CIRCUIT BREAKER MECHANISM
LUBRICANT PERFORMANCE ASSESSMENT:
Investigation and Field Experience

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Background

• Who we are, we...
  – Serve more than 14 million customers
  – Have provided electricity in region for more than 125 years
  – Maintain a service territory that includes more than 180 cities within a 50,000 square-mile area of
    central, coastal, and Southern California, excluding the City of Los Angeles and certain
    municipalities

• Our SCE Business Line: Substation Construction & Maintenance
  – Separate business line from Grid Operations, Transmission, and Distribution
  – Substation equipment
    • 12,000+ circuit breakers
    • ~3,000 transformers
    • 32,000+ relays
    • ~900 Transmission and Distribution Substations
  – Substation Personnel
    • 23 Maintenance Crews
    • 65 Test Crews
    • Construction, Battery, and Power Cable Crews
    • Staff Support Functions (Resource Planning & Performance Management, Technical Support & Strategy)
Utility Perspective

The Goals:

• Is fluorosilicone (FSi) grease with polytetrafluoroethylene (PTFE) thickener the best or proper grease to be using?
• How long can I go in between lubrication cycles?
• Can maintenance cycles be extended without impacting reliability or performance?

Utility Perspective

The expected outcome:

• Fluorosilicone (FSi) grease with polytetrafluoroethylene (PTFE) thickener is at the very least an adequate grease
  – SCE has seen a significant drop in the failure rates of the circuit breakers that utilize this grease.
• Effective lubrication does impact circuit breaker performance and overall maintenance requirements
  – Can be seen from the coil signature and timing
• Effective lubrication does extend maintenance cycles on circuit breakers.
Technical and Business Issues

All the same components as any other industry, but
• they do not move in the same way
• slower speeds
• long periods of inactivity
• large temperature swings
• outdoor exposure
• much longer service intervals
• wear is not usually an issue

Why do the oil makers not make an oil that meets CB needs?
• This is a business issue: the quantity is too small!

Topics for Today

Background
• EPRI research
• Greases and causes of failure
• SCE circuit breakers investigated
Plan to determine grease condition
• Tests, tools and analyses
• Development of a measure of degradation
Results of tests on SCE greases and bearings
Conclusions and Recommendations
EPRI Circuit Breaker Lubrication Research

Grease is Categorized Mostly by Oils and Thickeners

Oils
- Mineral oil - refined from crude oil
- Man-made (synthetic)
  - Polyalphaolefin
  - Silicone
  - Fluorosilicone

Thickeners
- Soap
  - Lithium, calcium, aluminum
- Non-soap
  - Clay, polyurea, PTFE
Degradation Mechanisms of Greases

Primary hydrocarbon grease failure cycle
- Evaporation of oil in vapor phase
- Evaporation of low MW oxidates
- Oxidation accelerates when additives depleted
- End of lubricating properties

Oil
Low MW oxidation
High MW oxidation
Sludge & varnish deposits

Primary fluorosilicone grease failure cycle
- Evaporation
- Gelled oil
- No oxidation
- Increased viscosity (lubricating properties still good)

Oil
Evaporation
Bearing surface

SCE Circuit Breaker Information

<table>
<thead>
<tr>
<th>CB</th>
<th>Mfr.</th>
<th>Model</th>
<th>Grease Install</th>
<th>Mech Type</th>
<th>Site description and altitude (ft)</th>
<th>Temp-F</th>
<th>Avg. Rain</th>
<th>Brief History</th>
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<td>SE31A</td>
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<td>SE31A</td>
<td>Mtn./valley 331</td>
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<td>10.91</td>
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<td>SE31A</td>
<td>Mtn./valley 331</td>
<td>52-75</td>
<td>10.91</td>
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</table>
EPRI Plan to Define Grease and Bearing Condition

- Determine composition of materials in the grease
- Measure relative grease degradation in terms of polymerization of oil and thickeners
- Quantify relative effect of degradation of new grease on timing performance in EPRI bearing lubrication simulator
- Analyze degree of degradation of grease samples vs. functional performance of the SCE circuit breakers
- Determine extent that bearing wear has on functional performance of mechanism

Tests and Equipment to Implement Analysis Plan

Fourier Transform Infrared Spectroscopy (FTIR)
- Identifies composition of materials
- Shows grease type and contaminants
- Location of peaks is important

Differential Thermogravimetric Analysis (DTA)
- Shows relative amount of oil remaining
- Indicates polymerization associated with aging of fluorosilicone oil
EPRI Bearing Lubrication Simulator and Visual Examination

Simulator quantifies relative effect of aging
• Movement adjustable 15° to 30° same as many circuit breaker mechanisms
• Does not duplicate the forces in mechanism
• Measures timing and coil current
Visual examination for wear
• Primary interest is functional operation of mechanism

Tests for Degradation of New Fluorosilicone Grease

New fluorosilicone grease was aged to accelerate gelation
• Samples were used to lubricate new bearings.
• Bearings were operated in the EPRI bearing lubrication simulator and trip times recorded
• Samples of the accelerated aged grease analyzed with DTA
• Ratio of thickener peak P2 and the oil peak P1 compared to simulator timing results

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Conclusions of Accelerated Aging Tests

DTA ratios of PTFE peak vs. oil peak P2/P1 correlate well with timing performance in the EPRI bearing simulator

• Results of the accelerated grease aging and simulator tests:
  - Ratio < approximately 1 is fresh grease
  - Ratio > 1 indicates beginning grease degradation. At this ratio, interpolation of the operating time of the simulator increased approximately 20% over Bearing 1 operating time.
  - Ratio > 2 indicates gelling enough to materially affect bearing operation in the simulator

The simulator timing and P2/P1 ratio results give a good measure of degradation of grease and the relative effect of degradation on operation

• Magnitude of forces in the CB mechanism will determine whether there is slowing of timing
• Thick application of grease will slow breaker operation as the grease ages

Functional Performance of Circuit Breaker Mechanism

Best measure of functional performance is timing of mechanism operation.

• First trip timing information was available for all circuit breakers
• Intervals between taking first trip information varied from four to seven years
• Sample first trip diagram shown to right
Results of FTIR and DTA Tests for Grease in Breaker 1-1

As noted on the graph, FTIR identifies this as fluorosilicone grease with PTFE thickener and low moisture. It has hydrocarbon contamination as noted by the triple peak at 3000 to 2800 wave number. DTA graph: reduced oil peak (blue) and slump to right indicates degradation of FSi oil in the grease. P2/P1 ratio of 1.81 confirms this. This did not affect first trip timing.

Results of Degradation of Grease in All Bearings

Greases in all bearings showed some degree of degradation. The P2/P1 ratio from DTA tests was greater than the new grease, 0.78.

<table>
<thead>
<tr>
<th>Grease</th>
<th>P2/P1 Ratio</th>
<th>P2/P1 Ratio</th>
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<tr>
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<td>CB 1-6</td>
<td>1.49</td>
<td>CB 2-5</td>
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</table>

Degradation of the fluorosilicone greases in these 15 to 17 year old bearings did not cause measurable increase in first trip timing of the mechanisms
• Possible contribution of PTFE thickener to maintaining lubricating properties of the grease is unknown
Results of Visual Examination of Bearings

There was light scuffing of some rollers and races
- No wear that would inhibit operation of the bearings

Summary of Analyses of All Bearings and Greases

<table>
<thead>
<tr>
<th>CB #</th>
<th>Greased</th>
<th>Noteworthy Findings</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>1999</td>
<td>FSi grease; viscosity increasing; contamination; timing stable</td>
<td>Valley – 1,242’</td>
</tr>
<tr>
<td>1-2</td>
<td>1997</td>
<td>Hydrocarbon grease, not FSi. Contamination</td>
<td>Wind, desert 2,500’</td>
</tr>
<tr>
<td>1-3</td>
<td>1998</td>
<td>Not FSi grease, possibly Chevron SRI #2 petroleum grease</td>
<td>Valley – 157’</td>
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<td>1-4</td>
<td>1997</td>
<td>FSi grease; viscosity increasing; timing stable</td>
<td>Valley – 171’</td>
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<td>1-5</td>
<td>1997</td>
<td>FSi grease; viscosity increasing; contamination; timing stable</td>
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<td>1998</td>
<td>FSi grease; viscosity increasing; contamination; timing stable</td>
<td>Valley/ Mtn.- 571’</td>
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<td>Valley – 722’</td>
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<td>1998</td>
<td>FSi grease; viscosity increasing; timing stable</td>
<td>Valley/Mtn.- 331’</td>
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Conclusions and Recommendations

• Techniques for the application and analysis of DTA and FTIR were developed and applied to the unique circumstances of aged bearing lubricant investigation.
• Nine of the eleven bearings had base oil consistent with fluorosilicone grease. The grease in these bearings was in circuit breakers in operation for 15 to 18 years.
• There was no change in first trip times over a six to seven year time interval between first trip measurements of any of the nine circuit breakers.
• There was light scuffing of some rollers and races, but no wear that would impact operation of the breaker was observed in any of the bearings that were visually examined.
• Gelation with viscosity increase is an age and temperature related fluorosilicone oil failure mode. Lubricating properties do not seem to be impaired as this gelling occurs. The bearings in the study showed various degrees of gelling. The thickening or gelling of the oil was not sufficient to slow the operation of the mechanisms.

Conclusions and Recommendations

• Environmental factors are known to accelerate aging of lubricants. There was no data in this sample to prove or disprove this.
• Two of eleven bearings had greases that were not fluorosilicone grease; three others had evidence of sprays or solvents being used. It is not a recommended practice to use hydrocarbon sprays or solvents on mechanisms.
• The present state of the FSi greases examined was satisfactory for proper breaker operation but the sample size of bearings tested (nine) is too small to understand the future life of the grease.

RECOMMENDATIONS

• Conduct first trip tests on a larger sample of circuit breakers every four years to assess whether lubrication with new grease is required. Sample size and allowable number of slow trips to be determined by allowable risk.
• Use of fluorosilicone greases with PTFE thickener when lubricating bearings or sliding surfaces in circuit breaker mechanism applications is appropriate.
• Do not use sprays, penetrants or solvents on bearings.