>
<th>CE</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Dust Thickness</td>
<td>1/8”</td>
<td>1/4”</td>
<td>OK</td>
</tr>
<tr>
<td>High Dust Build-up</td>
<td>1/4”</td>
<td>1/2”</td>
<td>Increase cycles and/or intensity</td>
</tr>
<tr>
<td>Severe Dust Build-up</td>
<td>1/2”</td>
<td>1”</td>
<td>Change or upgrade rapping design</td>
</tr>
</tbody>
</table>

![Dust Build-up Images]
Rapping

- Opacity Average?
Rapping

- Double spike detected every 5 min
- Correlates to outlet field rapping program (Round Trip Time/ No. Rappers)
Rapping

- Startup
- Spikes Increasing
- Rappers Off
- Reduced intensity on Outlet field rappers
- Reduced round trip time (less time between raps)
Rapping

- Changes do not result in immediate results!
- Rapping programs and power levels should be monitored throughout shift at steady load

- Target
  - Lower Baseline
  - Decrease Spiking “Peaks” and frequency

Program modified
Rappers off
Rapping

If modifications are made to the rapping program, the following should be kept in mind:

- Excessive rapping of collecting electrodes causes re-entrainment of collected ash, and loss of collection efficiency.
- Excessive rapping may cause fatigue failure of internal components.
- Inadequate rapping causes high spark rates, low power, and loss of collection efficiency.
- Because particulate collection is concentrated at the inlet of the precipitator, rapping should be hardest and most frequent on the inlet field, and progressively less on downstream fields.
Rapping

- Fine tuned rapping program in operation at full load (P-C med. sulfur coal)
High Gas Velocities and Re-entrainment

PROBLEM:
• Excessive emissions while precipitator is operating at high power.

SYMPTOMS:
• Normal primary and secondary voltage.
• Normal primary and secondary current.
• Abnormally high stack opacity.

CAUSES:
• Rappers misadjusted to excessively high intensity or short cycles.
• Volume of flue gas above design.
• Poor gas distribution within precipitator due to pluggage of perforated distribution plate, or dust buildup in plenum.
Troubleshooting Impulse Rappers

- **SHORT CIRCUIT (SINGLE RAPPER)**
  - High level current alarm
  - Shorted coil
  - Coil tube wear
  - Shorted field cable

- **OPEN CIRCUIT**
  - Low level current alarm
  - Disconnected field cable or coil

- **COIL RESISTANCE**
  - Resistance can be measured at rapper or control cabinet
  - Check with rapper vendor for acceptable values and compare all values
Troubleshooting using Waveforms

• Oscilloscope waveforms are obtained by connecting across the current sensing resistor (providing feedback to the controller)

• Measures voltage across resistor and compares to “normal” value

• Short circuit condition
  Control detects high level voltage
  Fires for 1 half cycle to protect the components from high current
Common Upgrades

• Tumbling Hammer to Top Rapping Conversion.
  – Top rapping systems using magnetic impulse type rappers offer more flexibility for changing intensity and rapping frequencies

• Splitting anvil beams
  – Older P-C ESPs had as many as 9 or 10 CE’s per anvil beam
  – Splitting anvil beams increases rapping density and sectionalization, reduces fly ash re-entrainment
Common Upgrades

• Splitting anvil beams
Common Upgrades

• Flue Gas Conditioning
  – \( \text{SO}_3 \) conditioning used to improve electrical characteristics of fly ash (improve resistivity)
  – \( \text{NH}_3 \) conditioning used to agglomerate fly ash particles
  – Flue gas conditioning used in an effort to offset the adverse affect of low sulfur coal, particulate fines, and high resistivity.
QUESTIONS?

THANK YOU