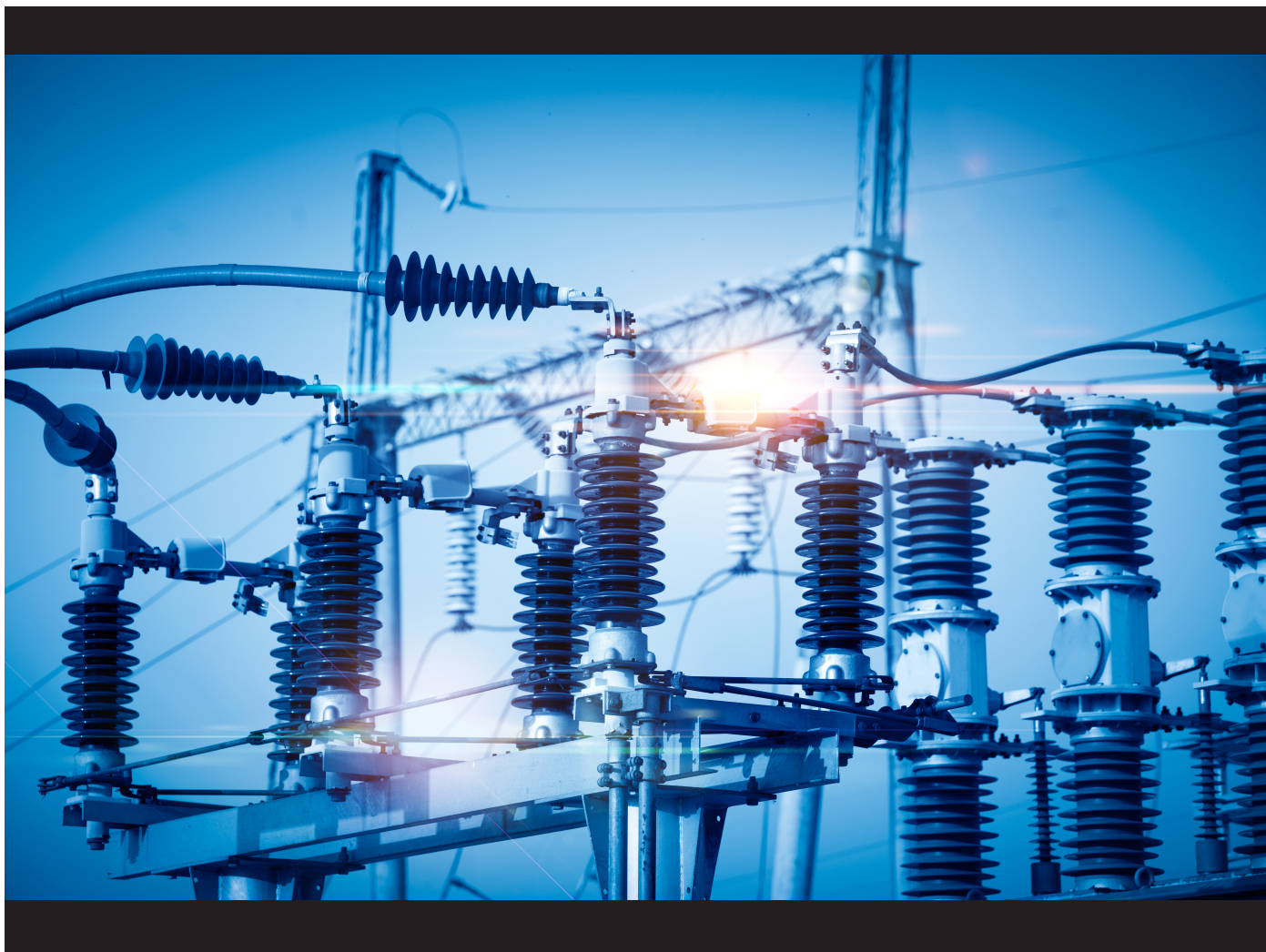


TECHNOLOGY EVALUATION OF SUBSTATION ON-LINE MONITORS

An Executive Summary



August 2021



Introduction

The adoption of on-line monitoring in substations is rapidly increasing. There is a need for utilities to better understand the technologies prior to wide-spread deployment. In the absence of this knowledge, significant time and money could be wasted through trial and error.

To increase the reliability of power delivery and predict the condition of substation assets prior to the onset of severe issues, several on-line monitoring devices have been developed by various vendors. For example, new transformers are generally equipped with temperature sensors, cooling control monitoring devices, oil level indicators, load sensors, and protection sensors such as Buchholz relay. However, Dissolved Gas Analysis (DGA) monitoring, bushing monitoring, and partial discharge monitoring systems are optional devices that could give additional information on the condition of the transformers, bushing, and load tap changers.

The key advantage to the on-line monitoring system is the ability to capture data continuously which provides the utilities the possibility to detect deteriorating conditions early to prevent premature failures. But questions remain as to how effective the different vendor specific monitoring solutions are in detecting faults and deteriorating asset conditions – and what the life cycle cost of these monitors is likely to be.

This paper presents the industry challenges and describes the EPRI response.

Industry Challenges

The reliability and predictability of power transformer and other substation equipment is of utmost importance. These assets are costly and, in most cases, have a long lead time for replacement. For example, a transformer failure may cause loss of production leading to loss of revenue and in some cases penalties. Around 20% of transformers today fail due to bushings, 30% due to tap-changers and 40% due to different winding related issues [4]. A transformer catastrophically failing due to bushings, tap- changers or winding related issues may also lead to large collateral damage.

To increase the reliability of power delivery and predict the condition of substation assets prior to severe issues arising, numerous on-line monitoring devices have been developed by a wide array of vendors – many employing different underlying monitoring techniques.

The industry challenge is the optimal specification and application of these on-line monitoring devices. This, in turn, poses the following key questions:

- 1. How accurate and reliable are the monitoring devices today?
- 2. How do they compare to off-line measurements?
- 3. How do they perform during different environmental conditions?
- 4. What is the cost of maintenance for the different monitoring solutions?

Industry Trends on On-Line Monitor Evaluation

In 2016, a CIGRE study summarized the different partial discharge techniques for GIS, cables and transformers [5]. The summary presented useful case studies. On the DGA (Dissolved Gas Analysis) front, industry activity in systematic laboratory evaluation of on-line DGA monitoring technologies has been limited to a number of small-scale experiments in university laboratories [6,7]. A CIGRE round- robin test involving 19 laboratories and numerous on-line DGA monitors was conducted 11 years ago [8] and updated in 2019 [9]. The findings were useful in understanding the typical errors between laboratories and different instrument technologies, but the need still remained for long-term systematic tests in a research substation using faults similar to those seen in the field. This prompted EPRI to engage in a larger-scale and longer-duration effort in a substation laboratory environment.

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This white paper was prepared by EPRI.

What is EPRI Doing?

To meet this industry challenge, EPRI has commissioned (and is now in year 4) of running a new 138 kV Research Substation in Lenox, MA, Figure 1. The research substation provides the opportunity to execute well-defined test protocols for a wide range of on-line monitors. The test protocols can be applied in a repeatable way and reflect similar conditions seen in a utility substation, with the key difference being that the assets in the 138 kV yard can be intentionally faulted in order to evaluate the different monitoring performances. The results provide an important data set that utilities can use to inform decisions on which on-line technologies would be of most benefit in their business.

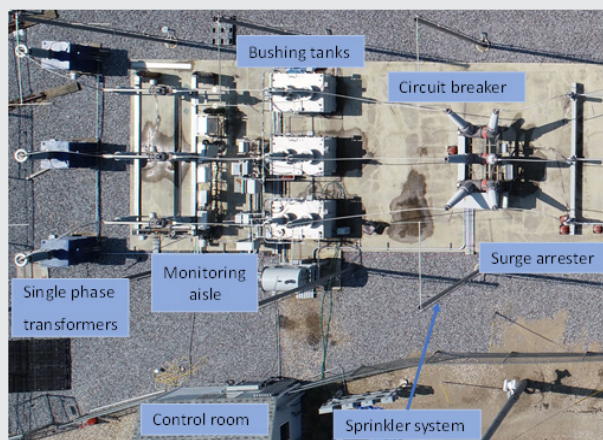


Figure 1. 138 kV research substation in EPRI Lenox MA.

The research substation, Figure 1, has substation assets such as arresters, breakers and three bushing tanks that represent single phase transformers in a utility substation. Each bushing tank has one oil filled bushing and one polymer bushing to evaluate the effectiveness of bushing monitoring systems when measuring either an oil filled or non-oil filled bushing. The single-phase transformers shown in Figure 1 are feeding voltage to the research substation up to 138 kV. The whole substation also has a sprinkler system that during April-October creates an extremely humid environment. Currently, 32 different monitoring systems of different types and different vendor solutions are being evaluated. The monitors under evaluation include substation monitors that are part of the EPRI RF Monitor Suite. The monitor technologies under evaluation are summarized

in Table 1. To further support the research substation, EPRI also runs smaller-scale monitor evaluations in the Charlotte laboratory. The smaller scale allows for fast, in-depth studies on unique challenges on-line monitors face. For example, monitors can be rapidly tested in very cold, controlled environments and monitors can be evaluated in different insulating fluids.

The key aspect to evaluate each monitoring technology properly is to develop and execute a well-defined test protocol. The developed test protocols consider influences due to overload, voltage and current fluctuation, high humidity, high temperature, low temperature, rain, snow and ice, and DGA gas generation due to partial discharge and overheated insulation/ oil. The test protocols are both repeatable and representative of in-service problems that could occur in a utility substation. The long-term evaluation of the monitoring systems in the 138 kV yard also enables capturing maintenance cost for each technology. Figure 2 shows a view of some of the monitors deployed in the EPRI research substation.



Figure 2. EPRI 138 kV research substation with some of the on-line monitors shown.

Prior to the commissioning of the EPRI R&D substation, the only option open to utilities was to pilot each new technology in the field – which was both costly and challenging since a utility cannot intentionally introduce faults. Furthermore, it is very difficult in the field to evaluate a wide range of monitors under the exact same conditions.



EPRI Transmission and Substations

EPRI research is revealing some useful insights. For example:

- The different DGA monitoring are producing different accuracies. Since the technologies are at different price points, these insights help utilities make decisions on which technologies would best suit their budgets and objectives.
- The insights gathered from the laboratory go beyond what one can read on a typical data sheet and highlight important aspects such as challenges during a power outage or sensitivity to ambient temperature.
- The on-line bushing and partial discharge monitor research has been able to demonstrate the effects of rain and temperature on the readings - aiding utility selection and interpretation.

Table 1. Monitoring system evaluated in the 138 kV Research Substation.

On-Line Monitoring Technology	Devices Evaluated in EPRI Laboratories
On-line DGA monitoring technologies: • Gas Chromatography • FTIR • Photoacoustic • NDIR • Solid State sensor	9
On-line bushing monitor technologies: • Sum of current method • Absolute reference method • Relative Power Factor method • Monitors that employ a combination of the above methods	4
On-line Partial Discharge monitor technologies: • On-line bushing monitors that measure PD • UHF detection via plate and hatch sensors • UHF detection via drain valve sensors • Acoustic Emission PD detection • RFI detection of PD	10
On-line Circuit Breaker monitoring technologies: • On-line SF₆ density monitoring • On-line travel time and travel curve monitoring • On-line heater cabinet temperature monitoring	1
On-line Arrester monitoring technologies: • On-line monitoring of leakage currents	3
On-line temperature monitoring technologies: • Fiber-optic hotspot monitors • RTD oil temperature monitors	3
On-line IR monitoring system technologies	2

- The full range of on-line bushing monitor approaches has been deployed in the research substation. The findings (coupled with the costs for each technology) guide utilities on balancing cost against the ability to report absolute power factor measurements.
- Maintenance costs are important to a utility and the research is showing that different monitors have different maintenance costs. These emerging insights will be valuable as utilities continue to optimize O&M expenditure.
- EPRI research is also documenting the time and cost of installation and the results are highlighting the savings potential for rapid deployment concepts such as wireless data transmission (to eliminate cabling), magnet-mount solutions and self-powered (or power harvesting) solutions.
- These (and many more) insights are regularly gathered and shared with the participants.

Summary

The needs for effective evaluation of on-line monitors are driven by several factors:

- The continued demand for highly reliable electricity supply
- The increase in the volume and complexity of on-line monitoring solutions
- The need for utilities to maximize the value of the deployments whilst reducing the overall expenditure.

EPRI has responded to meet this important need through the commissioning of a full 138kV research substation to effectively evaluate a wide range of on-line monitors under simulated fault conditions. To-date 32 on-line monitors have been deployed. This ongoing research is guiding the industry on monitor specifications and maintenance costs.



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Substations

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