Recommendations for an Effective Substation Equipment Testing & Maintenance Program

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Why Test?

- Safety
- System Reliability
- Customer Satisfaction
- Maximize Revenues
- Return on Equipment Investment
- Current/Future Regulatory Requirements
Testing Categories

- Acceptance Testing – New Electrical Devices
- Commissioning – Functional Testing of the Devices in the Integrated Substation System
- Maintenance Testing – Existing Electrical Devices
Maintenance Program Considerations

- Qualified Test Personnel
- Safety Program
- Testing Methodology
- Test Equipment
- Reporting
- Database/Trending
Qualified Test Personnel

- ANSI/NETA ETT-2010
- Standard for Certification of Electrical Testing Technicians
- Practical Experience and Examination
- Safety, Electrical Theory, Tool/Equipment,
- NETA I(0), II(2), III(5), IV(10) Classifications(Exp.)
- Company Based Training/Mentoring Program
Safety Program

- Lockout/Tagout
- Safety Procedures/Briefings
- Arc Flash Protection
Testing - ANSI/NETA MTS-2011

- Standard for Maintenance Testing Specifications for Electric Power Systems and Equipment
- InterNational Electrical Testing Association
- American National Standards Institute
- Electrical/Mechanical Tests by Device Type
- Recommended Test Intervals
- Supplemented or Superseded by Local Test Methods
Testing Details

- Device Type
- Typical Tests
- Test Equipment
- Sample Test Report
- Potential Impact Without Maintenance
Flooded Lead Acid Battery

- Visual & Mechanical Inspection
  - Verify Ventilation, Racks & Spill Containment
  - Inspect Physical Condition
  - Verify Electrolyte Level & Specific Gravity
  - Clean Terminals & Tighten Connections

- Electrical Tests
  - Resistance
  - Charger Float Voltage
  - Cell Voltage
  - Intercell Connection Resistance
  - Load Tests

- Test Equipment
  - Alber BCT 2000 Capacity
  - Alber CRT400 Cell Resistance
# Battery Test Report

## Cell General

### Test End Voltages

<table>
<thead>
<tr>
<th>String: String 1</th>
<th>1 = &lt; 1.742&gt;</th>
<th>2 = 1.763</th>
<th>3 = 1.764</th>
<th>4 = 1.764</th>
<th>5 = 1.785</th>
<th>6 = 1.802</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 = 1.751</td>
<td>8 = 1.761</td>
<td>9 = 1.770</td>
<td>10 = 1.781</td>
<td>11 = 1.757</td>
<td>12 = 1.765</td>
<td></td>
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<tr>
<td>13 = 1.776</td>
<td>14 = &lt; 1.746&gt;</td>
<td>15 = &lt; 1.742&gt;</td>
<td>16 = 1.772</td>
<td>17 = 1.771</td>
<td>18 = 1.771</td>
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<tr>
<td>19 = 1.775</td>
<td>20 = 1.801</td>
<td>21 = 1.768</td>
<td>22 = 1.768</td>
<td>23 = 1.765</td>
<td>24 = 1.782</td>
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</tr>
<tr>
<td>25 = 1.782</td>
<td>26 = 1.785</td>
<td>27 = 1.770</td>
<td>28 = 1.776</td>
<td>29 = 1.775</td>
<td>30 = 1.801</td>
<td></td>
</tr>
<tr>
<td>31 = 1.783</td>
<td>32 = 1.787</td>
<td>33 = 1.776</td>
<td>34 = 1.775</td>
<td>35 = 1.767</td>
<td>36 = 1.773</td>
<td></td>
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<tr>
<td>37 = 1.791</td>
<td>38 = 1.770</td>
<td>39 = 1.765</td>
<td>40 = 1.779</td>
<td>41 = &lt; 1.741&gt;</td>
<td>42 = 1.766</td>
<td></td>
</tr>
<tr>
<td>43 = 1.764</td>
<td>44 = &lt; 1.727&gt;</td>
<td>45 = 1.752</td>
<td>46 = 1.763</td>
<td>47 = 1.752</td>
<td>48 = 1.763</td>
<td></td>
</tr>
<tr>
<td>49 = &lt; 1.749&gt;</td>
<td>50 = &lt; 1.734&gt;</td>
<td>51 = 1.761</td>
<td>52 = &lt; 1.746&gt;</td>
<td>53 = 1.759</td>
<td>54 = &lt; 1.733&gt;</td>
<td></td>
</tr>
<tr>
<td>55 = &lt; 1.741&gt;</td>
<td>56 = &lt; 1.739&gt;</td>
<td>57 = 1.762</td>
<td>58 = 1.756</td>
<td>59 = 1.756</td>
<td>60 = &lt; 1.737&gt;</td>
<td></td>
</tr>
</tbody>
</table>

- **Test Time:** 03:30:51
- **Battery Voltage:** 104.0
- **Amps:** 88.2
- **Kw:** 9.2
Potential Impact Without Maintenance

- DC Backup Capacity and Time Reduced
- Hydrogen Gas Buildup Without Proper Ventilation
- Environmental Issues if Jar Cracked or Liquid Level Low
- Loss of Protection System if There is a Loss of DC Power
- Battery charger – Reduced Battery Life Expectancy Due to Improper Charging
Transformer Testing

- Visual & Mechanical
  - DGA – Internal Arcing
  - Check for PCB Label
  - Controls, Trip Circuits, Fans, Pumps
- Electrical (TX, NLTC, LTC)
  - PF Test – Insulation
  - TTR – Winding Short
  - Winding Resistance
- Test Equipment
  - Doble M-4000 (Multiple Electrical Tests)
  - Vanguard Winding Resistance Test Set
  - Vanguard Three Phase TTR Test set
Transformer Test Report

Transformer Turns Ratio Tests

Acceptable Percent Error: 0.50%

Transformer Inspection

Customer: Florida Electric Cooperatives Assoc
Address: 2916 Apalachee Parkway, Tallahassee FL 32301
Owner: Florida Electric Cooperatives Assoc
Location/Plant: Sandpearl Resort
Date: 6/3/2014
Temperature: ℃
Humidity: %
Equipment Location: Sandpearl Resort

<table>
<thead>
<tr>
<th></th>
<th>OHMS</th>
<th></th>
<th>OHMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2 - H0</td>
<td>0.2078</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3 - H0</td>
<td>0.2242</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X2 - X3</td>
<td>0.04429</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X3 - X1</td>
<td>0.04574</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The power factor for this transformer is abnormally high. It is uncertain if the power factor is abnormally high due to moisture (humidity/dew point) or if the high power factor is a result of high losses in the material in the transformer. Standard industry data suggests that an insulation power factor of less than 1% may be more normal. Recommend re-testing this transformer in one year. Any significant increase of the insulation power factor over the present level would warrant further investigation.

<table>
<thead>
<tr>
<th>25</th>
<th>26</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSTg-R</td>
<td>GSTg-R</td>
<td>GSTg-R</td>
</tr>
</tbody>
</table>

Primary Bushings: Top/Accessible: Secondary Bushings: Top/Enclosed: Other: N/A
PCB Content: <1 ppm EPA Label: Yes

EMERSON Network Power
Potential Impact Without Maintenance

- Failure Due to Gassing/Arcing
- Overheating/Overload
- Insulation Degradation
- Fire/Explosion
- Same issues for LTC
- Secondary Voltage Out of Tolerance
Relay Testing

- Visual & Mechanical (E/M)
  - Verify Setting to Coordination Study
  - Verify Presence of Any Foreign Material
  - Verify Disk Mobility and Parts Clearance
  - Verify Cover Integrity
- Electrical (E/M)
  - Determine Pickup and Dropout of Targets
  - Settings, Pickup, T/C Curve
  - Calibration
- Electrical (MP)
  - Settings, Pickup, T/C Curve
  - Pass/Fail
  - Check Logic
- Test Equipment
  - Doble F-6150, Manta 5000, Omicron
  - Enoserv RTS Software
  - Doble ProTest Software
Relay Test Report

### RTS Relay Test Results

<table>
<thead>
<tr>
<th>Relay Test Results for:</th>
<th>51G</th>
<th>GND PICKUP</th>
<th>(51G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PICKUP</td>
<td>CURRENT</td>
<td>IDEAL</td>
<td>%ERROR</td>
</tr>
<tr>
<td>0.505</td>
<td>0.500</td>
<td>1.00</td>
<td>0.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relay Test Results for:</th>
<th>51G</th>
<th>GND TIMING</th>
<th>(51GT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MULTIPLE</td>
<td>VALUE</td>
<td>TIME (CY)</td>
<td>TIME (SEC)</td>
</tr>
<tr>
<td>2.00</td>
<td>1.000</td>
<td>1038.31</td>
<td>17.305</td>
</tr>
<tr>
<td>3.00</td>
<td>1.500</td>
<td>432.71</td>
<td>7.212</td>
</tr>
<tr>
<td>4.00</td>
<td>2.000</td>
<td>263.10</td>
<td>4.385</td>
</tr>
</tbody>
</table>

### Chart: 51G GND TIMING (51GT)

![Chart showing time vs multiple of tap for 51G GND TIMING](chart)

<table>
<thead>
<tr>
<th>Relay Test Results for:</th>
<th>59P</th>
<th>OV PICKUP</th>
<th>(59A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PICKUP</td>
<td>VOLTS</td>
<td>IDEAL</td>
<td>%ERROR</td>
</tr>
<tr>
<td>60.000</td>
<td>60.000</td>
<td>0.00</td>
<td>PASS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relay Test Results for:</th>
<th>59P</th>
<th>OV 3PH PICKUP</th>
<th>(3P59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PICKUP</td>
<td>VOLTS</td>
<td>IDEAL</td>
<td>%ERROR</td>
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<tr>
<td>60.600</td>
<td>60.000</td>
<td>1.00</td>
<td>PASS</td>
</tr>
</tbody>
</table>
Potential Impact Without Maintenance

- Higher Pick up level and longer trip times for E/M
- Out of Zones Operations
- Relay Mis-Operation
- Failure to protect other equipment and system operating integrity
- Failure to support the protection scheme as designed
- Sub-optimization of operation and protection
Vacuum Breaker

- Tests
  - Insulation
  - Contact Resistance
  - Vacuum Integrity
  - Current Transformers

- Test Equipment
  - Vanguard100 Amp Ductor
  - AC Hi-Pot or Vacuum Interrupter Test Set
  - Vanguard Multi-Tap CT Test Set
# Vacuum Breaker Test Report

## Vacuum Circuit Breaker Inspection and Test

**Vacuum Integrity**
- Test Voltage: 27 kVAC
- Test Duration: 1 minute(s)
- All test results: Pass / Fail

<table>
<thead>
<tr>
<th>Pole 1</th>
<th>Pole 2</th>
<th>Pole 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overpotential</th>
</tr>
</thead>
</table>
- Test Voltage: 27 kVAC
- Test Duration: 1 minute(s)
- All test results: Pass / Fail
- All phases not under test were grounded.

<table>
<thead>
<tr>
<th>Pole 1 to GND</th>
<th>Pole 2 to GND</th>
<th>Pole 3 to GND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>PASS</td>
<td>PASS</td>
</tr>
</tbody>
</table>

## Pole Resistance in Micro-Ohms

<table>
<thead>
<tr>
<th></th>
<th>Pole 1</th>
<th>Pole 2</th>
<th>Pole 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Found</td>
<td>32</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>As Left</td>
<td>32</td>
<td>30</td>
<td>29</td>
</tr>
</tbody>
</table>

## Opening Speed
- Design: 0
- Tolerance: + -
- Pole 1: 0
- Pole 2: 0
- Pole 3: 0

## Closing Speed
- Pole 1: 0
- Pole 2: 0
- Pole 3: 0

## Control Wiring - Megohms
- Reading: 0
- Temperature: 20°C
- Counter Reading: Begin: 00021
- End: 00022

## Comments:

## Deficiencies & Recommendations:

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Eqpt. Inventory No.: 51-01318, 51-01302, E81-01233

Tested by: Gonzalez Guehdez, Gustavo / Pat Adams
**Potential Impact Without Maintenance**

- Loss of vacuum bottle integrity
- High contact resistance – erosion of main contacts
- Mechanical linkage failure
- Slow mechanical response due to lack of lubrication that impacts interrupting time
- Longer fault clearing time leading to potential equipment failure or personal injury
Other Substation Devices

- Instrument Transformers
- Arrestors
- Oil/Gas Breakers
- Disconnect Switches
- Voltage Regulators
- Capacitor Banks
- Reclosers
- Grounding Systems
- Test Procedures in ANSI/NETA MTS-2011
Database/Trending

- Inventory Assets
- Schedule Maintenance
- Track Performance
- Optimize Testing for Reliability
- Structure for Future Compliance
Summary

- A regular maintenance program improves reliability, safety and system operation
- Customers and regulatory organizations expect these results
- Qualified resources and an implementation plan will support these goals long term
- Timely reports and documentation will lead to continuous improvement and responsiveness to current and future regulatory requirements
Questions?

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