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Partial Discharge Monitoring: Lessons Learned and Consequential Safety Improvements at AEP

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SUMMARY

As part of its asset management program, AEP has begun an intense program asset monitoring regime that includes data analytics and smart monitors providing real time data increasing accuracy in the analytic outputs. The Asset Health Center software provides health, replacement priority, and maintenance scores for assets within the AEP system. The smart monitors continuously feed data into the software improving the quality of the various scores and aiding a plan for replacement and maintenance appropriately. Additionally, these smart monitors provide instantaneous alarms to AEP's Transmission Operations Center enabling the utility to prevent failures. These smarts monitors include the following sensors: two and nine gas analysers, bushing health sensors, winding and oil temperature sensors, and partial discharge sensors. AEP uses two separate types of partial discharge monitoring, which include electrical and ultra-high frequency (UHF) on their EHV level transformers and reactors. Furthermore, AEP is the first utility to utilize UHF partial discharge on this type of equipment. This UHF partial discharge technology is more commonly utilized on gas insulated substations (GIS). There is vast knowledge on temperature and dissolved gas signatures in transformer and reactor failures, but there is very little knowledge on partial discharge failure signatures. AEP had no experience previously with partial discharge, thus it was difficult to comprehend the signatures from the data that was being collected. Through two fully monitored failures, AEP has learned partial discharge failure signatures. These signatures now provide the baseline alarm set points on the transformers and reactors. From the distinct signatures, AEP has implemented new safety procedures for employees working near the equipment.

KEYWORDS

Asset health, partial discharge, safety, transformer, failure, monitoring

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I. Introduction:

Electrical power transmission utilities have long been tasked with upgrading, replacing, and maintaining an interconnected fleet of substation equipment. American Electric Power (AEP), along with many other utilities are facing both an aging fleet and downward pressure on Operations and Maintenance (O&M) expenses. For instance, at AEP, 33% of transformers are 50 years or older and nearly 18% are 60 years or older [1]. The implication is that utilities must now operate and maintain assets in the most effective way possible to prevent catastrophic failure of costly critical equipment.

As part of AEP's Asset Health Center program, critical assets are equipped with smart monitors that collect significant diagnostics data. These smart monitors measure data in real time specific to asset health and either replicate or imitate traditional equipment testing on an asset while providing on-board intelligence [2]. Historically, data that was collected for asset analysis by field engineers was completed on a routine basis. The most efficient and effective way to make decisions on maintaining, replacing or removing assets from service is collecting up to date inputs from the smart monitors.

The AEP standard package of asset health monitoring equipment for new as well as retrofitted EHV auto-transformers and oil filled shunt reactors includes the following sensors: dissolved gas monitors, bushing health monitors, and partial discharge monitoring. All of these systems are connected to a data concentrator which sends data to a station parametric information (SPI) system via the non-critical local area network (LAN) network in the control house [2]. Critical analog data along with digital alarms are provided to supervisory control and data acquisition (SCADA) to provide continuous monitoring of the assets. The types of data are segregated to these two routes based upon their significance in terms of fast acting failures. The ability to compare instantaneous partial discharge measurements with slower percolating gas levels has proven more valuable than either type of monitoring alone. When multiple monitoring systems are used on a particular asset, AEP has the ability to more accurately track what is occurring within the asset.

One of the key company values at AEP is the concept of Zero Harm. This is defined as the following statement: "No one gets hurt and everyone goes home in the same or better condition than they came to work. [3]." This concept of Zero Harm can also be applied to the asset health monitoring equipment. Online monitors alert field engineers ahead of an impending failure, prevent maintenance personnel from entering a potential blast zone by way of safety procedures. The overall safety of the high voltage substation increases with additional benefits to the utility employee and customer because of these smart monitors.

II. Types of Partial Discharge Monitoring in Use at AEP

AEP utilizes the following two types of partial discharge monitoring on its EHV transformers and oil filled shunt reactors: ultra-high frequency (UHF) partial discharge monitoring and electrical partial discharge monitoring. Both systems monitor partial discharge inside the main tank of the transformer / oil filled shunt reactor.

Ultra High Frequency Partial Discharge Monitoring

The UHF partial discharge monitoring system utilizes six antennas that are placed in dielectric windows on the tank wall of the transformer or reactor. These sensors are connected to a data concentrator sending the data to a central server within the control house for analysis. The data concentrator also has a noise antenna to eliminate any signals that would come from outside the transformer tank. The central server does real time analysis and visual aggregation of the partial discharge signals being detected in the asset, providing phase resolved partial discharge (PPRD) plots for each event as well as intensity, and discharge rate analysis.

This UHF partial discharge monitoring system was originally built for gas-insulated switchgear but AEP has implemented this system, including it in the standard monitoring package for single phase auto-transformers and oil filled shunt reactors. AEP is one of the first utilities to use this system on its 765kV auto-transformers as well as 765kV oil filled shunt reactors. Due to the cost of the monitoring equipment, this UHF partial discharge monitoring system is only installed on new 765 kV single phase transformers and oil filled shunt reactors, never retrofitted on an existing transformer.

Electrical Partial Discharge Monitoring

The electrical partial discharge monitoring system utilizes bushing tap sensors and Rogowski coils to detect electrical impulses in the circuit of the transformer which are created from partial discharge events. The bushing tap sensor looks for electrical impulses in a specific frequency range as evidence of partial discharge. One issue for this type of sensor is the possibility of external signals being detected by the bushing tap sensor. This is mitigated by using a Rogowski coil in conjunction with the bushing tap sensor cancelling external signals.

The electrical partial discharge monitoring equipment has greater flexibility due to its un-intrusive nature to the transformer. This system is used as the standard partial discharge detection system on all new EHV transformers and oil filled shunt reactors in the AEP footprint of 345kV and above. This system was originally not included as part of the single phase 765 transformer and oil filled shunt reactors monitoring package due to the UHF partial discharge detection setup. After the failures to be mentioned in section III, it was decided by the equipment standards group to use this system as a back-up partial discharge system to the UHF partial discharge monitoring on all new 765 single phase transformers and oil filled shunt reactors. The electrical partial discharge can also be retrofitted to existing transformers, providing a form of partial discharge detection on older, closer to end of life. This enhanced monitoring on older assets provides a window into the health of equipment nearing its end of life, or may have undergone normal degradation processes expectant of power transformers and oil filled shunt reactors.

III. Failures / Knowledge Gained

February 2014 Failure Event

In February of 2014, AEP experienced the catastrophic failure of one of its single phase 765kV auto-transformers. This transformer bank had been energized for approximately two months before it failed catastrophically. This transformer bank was new from the factory and had passed all factory and site acceptance testing and was equipped with the standard monitoring package of dissolved gas monitors, bushing health, temperature monitoring and UHF partial discharge detection monitoring. This was the first fully monitored failure in AEP history. The standard gas monitoring equipment that this single phase transformer bank was fitted with did not give any indication of this fast acting failure. Only the partial discharge monitoring system gave any indication of trouble. The transformer failed catastrophically and caught fire due to the energy of failure.

The UHF system indicated an increase in partial discharge activity on all six sensors with five out of six sensors at a measurement reading of 100% amplitude. This activity continued until the unit failed catastrophically at approximately 11:45 EST. The discharge rate measurement also increased significantly during this time frame. The partial discharge signature seen below in Figure 1, shows that the measurements of the partial discharge were present for about eight hours before the unit failed.

One of the major concerns with this failure was that the area around the transformer was an active construction site at the time of failure. Oil containment was being installed around the single phase units that day. Ten to twenty construction personnel were around the transformer right before the unit failed. Fortunately, the transformer failed at the best time it could have, while everyone was on lunch, away from the unit. If this unit had failed earlier or later on that same day even by a margin of thirty minutes, the resulting explosion of the transformer could have been life-threatening to those working on the site. The root cause analysis of this failure is still on-going. Below is a screen-capture of the pre-catastrophic failure signature collected from the UHF partial discharge sensors.

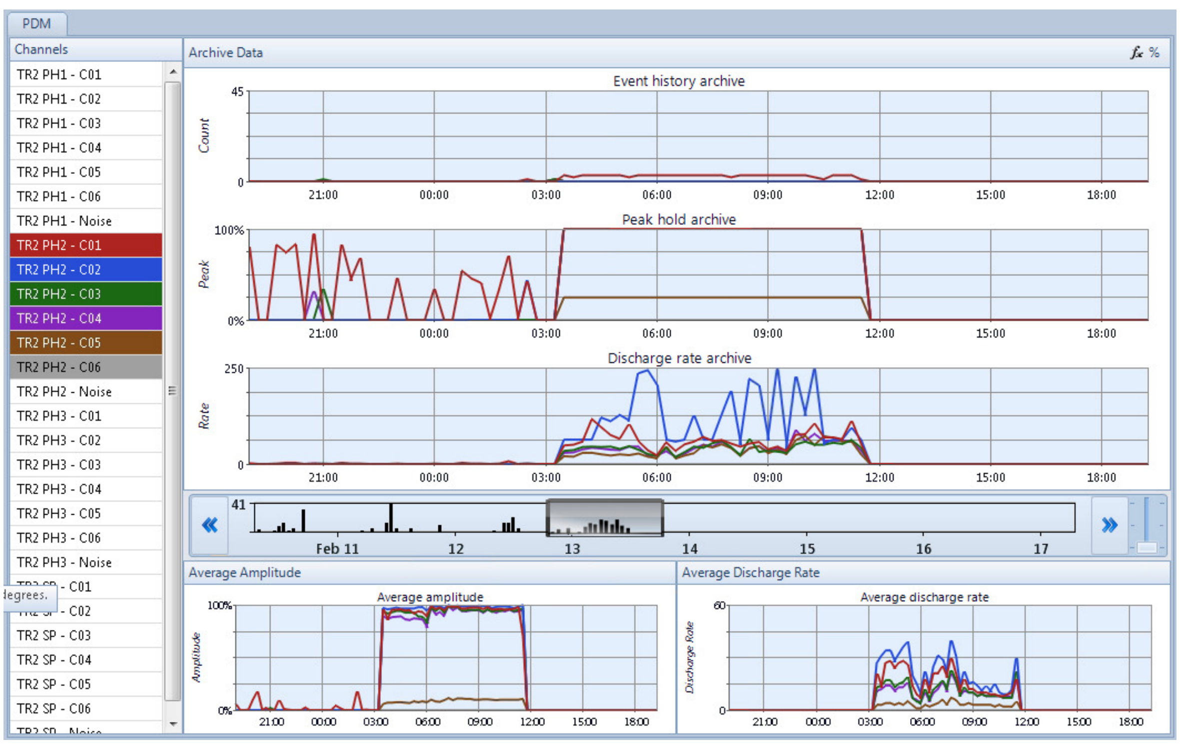

Figure 1: February 2014 Failure Event - UHF Partial Discharge Detection System Data Summary

January 2015 Failure Event

In January of 2015, AEP experienced a second catastrophic failure of a single phase 765 kV autotransformer. This transformer had been energized and in service for about one year before failing violently. This unit was also fully equipped with the standard set of monitoring equipment including the bushing health monitoring, UHF partial discharge monitor, temperature monitor and dissolved gas monitor. This failure was a much faster acting failure than the February 2014 event, with a timeframe of three hours compared to eight hours, with the activity spiking in the same manner with all six sensors showing increased amplitude and discharge rate with five out of six sensors reaching the 100% peak amplitude measurement as shown in Figure 2 below. The same pre-catastrophic failure signature appeared in this failure as in the February 2014 failure event shown below in Figure 2.

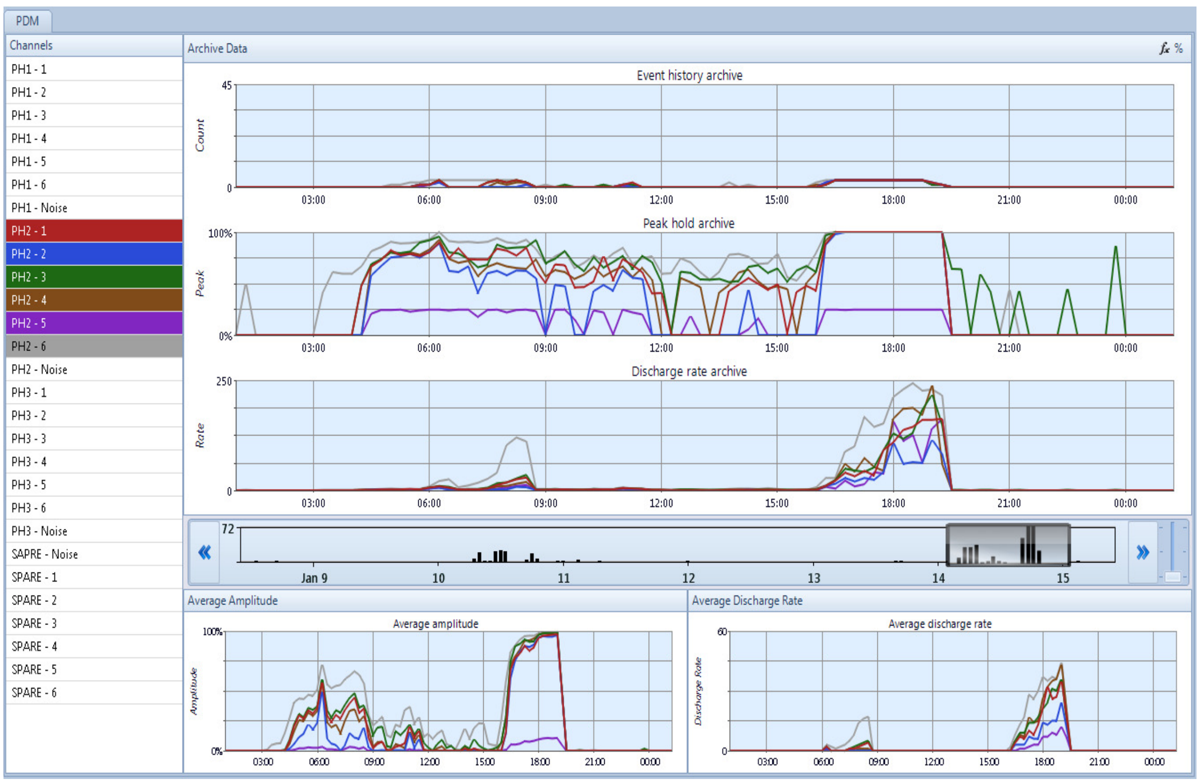

Figure 2: January 2015 Failure Event - UHF Partial Discharge Detection System Data Summary

As in the first failure event, the dissolved gas monitoring equipment did not see this failure until after the transformer had tripped out of service. Unfortunately, the failure occurred between the scheduled dissolved gas measurements timeframes, thus not capturing an increase in gas composition until after the unit had failed.

From a safety concern, this transformer failed in the evening in a non-active construction site during which personnel would not normally be in the substation. If this failure had occurred during normal working hours, this could have been a serious safety hazard to those working in the substation.

IV. Safety Improvements

Safety to employees is of the highest importance to AEP. It's built into the culture in a multitude of ways from safety debriefings before entering substations to safety moments before a conference call in the office. Safety never takes a break at AEP. With the knowledge gained from the two fully monitored failures in the AEP footprint, the utility implemented multiple ways to improve safety for its employees.

After the two failures described above, a new alarming scheme was implemented at all sites where the UHF partial discharge system was installed. Rather than relying on any individual sensor, a combination of three sensors, one at or above a magnitude of 95% coupled with two additional sensors with magnitude readings at or above 75% is used to alarm. This three sensor combination signature initiates a "rapid partial discharge alarm" to the Transmission Operations Center who would alert employees to the possibility of catastrophic failure of the transformer or shunt reactor at the substation. All other alarms or warnings due to a single sensor are sent to the Asset Health Center Team for further analysis via email alerts.

Many EHV single phase units are surrounded by ballistic wall structures to protect the assets from unwanted intruders. Additionally, these walls protect other station assets by containing fragments from potential explosions from a catastrophic failure. Although these walls promote protection of critical substation assets, the walls bring up safety concerns to AEP's field employees. These employees frequently work within the ballistic wall structures to complete maintenance actions on the transformers or reactors. To mitigate these safety concerns, Transmission Operations implemented a procedure that requires all personnel to call the AHC Team to approve safe entry to the ballistic wall enclosure. The AHC team will review the partial discharge data and inform field employees of the current conditions of the transformer or reactor before said employee enters the ballistic wall enclosure. Partial discharge is continuously monitored while the employee works within the enclosure. If conditions change, the employee is alerted and can halt his or her work to move to a safer location.

In addition to the communication path between the field employees and the AHC Team, AEP has implemented automatic alarming systems within EHV substations. Loud sirens and strobe lights alert employees in the yard that there is a partial discharge alarm. These sirens and lights are mounted in multiple places around the single phase units so that employees on site are made aware of alarms immediately. When a partial discharge alarm becomes active, the sirens and lights initiate, and employees are required to evacuate the area immediately to a safe distance of at least seventy-five feet away from the offending bank.

These newly implemented safety procedures, produced from the knowledge gained from the two fully monitored failures mentioned above, improve the safety for all of AEP's employees. The procedures improve safety for field employees completing routine maintenance and scheduled work by alerting them of real-time asset conditions. The safety of office personnel is also enhanced when on site for project scoping purposes and meetings.

V. Future Safety Improvements

AEP's goal is to install new sensors and the data monitoring systems to deliver maximum performance from the existing and new assets while enhancing safety and reliability of the grid. AEP is investigating various types of new sensors and monitoring devices for overhead transmission lines, underground cables, EHV and HV transformers, circuit breakers, and station batteries. These devices include sensors for geomagnetically induced currents (GIC) for lines and transformers, arresters, bushings, transformer ballistic walls, transmission line conductors and structures, insulators, transformer vibration, transformer breathers, and partial discharge for underground cables.

VI. Conclusion

The existing aging infrastructure needs gradually replaced with new assets equipped with technologies that can assess the condition throughout the life of equipment and systems. New technology sensors and monitoring devices help identify risks providing improved safety, reliability, and resiliency for the grid. In addition, this supports the asset manger's decision to prioritize both maintenance and replacement of assets.

In conclusion, AEP utilizes two types of partial discharge monitoring on its EHV transformers and shunt reactors which includes electrical and UHF partial discharge sensors. With the knowledge gained from the two fully monitored failures described above, AEP has implemented multiple steps, summarized below, to improve safety for its employees:

1. New partial discharge alarms are sent to Transmission Operations alerting them to impending catastrophic failures.
2. Transmission Operations in conjunction with the AHC Team are to approve safe entry to the transformer ballistic wall enclosures.
3. Partial discharge is continuously monitored while the employees work within the enclosure.
4. Sirens and strobe lights alert employees in the yard that a partial discharge alarm is active.

Overall, through the implementation of lessons learned from the failure events, safety for AEP's employees entering substations has been improved by the partial discharge technology sensors and the implementation of additional safety procedures.

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