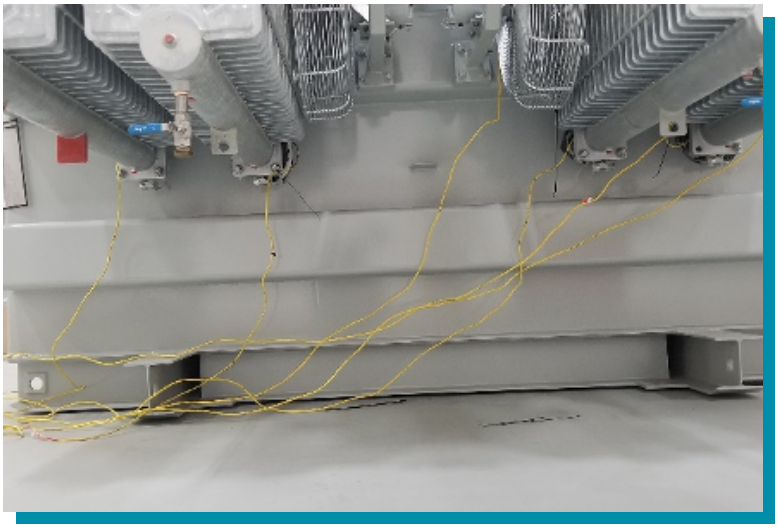


Distribution Automation / Substation Automation, Executive Insight, Outage Management, T&D

Comparing power transformer health with human body health: A lesson in asset maintenance

By Ali Naderian | 6.30.20

The objective of this article is to help younger engineers, non-engineers, and others in the energy sector who do not have extensive background on power transformers to understand the importance of the diagnostics and testing concepts used for power transformers condition assessment.

Power transformers are static electric machines used to step-up or step-down voltage in electric power applications. The capital cost of a power transformer in the range of 100MVA can be $1M or more, and by the time it is under operation, the price is increased. The average age of installed large power transformers (LPTs) in the United States is approximately 45 years, with 70% of LPTs being 30 years or older. The lead time of LPTs can vary from 1 year to 2 years. Many transformers are approaching the end of their technical life, and most have reached the end of their financial life. While the life expectancy of a power transformer varies depending on the design and how it is used, aging power transformers are subject to an increased risk of failure.

The challenge facing today's power industry, especially during the COVID-19 era, is in leveraging the most out of existing assets without reducing customer service. The funds for replacing the assets may be subjected to adjustment, which can cause delays in new installations or refurbishment. Therefore, all parties involved in the electric energy sector, such as asset owners and managers, operations, and maintenance team are required to fully understand the condition of old and often highly loaded LPTs.

There have been several analogies associated with the human body in the electrical and mechanical world. As an example, the human body is like an engine that continuously generates large quantities of heat, and its radiator disperses heat least effectively in hotter climes. It is likely that most of the readers of this article have personal experience with basic human body diagnostics and are familiar with some of the tests. I have used the analogy of human body tests to explain or teach power

transformer diagnostics, and it has been a success. Here I try to provide a summary of using the human analogy for diagnostics of power transformers.

The objective of this article is to help younger engineers, non-engineers, and others in the energy sector who do not have extensive background on power transformers to understand the importance of the diagnostics and testing concepts used for power transformers condition assessment. It is not meant to explain the details of the diagnostic tests; rather giving a high-level introduction.

Transformer DGA v.s. Blood Test

Dissolved Gas Analysis (DGA) is a diagnostic technique like your medical blood test check-up that is applied to power transformers. DGA is a very effective and strong test and has been used for more than 50 years to detect faults and prevent thermal and electrical failures. Degeneration of transformer oil produces various types of gases, most essential gases include H2 – hydrogen, CH4 – methane, C2H4 – ethylene, C2H6 – ethane, C2H2 – acetylene, CO – carbon monoxide, and CO2 – carbon dioxide. DGA is done on a yearly basis for healthy large power transformers. The more frequent test may be required if there is any defect detected.

Similar to the blood test, a syringe of oil sample is taken from the transformer and the sample is sent to a laboratory for analysis. A larger oil sample in a jar is also taken along with the syringe sample for further analysis. The analogy for the jar sample could be the urine sample that is used to reveal other health information.

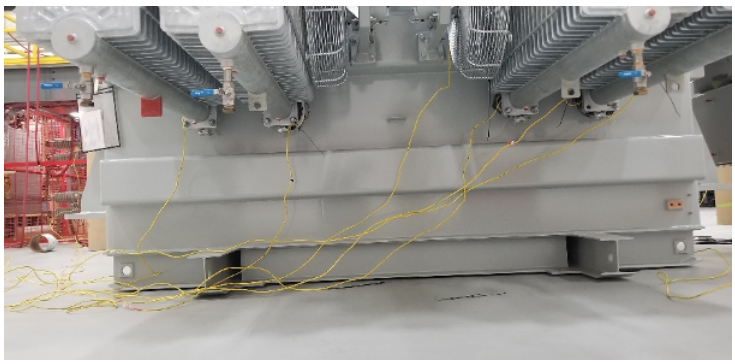
DGA is one of the most widely used diagnostic tools for transformer condition assessment because experience has proven it to be a very useful tool. The newly revised IEEE C57.104-2019 provides the latest best industry practice for interpretation of DGA. Similar to a blood test, DGA has limitations that one has to be careful to get a meaningful test result. Collecting samples incorrectly, misidentification, inaccuracy of test equipment, and multiple phenomena occurring at the same time can affect the test results.

Heat Run Test v.s. Exercise Stress Test

Heat run test, also called temperature rise test, is a part of the Factory Acceptance Test (FAT) conducted in an HV laboratory equipped with large power sources to verify the performance of the transformer at full-load or simulate temporary overload conditions. This test is also standard for many other electrical assets such as motors, generators, switchgear, cables, etc.

One can notice the similarity of heat run test with the human exercise stress test. An exercise (cardiac) stress test is used to determine how well your heart responds during times when it is working its hardest. Like heat run that several sensors are attached to the transformer tank to monitor the transformer, during a cardiac test, the heart's ability to respond to external stress in a controlled clinical environment is measured.

Transformer Heat Run Test



Transformer Heat Run Test: here temperature sensors are attached to yellow wires

around the transformer

Cardiac Stress Test

Stress tests on the human body are performed while running on a treadmill

Furan Test v.s. Urine Protein Test

Furan test is a diagnostic technique to estimate the degradation of transformer paper insulation. The cellulosic insulation degradation produces furan (2-furaldehyde) and other byproducts that is released to oil. In humans, urine protein tests measures the amount of protein present in urine. Healthy people don't have a significant amount of protein in their urine. However, protein may be excreted in the urine when the kidneys are not working correctly or when high levels of specific proteins are present in the bloodstream. Similar to a urine protein test, an oil sample is collected in a jar and the sample is sent to the lab for byproduct analysis. As a rule of thumb, a transformer with 0.1 ppm furan has a normal thermal aging and a healthy insulation condition. If the furan gets to 1ppm, further investigation is required. If the measured furan is 10 ppm, the transformer is probably close to the end of life.

Summary of Power Transformer & Human Body Analogy

There are several other basic or advanced diagnostic tests for power transformer condition assessment which are similar to the human body tests. The summary is presented in the table below, including oil voltage breakdown, SFRA, DFR, partial discharge test, and degree of polymerization (DP).

Similar to a medical doctor, a transformer specialist more likely to recommend starting the condition assessment with basic tests and then do more advanced tests if required. By putting the results of multiple tests, the transformer specialist can determine the possible defect, fault, or health condition of the power transformer.

In some cases, this requires de-rating the transformer's planned loading capacity for normal and overload condition. It is recommended to consider the health of the transformer for the planned loading limits.

Transformer Diagnostics Test	Medical Test
DGA– procedure consists of sampling of oil from the transformer, extracting of gases from the oil in the lab and detect various faults based on the gases concentration.	**Blood Test**– a variety of blood tests are available that help to do a preliminary diagnostic. Commonly 10 blood tests are recommended to do on a yearly basis.

Heat Run Test– is conducted in the lab to reproduce conditions of continuous rated load and overload to monitor the temperature rise occurring during extreme conditions.

Oil Voltage Breakdown – Oil sample is taken to test in the lab for the electrical withstand test and check the quality of oil.

Furan– Measuring byproduct of insulation degradation deposited in oil using oil sampling.

Degree of Polymerization (DP)– shows the actual paper degradation but requires opening the transformer to take the paper sample.

Partial Discharge (PD) Test –PD is a localized electrical discharge that only partially bridges the insulation of electrical equipment. PD test is conducted by applying a high voltage and measuring electrical PD signals with advanced sensors & data acquisition.

Dielectric Frequency Response (DFR) – is an advanced electrical test that measures the dielectric properties of the transformer's insulation as a function of frequency.

Sweep Frequency Response Analysis (SFRA)- is an electrical test to evaluate the mechanical integrity of transformer structure including core, windings and clamping structures.

Acoustic Emission (AE) Test– is advanced nondestructive testing that used for further investigation to detect faults such as partial discharges (PD). Acoustic sensors are placed around the transformer tank. This is a follow up test if DGA flags for PD.

DGA– procedure consists of sampling of oil from the transformer, extracting of gases from the oil in the lab and detect various faults based on the gases concentration.

Exercise Stress Test– Determine how well your heart responds during times when it's working its hardest.

Hemolysis Test– The sugar-water hemolysis test is a test to detect fragile red blood cells by testing how well they withstand swelling in sugar (sucrose) solution.

Urine Protein Test– is a screening test to look for the presence of proteins.

Biopsy– such as bone marrow examination requires the collection and examination of a sample of bone marrow. This is done to check if the tissue is healthy and blood cell production is normal.

Electromyography (EMG)– It is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). An EMG uses electrodes to translate the signals into graphs, sounds or numerical values that are then interpreted by a specialist.

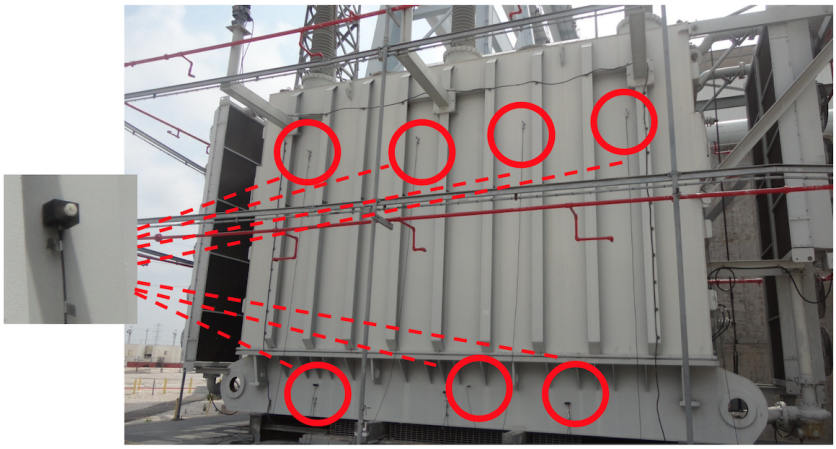
Magnetic Resonance (MR) spectroscopy – is a noninvasive diagnostic test for measuring biochemical changes in the brain or spine, especially the presence of tumors.

X-Ray – is often used to check the integrity of the bones. Soft X-rays have fairly short wavelengths and are placed in the electromagnetic (EM) spectrum.

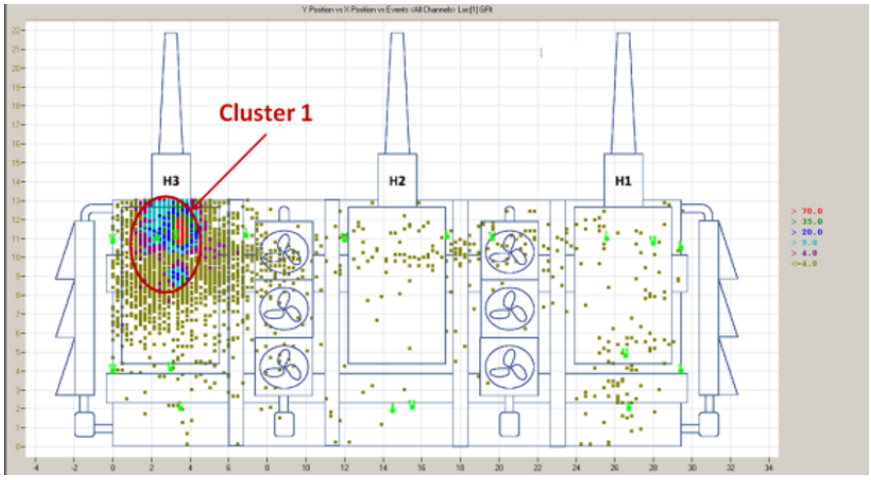
Ultrasound Scan- uses high-frequency sound waves to create images of the inside of the body. Unlike other imaging techniques, ultrasound uses no radiation.

Blood Test– a variety of blood tests are available that help to do a preliminary diagnostic. Commonly 10 blood tests are recommended to do on a yearly basis.

600MVA Generating Plant Transformer, Acoustic Emission PD simulation based on actual onsite AE monitoring to reveal internal faults



Similar to Ultrasound, Acoustic Emission (AE) E can be used to detect internal defects. Here is a 600 MVA Generating Station Unit with possible internal fault flagged by DGA. Acoustic emission sensors were attached to the tank to perform onsite AE monitoring for 72 hrs



Acoustic Emission PD simulation based on onsite AE monitoring of above 600 MVA GSU revealed the location of the internal faults at the H3 leads.

The health check and condition assessment of power transformers is critical to the security and stability of power system operation. Similar to a human, the frequency of checkups and attention required can naturally increase by the age of the asset. During the last decades, major work has been being carried out for the development of reliable and accurate condition assessment techniques such as online monitoring. It is recommended to consider such methods for critical assets.

It is expected that some of the utility and government funds allocated for power equipment replacement and refurbishment get affected or put on hold due to the COVID-19 condition. Therefore, it is more crucial than before to consider the health of existing aged power transformer.

Classic and advanced diagnostics techniques will help to extend the life of the existing valuable assets. Asset and O&M managers who have a strategy to evaluate the health of transformers frequently can take advantage of deferring capital spending on new equipment. Intervention options include de-rating, refurbishment, or enhancing transformer performance to reduce the stress and increase the life of the power transformer fleet.

Tags asset management

Ali Naderian

I am a professional engineer with 20 years of experience in high voltage testing, condition assessment, and diagnostics. During my career, I worked in multiple high voltage labs to test outdoor insulators, cables, transformers, switchgears, CT/PTs, CVTs, terminations, motors, and generators. At METSCO, I lead HV projects including commissioning, maintenance, diagnostics, root cause failure, and condition assessment of MV and HV power apparatus.

I am an active member of the IEEE Transfor mer Committee, the IEEE Insulated Conductors Committee, the CIGRE working groups including A2/D1.51: “Improvement to Partial Discharge Measurement for Factory and Site Acceptance tests”.

I have published more than 50 conference and journal papers in the area of HV testing and condition assessment. I am a senior member of IEEE and recognized reviewer of IEEE Power & Energy Society since 2009.

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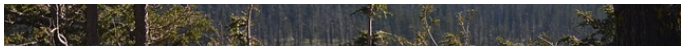

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