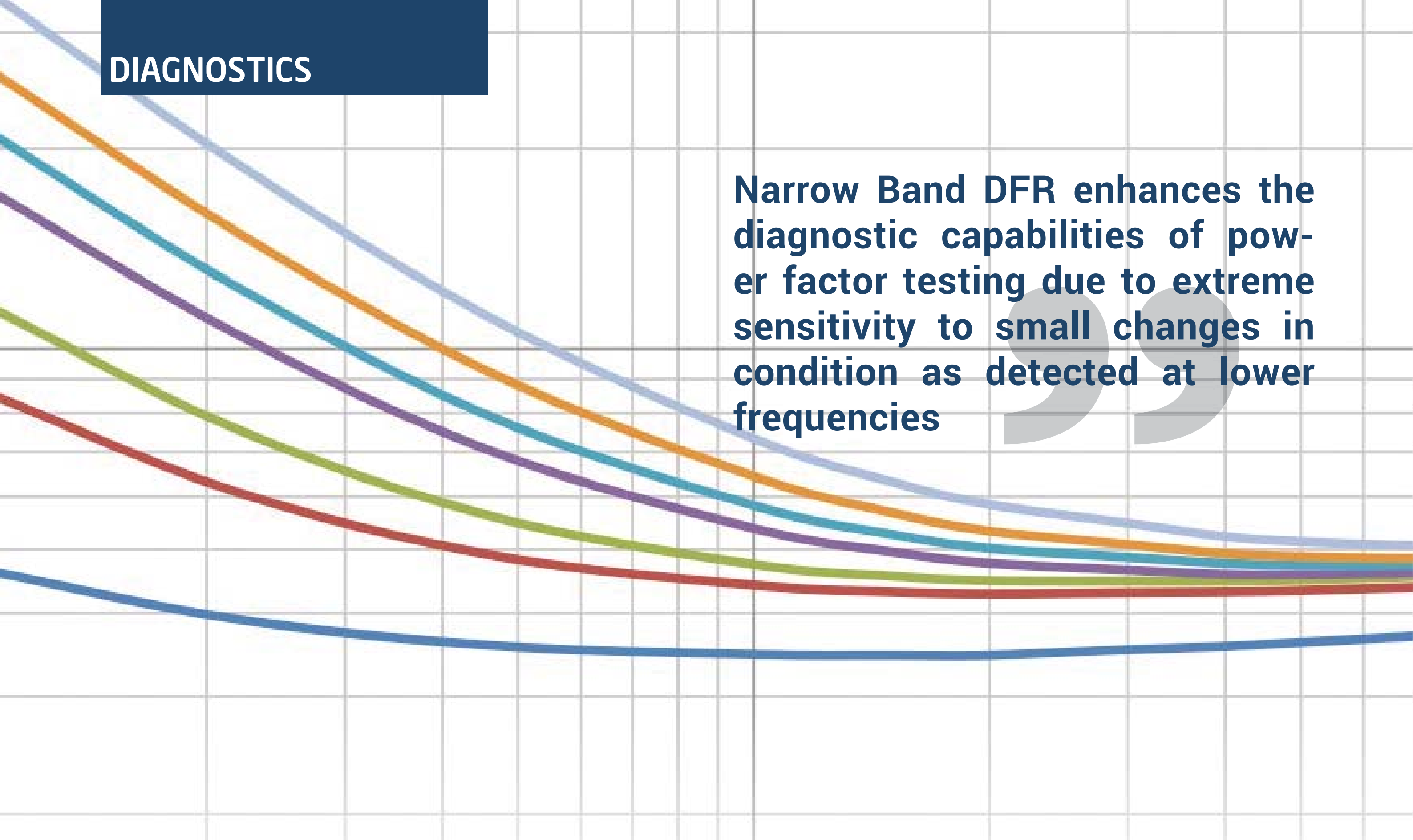

> **Narrow Band DFR enhances the diagnostic capabilities of power factor testing due to extreme sensitivity to small changes in condition as detected at lower frequencies**

Expanding the diagnostic impact of power factor testing

Interpretation of Narrow Band Dielectric Frequency Response

ABSTRACT

The Narrow Band Dielectric Frequency Response (NBDFR) test method consists of a series of power factor measurements ranging from 1 to 1000 hertz. This aggregate of the CHL (primary to secondary) measurements constitutes the dielectric response of the test specimen. The subsequent evaluation consists of a geometric analysis of a plot where the measured power factors and corresponding frequencies are graphed. As an insulation system ages, the response migrates towards the high frequency end of the plot. When the frequency corresponding to the lowest magnitude within the response (the trough) is used as a reference point, the movement of the response may be quantified; enabling the transformer may be classified in terms of condition.

KEYWORDS

power factor; insulation; oil; dielectric response; transformer

1. Unlocking the secrets of the NBDFR trace

The trace shown in Fig. 1 corresponds to the narrow band response of a 15 kV class 2.5 MVA transformer. The bandwidth between 1-10 hertz is dominated by the influence of oil conductivity. The influence of inter facial polarization (IFP), which is driven by winding geometry, is also present in this portion of the response. As the physical dimensions of the winding increase, the overall surface area of the winding interface increases. This enlarged surface area enables a proportionally larger number of charged particles to migrate and align themselves at the edges of the interface. This entire process generates mobile charge polarization losses which are manifested in the large geometric hump seen in the full DFR at lower frequencies. The winding in this case is relatively small, which suppresses the effects of IFP.

Due to the remarkably flat response in this region of the trace, it may be ascertained that the oil in this unit is in excellent condition.

The NBDFR test method consists of a series of power factor measurements ranging from 1 to 1000 Hz

The bandwidth from 10-100 hertz is dominated by the condition of the cellulose components of the insulation system. The negligible conductive losses, combined with dense winding design, results in a trough location at 15 hertz. The magnitude at line frequency should be noted, as this is the conventional parameter used in condition assessment.

Although it is not a definitive characteristic, the slope at line frequency should also be noted, as this, along with power factor at lower frequencies, will assist in evaluating the insulation condition. The bandwidth from 100-1000 hertz is influenced by static charge polarization losses, most notably from 400 to 1000 hertz. As this unit begins to age, an increase in pitch is observed from 400-1000 hertz as polarization losses become visible. As degradation progresses, the entire response moves towards the high frequency end of the graph. The elevated tail will be pushed past 1000 hertz, which will create the illusion that the high frequency tail is flattening out.

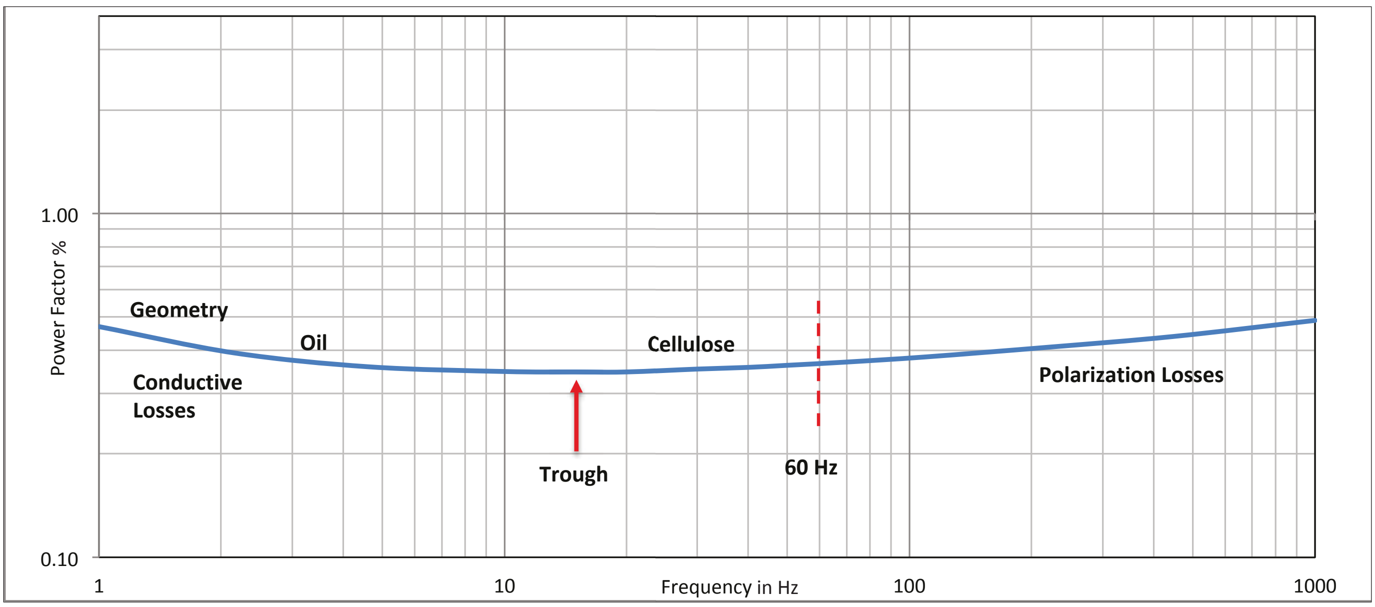

Figure 1. Typical narrow band response for new transformer

2. Trough location: The magic key to condition assessment

A prevailing interpretation states that, if the response slope is positive at line frequency and at 20 °C, the insulation system is in acceptable condition [1]. This paradigm would seemingly provide a pass/fail acceptance criteria for condition assessment. This, however, is an oversimplification, as slope is a result of trough location. As the insulation (cellulose and oil) degrade, increasing conductive losses cause the response to migrate towards the high frequency side of the plot. The trough moves proportionally as the response migrates; therefore, the trough functions as a marker by which the degree of movement may be observed. By monitoring the frequency at which the trough is located, insulation condition may be progressively and incrementally tracked. As a robust data base is established for a particular make and model of a transformer, condition classifications may be assigned based on trough frequency.[2]

3. Winding degradation and changes in dielectric response

When a transformer is under-loaded, the dielectric response may not change to any significant degree for a long period of time. This is especially true for units designed for 55 °C rise. When a transformer is loaded as per design temperature, the CHL at 60 hertz slowly increases with very moderate changes in response trace geometry as shown in Fig. 2 (red, black, and blue traces).

Trough movement if present is minimal, and slight increases in pitch are observed above 400 hertz, and below 10 hertz. As the insulation system slowly degrades, eventually, a point is reached at which any further increase in resistive losses causes increasingly exponential changes in the dielectric response. These changes are manifested in the form of disproportional increases in magnitude at low frequencies and trough migration towards the higher frequencies.

Southern California Edison (SCE) conducted a controlled experiment where identical transformers were subjected to continuous loads ranging from 90 to 150 %. NBDFR tests were performed at regular intervals to document the deterioration process. Units loaded at 90 % showed no discernable changes after 6 months. As depicted in Fig. 2, units loaded at 115 % exhibited a slight increase in pitch at lower frequencies, due to a slight increase in conductive losses. At 135 % load, a significant increase in conductivity and polar contaminates resulted in a dramatic distortion at low frequencies, with rapid trough migration well past 60 hertz. At 150 % load, the exponential increase in watt losses resulted in further distortion of the response with the trough migrating to 1000 hertz. In this case, the migration of the response is so severe that the magnitude of the response at 60 hertz actually decreases. Obviously, in this scenario the measured CHL at 60 hertz is no longer a valid parameter for condition assessment, as it no longer reflects the condition of the insulation system. SCE has documented that in most cases where distribution transformers are operated outside the design temperature, abnormal migration of the trough will occur long before the magnitude at line frequency will reflect the existence of an abnormal condition. As seen in the aforementioned 135 % and 150 % test cases, this trough migration may be rapid [3].

As an insulation system ages, the response migrates towards the high frequency end of the plot

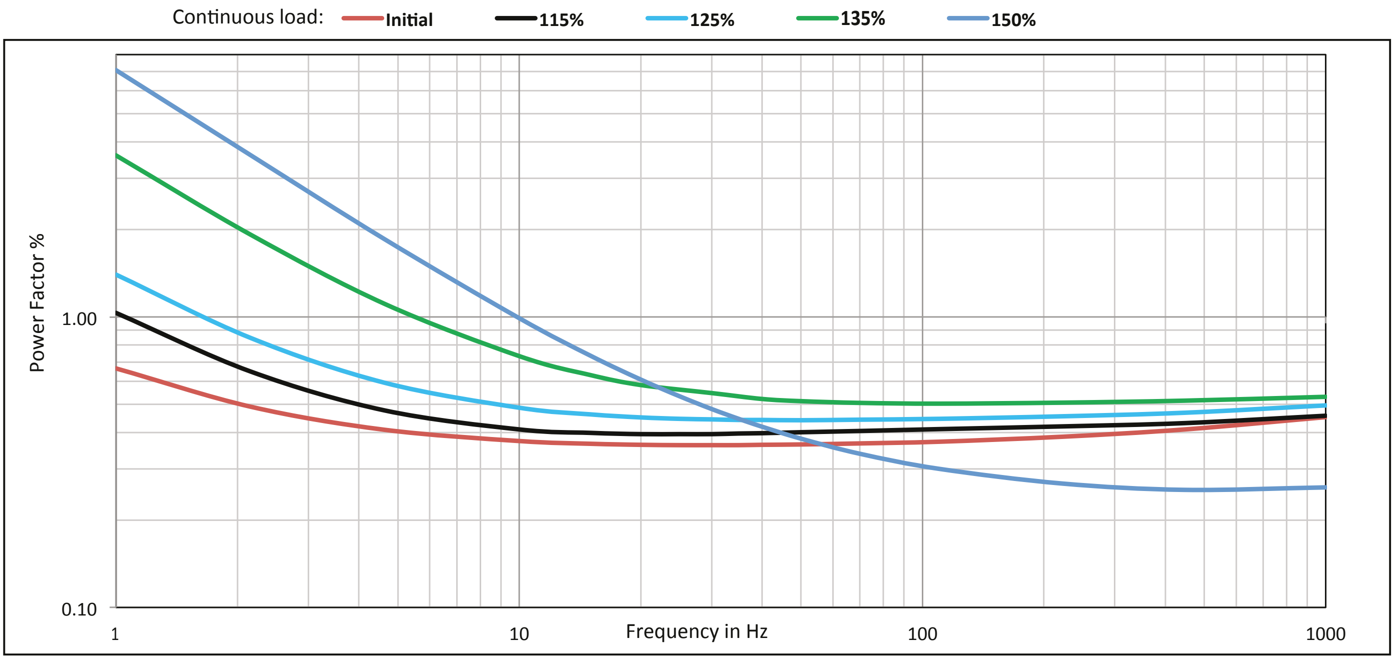

Figure 2. Narrow band response in distribution transformers loaded continuously for 6 months

4. Three phase transformers

SCE has found that the CHL NBDFR measurement is the most accurate indicator in condition assessment of three phase distribution (>500 kVA) and medium power (750-3750 kVA) transformers. However, when overall CHL power factor measurement is performed on a three phase winding, the measured CHL is the composite average for the three individual phases. As a result, conventional winding tests cannot discriminate between homogenous condition vs the presence of a significant localized anomaly. There are two methods to circumvent this limitation. The first is to sectionalize the winding insulation. The second is to test the winding insulation over a wide range of frequencies. [4] SCE utilizes a protocol which combines both of these methods, using the delta-wye open tap-changer crosscheck method to extract CHL NBDFR responses on a per phase basis to detect anomalies which could be localized in a single winding [5].

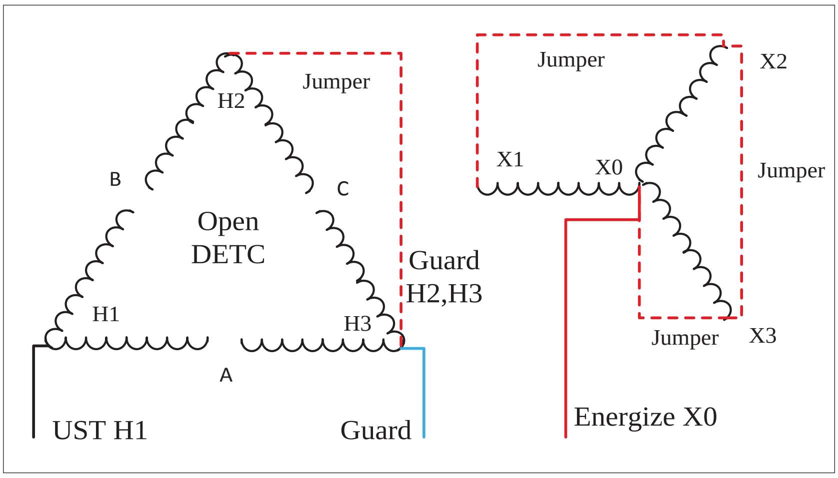

Figure 3. Delta-wye open tap-changer crosscheck method

As depicted in Figure 3, the tap-changer is placed between taps, and the secondary terminals are shorted. The guard lead is connected to two of the primary terminals which are shorted. The UST (ungrounded specimen test) measuring lead is connected to the other primary terminal. The secondary winding is energized at 500 volts and a UST measurement is performed to extrapolate a single phase CHL measurement. As depicted in the diagram, CHL data is collected only from the winding interface common to the H1 terminal.

By monitoring the frequency at which the trough is located, insulation condition may be progressively and incrementally tracked

As depicted by the violet trace in Fig. 4, an overall CHL NBDFR measurement was performed on a 500 kVA D-Y configured transformer. The CHL at 60 hertz was within the normal range, with the trough at 40 hertz. Although the CHL and trough are acceptable, it is possible that an ano-

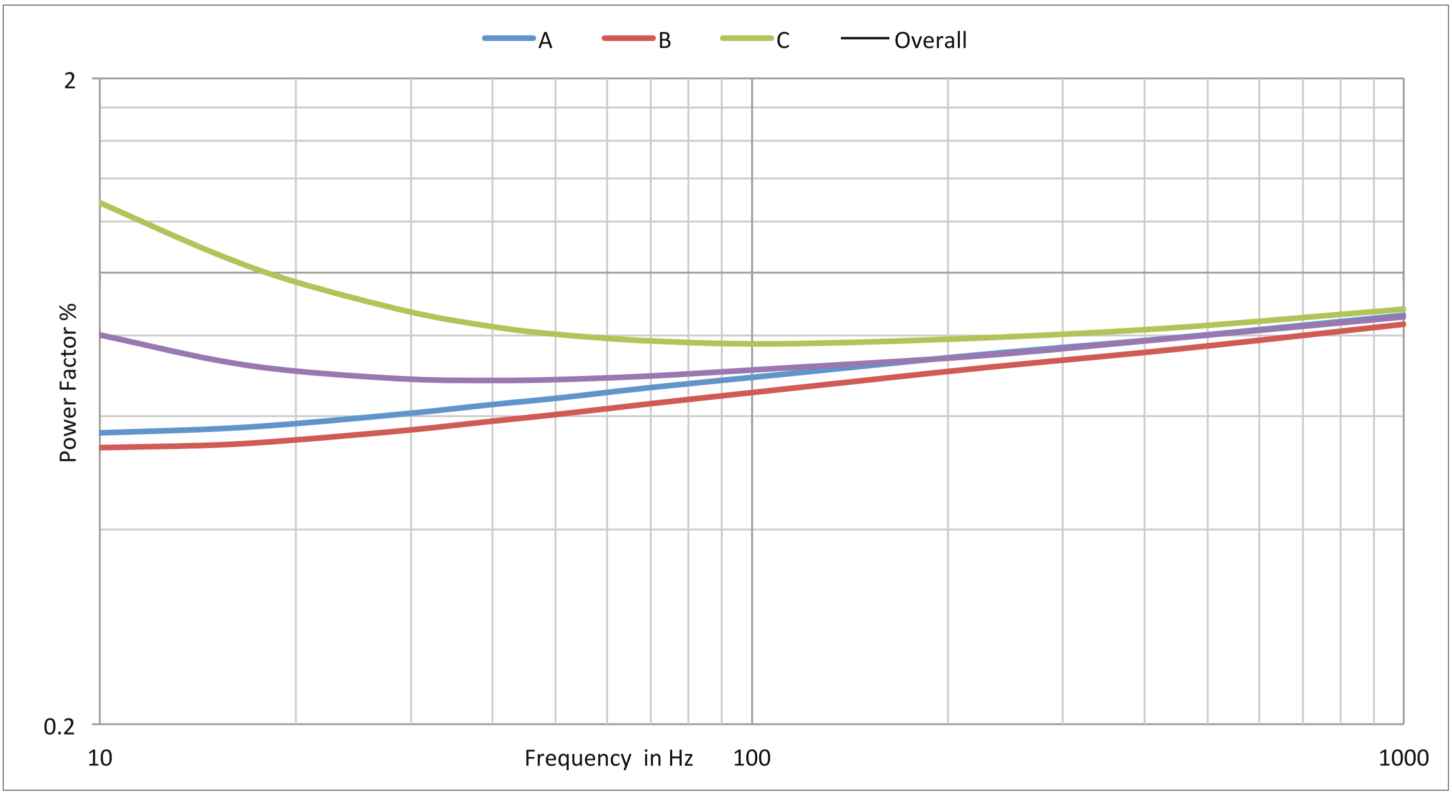

Figure 4. Open DETC crosscheck and overall NBDFR CHL traces for defective D-Y unit

The NBDFR measurement will detect conditions related to oil degradation and moisture contamination, but the full DFR must be performed to differentiate the actual nature of the abnormal response

maly could exist in one or more windings. The delta-wye crosscheck protocol was performed to measure per phase NBDFR CHL responses. The A and B phase windings were in essentially new condition with troughs located at 10 hertz, as seen in the red and blue traces. Conversely, the C phase dielectric response differed significantly, with an elevated CHL at 60 hertz and the trough located at 110 hertz, as seen in the green trace. This anomaly would have been undetectable when using conventional insulation power factor testing methods.

Conclusion

Moderate changes in resistive losses are marginally detectable at line frequency. Narrow Band DFR however, enhances the diagnostic capabilities of power factor testing due to extreme sensitivity to small changes in condition as detected at lower frequencies. With an understanding of the information contained in the response geometry, inferences may be made in regards to specific characteristics of the insulation system. It should be noted that, although the NBDFR measurement will detect conditions related to oil degradation and moisture contamination, the full DFR must be performed to differentiate the actual nature of the abnormal response.

Utilization of a bandwidth ranging from 1-1000 hertz in a logarithmic plot, will provide more information than the 15-400 hertz bandwidth on a linear plot as provided in some test sets. The conductive losses are most visible in the lower frequency spectrum and information from 1 Hz to 20 Hz trace along with its "shape" can provide a great insight to the insulation condition assessment. It is worthwhile to note that, for low to moderate insulation deterioration, it is not easy to identify a bad response from a good response in the frequency range of 20 Hz and above. Lower frequencies (20 Hz and below) allow a distinction to be made between good and bad traces by looking at the trajectory of the curve, in which direction it is heading at lower frequencies, and the end resting point response at 1 Hz. It is recommended to use logarithmic scale for frequency and, based upon the type of analysis to be performed, linear or logarithmic scale can be used for power factor. Location of trough and its movement is easier to monitor and trace using a logarithmic plot. When looking at the shape of the curve and sharp increase in losses at lower frequencies with respect to nominal frequency, it is beneficial to look at the linear response on Y-axis.

The NBDFR protocol may be applied to the delta-wye crosscheck method for measurement of single phase CHL responses, but the current limitations of the DFR test equipment dictates that the open tap-changer variation of the delta wye crosscheck must be utilized. As a winding ages and the CHL trough begins to migrate towards the higher frequencies, it is a recommended practice to perform the DFR/Crosscheck protocol to verify that this change in response is not due to an incipient single phase anomaly.

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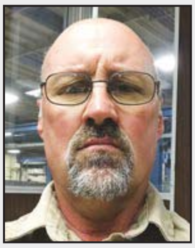

Robert Breazeal has 35 years of experience with the repair and testing of high voltage equipment with Southern California Edison. He currently provides technical oversight for transformer repair operations at the SCE Westminster Apparatus Repair Facility. Robert has published a number of papers and articles detailing research and diagnostic protocols developed at SCE.

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