Effectively Managing Today’s Transformer Challenges for Increased Asset Reliability & Sustainability

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Abstract – As decreased dependency on fossil fuels grows and demand for an all-electric world increases, so does the impact to the traditional grid design, especially with regards to the reliability and sustainability of in-service transformers. These demands exacerbate the current challenges placed upon transformer owners such as higher electrical stress, from increased transients and harmonics to higher temperatures resulting from increased loads. All of which lead to accelerated aging of the transformers’ insulation systems and reduces the reliable life of the transformer and challenges the industry’s ability to provide consistent reliable power to end users. This paper identifies current challenges transformer owners face, including new challenges that are exacerbating current obstacles and how a social demand for uninterrupted power is affecting the management of transformer reliability and sustainability. We will also identify solutions to assist the transformer custodian with increasing transformer asset reliability.

Keywords – Hydrogen, transformer, reliability, sustainability, DGA

I. INTRODUCTION

We are at the crossroads of an electrification boom. With it comes a new and unique set of objections related to modernizing the existing grid. We are moving out of the 20th century patchwork design configuration and into a 21st century bidirectional flow for both electricity and information.

When compounded, challenges currently facing the grid, increase the pressure on power distribution system assets and its custodians to push beyond its existing capacity; thus, if not addressed rapidly, creates the opportunity for a perfect storm of quality issues for the world’s power supply.

Traditionally our grid, by design, is very linear. Electrical power is generated at central power stations, then stepped up with Generator Step-Up transformers (GSUs) to higher voltages and transmitted across the land through overhead transmission lines that efficiently transport high voltages over long distances. At the end of these transmission lines are the distribution sub-stations. These distribution sub-stations utilize step-down transformers to decrease the voltage from higher to medium and low voltages for delivery to and consumption by end users. This traditional model of a one-way flow was easy to manage as the predictability of energy demands were steady and electrical assets were maintained through a series of controls. This 20th century grid design was and is essential to modern life. However, as we move into a world where the demand for power steadily increases, modernization to a 21st century “Smart Grid” becomes increasingly difficult.

Figure 1. Example of Traditional Grid design and operation.
II. Current Challenges

Previously, the challenges transformer professionals experienced included: comprehension and interpretation of chemical, electrical and mechanical data from service providers on the health of the asset, data silos of transformer health information, and management of a fleet of transformers that ranged from pre-computer aided design (CAD) to post CAD influence. While these challenges remain, newer more influential issues have arisen that compound the complexity of the power system asset management. Challenges such as an influx of digital and computerized technology, government incentives influencing individuals and corporations to go fully electric, load management, Distributed Energy Resources (DERs), supply chain issues in electrical asset manufacturing, loss of industry knowledge, reduction of operation and maintenance budgets, more difficult planning, and a bid to move control to consumers, are only a handful of the new challenges moving us to modernize and create a two-way, interactive 21st century Smart Grid. The combination of all issues mentioned above and those not mentioned are placing significant pressure on current in-service distribution assets to maintain status quo.

A. Comprehension and Interpretation of Data

It can be difficult to justify maintenance of an asset, such as the transformer, whose Mean Time Between Failure (MTBF), or frequency between failure, is typically around one percent. Often when we talk about Mean Time to Repair (MTR) this value becomes inconsequential as typically when a transformer fails, it cannot be repaired in the field. Instead, the most common response is to remove and replace the asset, followed by sending it to a repair or rewind facility to be refurbished and then stored as a spare. The most common reason for transformer failures is premature aging of the solid insulation. It is estimated that “Nearly 30 percent of today’s transformers have aged prematurely. And in 70 percent of those cases, no corrective action has been taken.” (SDMyers, 2022) Lack of knowledge and understanding of what tests to run, and when combined with an ill-fated complacent mentality that these transformer assets have been running steady for the last 20+ years, ‘why do I need to pay attention to them,’ creates an environment of extreme risk. These issues can easily lead to catastrophic failure risking personal safety and effect reliability of other systems.

B. Data Silos

Not uncommon in the transformer world is the separation of asset data. In many cases, the service provider will do their specific job, whether it’s analyzing the chemical data from a sample of dielectric fluid, performing field electrical tests, visual monthly inspections, infrared imaging, ultrasound, or servicing the unit in the field (degassing, replace gaskets, moisture reduction, or reclaiming the oil), and provide a report or record of these actions, then move on to the next job. This report is then filed away by the transformer owner in a folder (either physical or electronic) and referenced in one of two situations:

1. to show proof that insurance requirements were met
2. to perform post incident evaluations

In either case, the ability to have a complete picture on the health of that individual asset is hindered by poor data management.
C. Managing multiple units that vary in age

Transformers, by their very nature, are designed for longevity. With the average lifespan ranging from 13 years to 50 years, it’s no wonder they are often taken for granted and not maintained well. This can be a challenge for a new transformer professional who has multiple assets that vary in age, condition, and criticality. When it comes to transformers, no two are the same. Sister units may have the same specifications; however, the build process is still very much done by hand which leaves margins of manufacturing differences between builds.

The management of in-service transformers from varying decades of design and manufacturing will be different for each unit. The testing that is performed will remain the same; however, due to differences in components and slimmed down builds, tolerances will vary among individual assets.

III. Outpacing modernization of the grid

Currently, the demand for increased power is on track to outpace our ability to successfully modernize the grid. Increased presence of Distributed Energy Resources (DERs), government influence – incentives and regulation, pressures for industries to convert finished product lines to one-hundred percent electric – automotive, new home construction, etc., and supply chain shortages are affecting the ability of energy providers to deliver sustainable, high-quality power to the end user.

A. Distributed Energy Resources

Distributed Energy Resources, solar panels, small natural gas-fueled generators, small wind systems, Energy storage/UPS systems, hydrogen fuel cells, etc. are small power sources, typically behind the meter, that are changing the way power is generated and transmitted to the grid. DERs are paving the way for a two-way flow of energy and the incorporation of new, connected technologies for power generation.

While DER technologies bring a host of benefits to the grid with increased energy options and flexibility, they also bring challenges. Questions of reliability and resiliency prevail as we move away from baseload power sources. One must also consider negative environmental impacts of the assets at the end of their useful life when they are replaced or removed from service. How much of a wind turbine or solar panel can be recycled? What is true cost and the environmental impact of disposal?

Have studies been performed to understand what happens to distribution transformers when the generation from residential DERs outpace the load? Distribution transformers are designed for power to flow from the grid to the end user (high voltage to low voltage). When the power flow reverses and the transformers feed power from low voltage to the grid, how will the transformers perform? When wind farms started being built, designers chose to use standard distribution transformers to step up the voltage from each turbine to the grid. This resulted in failure rates of greater than 50% within a few years. Today, wind turbine step-up transformers are designed specifically for the application and have reliability similar to other transformer types. In areas with large DER populations, distribution transformers may need to be replaced with more expensive transformers that can handle the increased duty.

B. Government Influence

Incentives and regulations at the state and federal level are accelerating the drive for grid modernization. Financial incentives for individuals and corporations to go “all electric” increase load demands on distribution systems. Pushing transformers to operate beyond rated capacity leads to increasing failures and blackouts. Incentives to increase production goals for industries such as automobile manufacturing to convert their lines to one-hundred percent electric by 2030 or 2035, coupled with the current economic situation, are
causing drivers to consider owning all electric vehicles.

In states such as California, initiatives have been announced that require one-hundred percent clean energy by 2045, increasing the sense of urgency to modernize and improve the grid. Even in the manufacturing of new homes, there have been announcements that new home construction will be all electric in the next decade to remove dependency on natural gas resources.

These initiatives, while well intended, are causing some panic among current power asset owners and operators as they will effectively double the demand for reliable power from an aging system that, for the moment, can barely keep up.

C. Supply chain issues

Current economic situations have caused an increased strain in already stretched resources. A recent report on the availability of copper (a key component in transformer manufacturing and other electrical applications) notes that demand for this trace mineral is outpacing supply. Recent forecasts suggest that copper demand will nearly double by 2035, jeopardizing net-zero emissions targets. Compound this with the ability to deliver new transformer assets and lead times will likely double. Forcing an already taxed infrastructure to continue to operate in high-risk environments will affect asset reliability and sustainability.

IV. Solutions

Transformer life-cycle costs or “Total Owning Cost” (TOC) must include the cost to operate and maintain the transformer over its life, not just the initial purchase, installation, and start-up costs. Since transformers can typically be expected to operate 20-30 years or more, the Total Owning Costs are reduced significantly. Preventative and Predictive Actions, such as routine testing – chemical and electrical, online monitoring, infrared & ultrasound, efficient data management, timely remediation and repair actions, as well as regular operator education programs, are all key elements of an effective asset management program.

When you factor in the current cost of transformer replacement, lead times and cost effects of system down time versus the costs for proactive and preventative maintenance, the decision to start or modify a maintenance program will be an easy one.

A. Routine Sampling of Dielectric Fluid

Annual chemical analysis of transformer dielectric fluid provides you with important information on the conditions inside the transformer tank. It can alert you to potential active faults, oil quality issues and degradation of the solid insulating system. A study by SDMI based on 1,534 decommissioned oil-filled transformers greater than 500kVA has shown that performing one oil service to improve the quality of the oil in a transformer can increase the life of that asset by 7 years.

![Figure 3. SDMI](image)

Annual sampling is only a snapshot of a single point in time. Understanding the overall health of your transformer requires more than a snapshot.

B. Electrical Testing

Many transformer owners agree that field electrical testing of their transformers helps them to ensure their units are operating correctly and efficiently. However, unlike chemical analysis of a sample of dielectric fluid, which can be obtained while energized, electrical testing involves an outage and is only done every three to five years. In many cases, transformer owners cannot afford the downtime and miss a valuable
opportunity to ensure the health of this critical asset.

C. Online Monitoring

Online monitoring of transformer assets has traditionally been left to Power Transformers with approximately 15 percent having online Dissolved Gas Analysis (DGA) monitoring systems. While less than one percent of distribution units are equipped with online DGA monitoring systems. However, online monitoring of transformer assets can provide you with continuous data in between manual samples.

Hydrogen (H\textsubscript{2}) is a key indicator gas that, much like the check engine light of your car’s dashboard, alerts you to potential hazardous issues such as overheating, partial discharge and arcing that can occur in transformers. Unlike other gases that are formed during the breakdown of oil, Hydrogen gas in oil is created at all fault temperatures and the generation rate increases as temperature increases.

![Figure 4. USBR.GOV](image)

Except for cellulose aging and leaks in oil expansion systems, most electrical or thermal fault conditions will have Hydrogen gas present in the oil. An increase in the production of Hydrogen correlates directly with the severity of a problem in the transformer.

In the current economy, and with the challenges that are being imposed upon distribution systems, it is highly recommended that the custodians of these systems consider the installation of a simple hydrogen monitor to alert them to potential issues with the transformers operation. Making the case for a single gas online monitor system for distribution transformers has not always been easy. Often the cost of the monitor system exceeded that of a replacement transformer. However, with inflation, supply chain issues and extended delivery times significantly impacting the purchase price of a new transformer, it is fast becoming a more economical and financially sound decision to install Hydrogen sensors on these assets. Besides the dramatic increase in transformer costs, new technologies have significantly reduced the cost to add Hydrogen sensors that last 10+ years with no maintenance.

D. Infrared Thermal Imaging & Ultrasound

Infrared allows you to see what you cannot, and ultrasound helps you to hear what you cannot see. In addition to annual sampling, electrical testing and online monitoring, infrared thermal imaging of your electrical assets can alert you to potential hotspots. Combine this tool with ultrasound, which can alert you to partial discharge, and you can start to see and understand the true health of your assets.

V. CONCLUSION

While it may seem like an uphill battle to maintain the quality of essential assets in your electrical system, it is not impossible. Online transformer monitoring has become a well-accepted best practice on high voltage assets. As the stress increases on distribution assets, the same principles apply. A high-quality, reliable, and sustainable grid is achievable with proper planning, evaluation, preventative maintenance and proactive monitoring.