Longevity approach

Assess & Avoid Failures

ROTATING ELECTRICAL ASSET PROGNOSTIC CARE
# Failure Statistics

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Number of Motors</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other — Unspecified</td>
<td>313</td>
<td>35.9</td>
</tr>
<tr>
<td>Insulation to Ground</td>
<td>161</td>
<td>18.5</td>
</tr>
<tr>
<td>Sleeve Bearing</td>
<td>85</td>
<td>9.7</td>
</tr>
<tr>
<td>Ball Bearing</td>
<td>43</td>
<td>4.9</td>
</tr>
<tr>
<td>Thrust Bearing Vertical</td>
<td>41</td>
<td>4.7</td>
</tr>
<tr>
<td>Oil Leakage</td>
<td>36</td>
<td>4.1</td>
</tr>
<tr>
<td>Turn Insulation (Short)</td>
<td>32</td>
<td>3.7</td>
</tr>
<tr>
<td>Rotor Bar Failure</td>
<td>31</td>
<td>3.5</td>
</tr>
<tr>
<td>Roller Bearing</td>
<td>20</td>
<td>2.3</td>
</tr>
<tr>
<td>Bearing Seal</td>
<td>20</td>
<td>2.3</td>
</tr>
<tr>
<td>Loose Blocking</td>
<td>16</td>
<td>1.8</td>
</tr>
<tr>
<td>Rotor Shaft</td>
<td>13</td>
<td>1.5</td>
</tr>
<tr>
<td>Oil System</td>
<td>12</td>
<td>1.4</td>
</tr>
<tr>
<td>Stator Slot Wedges</td>
<td>11</td>
<td>1.3</td>
</tr>
<tr>
<td>Loose Iron</td>
<td>9</td>
<td>1.0</td>
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<tr>
<td>Stator Frame</td>
<td>7</td>
<td>0.8</td>
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<tr>
<td>Line Cable</td>
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<td>0.8</td>
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<tr>
<td>Coil Connection</td>
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<td>0.6</td>
</tr>
<tr>
<td>Balance Weights</td>
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<td>0.6</td>
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<tr>
<td>Accessories</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>Thrust Bearing Horizontal</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

![Pie Chart](image)
Failure Statistics …

Chart showing failure statistics for different categories:
- **Bearings**
  - 1983 EPRI: 60
  - 1985 IEEE: 40
  - 1995 IEEE: 28

- **Windings**
  - 1983 EPRI: 30
  - 1985 IEEE: 10

- **Rotors**
  - 1983 EPRI: 5

- **Other**
  - 1983 EPRI: 20

Pie chart showing failure causes:
- **During Operation**: 66.7%
- **Maintenance/Testing**: 28%
- **Other**: 3.6%
- **Not Specified**: 1.7%
Failure Statistics ...

Failure distribution statistics,
Source: IEEE Petro-Chemical Paper PCIC-94-01
No details on root cause analysis of failure.
Failure Statistics …

- Mechanical: 44%
- Over current: 30%
- Single Phasing: 14%
- Other: 12%

* Based on 9,000 failure events researched by the Electric Motor Manual which was written by Robert Lawrie in conjunction with the staff at Electric Construction and Maintenance Magazine.
Failure Statistics …

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Failure Statistics …

Generator Vibration (displacement >125µm):
• End-winding 82.1%
• Stator core 10.7%
• Phase (Circuit / Parallel / Connection Rings) 39.3%
• Phase drop (phase rings with bushings) 21.4%

Cause of excessive vibration
• Design 57.7%
• Assembly/workmanship 19.2%
• Unusual operation 3.8%
• Improper repair 7.7%
Stator Winding integrity: stator winding replacement, stator core restacking and rewedging
Stator Failures

Material Aging
Bad Wedging
Operating Conditions

Material Powdering
Insulation Degradation

Wedge Loosening

In-Slot Bar Vibration

Mechanical Effects

Breakdown
Short-circuits

“Corona” Effect
Partial Discharges

Abrasion of Faraday Shield

Overheating
Stator Failures

Abrasion on bar insulation from in-slot vibration against stator laminations

Deposit of oil mist on stator core contributing to bar vibration
Stator Failures
Poor manufacture / De-lamination

Thermal Cycling

Discharges During HV Test
Stator Failures

- Failures due to windings’ insulation failure caused by various factors such as electrical, thermal, environmental and mechanical stress factors.
- Mechanically induced defects attributes to Loose wedges, erosion due to bar vibration etc. Accelerated degradation process.
- Discharge between phases due to cracks / low spacing
- Contamination of end windings.
- Others: internal voids, insulation ageing, de-lamination.
- Electrical partial discharges
Stress

- Temperature
- Electrical
- Ambient
- Mechanical
Stress ...

**THERMAL STRESS**
- Thermal Aging
- Voltage variation
- Cyclic loading
- Restricted Ventilation
- Ambient

**ELECTRICAL STRESS**
- Dielectric Aging Tracking / Corona / Partial Discharge
- Harmonic Distortion
- Voltage Spikes / Transients
- Voltage /Phase imbalance

**MECHANICAL STRESS**
- Stator Coil Movement
- Rotor Damages / Rubbing
- Torsional load variation
- Vibration / 2 x LF Air gap
- Improper lubrication

**AMBIENT STRESS**
- Moisture / Humidity
- Corrosive Chemical Abrasion
- Damage parts
- Rodents & Insects
Assess Stator Insulation

- Capacitance deterioration
- Insulation Resistor (IR)
- Polarization Index (P.I.)
- Di-electric Loss Factor: Tangent Delta
- Partial Discharges (PD)
Assess Stator Insulation …

Total Current (TIME / Temperature Dependent) =
Capacitive Current Charging + Absorption Current –Polarisation + Leakage Current
Partial Discharge Study
Partial Discharge Phenomena

- Loose wedges/bar vibration/slot discharges
- Cracked and broken conductors
- End winding surface contamination
- Damage/corrosion of the corona suppression unit
- Connection ring external discharge due to vibration
- Inter-phase discharge
- Insulation degradation
- Collector ring, brush sparking
- Faults in generator high voltage accessories
Partial Discharge Trending

- Curing Process
- Repair/action needed
- 3 – 6 months
- ??? Years

* Inter-turn fault can be identified online ESA – negative sequence current / Impedance imbalance
Tan Delta is the ratio of in-phase (resistive) current to the 90-degree (capacitive) current.

Tan Delta equals Dissipation Factor:

\[
\text{Tan } \delta = \frac{I_{\text{Resistive}}}{I_{\text{Capacitive}}}
\]

Power Factor \( \Phi = \frac{I_{\text{Resistive}}}{I_{\text{TOTAL}}} \)
Options

- **REPAIR / REWIND**
- **REPLACE**
- **REVITALISE / REFURBISH**
- **RELIABILITY (LONGEVITY by PROGNOSTICS)**

Residual Life Assessment / Failure Prediction
Analyse Insulation Dielectric properties, mitigate the risk of catastrophic failure and extend periods between outages
REAP Solutions

Online Electrical Machine Fault Diagnosis
REAP Solutions

ROTATING ELECTRICAL MACHINES

• Vibration
• Noise / Sound
• Ultrasonic
• Current / Flux
• Pressure, Flow, Load, etc.
REAP Solutions .. Wired / Wireless Vibration Alert System
REAP Solutions .. assess Insulation

- Capacitance
- Winding Insulation Resistor (IR)
- Polarization Index / Current charging
- Di-electric Loss Factor : Tangent Delta
- Partial Discharge (PD) with Voltage source
Know more!