Facility Maintenance
Best Practices
Making the Most of What You Have

Jeff Womack
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About the Speaker

Jeff Womack

• Vice President & Project Executive with Hood Patterson & Dewar

• 12 years of electrical design experience
  ◦ Commercial Electrical Design
  ◦ Data Centers
  ◦ MTSO Facilities

• 20 years of electrical testing, electrical commissioning experience
  ◦ Data Center Commissioning / Integration
  ◦ Live Site Commissioning
  ◦ Facility Assessments
  ◦ Failure Analysis
  ◦ Acceptance and Maintenance Testing
• Facility Maintenance
• NFPA 70B Recommended Practice for Electrical Equipment Maintenance
• What are Best Practices?
• Considering all the angles
• Determining the best approach
• Examples – What not to do
• Arc Flash and Other Considerations
Why Preventative Maintenance?

An Effective Program Pays Dividends

- Improves equipment lifespan
- Reduces downtime
- Helps prevent accidents, lost production, and loss of profit
- Reduces equipment failure to a minimum consistent with good economic judgement
- Success requires management support
• Which recommendations should you follow?
• What is a best practice?
• Where should you spend the money?
Preventative Maintenance

Basics

• A good program begins with good design
• Well qualified and properly trained individual needs to be responsible
• Maintenance Plan is very Important
• Test and analysis
• Programmed inspections
• Diagrams
• Maintenance Procedures – Do they meet the minimums and maximums?
Project Example

Telecom Provider Generator Abuse

- Generator load testing
- 100% block loading every week leads to damage of multiple alternators
- 2nd Failure prompted testing of all generators
Project Example

Credit Card Company has Facilities and IT disconnect

- IT equipment added
- Facilities not allowed to shut down power to verify proper A-B cording
- No coordination between departments
- UPS system failure reveals dual corded loads are connected to the same power source
• Equipment is out of date and needs upgrade
• Upper management doesn’t understand importance
• Budget gets lost in buyout
• UPS battery failure drops critical load
• Failures don’t wait for decisions to be made
• Facility constructed in early 1990s
• Never had a utility power disruption
• Maintenance personnel have difficulty convincing management to replace obsolete UPS modules
• At the time of replacement there were not enough batteries left in the string to support an outage
• Intended to reduce hazards to life and property that can result from failure or malfunction of electrical systems and equipment

• Explains the benefits of an Effective Electrical Preventative Maintenance (EPM) program

• Explains the function, requirements, and economic considerations used to establish and EPM program

• Not intended to replace manufacturers recommendations
NFPA 70B-2019

Reference Publications

- NFPA – National Fire Protection Association
- ATSM – American Society for Testing and Materials
- EASA – Electrical Apparatus Service Association
- IEEE – Institute of Electrical and Electronics Engineers
- NEMA – National Electrical Manufacturers Association
- NETA – International Electrical Testing Association
- OSHA – Occupational Safety and Health Administration
- UL – Underwriters Laboratories
- Publications from public agencies such as FEMA
Preventative Maintenance

How often?

- Inspection Frequency
- Maintenance Frequency
- Replacement Frequency
Preventative Maintenance Frequency Impact
## MAINTENANCE FREQUENCY MATRIX

<table>
<thead>
<tr>
<th>Equipment Reliability Requirement</th>
<th>Equipment Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Medium</td>
<td>0.50</td>
</tr>
<tr>
<td>High</td>
<td>0.25</td>
</tr>
</tbody>
</table>

## Frequency of Maintenance Tests

**Inspections and Tests**

**Frequency in Months**

(Multiply These Values by the Factor in the Maintenance Frequency Matrix)

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Visual</th>
<th>Visual &amp; Mechanical</th>
<th>Visual &amp; Mechanical &amp; Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Switchgear &amp; Switchboard Assemblies</td>
<td>12</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>7.2</td>
<td>Transformers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2.1.1</td>
<td>Small Dry-Type Transformers</td>
<td>2</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>7.2.1.2</td>
<td>Large Dry-Type Transformers</td>
<td>1</td>
<td>12</td>
<td>24</td>
</tr>
</tbody>
</table>
Project Example

• Infrared scan never completed
• Aluminum bussing in switchgear start phase to phase “busicle”
• Arc between phases clears the “busicle”
• B phase voltage goes from 277 to 42 due to bad connection

County Jail Starts Riots
Preventative Maintenance

The Cost of Data Center Outages

• Average cost increased from $505,502 to $740,357 between 2010 & 2016
  ° 38% increase

• Maximum downtime cost of the 63 data centers studied was $2,409,991

• UPS system failure still the number one cause
### Preventative Maintenance

#### The Cost of Data Center Outages

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2013</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business disruption</td>
<td>256.0</td>
<td>179.8</td>
<td>238.7</td>
</tr>
<tr>
<td>Lost revenue</td>
<td>183.7</td>
<td>118.1</td>
<td>208.6</td>
</tr>
<tr>
<td>End-user productivity</td>
<td>140.5</td>
<td>96.2</td>
<td>138.2</td>
</tr>
<tr>
<td>IT productivity</td>
<td>53.6</td>
<td>42.5</td>
<td>61.9</td>
</tr>
<tr>
<td>Detection</td>
<td>22.3</td>
<td>23.8</td>
<td>26.7</td>
</tr>
<tr>
<td>Recovery</td>
<td>20.9</td>
<td>22.0</td>
<td>21.2</td>
</tr>
<tr>
<td>Ex-post activities</td>
<td>9.1</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Equipment</td>
<td>9.7</td>
<td>9.6</td>
<td>9.5</td>
</tr>
<tr>
<td>Third parties</td>
<td>7.0</td>
<td>8.6</td>
<td>9.9</td>
</tr>
</tbody>
</table>
Preventative Maintenance

The Cost of Data Center Outages
Preventative Maintenance

The Cost of Data Center Outages
Preventative Maintenance

Choosing an Approach

• Run to failure
  ◦ Reactive
Preventative Maintenance

Choosing an Approach

- Run to failure
  - Reactive

- Predictive or condition-based maintenance
  - Test & trend, then react
Preventative Maintenance

Choosing an Approach

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• Predictive or condition-based maintenance
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• Preventative or condition-based
  ◦ Based on run time, condition, or operator recommendation
Preventative Maintenance

Choosing an Approach

• Run to failure
  ◦ Reactive

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• Reliability Centered Maintenance (RCM)
  ◦ When it is too big or too expensive to treat every component the same
Reliability Centered Maintenance Defined

- Determines a logical way to determine if a PM makes sense for a given item
- Preserves system functionality
- Focused on the system rather than the component
- Acknowledges design limitations
- Is an ongoing process
Reliability Centered Maintenance

Elements

• Functions of equipment
• Functional failures likelihood
• Failure modes/failure analysis
• Failure effects/logic tree analysis
• Failure consequences
• Mean Time Between Failure Calculations
• Proactive tasks, task intervals
• Default actions
• What does the asset do
• How can the asset or its sub-components fail
• What are the likely failure modes
  ◦ Fail to Bypass, EPO
• What are the likely chain of events associated with the failure
• What are the Costs associated with the failure
Preventative Maintenance

From Design to Commissioning Through End-of-Life

• Design
• Acceptance testing (commissioning)
• Develop commissioning plan
• Develop scripts
• Execute test
• Training
• Preparation, records, procedures, and tools for maintenance
• CTs tested
• Relays tested
• Interconnect wiring not proven via current injection
• Differential circuits wired improperly
• Caused startup delays because generators wouldn’t stay connected to the bus
• Electrical and mechanical systems were tested and commissioned
• Did not fail power to individual panels
• Facility-powered gate did not have manual release
• No walk gate
• Facility drops critical load after a generator failure while fire department cuts gate open
• Abbreviated Cx does not reveal system timer settings
• Back up air cooled chillers shut down after 45 minutes after transfer
Establishing a Program

Consider Your Unique Business Situation

• Business model and objectives
  ◦ System design
  ◦ Growth strategy
  ◦ Work blackout periods
  ◦ Customer requirements/Service Level Agreements

• Risk tolerance
  ◦ IT redundancy

• Operating cost control priorities
  ◦ Improving energy efficiency
  ◦ Extending equipment lifecycles
  ◦ Reducing/mitigating downtime
Establishing a Program

Facility Factors to Consider

• Future Use
• Site expansion strategy/capability
• Design deficiencies and challenges
  ◦ Redundancy (or lack thereof)
  ◦ Physical constraints
• Environmental considerations
  ◦ Seasonal impact on energy consumption
  ◦ Location/regional impacts
Establishing a Program

Facility Factors to Consider

• Safety is paramount. Always.
  ◦ Proper labeling
  ◦ Lock out/tag out

• Installed equipment
  ◦ Existing maintenance agreements/warranties
  ◦ Legacy equipment service/parts availability
  ◦ Manufacturer recommendations
  ◦ Criticality of components
• **Maintain vs. replace**
  ◦ Consider total cost of ownership
  ◦ Expected lifespan remaining
  ◦ Physical access constraints
  ◦ Availability of parts/qualified repair technicians

• **System redundancy**
  ◦ Affects how maintenance is conducted
Equipment Maintenance

Resource Considerations

- Standard procedures
  - Operating
  - Maintenance
- Accurate drawings and documentation
- Realistic schedules
- Maintenance personnel
  - In-house or outsourced
  - Vendor selection
  - Capabilities
Maintenance Program

Logistical Considerations

• Restricted access/maintenance times
  ◦ Additional costs such as after-hours/weekend shut down, load transfer, etc.

• Resources and training of personnel
  ◦ In-house support staff
  ◦ Equipment manufacturer staff
  ◦ 3rd party consultants
  ◦ Maintenance service provider
Equipment Maintenance

Personnel Safety

• NFPA 70E
• Proper grounding during maintenance
• Power Quality
• Short Circuit Coordination Studies / Arc Flash Studies
• Load Flow Studies
• Reliability Studies / Risk Assessment Studies / Mean Time Between Failure Studies
• Maintenance Related Design Studies
Power Quality

- **Harmonics**
  - Influenced voltage waveform
  - Zero crossings
  - Noise Interference
  - Equipment Failure
  - Nuisance operation

- **Transients**
  - Equipment damage
  - Mis-operation
Power Quality

• Voltage Sags and Swells
  ◦ Outages
  ◦ Equipment damage

• Unbalanced Voltages
  ◦ Motor damage
  ◦ Conductor heating
• Acceptance testing
  ◦ Establishing your baseline

• Maintenance testing
  ◦ Routine
  ◦ Special

• Pretest circuit analysis

• As-found and as-left test

• Frequency of test
Electrical Equipment Maintenance

Long Intervals Between Shutdowns

- In many cases required more frequent maintenance
- More frequent non-invasive testing such as Infrared or Ultrasonic scanning
- More thorough testing when an outage can be facilitated
• For MV breaker maintenance, critical load transferred to system bypass

• Bypass breaker (480 volt, 4000 ampere) with new trip unit was improperly installed
  ◦ Caused breaker to revert to 1600 ampere trip setting
    ▪ Load was 2850 amperes

• Breaker was only secondary injection tested
  ◦ Issue would’ve been found with primary injection
Disaster Recovery

• Limit damage
• Assess damage
• Prioritize the corrective action
• Repair or replace
• Execute
• Emergency Procedures
• Adequate Emergency Documentation
Changing Equipment

PV, Electrical Charging, Fuel Cells, and Wind Power Systems

- Cleaning
- Periodic maintenance
- Structural considerations
- Yaw systems
- Cable support systems
- Must develop a plan for new systems
Safety First

Arc Flash

• What is an arcing fault
• What are the danger levels
• Misunderstandings exist
Critical power systems are complex
Multiple energy sources
Multiple operating modes
Code only requires worst case conditions to be posted
## Fault Current and Incident Energy

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Available Fault Current</th>
<th>Incident Energy at UPS module A1 (cal/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed transition Transfer to Generators</td>
<td>47,490</td>
<td>28</td>
</tr>
<tr>
<td>Operating on Utility A</td>
<td>47,120</td>
<td>27</td>
</tr>
<tr>
<td>Operating on Utility B</td>
<td>40,330</td>
<td>122</td>
</tr>
<tr>
<td>Operating on (2) 2500 kW Generators (N+1)</td>
<td>23,280</td>
<td>82</td>
</tr>
<tr>
<td>Operating on (2) 2500 kW Generators with incident energy reduction enabled at</td>
<td>23,280</td>
<td>69</td>
</tr>
<tr>
<td>generator main tie breaker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating on (2) 2500 kW Generators with incident energy reduction enabled at</td>
<td>23,280</td>
<td>2.7</td>
</tr>
<tr>
<td>feeder breaker</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Level of fault current does not correlate with the incident energy level because of the speed at which and arcing fault will be cleared.
Fault Current and Incident Energy

- Depends on
  - Breaker curves
  - Breaker settings
  - Automatic failovers

- Maintenance mode switches make the most difference

- Has to be modeled to be determined
Energized Maintenance

- Arc flash mitigation
- Zone Interlock
- Incident energy reduction switches
- Label can provide energy level for additional modes
Plan Maintenance on the best Power Source

- Coordinate maintenance operations and incident energy label with operating procedures
- Limit risk by considering all the options
- Maximize maintenance access
• Significant costs due to failure
  ◦ Flights grounded worldwide for 24 hours
  ◦ Flights cancelled, delayed or otherwise affected for 3+ days
  ◦ Bad press, reputation
• Develop metrics
• Develop Key Performance Indicators (KPI)
• Track and trend to improve the process
• Learn from each test, failure, inspection, etc.
• Modify the plan based on new information
Typical Pitfalls

• Maintenance budget is the first to go
• Afraid to operate the system
• Afraid to shut down components
• Need approval for a black hole test (pull the plug)
• Don’t learn from mistakes, they learn to run from mistakes
In Summary

• Understand your business model, strategies, challenges, and priorities

• Obtain an independent comprehensive facility assessment

• Identify existing and needed resources, procedures, and training

• Determine your preferred maintenance approach (RCM)

• Develop a plan based on your real-world facility, conditions, and requirements

• Track and trend KPI to monitor results and promote continuous improvement

• Don’t generalize
Thank You
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