Load growth coupled with aging transformers is a disaster waiting to happen

ABSTRACT

Infrared Thermography, Ultrasonic Noise Analysis, Partial Discharge Detection, Dissolved Gas Analysis, Vibration Analysis – all these techniques are great stand-alone diagnostic tools; however, when used properly, combining the data obtained through each technique, an incipient fault can be identified long before it degrades the insulation and creates a failure.

This paper will provide guidance in setting up a complete Predictive Maintenance program to be able to provide owners of oil-filled power transformers (4 kV and up), i.e. utilities, refineries, military, mining, etc., with a complete health report and condition assessment of critical oil-filled power transformers and ancillary substation components. The testing described in this paper is done on energized, fully loaded transformers.

Author's vast experience with doing Partial Discharge testing reveals that nearly 80 % of all oil-filled power transformers exhibit some PD. This low level PD activity is not detrimental to the health of the transformer. It is usually a burr or sharp corner that is producing the activity. I consider this just nuisance PD and most times it continues for the entire life of a transformer without a failure related to PD.

KEYWORDS

Partial Discharge, Transformer Condition Assessment, Risk Analysis Tool

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Advanced transformer condition assessment

Part II

Transformer lifecycle and risk assessment

Lightning/Surge arrester testing

The two screenshots in Figure 7 indicate internal arcing in a 500 kV lightning arrester (LA), energized at full voltage. and the test set is in the HFCT trigger mode. Twenty minutes is the agreed-upon test time that was determined by years of experience.

Normally, lightning arresters have no activity; if this arcing problem had not been detected and corrected early, the fault would likely have resulted in a catastrop hic failure. This arrester was consequently removed from service, tested off-line and disassembled. Off-line testing (watts loss) was done at 10 kV and did not find the problem. Upon disassembly we found evidence of moisture ingress and major arcing. Testing LAs/SAs at full voltage is the best way for determining the health. Using infrared inspections while they are energized is the other recommended method for arrester testing. If the arrester is arcing, it will normally not display any heating. If it is heating, it will normally not be arcing. This is what my experience has shown. There may be a case where there is arcing and heating in the same unit, however, I have never seen it.

Vibration and sound level analysis of transformer main tank

In order for a transformer to withstand through-faults or switching surges that include heavy load conditions, the core and windings must be securely blocked and clamped during the manufacturing process to prevent movement, shifting or distortion during its lifetime. Clamping pressure must be maintained to prevent looseness of core and windings. Deterioration of the pressboard due to moisture or heat may cause shrinkage and looseness, over time. Trending vibration and sound level data is critical to gauge the health of a transformer. In 1992 the EPRI transformer project started taking vibration data on transformers at 14 utilities. This was a pilot project to determine if vibration analysis had any value in determining transformer health. Now 24 years and thousands of transformer tests later, I can say without a doubt that vibration and sound level can and do detect looseness.

SFRA (Sweep Frequency Response Analysis) is a technique that can be used off-line to **provide confirmation data when the vibration spectrum indicates looseness.** The major benefits to vibration analysis over SFRA are that the test only takes a few minutes to accomplish and can be done without taking the transformer out of service, the test equipment is much less expensive and often already in use on site.

> **A good arrester will have no activity and indicate a straight line green trace on the scope**

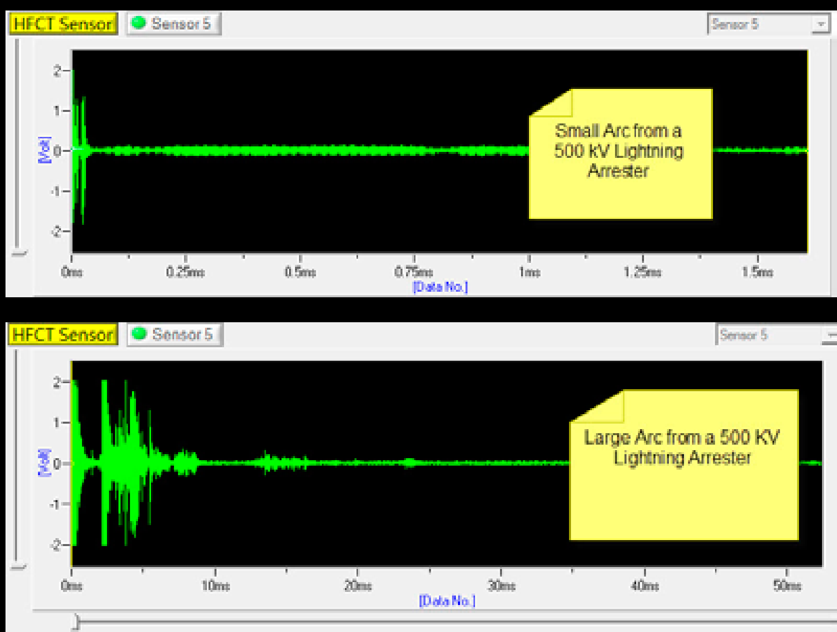

Figure 7. Screenshots of a 500 kV lighting arrester arcing at full voltage

In order for a transformer to withstand through-faults or switching surges that include heavy load conditions, the core and windings must be securely blocked and clamped

A normal core form transformer takes 4 minutes to gather the vibration data.

Acquiring vibration data

An accelerometer attached to a magnetic base is used to collect vibration signals; this data is stored in a vibration instrument then downloaded to a computer for analysis with standard vibration software. After 10 years of vibration analysis through the EPRI vibration project, it was determined that only eight data points are needed on each transformer. Vibration sampling results are displayed as waterfall plots, such as those shown in Figures 8 and 9. Starting on the high-voltage side, arbitrarily named side #1, and moving counter-clockwise, data is acquired from two points on each side, or wall, of the transformer. The exact data point locations are determined by the size and configuration of the transformer, either core form or shell form. It is crucial that the data is gathered by experienced personnel and taken at the correct locations for each type of transformer. Pump vibration data is taken on the axial plane only, looking for thrust bearing problems.

The ideal spectrum of a steady-state vibration signal from a healthy, tight transformer will contain frequencies that indicate a normal signature. First and foremost, 120 Hz pressure waves are detected; these pressure waves are two times 60 Hz line frequency, i.e. each 60 Hz shift from positive to negative creates a 120 Hz pressure wave that travels through the core, blocking and oil to the transformer wall. Harmonics of 120 Hz will also be detected. It is the combination of data and the shifting of energy that indicates whether a unit is tight or loose.

Analyzing vibration data

Recognizing the symptoms of core or blocking looseness is very significant in diagnosing transformer condition. **Original methods of transformer vibration analysis considered only amplitude**. This was based on severity criteria measured in inches per second. Subsequent testing has shown that frequency shifts point toward core and winding looseness regardless of amplitude. Since vibration analysis is only 24 years in the making and few companies have taken an interest in gathering this data, the only reference is the original EPRI report [1] and my experience in this method. This was a Tailored Collaboration (TC) that started in 1992 and lasted 6 years. The final report is available for free from EPRI.com. As stated above, continued work has shown that the original findings were not totally accurate.

Analyzing sound levels

Sound level readings are affected by looseness and have been able to track along with the vibration analysis. Four readings are all that is needed on each transformer; one on each side, 6 feet (1.8 meters) from the transformer. The readings are taken in C weighting which takes into account the 120 Hz normal sound coming from the transformer. This is an easy trending tool and worth the effort in the war on transformer failures.

Case study 1: Normal oil-filled power transformer - waterfall plot

The transformer in case study 1 is a fully loaded 30 MVA transformer (Figure 8). Because of the angle of the plot, the first peak appears to be at 100 Hz; however, it is actually 120 Hz. The next peaks shown on the plot are all harmonics of 120, which are 240, 360, 480 and 600 Hz. Notice the amplitude is only 0.14 inches per second (3.56 mm/s).

Case Study 2: Loose core form transformer

The transformer in case study 2 is loaded to approximately ½ load. Notice the shift

Four sound level readings, one on each side of the transformer, are all that is needed for the sound level analysis

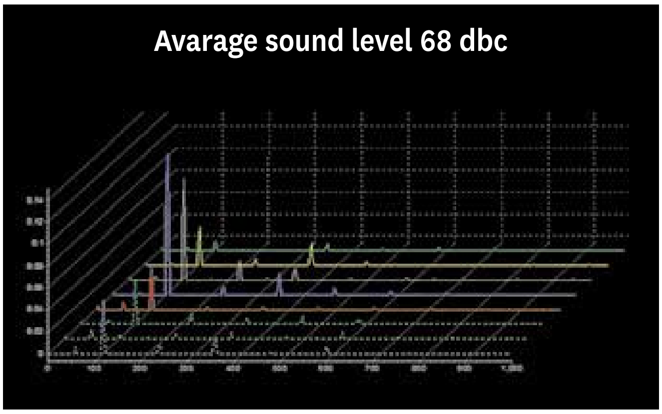

Figure 8. Normal, tight signature of an oil-filled power transformer. Note the sound level in "C" weighting

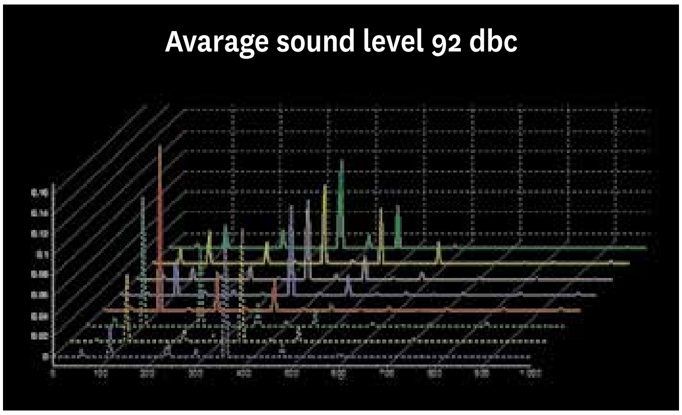

Figure 9. Typical loose signature with accompanying increase in sound level. Note the energy shift to the right

in the spectrum out to 360 Hz and the increase in sound level to 92 DBC. The sound level is always increased when the transformer is loose. Notice also that the 120 Hz has dissipated where the energy has shifted.

Recent findings

Figure 10 shows a 500 kV transformer that failed catastrophically, with smoke still coming from the bushing mounts. Its sister transformer, which is 40 feet (12 meters) away and still operating, has been tested showing PD and arcing. Although these issues are different from those on the failed transformer, they will have to be addressed soon. The burst interval for the operating transformer is 4 milliseconds.

Conclusions

Combining results from the presented on-line test methods with those you might currently be doing, and using the data from all the available techniques greatly improves your success of life cycle management.

The realities are:

- Doing a complete condition assessment as described in the paper is preventing catastrophic failures and extending the life of transformers under this program.
- The risk of a failure is real; managing that risk is a full-time job!
- Aging electrical equipment is increasingly likely to fail!
- These failures will cost time and money!
- A small investment in the latest technology will pay for itself quickly! One save will more than pay for whatever you have invested in time and money.
- A quality PdM program controls costs and prevents unexpected failures. Note that there will be failures, but you will know about them and have more control when to do a replacement.
- Replacement prior to a catastrophic failure is always less expensive than doing a rebuild of a station due to fire and oil spills.

Bibliography

[1] EPRI, TC Project #7014, Lessons Learned from Substation Predictive Maintenance Project

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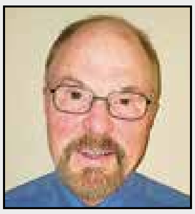
Figure 10. Catastrophically failed 500 kV transformer

Author



Jon L. Giesecke is an expert in combining technologies used in in-service inspection of high voltage oil-filled power transformers and substation diagnostics, with over 20 years of experience in transformer/substation predictive maintenance and over 25 years in substation electrical maintenance. Prior to forming JLG Associates LLC in 2006, he was employed by EPRI Solutions as a senior project manager in the Substation Predictive Maintenance business area. Mr. Giesecke is also an ITC level III thermographer and has instructed at the FLIR ITC training center. He served on the board of directors of the International Society of Professional Thermographers, Inc. (ISPoT), and chaired the ethics committee. He was also responsible for PdM template development for fossil and nuclear applications. His career in electrical maintenance spans over 30 years with Exelon, formerly Philadelphia Electric Company. During his career with PECO, he held many positions, from helper to foreman, including 4 years of Doble testing, 2 years in outage planning, 2 years as training coordinator for the nuclear group, and 2 years as turbine/generator foreman.