Substation Commissioning
Topics

• Project Overview
• Review Work Plan
• Substation Equipment Testing
  Power Circuit Breakers
  Power Transformers
  Capacitors
Project Overview

- Reviewing the Work Plan
- Planning and Co-ordinating the Work Plan
- Communicating
- Verifying
- Testing
- Troubleshooting, Re-verifying, Re-testing
- Completing Project Documentation
Review the Work Plan

- Identify what’s happening
- Who will be involved?
- Identify Responsibilities
- Review Project Documentation
- Develop Work Sequence
Power Circuit Breakers
Power Circuit Breaker Guidelines

Record Nameplate Data
Verify Prints
Physical Orientation
Wiring & Jumpers
Measure Coils & Megger
Test CTs
Testing CTs

Ratio, Polarity, & Burden

Open Circuit Excitation

Buzz & Megger Cables

Terminate Hardwired Shorts on Spares

Verify CT circuits only grounded @ one point

Verify Shorting Bar is GROUNDED
Power Circuit Breaker Guidelines

Record Nameplate Data
Verify Prints
Physical Orientation
Wiring & Jumpers
Measure Coils & Megger
Test CTs
Gas Fill & Measure
SF6 Parameters

SF6 QUALITY PARAMETERS

1. SF6 Purity (required diagnostic test):
   - Reason for measurement: SF6 must have a certain level of purity to ensure two things: 1) interrupting capability of the breaker, and 2) dielectric strength across the open contacts.
   - 95.0% and above: acceptable
   - 80.0% to 94.9%: swap gas during next service (As per Ken Edwards: Breakdown in SF6 Gas Mixtures.pdf, pg 9 shows that GIS can dielectrically operate as low as 80%; CIGRE 360.pdf, pg 38 indicate that extinguishing capabilities for some types of mixed gas actually get better than for pure SF6).
   - 79.9% and below: remove from service and swap gas

2. SF6 Moisture (required diagnostic test):
   - Reason for measurement: Moisture combines with switching byproducts to create hydrofluoric acid. This acid will cause dielectric issues across insulating surfaces inside the breaker (i.e.: interrupter support tube, nozzles). The amount of acid is related to the amount of moisture in the SF6.
   - 0 to 50 PPMV: acceptable (new equipment, as per Brad Folden - 2009.12.04)
   - 0 to 200 PPMV: acceptable (in-service equipment)
   - 201-400 PPMV: perform gas dryout during next service
   - above 400 PPMV: remove from service & perform gas dryout

3. SF6 Decomposition (not yet required for standard diagnostic testing):
   - Reason for measurement: SO2 is an indication of oxides in the gas, and oxides come from metals in the breaker that are vaporized during arcing. Arcing occurs during current interruption, during a prolonged restrike on the main contacts or during a L-G fault. Measuring SO2 indicates two things: 1) possible damage to the interrupter main contacts (which will be confirmed with micro-ohm testing), or 2) a L-G fault inside a dead-tank breaker.
   - 0 to 250 ppm: acceptable
   - 251-500 ppm: recondition gas during next service (filter out byproducts)
   - above 500 ppm: Remove from service & process as faulted:
     - Contact TESM to discuss results.
     - Request SF6 emergency response trailer & personnel through Dennis Pelton.
     - Follow existing process outlined in Sub Maint SG XI.D.1, “SF6 Handling” and perform an internal inspection.
Power Circuit Breaker Guidelines

Record Nameplate Data
Verify Prints

Physical Orientation
Wiring & Jumpers

Measure Coils & Megger
Test CTs
Gas Fill & Measure
Wiring Checks

Check Timing
Breaker Timing

Purpose: Verifies Breaker Contacts are Opening & Closing within acceptable time limits

Method: Measure Tripping & Closing Times

Analysis: Contact Velocities & Inter-pole Spread
## Timing Checklist for 242 PMG Circuit Breakers

<table>
<thead>
<tr>
<th>Item to Check</th>
<th>Actual Value</th>
<th>Specified Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening Time (2 Cycle)</td>
<td></td>
<td>13 to 19 ms</td>
</tr>
<tr>
<td>Opening Time for 3-Cycle Rating and 35 ohms</td>
<td></td>
<td>15 to 23 ms</td>
</tr>
<tr>
<td>Opening Velocity (mechanism fully charged)</td>
<td></td>
<td>8.8 to 10 m/sec</td>
</tr>
<tr>
<td>Inter-Pole Spread Opening</td>
<td></td>
<td>2.0 ms maximum</td>
</tr>
<tr>
<td>Closing Time*</td>
<td></td>
<td>50 to 65 ms*</td>
</tr>
<tr>
<td>Closing Velocity (mechanism fully charged)</td>
<td></td>
<td>3.8 to 4.9 m/sec</td>
</tr>
<tr>
<td>Inter-Pole Spread Closing</td>
<td></td>
<td>3.0 ms maximum</td>
</tr>
<tr>
<td>Reclose Time</td>
<td></td>
<td>20 cycles minimum</td>
</tr>
<tr>
<td>Close-Open Contact Dwell Time</td>
<td></td>
<td>35 ms maximum</td>
</tr>
<tr>
<td>Close-Open Travel Distance</td>
<td></td>
<td>195 mm minimum</td>
</tr>
</tbody>
</table>

CLOSE speeds are calculated from 55 mm of travel to 45 mm differential
OPEN Speeds are calculated from 65 mm travel to 75 mm differential

*Notice: Subtract 8-10 ms for the Pick-Up Time of the X-Relay if close timing tests are performed with the X-Relay in the circuit.
Time & Travel for Close (Contact Velocity)

36 mm/ 14 ms = 2.57 m/s
Breaker Timing Test

Plan

Trip (Both Trip Coils)

Close w/ X Coil Included

Close w/ X Coil Excluded

Reclose using each Trip Coil

Trip-Free using each Trip Coil
## Breaker Timing

<table>
<thead>
<tr>
<th>PCB Open</th>
<th>PCB Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start w/ a Close Shot</td>
<td>TC1 Reclose</td>
</tr>
<tr>
<td>Trip &amp; Trip Free on TC1</td>
<td>App note 7 close</td>
</tr>
<tr>
<td></td>
<td>(Move leads to TC2)</td>
</tr>
<tr>
<td></td>
<td>App note 7 reclose w/TC2 connected</td>
</tr>
<tr>
<td>Trip &amp; Trip Free on TC2</td>
<td></td>
</tr>
<tr>
<td>All done with only 8 operations</td>
<td></td>
</tr>
</tbody>
</table>
Power Circuit Breaker Guidelines

- Record Nameplate Data
- Verify Prints
- Physical Orientation
- Wiring & Jumpers
- Measure Coils & Hand Megger
- Test CTs
- Gas Fill & Measure (after 24 hrs)
- Wiring Checks

- Check Timing
- Primary Contact Resistance Checks
- Energy Storage Checks
Energy Storage Systems

Spring Pressure Rundown Checks

Spring Discharge
Low Spring Alarm
Operation Block
Motor Start/Stop
Overnight Sag
Energy Storage Systems

Gas Density Checks

Temperature Compensated

SF6 Purity & Moisture
# Millivolt Drop, Gas Pressure Switches, and Moisture Content

## Millivolt Drop

<table>
<thead>
<tr>
<th>Phase</th>
<th>Current</th>
<th>Volts (mV)</th>
<th>Resistance (μΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100 A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>100 A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>100 A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

## SF₆ Gas Density Monitor Settings

<table>
<thead>
<tr>
<th>Temperature</th>
<th>68 °F</th>
<th>20.0 °C</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Contact and Function</th>
<th>Nameplate @ 68 °F</th>
<th>Temp Adjusted Nameplate</th>
<th>A PH</th>
<th>A Reset</th>
<th>B PH</th>
<th>B Reset</th>
<th>C PH</th>
<th>C Reset</th>
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<tbody>
<tr>
<td>Nominal</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>63-2C (ALARM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>63-2B1 (BLOCK)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63-2B2 (BLOCK)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note tolerance on density monitor ± 2 psi*

## Water Moisture Content

<table>
<thead>
<tr>
<th>Temperature</th>
<th>68 °F</th>
<th>20.0 °C</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>A PHASE CONTENT</th>
<th>B PHASE CONTENT</th>
<th>C PHASE CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPM</td>
<td>PPM</td>
<td>PPM</td>
</tr>
</tbody>
</table>
Power Circuit Breaker Guidelines

Record Nameplate Data
Verify Prints
Physical Orientation
Wiring & Jumpers
Measure Coils & Megger
Test CTs
Gas Fill & Measure
Wiring Checks

Check Timing
Primary Contact Resistance
Energy Storage
Power Factor
Operational Checks / Load Overall
Accessory and Alarm Checks
Final Moisture
Final Checks
Final Checks

Trip Checks - Local & Remote
Alarms & Indications - Local & Remote - SCADA
CT Final Checks
Bridge & Dummy Load PT Circuits
Gas Pressures
Ground Switches Open / All Relays in Service
Hi-Pot w/ System Voltage
Close PCB & Pick-up Load
QuickTime™ and a H.264 decompressor are needed to see this picture.
PCB Final Checks

Trip Checks - Local and Remote
Alarms - Local & Remote - SCADA
CT Final Checks
Bridge & Dummy Load PT Circuits
Gas Pressures
Ground Switches Open / All Relays in Service
Hi-Pot w/ System Voltage
Close PCB & Pick-up Load
In Service Checks
Transformer Testing Guidelines

- Record Nameplate Data
- Auxiliary Components
- Physical Orientation
- Wiring & Jumpers
- Hand Meggering
- Test CTs
- Oil Processing / Sample
- Insulation Power Factor
Insulation Power Factor
Insulation Power Factor

Capacitive Current

Capacitance represents ability to store energy when voltage is applied

Leakage Current

Dissipated energy and heating from applied voltage across insulation

Measuring Dielectric Loss
Insulation Power Factor

% Power Factor in general: Ratio of Watts to Total Power.
Here it is Ratio of Dielectric Losses to Total Power supplied, or ratio of leakage current to total current.

Example: Total Power = 460 mVA with 3.3 mW : Calculated % PF = 0.72
Insulation Power Factor

- Grounded Specimen Test (Ground)

b) Low-voltage switch in ground—
Measure $C_A$ and $C_B$ (grounded-specimen test mode GST)
Insulation Power Factor

• Grounded Specimen Test w/ LV guarded out (Guard)

c) Low-voltage switch in guard—Measure $C_A$ only (grounded-specimen test mode GST)
Insulation Power Factor

- Un-grounded Specimen Test (UST)

![Diagram of high-voltage test setup with a grounded guard, high-voltage transformer, high-voltage test cable, I & W meter, low-voltage lead, and capacitors C_B and C_A.]

a) Low-voltage switch in UST—Measure C_B only (ungrounded-specimen test mode UST)
Insulation Power Factor

- Ground, Guard, & UST

<table>
<thead>
<tr>
<th>Test Mode</th>
<th>Energize</th>
<th>Ground</th>
<th>Guard</th>
<th>UST</th>
<th>Measure</th>
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</thead>
<tbody>
<tr>
<td>GST</td>
<td>High</td>
<td>—</td>
<td>Low, Tert.</td>
<td>—</td>
<td>$C_H$</td>
</tr>
<tr>
<td>GST</td>
<td>Low</td>
<td>—</td>
<td>Tert., High</td>
<td>—</td>
<td>$C_L$</td>
</tr>
<tr>
<td>GST</td>
<td>Tert.</td>
<td>—</td>
<td>High, Low</td>
<td>—</td>
<td>$C_T$</td>
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</table>

Supplementary Test for Interwinding Insulations

<table>
<thead>
<tr>
<th>Test Mode</th>
<th>Energize</th>
<th>Ground</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>UST</td>
<td>High</td>
<td>Tert.</td>
<td>$C_{HL}$</td>
</tr>
<tr>
<td>UST</td>
<td>Low</td>
<td>High</td>
<td>$C_{LT}$</td>
</tr>
<tr>
<td>UST</td>
<td>Tert.</td>
<td>Low</td>
<td>$C_{HT}$</td>
</tr>
</tbody>
</table>
Ground

Power Factor Test Connections
2 Winding 3φ Transformers

Test Connections:
Short circuit high voltage &
low voltage bushings. Connect
P.F. set H.V. lead to H.V. WDG &
P.F. set L.V. lead to L.V. WDG.

Test #1 — Measures H.V. WDG & bushings
to core & GND & measures H.V. WDG
to L.V. WDG.
Set L.V. switch to "IN" or
"GROUND" position.
Guard

Test #2 - Measures H.V. Wdg's & Bushings to Core & Gnd.

Set L.V. switch to "Midpoint" or "Guard" position.
CHECK TEST - MEASURES H.V. WDG'S TO L.V. WDG'S. RESULTS OF THIS TEST SHOULD EQUAL THE CALCULATED DIFFERENCE BETWEEN TESTS NO. 1 & NO. 2.

SET L.V. SWITCH IN “OUT” OR “UST” POSITION.
Ground

Test connections: Short circuit high & low voltage bushings. Connect P.F. set H.V. lead to L.V. bushings & connect P.F. set L.V. lead to H.V. bushings.

Caution: Do not energize L.V. bushings, if rated at 15kV, over 8.5 kV

Test #3 measures L.V. WDG's & bushings to core & GND. Measures L.V. WDG's to H.V. WDG's. Set L.V. switch to "IN" or ground position.
Guard + UST

Test #4 measures L.V. Wdg's & bushings to core & grid.

Set L.V. switch to midpoint or guard position.

Check test measures L.V. Wdg's to H.V. Wdg's. Results of this test should equal the calculated difference between tests no. 3 & no. 4.

Set L.V. switch in "out" or "UST" position.
Excitation Current

---

Δ-Y Transformer

<table>
<thead>
<tr>
<th>Meas.</th>
<th>Energ.</th>
<th>UST</th>
<th>GND</th>
</tr>
</thead>
<tbody>
<tr>
<td>I₁-2</td>
<td>H₁</td>
<td>H₂</td>
<td>H₃</td>
</tr>
<tr>
<td>I₂-3</td>
<td>H₂</td>
<td>H₃</td>
<td>H₁</td>
</tr>
<tr>
<td>I₃-1</td>
<td>H₃</td>
<td>H₁</td>
<td>H₂</td>
</tr>
</tbody>
</table>

Secondary should not be left floating. GND, but do not short windings.
Excitation Current

--- Y-△ XFORMER ---

- Meas  Energy  UST
- I₁₀ H₁ H₀
- I₂₀ H₂ H₀
- I₃₀ H₃ H₀

Secondary should not be left floating. GND, but do not short windings.
Bushings
Higher Voltages have potential taps w/ C2 > C1. Check Nameplate before applying voltages. Megger Bushing and its tap if no PF test set is available.
Transformer Testing Guidelines

- Record Nameplate Data
- Auxiliary Components
- Physical Orientation
- Wiring & Jumpers
- Hand Meggering
- Test CTs
- Oil Processing/ Sample
- Insulation Power Factor
- Winding Ratio, Polarity
Winding Ratio, Polarity

Purpose: Checks Turns Ratio & Polarity on all tap connections

Method: TTR Test Set continually through all taps.

Analysis:

Measured Ratio and Nameplate should match very closely (0.2%)

Measured Ratio will be slightly lower than calculated due to slight losses in TTR test set.

Shorted turns & high contact resistance indicated by high excitation current. Ratio error greater than 0.2% will be easily noted.
Transformer Testing Guidelines

- Record Nameplate Data
- Auxiliary Components
- Physical Orientation
- Wiring & Jumpers
- Hand Meggering
- Test CTs
- Oil Processing/ Sample
- Insulation Power Factor
- Winding Ratio, Polarity
- Impedance
Measuring Impedance

Purpose: Detect shipping damage & basis for future tests

Method: Compare with Nameplate at Nominal Taps

Analysis: Useful for determining core and coil shifting, loose or high resistance connections
Measuring Impedance
Measuring Impedance

In General:

\[ |\%Z = Z_{MEASURED} \cdot \frac{I_{RATED}}{V_{RATED}} \cdot 100 | \]

3 Phase wye-wye or wye-delta

\[ \%Z = \frac{1}{10} \cdot \frac{V_{MEASURED}}{I_{MEASURED}} \cdot \frac{KVA_{3\phi RATED}}{(KV_{L-L})^2} \]

3 Phase delta-delta

\[ \%Z = \frac{1}{20} \cdot \frac{V_{MEASURED}}{I_{MEASURED}} \cdot \frac{KVA_{3\phi RATED}}{(KV_{L-L})^2} \]

Zero-sequence

\[ \%Z = \frac{1}{10} \cdot \frac{V_{MEASURED}}{I_{MEASURED}} \cdot \frac{3(KVA_{3\phi RATED})}{(KV_{L-L})^2} \]
Transformer Testing Guidelines

- Record Nameplate Data
- Auxiliary Components
- Physical Orientation
- Wiring & Jumpers
- Hand Meggering
- Test CTs
- Oil Processing/ Sample
- Insulation Power Factor

- Winding Ratio, Polarity
- Impedance
- Calibrate Temperature
<table>
<thead>
<tr>
<th>TYPE OF TRANSFORMER</th>
<th>AVERAGE TEMP RISE</th>
<th>HOT SPOT TEMP ALARM SETTING</th>
<th>OPERATING</th>
<th>TOP OIL TEMP ALARM SETTING</th>
<th>OPERATING</th>
<th>COOLING ON AT HOT SPOT TEMP 1st Stage</th>
<th>2nd Stage</th>
<th>RECOMMENDED % OF MAX NAMEPLATE KVA WITH COOLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>OA REACTORS</td>
<td>55°C</td>
<td>95°C</td>
<td>105°C</td>
<td>110°C</td>
<td>100°C</td>
<td>85°C</td>
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<td>FA 100%</td>
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<td>100°C</td>
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<td>80°C</td>
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<td>95°C</td>
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<td>FOA 80%</td>
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<td>OA/FOA/FOA</td>
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<td>95°C</td>
<td>100°C</td>
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<td>85°C</td>
<td>80°C</td>
<td>90°C</td>
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<td>FOA 80%</td>
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<td>105°C</td>
<td>85°C</td>
<td>90°C</td>
<td>-</td>
<td></td>
<td>80%</td>
</tr>
</tbody>
</table>

*FOA & FOW TRANSFORMER BANKS WITH LOSS OF COOLING:

Above 100 MVA at maximum load ..............20 minutes 100 MVA or lower at maximum load ..............1 hour
Above 100 MVA energized with no load ..............1 hour 100 MVA or lower energized with no load ..............6 hours
Transformer Testing Guidelines

- Record Nameplate Data
- Auxiliary Components
- Physical Orientation
- Wiring & Jumpers
- Hand Meggering
- Test CTs
- Oil Processing/ Sample
- Insulation Power Factor
- Winding Ratio, Polarity
- Impedance
- Calibrate Temperature
- Bump Fans & Pumps
- Bushing Pot Devices
- DC Winding Resistance
- Megger Core Ground & Windings
- Trip Checks
Capacitors
Testing Capacitors (Impedance)

Start with Nameplate rating on Can:

200 KVAR @ 22800 V

Q (kVar) = V I sin (theta)

I = kVAR / kV
I = 200 / 22.8 = 8.77 A

Xc (per can) = I / jw(C) = V / I
Xc (per can) = 22800 / 8.77 = 2600 Ohms

C = 1 / 377 (Xc)
C = 1 / 377 (2600) = 1.02 microF

Each Can is then rated @ 1.02 microF
Testing Capacitors (Cont’d)

Number of Cells in Test? 22

1.02 * 22 = 22.4 microF Cap. per layer

Build Data Sheet

\[ C_{\text{meas}} = \frac{I_{\text{meas}}}{V_{\text{meas}}} \times 377 \]

with \( V_{\text{meas}} \) @ 100V, measure I

<table>
<thead>
<tr>
<th>( V_{\text{meas}} )</th>
<th>( I_{\text{meas}} )</th>
<th>( C_{\text{meas}} )</th>
<th>( C_{\text{calc}} )</th>
<th>d</th>
<th>%d</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.58</td>
<td>0.859</td>
<td>22.6</td>
<td>22.4</td>
<td>0.2</td>
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Wiring Checks

• Compare Schematics w/ Wiring Prints
• Buzz point to point
• Check Diodes
• Contact Makeups
• Test Switches
• Terminal Blocks
• Jumpers
• Wiggle Check Connections
In Service Checks
In Service Checks

- Pre-determine the measurements.
- Cutout your TRIPS
- Magnitude and polarity of each current and voltage (phase angle and rotation)
- Look for quantities where you do and don’t expect them to be.
- Open CTs & Shorted CTs
- Wrong Ratios
- Neutral Connections
- Proper Potentials
- Document your Reference Potential &
Thank you for joining us.

Stay SAFE...