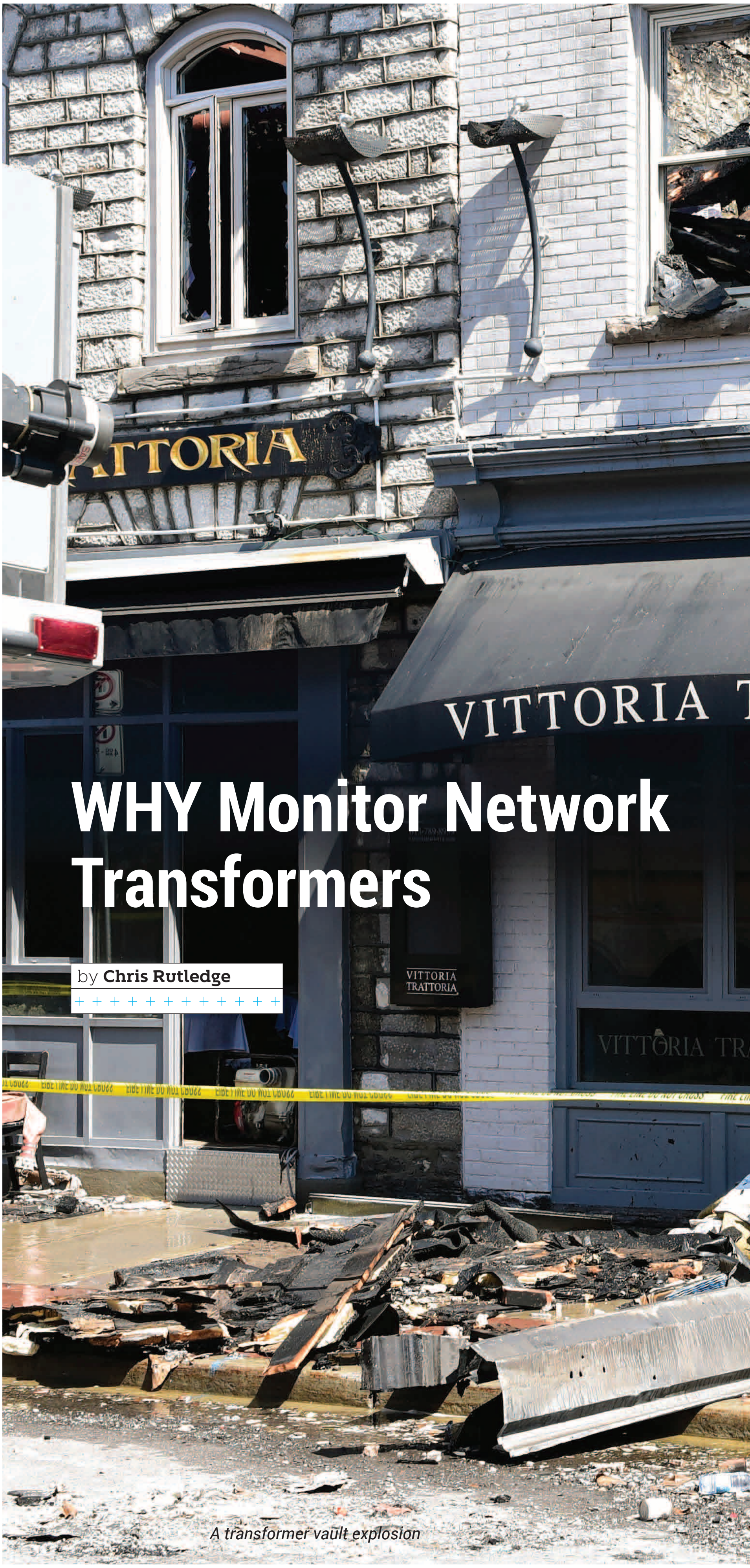
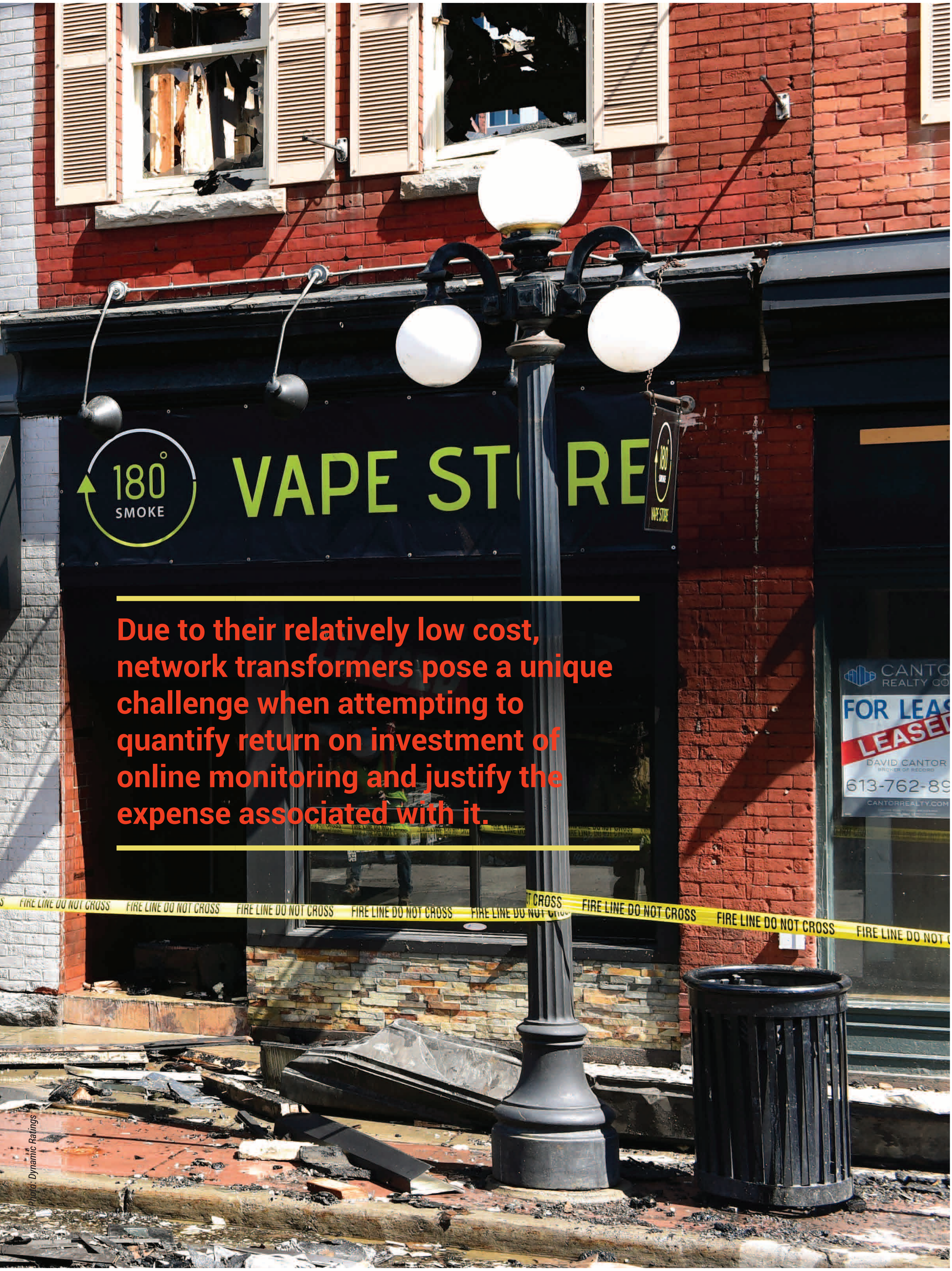


WHY Monitor Network Transformers

by **Chris Rutledge**

Chris Rutledge is currently an Applications Engineer at Dynamic Ratings, Inc. He joined the Dynamic Ratings team in July 2019. Prior to his present position, he served Substation Asset Manager and chairman of the Substation Safety Committee at Memphis, Light, Gas and Water. He has 27 years of experience in the utility industry, primarily focused on the installation, service and maintenance of both substation and distribution equipment. He has done extensive research and published multiple papers concerning the interpretation of dissolved gas analysis testing. Chris is dedicated to assisting customers in finding creative cost-effective solutions for improving safety and reliability across their entire electrical system.

A transformer vault explosion



Due to their relatively low cost, network transformers pose a unique challenge when attempting to quantify return on investment of online monitoring and justify the expense associated with it.

Photo: Dynamic Ratings

While the application of online monitoring has become common for most big-ticket substation items, from large power transformers to high voltage circuit breakers, little attention has been given to equipment outside the fence, as the relatively low cost of distribution equipment makes it difficult to justify the expense associated with online monitoring. However, network transformers pose a unique challenge when attempting to quantify this return on investment. Low voltage secondary network systems are used to increase reliability in the downtown areas of most major cities across the world, requiring these transformers to serve highly critical infrastructures such as hospitals and large office buildings, placing them in close proximity to large segments of the general public. These factors significantly increase the need to observe the *why* when considering the implementation of online monitoring on network transformers.

Low voltage network transformers used in downtown areas of most major cities across the world serve highly critical infrastructures such as hospitals and large office buildings, which is a significant factor when considering the why of implementing online monitoring on this equipment.

Over the last decade, improvements in intelligent electronic devices designed for online assessment of electrical equipment have markedly improved asset owner's real-time awareness of equipment condition, allowing for increasingly effective predictive maintenance programs to be implemented. However, despite all these advancements in monitoring technology, I feel that perhaps the most critical component of any asset management system is the understanding of the why. This understanding of why can encompass numerous variables and ultimately determines the level of success or failure of the desired outcome. This article presents several of the whys associated with monitoring network transformers.

Failure within the cable compartment generally results in damage significant enough to require replacing the entire transformer and can often be catastrophic, potentially injuring anyone nearby and causing damage to the surrounding structures.

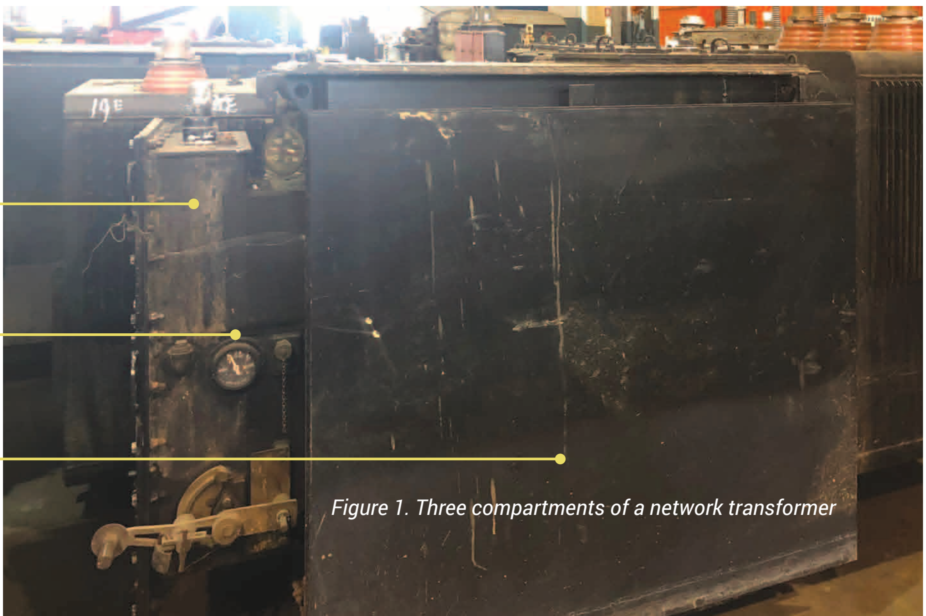


Figure 1. Three compartments of a network transformer

Photo: Dynamic Ratings

Why #1: Network Transformer Monitoring

Why does it fail? This is the most important why of any when determining the most effective approach to applying online monitoring to any equipment and should be answered before we proceed any further.

It seems simple enough, but a practical understanding of why a particular piece of equipment most commonly fails is the most critical component of any online monitoring application. An excellent example of this is the online monitoring of substation transformers. It is quite common to see multi-gas DGA monitors being utilized to monitor the internal conditions of the transformer. While this device is highly effective at detecting the presence of internal faults related to the transformer, it offers little to no indication of problems concerning the transformer's bushings or the power protection system, both of which can be attributed to a large percentage of transformer failures. So, despite the effectiveness of the DGA device, the asset owner is still left with a large blind spot to conditions that could lead to sudden failure of the transformer. As this relates to network transformers, you first need to understand how the overall design varies from that of other transformers.

Network transformers consist of three separate compartments (two in some of the newer designs), the cable termination compartment, the switch compartment, and the main tank, see Figure 1. Typically, these compartments are isolated from one another, each with its own insulating medium and headspace.

So, there are three compartments to be concerned with as opposed to the single compartment design that is common to most transformers. Monitoring all three compartments is key to avoiding undetected development of conditions that could lead to failure.

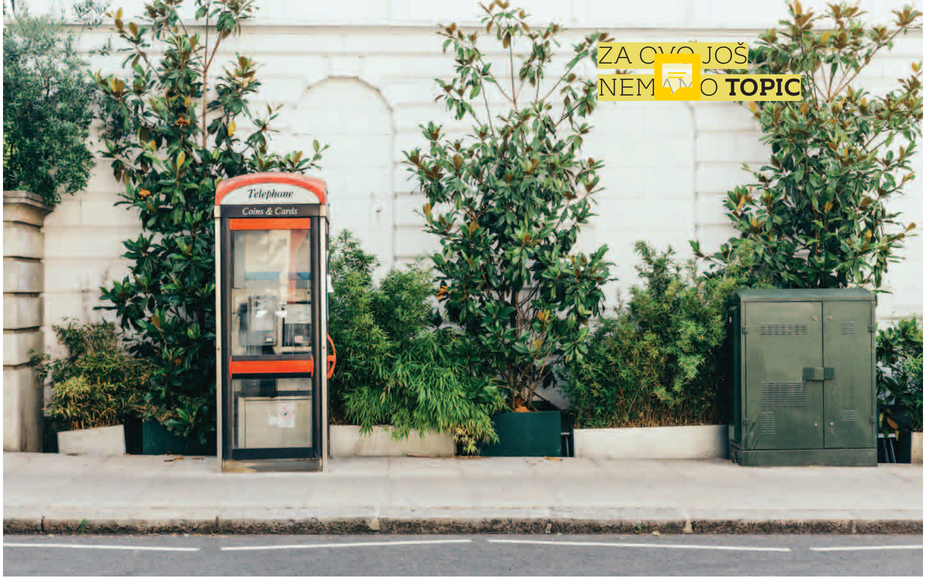
At this point, let's take a closer look at the function of each compartment. The cable termination compartment is designed to connect the transformer to the primary feeder coming from the substation. This compartment is usually filled with insulating oil and has small bushings in the bottom to transition from the cable compartment to the switch. There are several potential points of failure with this compartment. Many of these transformers have been in service for a long time, placing the cable and terminations in the compartment at a high risk of failure. Also, this compartment is relatively small, placing the cable within inches of a potential ground source should the cable insulation or the insulating oil start to deteriorate, reducing dielectric strength. The size of the compartment also makes it susceptible to ambient temperature variations, causing it to go into a significant vacuum during winter and causing excessive pressure during the heat of summer. This pressure variation can overtime compromise the compartments gaskets, increasing the potential for moisture, which in turn accelerates the degradation rate of the insulating systems. These combined factors present a lot of potential failure modes for this compartment and account for a large percentage of failures common to network transformers.

The switch compartment consists of another small oil filled compartment that houses a grounding switch connected to an electrical interlock to prevent operation while the transformer is energized. With the introduction of the switch, there is the possibility of contact overheating from contact wear or contact misalignment, the potential failure of moving parts, and the size of the compartment, leaving it vulnerable to the same pressure variations associated with the cable compartment. While the failure of the switch isn't as common as the cable compartment, it is still a potential failure point and should be observed.

When monitoring network transformers, there are three compartments to be concerned with as opposed to the single compartment design that is common to most transformers. Monitoring all three compartments is key to avoiding undetected development of conditions that could lead to failure.

The main tank houses the core and coil assembly. Failure risks for this part of the transformer are common to any core and coil assembly such as excessive mechanical and electrical forces from exposure to through faults, cellulose degradation due to excessive heat or moisture and flaws in design and manufacturing. The type of loads these transformers service also leaves them much more susceptible to the influence of harmonics, which can cause excessive heating of the core and coil assembly, leading to accelerated degradation of the cellulosic insulation system.

As previously illustrated, all these compartments present a potential failure risk. Therefore, any online monitoring or maintenance program implemented must consider all three compartments to be truly effective.



Why #2: Network Transformer Monitoring

Why would a specific piece of equipment need to be continuously monitored? Several factors play into this decision such as the cost of the equipment being monitored, the criticality of the equipment, loss of revenue and the possible consequences of a catastrophic failure.

For instance, I have a 50 KVA pad mount which supplies power to my house and two others on my street. If that transformer fails, it will likely only result in me and a couple of my neighbors having to sit in the dark for a few hours. While my wife may vehemently argue about the implications of that event, the consequences hardly justify placing $10,000 worth of monitoring on a $1,000 pad mount. However, when determining the cost-effectiveness of monitoring on a network transformer, the consequences of catastrophic failure are much more serious than in most transformer applications. Network transformers are usually located in vaults under the sidewalks and buildings of downtown areas. This places them near areas with a lot of foot traffic, significantly increasing the chances of causing serious injury or death should a catastrophic failure occur. This location in underground vaults also increases the cost associated with having to replace one of these transformers, as it can be a logistical nightmare to set up a crane in the middle of downtown, disrupting both traffic and commerce for extended periods. Network vaults are also susceptible to occasional flooding, making it paramount to ensure that the transformer always holds positive pressure and maintains its submersible integrity. These factors, combined with the criticality of the load these transformers service, which are generally some of the most critical infrastructures in any major city, provide a solid justification for the expense associated with online monitoring.

Network transformers are usually located in places near areas with a lot of foot traffic, in buildings or in vaults under the sidewalks susceptible to occasional flooding. These factors, combined with the criticality of the load these transformers service provide a solid justification for the expense associated with online monitoring.

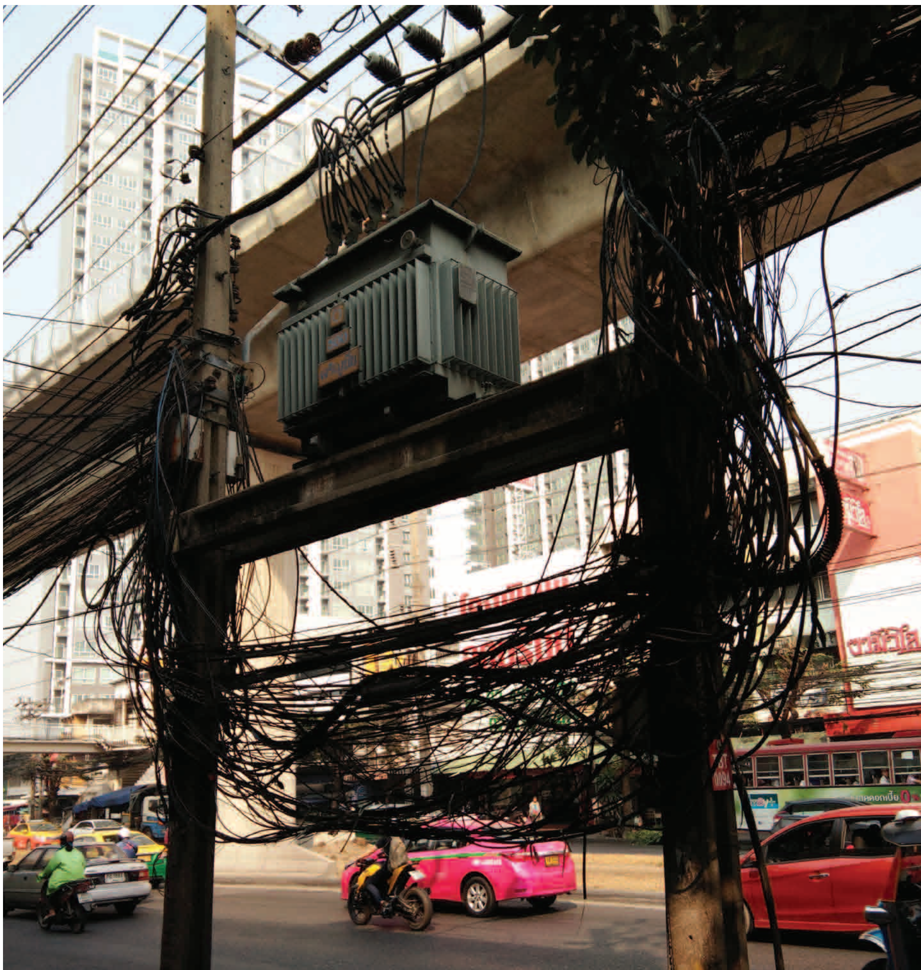
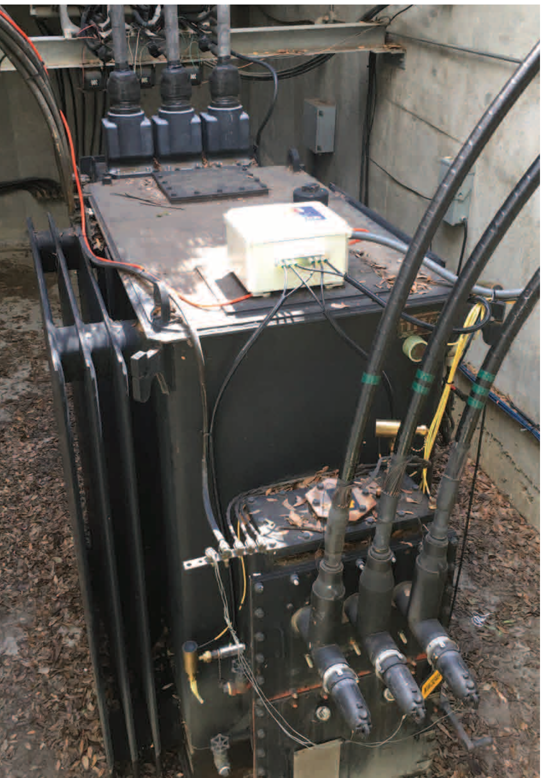


Photo: Dynamic Ratings

Why #3: Network Transformer Monitoring

Why use a particular monitoring technology? The user must consider the cost-effectiveness of the monitoring and what it is they hope to accomplish.

When deciding about online monitoring, the options can range from simply monitoring top oil temperature to a comprehensive diagnostic system including power factor, loading, partial discharge, thermal modeling, multi-gas DGA, etc. with price points varying from $100 to $100,000+. The cost of the equipment being monitored is a major factor in determining the type of system to install, but the asset owner should also consider the purpose of the monitoring. If the purpose of the monitor is to gather the level of data required to perform advanced analytics, then a multi-gas monitor would be the minimum level of monitoring that could be used. This would provide information concerning the production of hydrogen and the relevant hydrocarbon gases. With this data, the asset owner can access thermal conditions, such as arcing, using the ratio of acetylene to ethylene, or the deterioration of the cellulosic insulation system through trending of the CO/CO_2 ratio.



Partial discharge is another useful tool in detecting and determining the severity of insulation breakdown in its earliest stages through the use of coupling capacitors, RFCT or UHF sensors to detect high-frequency impulses. Though both technologies are highly useful in accessing the equipment condition and performing diagnostics, they are at a high price point, which may not be justifiable for most distribution level applications. In addition, when considering the three-compartment design of network transformers, it would require a monitor to be installed on each compartment to ensure incipient conditions were detected before leading to failure. Hydrogen monitoring is likely the most useful type of monitoring for network applications due to its lower cost and ability to detect any abnormal operation which generates thermal conditions in excess of 1500C. While not capable of providing the level of data required to perform diagnostics, hydrogen monitoring does provide a sort of smoke detector for the transformer, alerting the asset owner to the development of incipient faults, thereby allowing the transformer to be taken off-line for more conclusive testing. However, hydrogen monitoring would still need to be installed on each compartment to provide reliable protection of the transformer. Since network transformers are normally set in vaults that can be subjected to flooding for extended periods, placing the transformer in a highly corrosive environment, pressure monitoring to verify the integrity of each compartments tank and gaskets would also be advised. This combination of pressure and hydrogen monitoring should be adequate to provide early warning of conditions which could ultimately lead to transformer failure.

The cost of the equipment being monitored is a major factor in determining the type of system to install, but the asset owner should also consider the purpose of the monitoring.

Conclusion

While this article primarily addresses the concerns associated with network transformers, these principles can be applied to any level of asset management. A good understanding of why failures most commonly occur and the indicators which precede them must be the central focus of any successful preventative maintenance and monitoring program. With this knowledge, the asset owner can determine the most effective approach to achieve desired levels of reliability, rather it be the application of high level comprehensive monitoring to detect an adverse change of conditions in their earliest stages for extending the life of large substation equipment or merely trying to prevent in-service failure of distribution equipment through minimal monitoring and routine inspections.

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