CIRCUIT BREAKER MECHANISM LUBRICANT PERFORMANCE ASSESSMENT: INVESTIGATION AND FIELD EXPERIENCE

Alex R. Salinas - Southern California Edison
Bhavin Desai - Electric Power Research Institute
Jack Harley - FirstPower Group LLC
Bob Kinner - FirstPower Group LLC
Michael Lebow - Coplanar Consulting LLC

ABSTRACT

High voltage circuit breakers require very fast operation of complex mechanical assemblies for successful operation. Proper lubrication is essential to assure correct motion of various critical components of these mechanisms, such as bearings. Deteriorated or inadequate lubrication may result in circuit breaker mis-operations that potentially cause equipment damage and outages. In 1997 Southern California Edison implemented a maintenance strategy that included lubricating circuit breaker bearings with fluorosilicone grease. In the years following the implementation of this strategy, SCE experienced a significant downward trend in circuit breaker failures and improved overall reliability. SCE now seeks to determine whether the existing fluorosilicone grease that has been in these circuit breaker bearings remains in satisfactory condition for continued operation, or whether the grease or bearings should be replaced. To assess its breakers' grease condition and potential remaining life, SCE has collaborated with the Electric Power Research Institute (EPRI) to perform a series of tests on grease samples from the circuit breakers lubricated 15 to 18 years ago. The purpose of this testing is to gain an understanding of the chemical degradation of known grease that will provide a basis for future breaker lubrication decisions. This paper summarizes the critical importance of circuit breaker lubrication and EPRI's lubrication research, discusses the tests and methodology employed to improve understanding of the chemical degradation of field-aged circuit breaker grease, and presents test results and conclusions.

INTRODUCTION

High voltage circuit breakers perform essential protection and control functions on power transmission networks. Breaker mechanisms have multiple components that must operate in concert for the breaker to perform properly. If one component does not operate correctly, the circuit breaker may mis-operate or fail.

Based on experience and failure analysis, a significant portion of circuit breaker mis-operations are caused by deteriorated or inadequate lubrication of breaker mechanism components, such as bearing rollers and sliding surfaces. When such failures occur, backup relays, adjacent breakers, and associated components operate to clear the problem. Instead of quickly isolating system disturbances, the event can rapidly cascade, affecting the electrical grid and potentially causing equipment damage and outages, with significant customer service and financial impacts.

Recognizing the critical importance of proper lubrication to circuit breaker operation and grid reliability, Southern California Edison implemented a comprehensive and proactive maintenance strategy in 1997. Three main questions were considered: 1. What is the best lubricant to use? 2. How long can we go in between lubrication cycles? 3. Can maintenance cycles be extended without impacting reliability or performance? A key initiative in the strategy was the development and application of circuit breaker maintenance practices that included lubricating bearings with fluorosilicone (FSi) grease with polytetrafluoroethylene (PTFE) thickener. This synthetic lubricant was selected for its resistance to harsh environments, heavy load, and wide temperature range characteristics. Expected benefits included improved breaker performance and extended maintenance intervals. In the years following the implementation of this strategy, SCE experienced a significant downward trend in circuit breaker failures and improved overall reliability as measured in Average Customer Minutes of Interruption and Frequency of Interruption. [1]

SCE BREAKER RELIABILITY AND LUBRICATION INITIATIVES

Committed to maintaining breaker reliability at high levels, SCE now seeks to determine whether the existing fluorosilicone grease that has been in these circuit breaker bearings for 15 to 18 years remains in satisfactory condition for continued operation, or whether the grease or bearings should be replaced.

The condition of the existing grease depends upon the type of base oil, the impact of environmental factors, and the effect of work practices. Understanding these aspects is extremely important as electric utilities are continuously examining maintenance strategies and alternatives. Particularly with circuit breakers, deciding when to perform maintenance or when to replace antiquated and problematic apparatus are additional factors to be considered. Although circuit breaker lubrication is not the only aspect of a comprehensive maintenance strategy, it has proven to be extremely important. To that end, the life expectancy of lubricants now becomes a key issue.

To assess its breakers' grease condition and potential remaining life, SCE has collaborated with the Electric Power Research Institute (EPRI) to perform a series of tests on grease samples from the circuit breakers lubricated 15 to 18 years ago. The purpose of this testing is to gain an understanding of the chemical degradation of known grease that will provide a basis for future breaker lubrication decisions:

- Life of grease
- Circuit breaker performance and reliability as the grease degrades
- Impact of environmental factors
- Effect of work practices on life of greases

This paper summarizes the critical importance of circuit breaker lubrication and EPRI's lubrication research, discusses the tests and methodology employed to improve understanding of the chemical degradation of field-aged circuit breaker grease, and presents test results and conclusions.

TECHNICAL AND BUSINESS ISSUES

There is a large population of legacy circuit breakers in operation throughout the industry. The majority of these breaker types—oil, two-pressure SF_6 gas circuit breakers and air circuit breakers—were installed during the major build-out of the power system that occurred from the late 1960s to the 1980s. Because of their large numbers, extensive replacement would be costly and most are expected to remain in operation for many more years. Even many of the second-generation single-pressure SF_6 gas breakers utilize designs that are more than 30 years old. Consequently, the circuit breaker manufacturers' specifications for the lubricants used in these breakers do not reflect today's engineering knowledge.

The circuit breaker lubrication market is small relative to other lubricant user markets. Therefore, these lubrication products were not designed for this specialized application. Few lubricant suppliers are familiar with the service duty and maintenance intervals common in utility circuit breaker applications. Consequently, the expected service life of many lubricants used on circuit breakers will not accommodate the longer maintenance intervals desired by many utility managers.

Most high voltage circuit breaker mechanisms and hydraulic and pneumatic systems require major disassembly to maintain them properly. Consequently, labor costs can be high. In addition, with the retirement of many experienced workers, utilities may not always have the desired level of expertise and skill sets available to perform this work.

Based on the above, it is clear that lubricant selection, application and aging are areas where improved knowledge could mitigate circuit breaker component performance issues and thereby reduce the need or change the schedule for maintenance and/or refurbishment. Confidence would be gained to extend maintenance intervals without affecting circuit breaker reliability or availability.

CRITICAL IMPORTANCE OF CIRCUIT BREAKER LUBRICATION

High voltage circuit breakers require very fast operation of complex mechanical assemblies for successful operation. Consequently, various critical components of these mechanisms, such as bearings, must be properly lubricated to assure correct motion. Proper lubrication of circuit breaker components reduces friction and wear between moving surfaces, typically metal on metal; reduces or prevents corrosion and rust; repels many contaminants; and prevents heat buildup.

Understanding the importance of lubrication on critical components in circuit breaker mechanisms is more complex than most other lubrication applications. Circuit breaker mechanisms may stay dormant for long periods, not required to operate. Lubricated surfaces in a mechanism, such as bearings or sliding surfaces, do not perform full and continuous rotation as they are typically designed. In addition, circuit breaker manufacturers usually specify one lubricant for a breaker type regardless of operating environment. Utility crews are not always aware of grease compatibility issues or proper application techniques. Commercial greases are formulated for industrial applications where operation is usually continuous and maintenance intervals more frequent than typical utility practice. Intrinsic factors such as significant temperature cycling and harsh environmental conditions may accelerate aging of the lubricants.

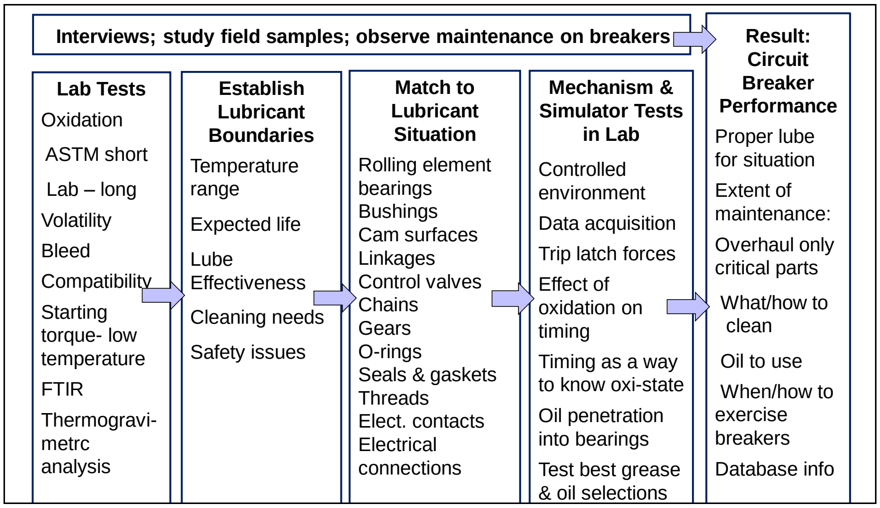
Aged or improperly specified or applied greases can slow mechanism operation beyond acceptable limits. Therefore, the choice of lubricants can affect the reliable operation of a breaker. Using incompatible or unapproved lubricants can lead to unacceptable performance or premature failure.

EPRI CIRCUIT BREAKER LUBRICATION RESEARCH

EPRI developed a comprehensive, multi-pronged research effort to define circuit breaker lubrication problems, increase understanding of application requirements, and develop new selection and training materials. The research process involved four key phases:

1. Develop a lubricant knowledge base
2. Determine factors relevant to circuit breakers
3. Identify and answer relevant utility operating questions
4. Provide decision support

The work began in 2006 with a literature search, utility visits, the collection of service-aged greases and bearings, and laboratory tests. This was followed by longer-term laboratory tests and mechanism simulator tests, continuing to complete mechanism tests in a controlled environment. Figure 1 provides an overview of the circuit breaker lubrication investigation plan. Interim results have been published in a number of technical update reports as well as illustrated pocket field guides that provide field personnel with a quick reference for the proper application of the various circuit breaker lubricants.



EPRI Circuit Breaker Lubrication Investigation Plan
Figure 1

TYPES OF LUBRICANTS

A typical formulation of grease consists of (1) 80% to 90% oil, which provides lubrication and is a temperature limiting element; (2) 10% to 20% thickener, which provides consistency and keeps the oil where needed. It is also a temperature sensitive element. And (3) 3% to 5% additives: anti-wear, anti-corrosion, anti-oxidation and viscosity modifiers.

Petroleum oils, often called mineral oils, are refined from crude oils.

- They are widely used because of their low cost and availability.
- They usually contain less than 10% additives to handle many load and speed conditions. Many additives are depleted over time.
- Petroleum oils are compatible with many grease thickeners.

For lubrication of high voltage circuit breakers, the disadvantage of petroleum lubricants is that they tend to change with time and environmental exposure—they might harden and/or leave a varnish-like residue on surfaces. They are stiff at low temperatures. These factors lead to slower operating performance of the circuit breaker.

Synthetic lubricants consist of chemical compounds that are artificially made (synthesized). They generally provide superior mechanical and chemical properties to those of traditional mineral oils:

- More inert than petroleum lubricants
- Better viscosity performance at low and high temperatures. This enables wider temperature ranges, speeds, and loads
- Better resistance to oxidation, thermal breakdown, and oil sludge problems
- Can be liquid (oil), semi-solid (grease or paste), or solid

The main synthetic lubricant types are diester, polyol ester (POE), polyalphaolefin (PAO), polyalkyleneglycol (PAG), silicone, fluorosilicone and perfluoropolyether (PFPE).

Thickeners used in circuit breaker greases can be soap or non-soap. Soap thickener can be combined with salts to raise the grease dropping point (the temperature at which the grease liquefies). Such greases are called *complex greases*.

- Common soap thickeners include lithium salt of hydrogenated castor oil fatty acid, calcium stearate (hydrous), calcium stearate (anhydrous), lithium complex, aluminum complex, and calcium complex.

Some lubricating greases are manufactured with non-soap thickeners.

- Non-soap thickeners include organoclays, polyurea compounds and polytetrafluoroethylene (PTFE).

SCE CIRCUIT BREAKER INFORMATION

Information on eleven SCE circuit breakers, the sources of the greases tested and bearings examined, is presented in Table 1. Multiple bearings from each circuit breaker were sent to EPRI. Chemical tests were done on one bearing from each breaker. Visual tests included several bearings from each breaker.

Table 1
Circuit Breaker Information

CB	Mfgr.	Model	Grease Installed	Mech Type	Site description and altitude (ft)	Temp -F	Avg. Rain Inch	Brief History
1-1	ITE	69KSB3500-12-B	1999	P24B	valley - 1,242	40-84	1.25	2000 failed close coil, 2009 internal arcing
1-2	MCGRAW EDISON	CF37-34.5-1500-12	1997	OA3	Dry, windy, desert - 2,500	40-84	1.25	
1-3	KELMAN	15RA2-B	1997	2HS	valley - 157	40-84	1.25	cleaned and lubed:2002,2008,2012
1-4	GE	FK14.4-350-1-6	1997	ML-10-1	valley - 171	40-84	1.25	
1-5	GE	FK69-1500-2Y12	1997	MA-14-9	cement factory - 2762	40-84	1.25	
1-6	GE	FK14.4-350-1-6	1997	ML-10-1	valley - 171	40-84	1.25	2013 replaced motor
1-7	KELMAN	7.2RA2TV-2A/3-6	1998	22	valley/mountain - 571	40-84	1.25	1998-overhaul, clean & lube: 2002,2006,2010
2-1	ITE	14.4KS500-12C	1997	SE31A	Valley - 722	52-79	9	
2-3	ITE	14.4KS500-12C	1997	SE31A	Valley -722	52-79	9	
2-4	ITE	14.4KS500-12C	1998	SE31A	Mountain/valley 331	52-75	10.91	
2-5	ITE	14.4KS500-12B	1998	SE31A	Mountain/valley 331	52-75	10.91	

TESTS OF SAMPLE SCE BEARINGS WITH AGED GREASE

Quantifying the acceptable limits or long-term performance of lubricants for proper circuit breaker operation is difficult. Standard laboratory tests were designed for assessing performance in industrial applications and do not provide an appropriate functional characterization for power circuit breaker applications. To address this gap, EPRI researchers have developed test methodologies and equipment for quantifying the operational effects of aged lubricants. EPRI has applied some of these test methodologies to assist SCE in evaluating the condition of the grease in sample circuit breaker bearings.

EPRI researchers conducted a series of tests on the field-aged greases and bearings from the SCE samples and new fluorosilicone grease and then correlated those test results with first trip timing results measured in the field. The tests conducted and the purposes of each are shown in Table 2.

Table 2
Tests and Analyses to Determine Amount and Effect of Degradation of Greases and Bearings

Test or Analysis	Purpose
Fourier transform infrared (FTIR)	Determine composition of materials in the grease
Differential thermogravimetric analysis (DTA)	Measure relative grease degradation in terms of polymerization of oil and some thickeners
• Accelerated aging of new grease in the laboratory • Measure performance of these greases in the EPRI circuit breaker bearing lubrication simulator	Quantify relative effect of degradation of greases on timing performance in simulator
Compare laboratory accelerated aging grease test results and field aged grease test results with first trip timing information from maintenance records.	Analyze degree of degradation of grease samples vs. functional performance of the SCE circuit breakers
Microscope inspection of needle rollers and races from bearings	Determine extent of bearing wear

Fourier Transform Infrared Spectroscopy

FTIR is a technique used to determine the composition of materials (generally reserved for liquids or gels). FTIR uses infrared light and detectors to measure the intensity of the light after it has passed through the sample and is being reflected back. This technique is used to determine the composition of greases in field-aged bearings.

FTIR testing gives results in the form of graphs with various peaks. These peaks are an indication of absorbance and they indicate chemical characteristics that permit identifying the composition of the material.

FTIR confirms the grease type and may show contaminants. In hydrocarbon oils, FTIR is used to determine the type of oil, thickener and presence of oxidation, moisture and additives. Petroleum oil and synthetic hydrocarbon oil such as PAO have similar characteristics and are difficult to differentiate based on FTIR. It may be possible to indirectly identify base oil from thickener or additive characteristics. In fluorosilicone oils, FTIR identifies the unique characteristics of the fluorosilicone material, shows the type of thickener and the presence of contaminants, for example due to the introduction of spray lubricants.

Reading FTIR

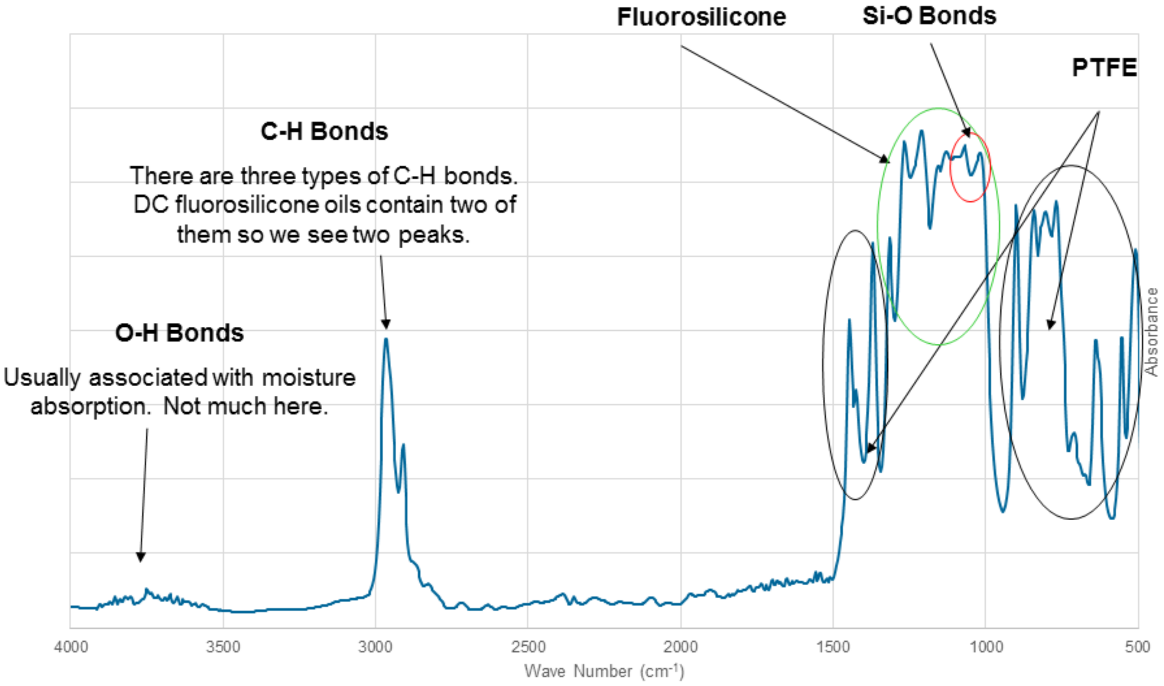
FTIR scans are qualitative for the purpose of these tests. The presence of a peak confirms the presence of materials.

Greases are a mixture of solids and liquids. They are not homogeneous in a microscopic scale of the cross section being analyzed. The sample thickness is not controlled. This will lead to fluctuations in relative peak intensity in the FTIR graphs. The scans may look different, but on closer examination convey the same information. There are large fluctuations in the relative size of the peaks associated with

PTFE based on how much was in the cross section of the beam; however, the peaks only provide information on the presence of PTFE and not the relative amount.

Figure 2 presents a reference FTIR scan of fresh fluorosilicone grease. Reading from left to right:

- The low activity in the 3800 to 3600 wave number region indicates there is not much moisture in this grease, which would be expected in a sample of fresh grease.
- The two peaks at 3000 to 2800 wave number identify a fluorosilicone bond. Three peaks in this region would identify a hydrocarbon bond, which could be either petroleum or synthetic hydrocarbon such as PAO.
- The peaks from 1500 to 1300 and 900 to 500 wave numbers identify PTFE thickener is in the grease.
- Fluorosilicone bonds are shown in the 1300 to 1000 wave number region.



Reference FTIR—Fresh Fluorosilicone Grease
Figure 2

Differential Thermogravimetric Analysis (DTA)

DTA is a qualitative analysis. It utilizes a high precision scale to monitor the weight of a sample as it is heated to note the weight loss at different temperatures. The area under the curve compared to fresh grease identifies the relative amount of oil left in the grease.

As oils age, some of their molecules break down and others build up (polymerize).

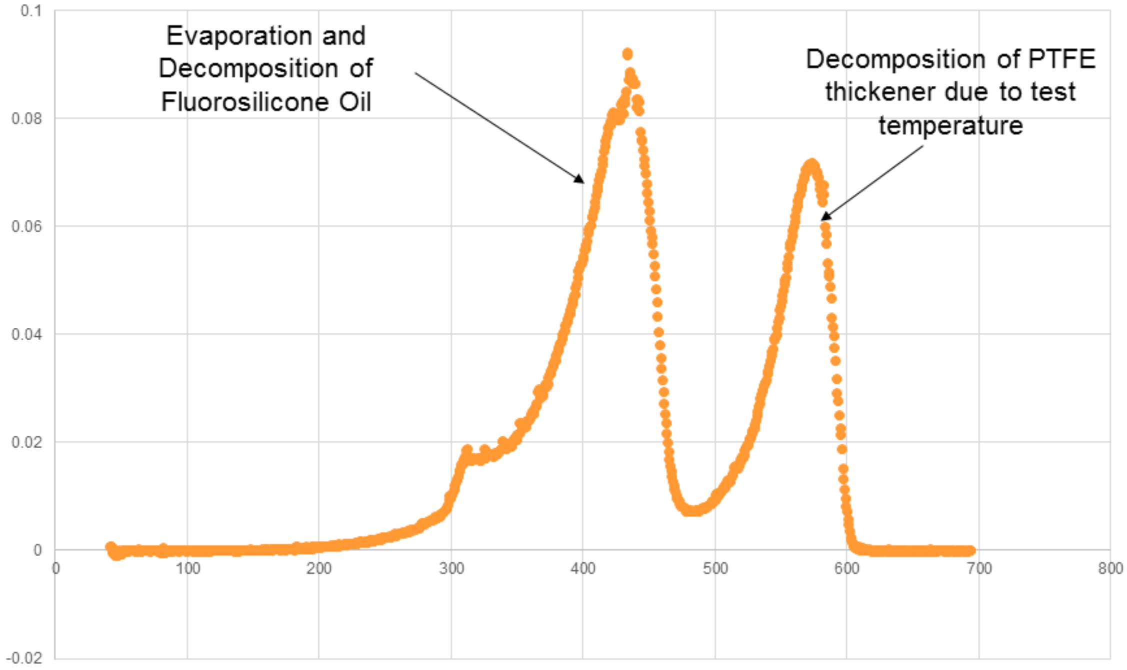
- Smaller molecules evaporate early
- Larger molecules evaporate later
- The wider the peak, the wider the distribution of molecule sizes

This part of the DTA test establishes degrees of polymerization and de-polymerization within the lubricating oil.

Reading DTA

In silicone and fluorosilicone greases, the base oil tends to shift its major peak to the right and slumps downward as it ages. This is because silicones and fluorosilicones often exhibit a tendency to gel over time. The PTFE thickener will not evaporate completely. As the PTFE particles begin to agglomerate over time, their surface area will decrease, leading to a lower peak.

Figure 3 presents a DTA curve for a fresh sample of fluorosilicone grease.

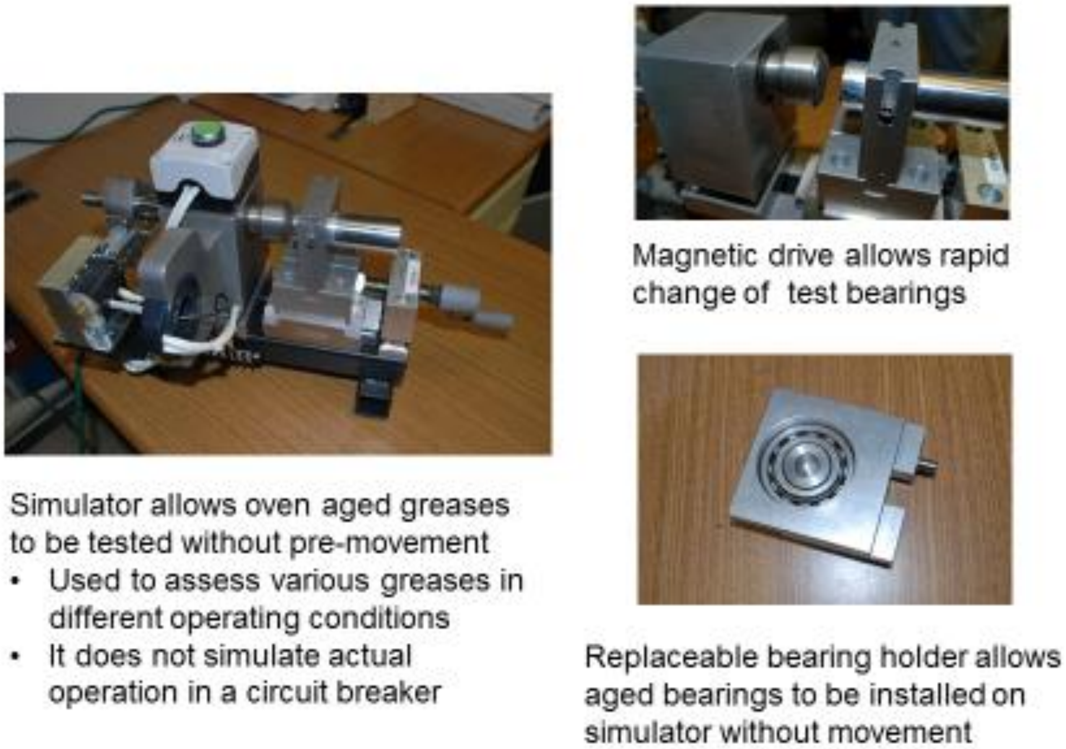


Reference DTA—Fresh Fluorosilicone Grease
Figure 3

EPRI Circuit Breaker Bearing Lubrication Simulator

The EPRI bearing lubrication simulator is an important tool used in the EPRI lubrication research. It is used to make relative assessment of various greases in different operating conditions. It is not meant to simulate actual loaded operation of a specific breaker. The simulator is shown in Figure 4.

The simulator was used in this series of tests to compare timing results of the accelerated aged greases discussed in the next section with DTA tests of the accelerated aged greases and new fluorosilicone grease. This in turn provided a reference to compare the degradation found in the DTA tests of the SCE bearing greases.



Magnetic drive allows rapid change of test bearings

Simulator allows oven aged greases to be tested without pre-movement

- Used to assess various greases in different operating conditions
- It does not simulate actual operation in a circuit breaker

Replaceable bearing holder allows aged bearings to be installed on simulator without movement

EPRI Circuit Breaker Bearing Lubrication Simulator
Figure 4

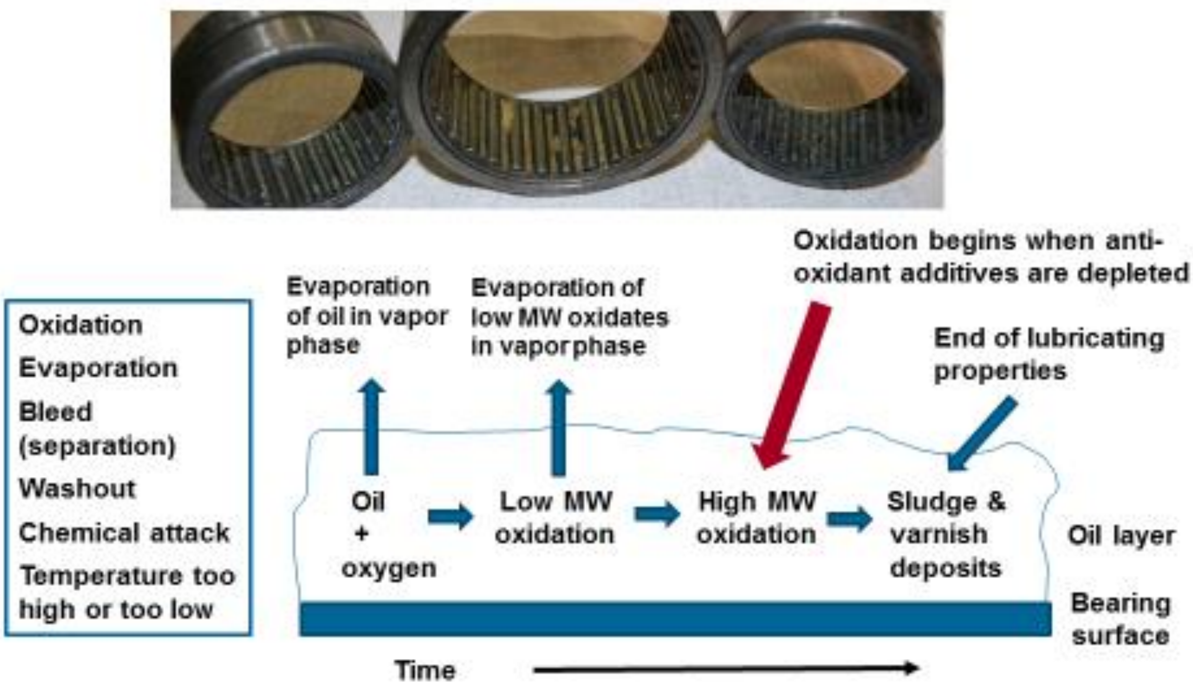
Failure Mechanisms of Greases

The lubricating properties of greases are reduced or become non-functional for many reasons depending on the type oil and thickeners, application method and thickness of grease applied, environmental factors such as high and low temperature and chemical exposure and length of time in service.

Hydrocarbon Grease

A primary failure mechanism of hydrocarbon greases is oxidation of the base oil in the grease. The sequence of oil combination with oxygen, evaporation of low molecular weight oxidates and depletion of additives as oxidation continues is shown in Figure 5.

The additives are generally used to buffer the effects of oxygen exposure. They are used up as exposure to oxygen continues. Oxidation accelerates rapidly after additives are depleted. The end result is usually sludge and/or a yellowish varnish deposit on equipment parts. When the sludge or varnish occurs, it is the end of the lubricating properties of the oil or grease.



Typical Failure Mechanisms of Hydrocarbon Oil
Adapted from Piet Lugt, Grease Lubrication in Rolling Bearings
Figure 5

Fluorosilicone Grease

FSi oil is highly inert, therefore oxidation is not a usual failure mechanism. One failure mechanism is gelling of the base FSi oil. Gelation occurs with temperature and age. This makes the molecules larger and viscosity higher.

Accelerated Aging Tests

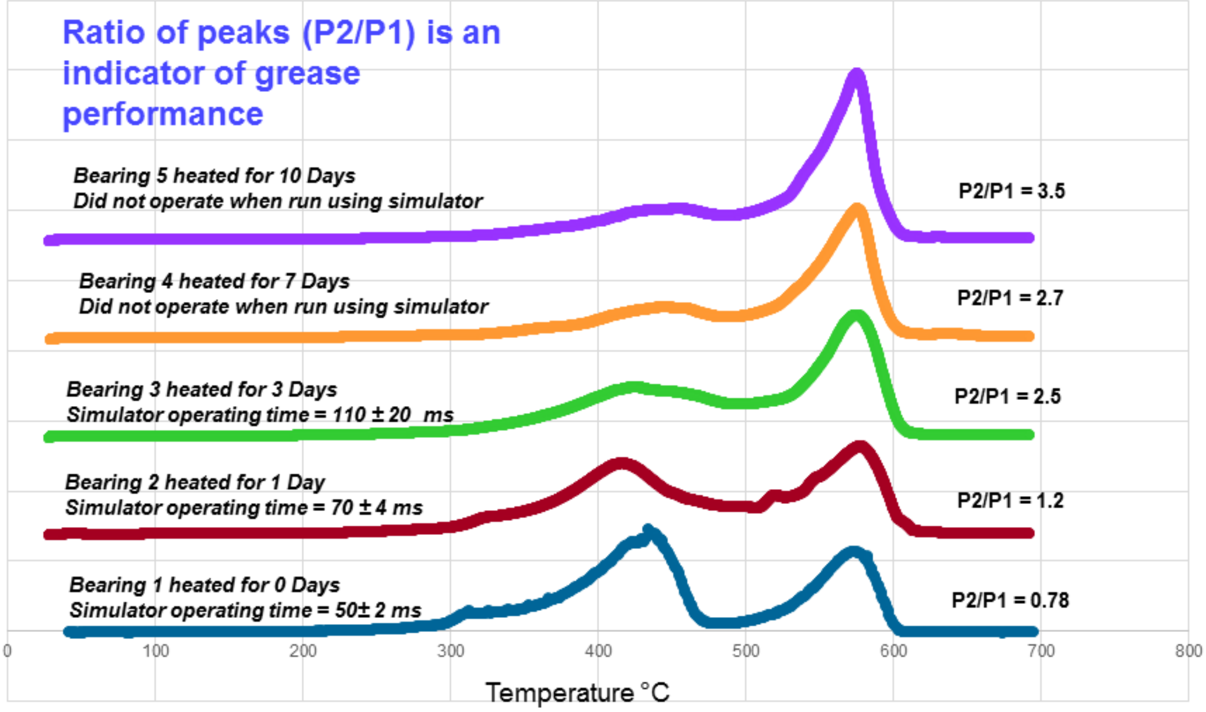
In order to understand the effect of gelling on simulator timing performance, researchers did the following:

- Fresh fluorosilicone grease samples were placed on a hot plate and heated to 130°C to accelerate the gelation process
- Samples were taken after 0,1,3, 7 and 10 days
- Bearings lubricated with the aged grease were placed in the EPRI circuit breaker lubrication simulator and operated multiple times. Trip times were used as a performance measure. Trip times in the simulator became progressively slower vs. days aged
- Samples from day seven and day ten did not trip. The samples gelled sufficiently to prevent operation of the simulator
- The samples of the accelerated aged grease were analyzed with the DTA method. The ratio of thickener peak, P2, and the oil peak, P1, was then compared to simulator timing.

The goal is to correlate the DTA degradation patterns and timing performance of the accelerated aged greases in the simulator with the DTA degradation patterns and the timing performance of the field-aged greases in the circuit breakers.

Figure 6 shows the results of progressive grease gelling on bearing lubrication simulator operating times. Peak ratios are shown to the right and above each curve. Simulator operating time is shown to the left and above each curve.

Notice the decay of the first peak as the grease ages. As shown in Figure 3, the first peak is the oil, the second peak is the thickener. The ratio of the second peak, P2, to the first peak, P1, correlates with the increase of timing in the simulator.



Results of Grease Gelling—DTA and Simulator Operating Times
Figure 6

Conclusions of Accelerated Aging Tests

DTA ratios of PTFE peak vs. oil peak,P2/P1, correlate 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 measure of degradation of grease and the effect of degradation on operation. The simulator is more sensitive to changes in grease than circuit breaker mechanisms. The magnitude of forces in the circuit breaker mechanism will determine to a large degree the effect of degradation on timing of the breaker mechanism. Another factor is the thickness of the grease. A thick application of grease will slow the breaker more as the grease ages.

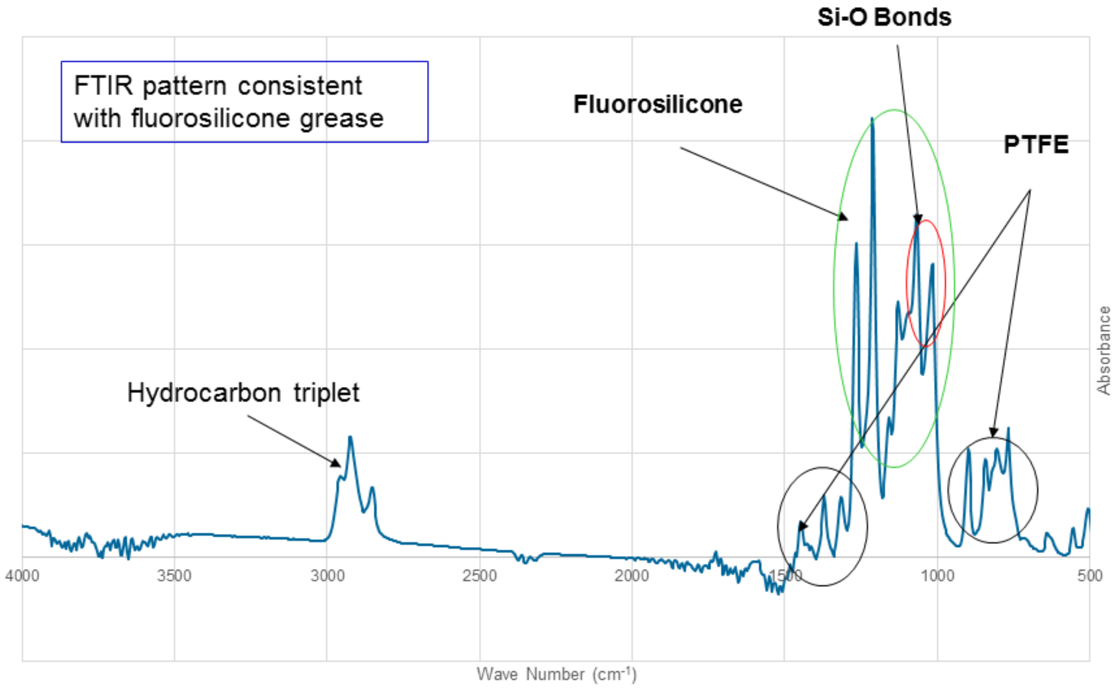
Tests on SCE Bearings

The above sections provide an overview of the test plan, describe the tools used and give the results of accelerated aging tests. Grease from a bearing from each of the SCE circuit breakers was tested using FTIR and DTA techniques. Example of one set of tests is shown below.

Example of FTIR test – Bearing 1-1

The FTIR graph for ITE Circuit Breaker 1-1 is presented in Figure 7. As noted in Table 1, ITE Circuit Breaker 1-1 was last lubricated 16 years ago. The FTIR graph indicates the materials in this grease. There is low moisture in the grease judging from low activity in the 3800 to 3600 wave number range; a hydrocarbon is indicated by the triple peaks between wave numbers 3000 and 2800, possibly from a solvent or other petroleum-based lubricant/penetrant; fluorosilicone oil is indicated by peaks 1300 to 1000 wave number; and PTFE thickener is identified by peaks from 1500 to 1300 and 900 to 500 wave numbers.

This grease can be identified as a fluorosilicone grease with PTFE thickener having hydrocarbon contaminants from an unknown source. The grease has low moisture content.



FTIR Circuit Breaker 1-1, Last Lubricated in 1999
Figure 7

Results of FTIR Tests of All Field Grease Samples

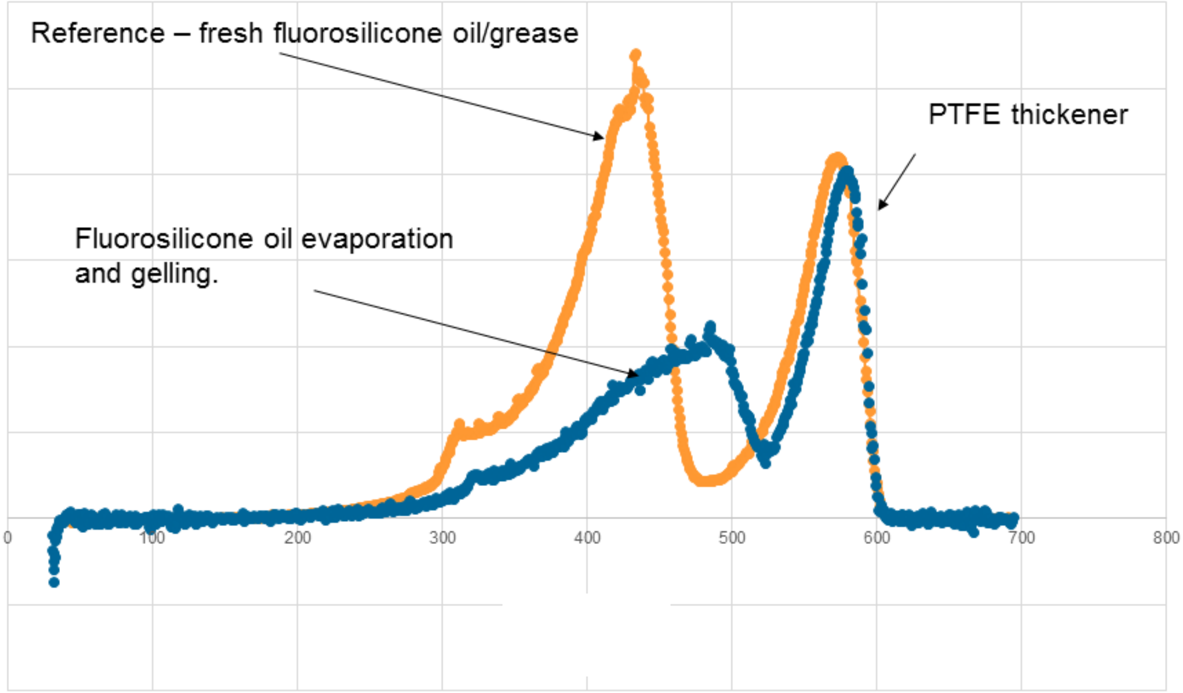
FTIR analysis showed three groups within the 11 samples:

- Greases that had fluorosilicone (FSi) oil and PTFE thickener
- Greases that contained FSi oil and PTFE thickener and had hydrocarbon contaminants
- Greases that did not contain FSi oil and PTFE thickener

Example of DTA Test – Bearing 1-1

The reduced oil peak and slump to the right at 450 – 500 on the DTA graph in Figure 8 indicates degradation of the FSi oil in the fluorosilicone grease in circuit breaker 1-1. The P2/P1 ratio of the thickener peak to the oil peak confirms this. The P2/P1 ratio for this grease sample is 1.81. The ratio for fresh FSi grease sample is 0.78.

This degradation and the presence of a hydrocarbon, possibly from a spray lubricant or solvent, did not affect the first trip performance of the breaker.



DTA Circuit Breaker 1-1, Last Lubricated in 1999
Figure 8

Results of DTA Tests of All Field-Aged Samples

DTA peak ratios P2/P1 for SCE circuit breaker bearings are shown in Table 3. The grease in only one bearing, Circuit Breaker 1-4, had a P2/P1 ratio greater than 2 indicating increase in viscosity sufficient to possibly cause a change in mechanism performance. The first trip timing for this breaker was not affected by the gelling of the grease.

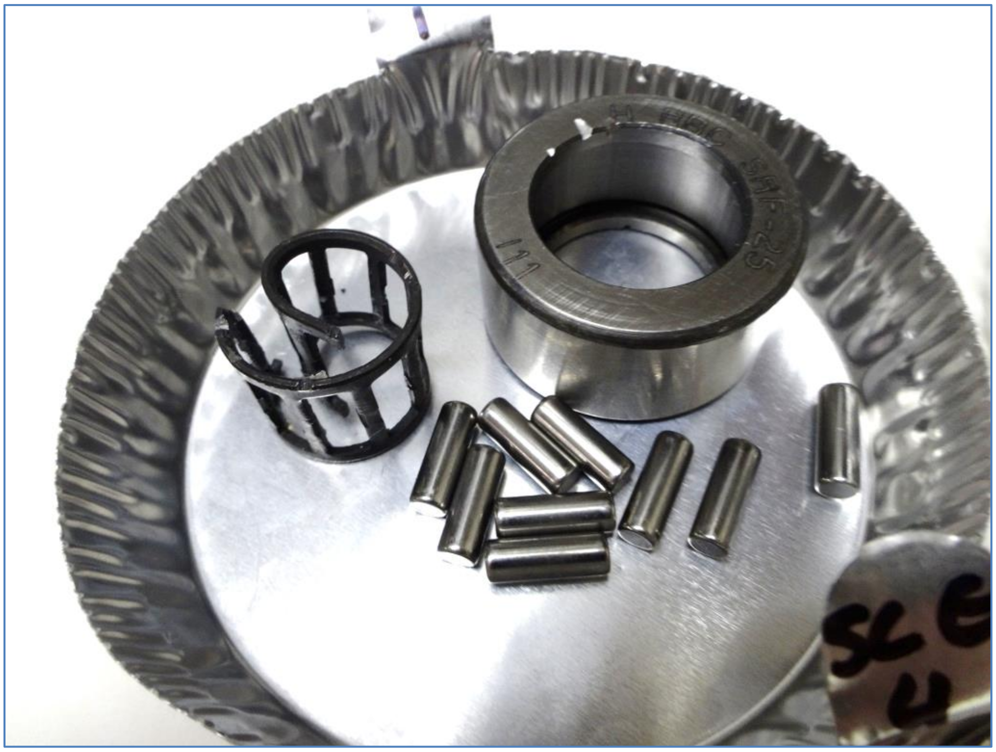
Table 3
DTA Oil Peak / PTFE Peak of Lubricants from SCE Bearings

	P2/P1 Ratio			P2/P1 Ratio
Reference	0.78		CB 1-7	1.06
CB 1-1	1.81		CB 2-1	0.95
CB 1-4	2.24		CB 2-3	1.56
CB 1-5	1.76		CB 2-4	1.27
CB 1-6	1.49		CB 2-5	1.31

Effects of gelling on actual breaker operation are dependent on the magnitude of forces in the operating mechanism and the degree of packing (amount of grease packed in the bearing). Application of a light film of grease instead of heavy packing of the bearing is less likely to lock up the bearing as the grease ages.

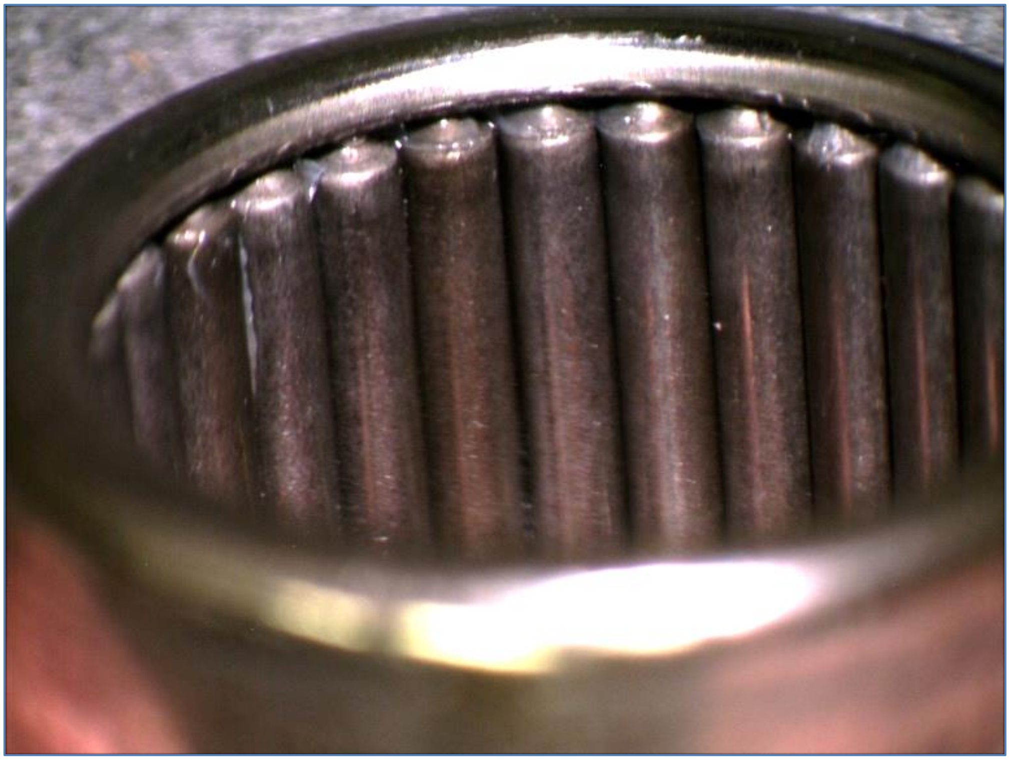
Visual Examination for Bearing Wear

A number of needle rollers and races from the SCE bearings were examined for wear using a microscope. Figure 9 shows a bearing from Circuit Breaker 1-1 selected for inspection. There is no wear that would inhibit the operation of the bearing.



Rollers and Race from Circuit Breaker 1-1 Bearing
Figure 9

Figure 10 shows a bearing from Circuit Breaker 1-4. Grease was installed in 1997. There is still a light film of fluorosilicone grease on the bearing rollers. It should be noted that many of the bearings in circuit breakers never make a full revolution. There is no wear that would inhibit the operation of the bearing.



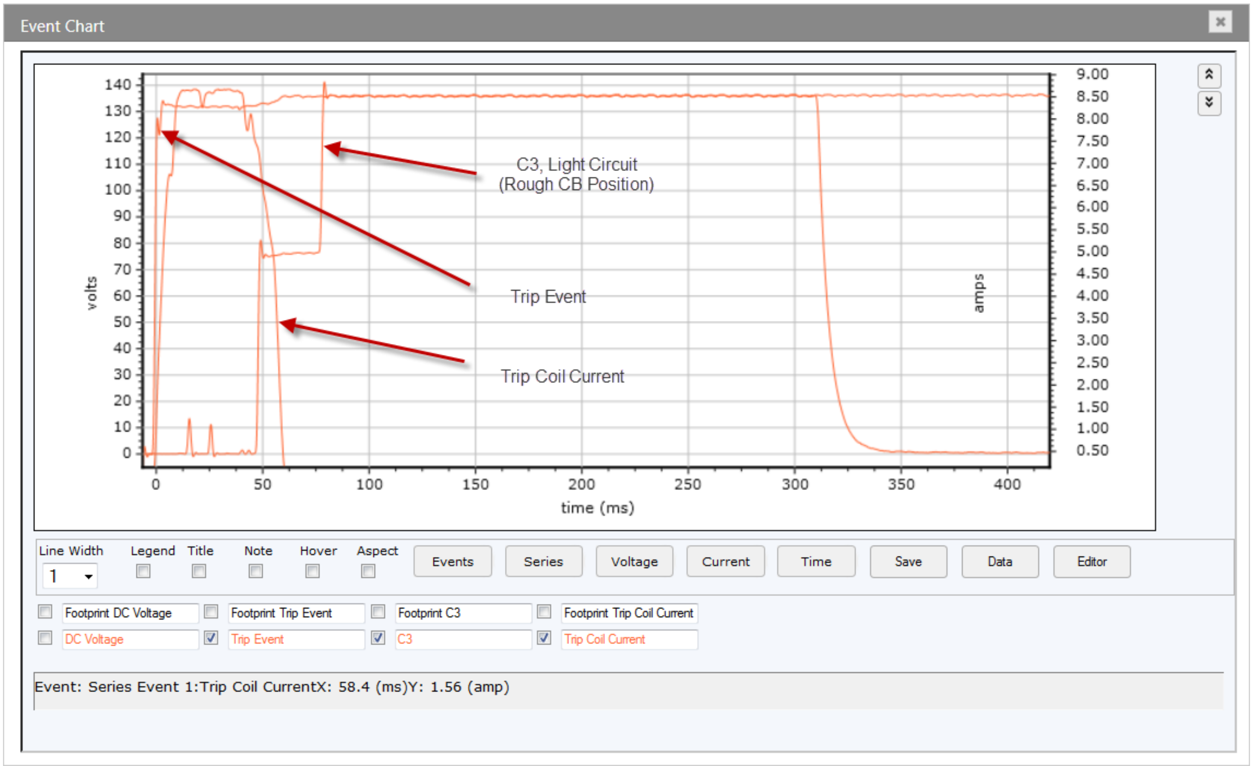
Needle Roller Bearing Circuit Breaker 1-4 Installed in 1997
Figure 10

Correlation of Laboratory Tests with First Trip Timing Measurements

Laboratory testing of nine SCE greases indicated that all except circuit breaker 2-1 had some degree of gelation resulting in viscosity increase. Simulator testing of accelerated aged greases established that greases with DTA test ratio of PTFE thickener peak to oil peak P2/P1 > 1.0 affected timing operation of the simulator.

Figure 11 shows a sample first trip timing diagram from field measurements of Circuit Breaker 1-1.There was no change in first trip measurements conducted in February 2008 and May 2013, five years later.

None of the nine SCE breakers that had fluorosilicone grease had a change in timing over the past five to seven years as measured by the first trip timing devices.



Line Width 1

Legend ☐ Title ☐ Note ☐ Hover ☐ Aspect ☐

☐ Footprint DC Voltage ☐ Footprint Trip Event ☐ Footprint C3 ☐ Footprint Trip Coil Current

☐ DC Voltage ☑ Trip Event ☑ C3 ☑ Trip Coil Current

```
Event: Series Event 1:Trip Coil CurrentX: 58.4 (ms)Y: 1.56 (amp)
```

Sample of First Trip Measurement
Figure 11

SUMMARY OF ANALYSES AND LEARNINGS TO DATE

Table 4 presents a summary of the analyses of the eleven bearings. “Viscosity increase” indicates ratio P2/P1 > 1.0.“Timing stable” denotes there was no change in first trip timing measurements over a five to seven year interval between two timed trips.

Table 4
Summary of Analyses

CB #	Last Greased	Noteworthy Findings	Location
1-1	1999	FSi grease. Viscosity increasing. Evidence of possible spray with heavy solvent. Timing stable.	Valley – 1,242’
1-2	1997	Hydrocarbon grease, not FSi. Evidence of possible spray with heavy solvent.	Dry, windy, desert – 2,500’
1-3	1997	Not FSi grease, possibly Chevron SRI #2 petroleum grease with polyurea thickener.	Valley – 157’
1-4	1997	FSi grease; viscosity increasing; timing stable.	Valley – 171’
1-5	1997	FSi grease. Viscosity increasing. Evidence of possible spray with heavy solvent. Timing stable.	Cement factory 2,762’
1-6	1997	FSi grease; viscosity increasing; timing stable.	Valley – 171’
1-7	1998	FSi grease. Viscosity increasing. Evidence of possible spray with heavy solvent. Timing stable.	Valley/ Mountain- 571’
2-1	1997	FSi grease; timing stable.	Valley – 722’
2-3	1997	FSi grease; viscosity increasing; contamination; timing stable.	Valley – 722’
2-4	1998	FSi grease; viscosity increasing; timing stable.	Valley/Mtn.- 331’
2-5	1998	FSi grease; viscosity increasing; timing stable.	Valley/Mtn.- 331’

Discussion of Analyses

Three greases, Samples 1-1, 1-5 and 1-7, had hydrocarbon contamination. Sample 2-3 had contaminants, but they were too small to be identified.

The contaminants did not affect performance of the breakers as measured by first trip timing.

Two of the greases did not contain fluorosilicone base oil (Samples 1-2 and 1-3). There was no knowledge of these greases so they could not be analyzed to the same degree that the fluorosilicone greases were.

The DTA results of all tested greases except that in breaker 2-1 indicate some level of gelling degradation. The mechanisms in these particular circuit breakers were strong enough that the aging and increase in viscosity of the greases was not sufficient to degrade timing performance.

There is no correlation between analysis results of these samples and elevation, rainfall and ambient temperature information provided.

Next Steps

If additional bearings with known grease become available from member utilities, EPRI will test them and compile results into a database to further understand degradation of performance.

OBSERVATIONS AND CONCLUSIONS

- 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.
- Based on no change in trip times and no wear that would impact operation in the breakers and bearings studied, effective lubrication does impact circuit breaker performance and overall maintenance requirements
- 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.
- 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.

REFERENCES

1. Salinas, A. “Enhancing Circuit Breaker Reliability through Effective Mechanism Maintenance and Lubrication.” Doble Engineering Company 2004.

2. *Circuit Breaker Lubrication: Engineering Application Guide and Selection Tool.* EPRI, Palo Alto, CA: 2014.3002003788.

3. *Circuit Breaker Lubrication: Compatibility and Selection—Laboratory Assessment.* EPRI, Palo Alto, CA: 2014. 3002000776.

BIOGRAPHY

Alex Salinas has been an employee with Southern California Edison (SCE) for more than 33 years within various field and management groups. As a current Principal Manager within the Substation Construction and Maintenance department, he is responsible for asset management, infrastructure replacement, regulatory compliance, work methods, and maintenance programs including condition based maintenance strategies. He has also been an active participant in several working groups which include, CIGRE, IEEE, Doble, CPUC, FERC, NERC, WECC, CALISO, EPRI and NEMA; and has presented papers on a variety of topics. He is the Chairman of Doble Advisory Committee and has served as Chairman of the Circuit Breakers Committee. He has an earned a BA degree in Business Administration and MBA degree from the University of La Verne, and also received a MS degree in Advanced Management from Claremont Graduate University.

Bhavin Desai is a Program Manager at the Electric Power Research Institute where he is responsible for managing EPRI’s R&D in Substations. He has 15 years of combined experience in the power industry ranging from substation equipment research, power system technical studies, transmission planning and developing risk based analytics for asset life cycle management. Desai has a BSEE degree from India (1998) and a MSEE from Oklahoma State University (2000), is a member of IEEE and CIGRE and registered Professional Engineer in the State of North Carolina.

Michael Lebow is a principal with Coplanar Consulting LLC, providing project management, design and application engineering support to the electric utility industry. Previously he worked for the Consolidated Edison Company of New York, where he held various management positions in engineering and research and development. Lebow earned BSEE and MSEE degrees from the University of Pennsylvania, is a Senior Life Member of IEEE and a register Professional Engineer in the Commonwealth of Pennsylvania.

Jack Harley is President of FirstPower Group LLC, which provides substation equipment and services to electric utilities and large industrial users of electric power. He is a Professional Engineer registered in Ohio, Life Senior Member of IEEE, Life Member ASME and Distinguished Member CIGRE. He is a graduate of University of Pennsylvania with BSME degree and Case Western Reserve University with EMBA degree.

Bob Kinner is a project manager at FirstPower Group, LLC. He received his Bachelor’s and Master’s degrees in Chemical Engineering from the University of Toledo. Bob is active in IEEE Transformers Committee.