Electrical Predictive and Preventative Maintenance

Mose Ramieh III – CE Power
Electrical and mechanical equipment is subject to failure, at the worst possible time, for no apparent reason.

- Mose Ramieh III
There are two types of facilities...
Those that have HAD a failure...
And those that will...
### Table 5-2—Percentage of failure caused from inadequate maintenance vs. month since maintained

<table>
<thead>
<tr>
<th>Failure (months since maintained)</th>
<th>All electrical equipment classes combined (%)</th>
<th>Circuit breakers (%)</th>
<th>Motors (%)</th>
<th>Open wire (%)</th>
<th>Transformers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 12 months ago</td>
<td>7.4</td>
<td>12.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.8</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>12 to 24 months ago</td>
<td>11.2</td>
<td>19.2</td>
<td>8.8</td>
<td>22.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>More than 24 months ago</td>
<td>36.7</td>
<td>77.8</td>
<td>44.4</td>
<td>38.2</td>
<td>36.4</td>
</tr>
<tr>
<td>Total</td>
<td>16.4</td>
<td>20.8</td>
<td>15.8</td>
<td>30.6</td>
<td>11.1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Small sample size; less than seven failures caused by inadequate maintenance.
Agenda

• Safety and Maintenance
• Types of equipment failures
• Non-Intrusive Predictive Options
• Somewhat Intrusive Predictive Options
• Intrusive Options
Electrical Maintenance & Safety
NFPA 70B, 70E, IEEE
NFPA 70E

Standard for Electrical Safety in the Workplace
– Electrical Arc, Flash, and Blast
– Safe work practices
– Energized Electrical Work Permit
– Minimum PPE Requirements
– Make systems electrically safe prior to work
– Mechanical controls (IR Windows)
States:

On multiemployer worksites (in all industry sectors), more than one employer may be responsible for hazardous conditions that violate safe work practices.
Reasons for Electrical Predictive and Preventive Maintenance
Safety

• To minimize unsafe conditions
• Avoid personnel injuries
• Reliability Centered Maintenance is directed by safety first, then economics. When determined that safety is not a factor, then preventive maintenance is justified on economic grounds. IEEE 493-2007 Section 5.5
Economics

• To avoid future and more costly equipment failures.
• To avoid premature equipment failures.
• To avoid interruption of services to production and processes.
Legal & Contracts

• Avoid legal consequences and/or to meet legislated mandates (Codes & Standards)

• To comply with insurance company requirements.
Go Green

• Avoid environmental damage
• Accomplish equipment life cycle extension.
Downtime = Money!

Einstein discovers that time is actually money.
FIGURE 4.2.6 Effect of EPM Inspection Frequency on Overall Costs.
IEEE 493-2007

5.3.2 Causes of Electrical Failure
IEEE 493-2007

5.3.2 Causes of Electrical Failure
Insulation Failures
<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage of insulation failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformers</td>
<td>84%</td>
</tr>
<tr>
<td>Circuit Breakers</td>
<td>21%</td>
</tr>
<tr>
<td>Disconnect Switches</td>
<td>15%</td>
</tr>
<tr>
<td>Insulated Switchgear Bus</td>
<td>95%</td>
</tr>
<tr>
<td>Bus duct</td>
<td>90%</td>
</tr>
<tr>
<td>Cable</td>
<td>89%</td>
</tr>
<tr>
<td>Cable Joints (splices)</td>
<td>91%</td>
</tr>
<tr>
<td>Cable Terminations</td>
<td>87%</td>
</tr>
</tbody>
</table>

*Based on IEEE Gold Book Table 36*
Mechanical Failures
Mechanical Failures
Non-Invasive PdM
House Keeping
What You Can’t See
What is Partial Discharge (PD)?

PD is a localized electrical discharge in an insulation system that does not completely bridge the electrodes.

Phase to Phase
or
Phase to Ground
What is Partial Discharge?

Partial Discharge Emission

- Light
- Heat
- Odor (Ozone)
- Sound
- Electromagnetic pulse

Typical PD Types

- Corona discharge
- Floating discharge
- Particle discharge
- Void discharge
- Surface discharge
PD Activity

Partial Discharge Pulses

Negative Polarity Pulse in positive half cycle and Positive polarity pulse in negative half cycle

TEV signal (nano Secs)
Level I PD Detection Services

Detection Bandwidth

- TEV: 3MHz ~ 100MHz
- UHF: 300MHz ~ 1500MHz
- AE: 20kHz ~ 300kHz
- Ultrasonic: 40kHz
- HFCT: 500kHz ~ 50MHz

Application
- GIS
- MV switchgear
- Power cable
- Transformer
Level I PD Detection Services

- UHF – Radio Frequency
- TEV – Transient Earth Voltage (capacitive)
- Ultrasonic (airborne acoustic)
### Typical Retrofit Switchgear Application

<table>
<thead>
<tr>
<th>Breaker Cubicle 1</th>
<th>Breaker Cubicle 2</th>
<th>Breaker Cubicle 3</th>
<th>Breaker Cubicle 4</th>
<th>Breaker Cubicle 5</th>
<th>Breaker Cubicle 6</th>
</tr>
</thead>
</table>

#### Sensor Selection Guideline

- **RFCT** – One for every cable-set (in or out)
- **Coupling Capacitors** – One set for every 3 structures

#### LEGEND

- **RFCT**
- **Coupling Capacitors**

#### Diagram Notes:

- **Switchgear Cable Compartment**
- **Cable Shields**
- **Load Cables or Bus**
- **MV Power Circuit Breaker**
- **Legend** (RFCT, Coupling Capacitors)
On-Line Partial Discharge Continuous Monitoring
Transformer Oil Samples

Fig. 2. Identification of Corona or Partial Discharge Problem.

Fig. 1. Identification of an Electrical Arc in Oil Problem.
Slightly Invasive PdM
Thermographic Surveys
Subject: 149.0
Ref: 41.1
* > 55.0°F
* < 35.0°F

Temperature range:
- * > 55.0°F
- * < 35.0°F

Values:
- 36.0
- 38.0
- 40.0
- 42.0
- 44.0
- 46.0
- 48.0
- 50.0
- 52.0
- 54.0
Survey Hazards
IR Windows
Short Outage PdM
5.3.2 Causes of Electrical Failure

- Dirt on moving parts can cause sluggishness and improper electrical equipment operations...
- Checking the mechanical operation of devices and manually or electrically operating any device that seldom operates should be standard practice.
Seldom Operated
“Traditional” Outage PM
When to Test?

NETA MTS and NFPA 70B

• Monthly
  – Visual Inspections
  – Make notes regarding operating status and house keeping

• Annually
  – Thermographic Survey
  – Out of Service Maintenance

• 1-5 Years
  – Follow Manufacturer Guidelines
  – NETA Guidelines (Handouts Available)
  – Check with Insurance Carrier for additional Guidelines.
Circuit Breaker Testing
Circuit Breaker Testing
“New” Vacuum Breaker Technology
Breakdown Voltage

Paschen Curve for Dry Air

Dielectric Strength (kV/cm)

Pressure (Pa)
Penning Diagram and Field Testing
NFPA 70E Chapter 2 Safety Related Maintenance Requirements

- Qualified Persons to conduct maintenance.
- Over-current devices shall be maintained.
- Housekeeping, Housekeeping
NFPA 70E Chapter 2 Safety Related Maintenance Requirements

“Failure to properly maintain protective devices can have an adversely effect on the arc flash hazard analysis incident values.”
Circuit Breaker Testing
Transformer Testing
Transformer Testing

- Insulation Resistance
- Winding Resistance
- Turns Ratio Test
- Power Factor (60Hz)
- Leakage Reactance
- On Load Tap Changer
Power Factor vs Frequency

So How Can We Detect the Water?

PF(f) Frequency Response

- Transformer A
- Transformer B

![Graph showing PF vs frequency for two transformers](image-url)
Besides.......The Moisture is All in the Paper!!

Moisture distribution

> Moisture exchange between cellulose and oil
  > Increasing temperature: water goes to the oil
  > Decreasing temperature: water goes back to the cellulose

> Most of the moisture is contained in the cellulose

> Thus it is important to know the water content of the cellulose, not of the oil

Moisture distribution example

> Power: 150 MVA
> Cellulose: 7 tons
> Mineral oil: 70 tons
> Temperature:
  \[40 \, ^\circ\text{C} / 104 \, ^\circ\text{F}\]

Water in oil
16 ppm
1.1 kg

Water in cellulose
3 wt.%
210 kg
Catch it Early or Pay Big $’s Later

Effect:
High temperature and moisture content will dramatically lower the mechanical strength of paper insulation

Risks:
- Lower the expected life of transformer
- Run transformer at lower rating

Dielectric Frequency Response

Sufficient data

Typical:

- **Dry transformer or low temperature**
  -> 0.1 mHz, 2:50 hours

- **Moderate wetness / temperature**
  -> 1 mHz, 22 min

- **Wet transformer or hot temperature**
  -> 0.1 Hz, 5 min
### Transformer Tests

<table>
<thead>
<tr>
<th>Dielectric</th>
<th>Thermal</th>
<th>Mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGA</td>
<td>DGA</td>
<td>SFRA</td>
</tr>
<tr>
<td>Oil Screen</td>
<td>Oil Screen</td>
<td>Leakage Reactance</td>
</tr>
<tr>
<td>PF/TD CAP</td>
<td>IR</td>
<td>PF/TD CAP</td>
</tr>
<tr>
<td>Exciting Ima</td>
<td>DC Winding RES</td>
<td>Exciting Ima</td>
</tr>
<tr>
<td>TTR</td>
<td></td>
<td>DC Winding RES</td>
</tr>
<tr>
<td>DFR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial Discharge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The General Curve Structure

- Core influence
- Winding structure influence
- Interaction between windings
- Earthing leads influence

Magnitude, dB

Frequency, Hz
Cable Testing
VLF Cable Testing
VLF Cable Test Results
Protective Relays and Meters

- **Monthly**
  - Visual Inspection
  - Record and Reset Targets

- **Annually**
  - Pick up Test and Time
  - Electromechanical Relays
  - Verify Setting of Solid State

- **1-5 Years (Out of Service)**
  - Pick Up Test
  - Timing Test
  - Verify Operational Scheme
• Existing Electro-Mechanical Relays (124); CEPS provided NERC/FERC testing.
• Scope of Work included engineering, design, material, installation, and commissioning.
• Material scope included SEL 300G, 387E.
Data and Oscillographic Records
Questions?
Answers