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Monitor Data Management for Transformer Failure Prevention

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SUMMARY

AEP Transmission has deployed a standard monitoring package on over 400 EHV and HV power transformer and oil-filled shunt reactor assets with the primary goal of failure prevention. Deploying a comprehensive monitoring package on a multitude of assets creates a high volume of alarms, notifications, and data, with varying degrees of importance. To prevent asset failures, an effective monitor data management plan must be implemented. Without this plan, valuable information will be overlooked or delivered to personnel who lack the knowledge base to respond appropriately.

An effective monitor data management plan must include three key components: data infrastructure, alarm ownership, and stakeholder training. These components must be designed for compatibility. The data infrastructure must support the transmission of data to the proper alarm owner and the owner must be trained to respond in a timely and knowledgeable manner.

AEP Transmission's asset monitoring data infrastructure relies heavily on data concentrators utilizing IEC 61850 protocol, email alerts, data mapped to the SCADA System, and a PI Historian to house monitor data.

AEP Transmission's alarm ownership strategy has evolved over time as a result of continuous improvement efforts. Recently, the Transmission Operations alarm management guide was revised. The response time to address an issue was reduced with clear ownership and action plans for operational alarms.

After the data infrastructure and alarm ownership are established, key stakeholders must be trained to respond appropriately to alarms. In the past year, there have been significant asset monitoring training efforts for AEP's field personnel and Transmission Operations group. As a result, both teams are better prepared to respond appropriately to the alarms for which they are responsible.

With an effective monitor data management plan in place, AEP Transmission has been able to prevent a wide variety of failure types on a number of timescales. For example, two bushing failures were prevented after alarms triggered further investigation over several weeks. In addition, a potential failure due to inadequate cooling was prevented by a response coordinated over several days. Finally, some failure preventions at AEP Transmission have required immediate action, such as a transformer with abnormal pressure.

Asset monitoring is extremely valuable when the data is managed properly. By implementing a monitor data management plan and preventing transformer failures, AEP Transmission has achieved cost savings, greater reliability, and increased safety.

KEYWORDS

Asset Health
Monitor Data Management
Data Infrastructure
Stakeholder Training
IEC 61580
Transformer Failure Prevention
Bushing Failure
Dissolved Gas Analysis

Introduction

Extensive asset monitoring can often lead to an overwhelming amount of information. This was the case when AEP Transmission deployed a standard monitoring package on over 400 EHV and HV power transformer and oil-filled shunt reactor assets with the primary goal of failure prevention. Deploying a comprehensive monitoring package on a multitude of assets creates a high volume of alarms, notifications, and data, with varying degrees of importance. To prevent asset failures, an effective monitor data management plan must be implemented. Without this plan, valuable information is overlooked or delivered to personnel who lack the knowledge base to respond appropriately. Ensuring the right data is delivered to the right personnel in the right timeframe is paramount to effectively using online asset monitoring systems.

Monitor Data Management Plan

An effective monitor data management plan includes three key components: data infrastructure, alarm ownership, and stakeholder training. These components must be designed for compatibility. The data infrastructure must support the transmission of data to the proper alarm owner and the owner must be trained to respond in a timely and knowledgeable manner. Issues can arise when the components are designed independently, without regard for future compatibility.

AEP Transmission's asset monitoring data infrastructure has two elements: operational awareness and engineering analysis. For transformer and reactor monitoring, operational awareness and engineering analysis are both achieved with data concentrators utilizing IEC 61850. For operational awareness, IEC 61850 GOOSE Messaging is used to send alarms and key analog values to an alarm annunciator in the control house. The alarms and key analog values are then sent to the Remote Terminal Unit (RTU) and ultimately AEP Transmission's SCADA System. Thus, all information with operational importance is available to AEP's Transmission Operations group.

For engineering analysis, IEC 61850 MMS is used to send all alarms, analog values, and status information to a PI Historian via an open platform communication interface server. As a result, all monitor data is readily available to asset monitoring personnel. Additionally, real-time email alerts from the data concentrators notify asset monitoring personnel of issues that need attention. Again, all necessary information is readily available to the proper personnel.

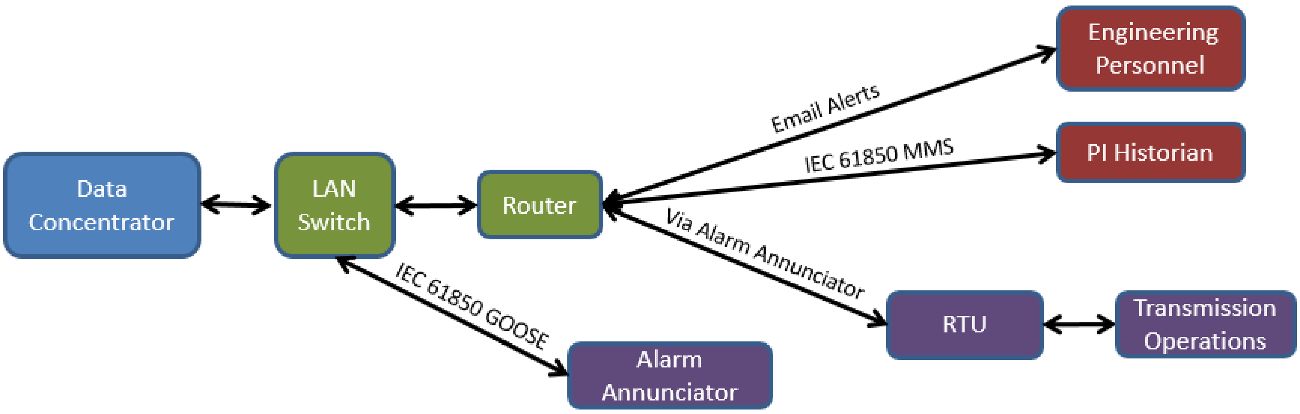

Figure 1: Operational Awareness and Engineering Analysis Data Paths Utilizing IEC 61850

Figure 1 summarizes AEP Transmission's use of IEC 61850 and the PI Historian for asset monitor data. Additional details regarding AEP Transmission's use of a PI Historian for asset monitoring data are available in other published works [1, 2, 3].

Implementing the monitor data management plan was not without challenges. Initially, AEP's Transmission Operations group was responsible for many asset monitoring alarms. Two primary opportunities for improvement were observed. First, the Transmission Operations group's responsibilities included alarms that were not readily actionable. Second, when readily actionable alarms were received, the appropriate team and expected timeframe for action were often unknown. AEP Transmission's culture of continuous improvement allowed this initiative to evolve and adapt over time. The Transmission Operations alarm management guide was revised. All stakeholders were included in the alarm management guide revision process to ensure buy-in and effective troubleshooting. The response time to address an issue was reduced with clear ownership and action plans for operational alarms.

Currently, the Transmission Operations alarm management guide includes four levels of response, outlined in the table below.

Alarm Category	Required Response
Category 1	Alarm is critical, requiring immediate action.
Category 2	Alarm is non-critical and can be addressed the next business day.
Category 3	Alarm does not require any operator action and will be addressed by field personnel.
Category 4	Alarm does not require any operator action and will be addressed by asset monitoring personnel.

Table 1: AEP Transmission SCADA Alarm Categories

This system allows operators to focus on Category 1 and Category 2 alarms, which are more readily actionable. This minimizes confusion and ensures that operators will not miss alarms that require their response.

Even with these levels of response, AEP Transmission needed a framework for connecting the alarms to personnel with the knowledge to fully address them. Thus, each alarm is assigned to an owner. When an operator receives a Category 1 or Category 2 alarm, the operator contacts the appropriate alarm owner. These ownership assignments proved to more efficiently connect alarms with the personnel who can respond with the necessary expertise.

After the data infrastructure and alarm ownership are established, key stakeholders must be trained to respond appropriately to alarms. In the past year, there have been two significant asset monitoring training efforts for stakeholders in AEP Transmission. First, a class was launched for field personnel, covering all transformer and reactor monitoring equipment. This class was developed in collaboration with training experts within AEP Transmission and includes both lecture and interactive content. As shown below in Figure 2, a full-scale monitoring equipment laboratory was installed at AEP Transmission's training center to facilitate hands-on learning. As a result of this training effort, field personnel are better prepared to respond appropriately to the alarms for which they are responsible.

Figure 2: Monitoring Equipment Laboratory at AEP Transmission's Training Center

In addition, AEP's Transmission Operations Shift Engineers were trained on asset monitoring equipment. These engineers provide 24/7 technical support for the operators and must be able to assist in alarm response. Providing this group with the necessary skills and expertise to respond to monitoring alarms outside of the normal business hours has enabled effective alarm response and support at any hour of the day.

Transformer Failure Prevention

Transmission companies must be postured to respond to a wide variety of failure modes. As shown below in Figure 3, transmission-level transformers exhibit failures based on a number of different components. In response to the diversity of transformer failure modes across the industry, AEP Transmission deploys a comprehensive monitoring package that monitors many transformer components. Further, the nuanced approach of AEP Transmission's monitor data management plan allows each failure mode to be addressed appropriately. As a result, AEP Transmission has seen success preventing a variety of failure modes on different timescales.

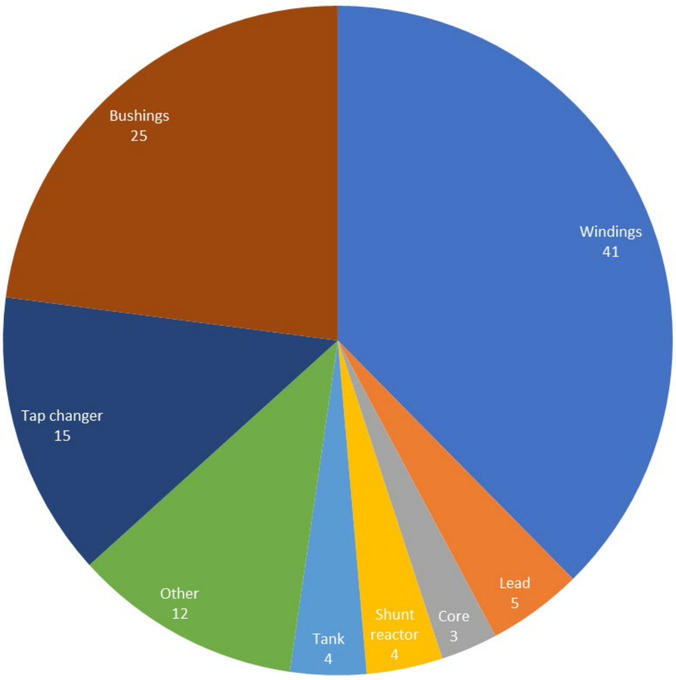

Figure 3: Doble's Transformer Failure by Component for Transformers > 300kV [4]

At AEP Transmission, alarms generated by bushing health monitors are not sent to the Transmission Operations group. Rather, they are sent directly to asset monitoring personnel via email. Based on experience at AEP Transmission, bushing health typically deteriorates slowly. As a result, bushing health alarms are not often readily actionable for Transmission Operators. Additionally, connection issues between the bushing sensor and the bushing health monitor can corrupt data and create false alarms. Sending bushing health alarms to asset monitoring personnel allows for the identification of false alarms and analysis of real alarms over a number of weeks as the situation develops.

By sending bushing health alarms to asset monitoring personnel and involving AEP's Transmission Operations group at the appropriate time, two bushing failures have already been prevented. The first case involved a 345kV to 138kV autotransformer, which initially alarmed on bushing temperature dependency. As shown below in Figure 4, the low side bushing imbalance percentage correlated strongly with the transformer oil temperature. This correlation is a good indication of a real bushing issue. In addition to the temperature dependency alarm, the low side bushing imbalance percentage exceeded the warning and alert thresholds before the transformer was removed from service.

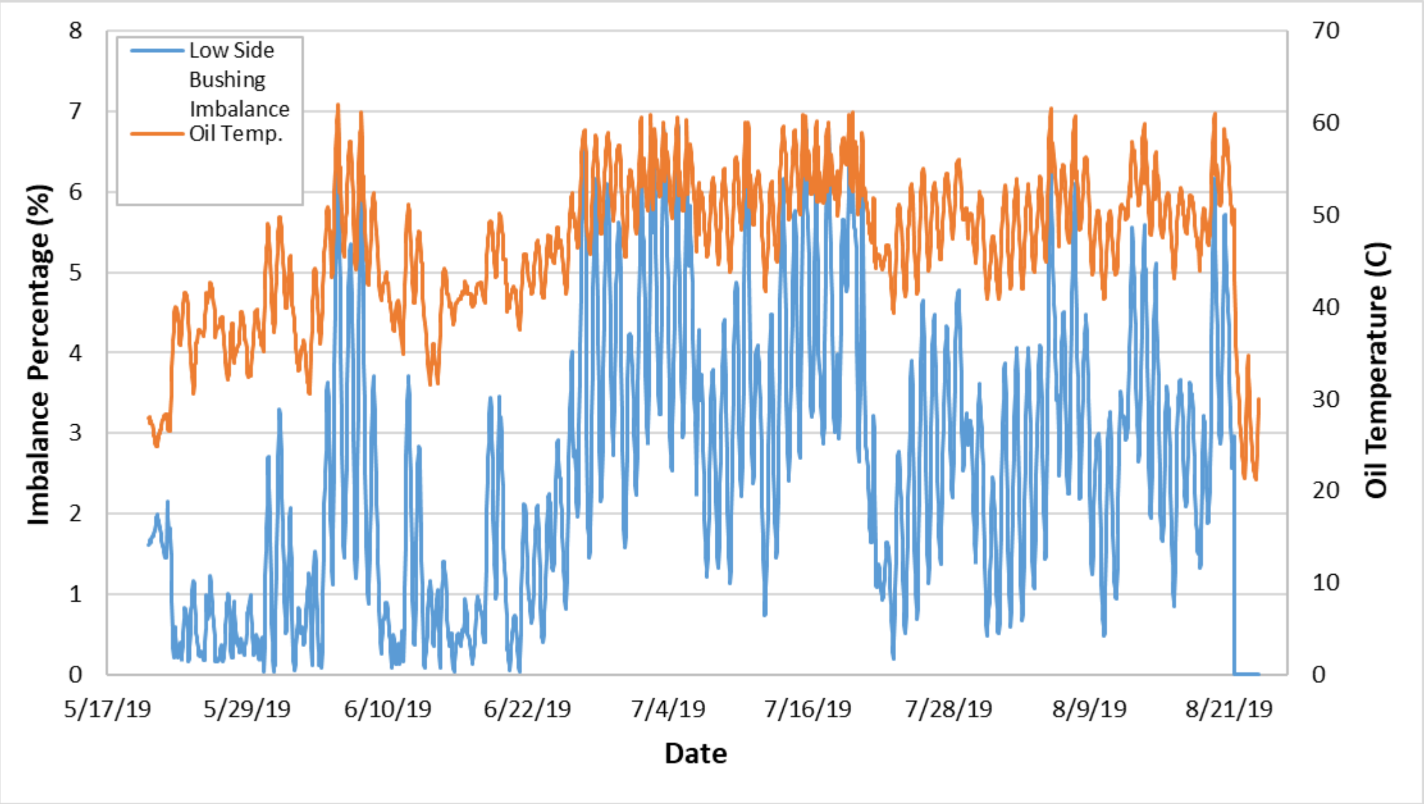

Figure 4: 345kV to 138kV Autotransformer Low Side Bushing Imbalance Percentage and Oil Temperature

This situation evolved over a series of months while asset monitoring personnel analyzed the data and collaborated with the monitor manufacturer. Ultimately, asset monitoring personnel worked with AEP's Transmission Operations group to remove the transformer from service. The X1 bushing was replaced, preventing a transformer failure. Moisture ingress is believed to be the root cause of this bushing issue.

The second case involved a 138kV to 69kV autotransformer, which alarmed on bushing imbalance percentage for the low side bushings. The low side bushing imbalance percentage quickly rose to 11% and then fluctuated between 10% and 19% until the transformer was removed from service three weeks later. The low side bushing imbalance percentage during this timeframe is shown below in Figure 5.

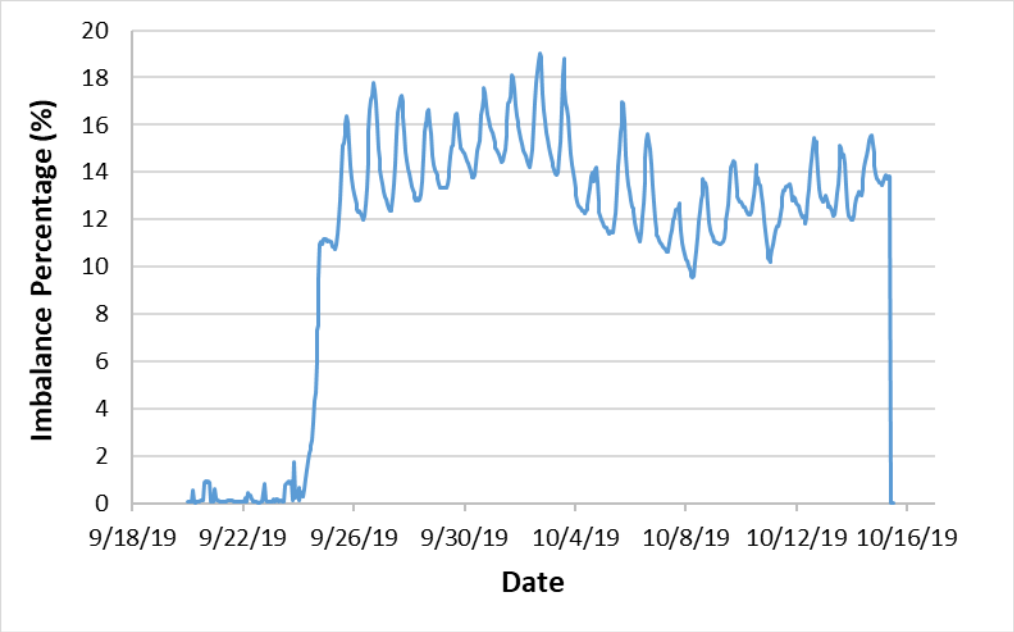

Figure 5: 138kV to 69kV Autotransformer Low Side Bushing Imbalance Percentage

During this three-week timeframe, asset monitoring personnel analyzed the bushing data, collaborated with the monitor manufacturer, and requested an on-site inspection. The inspection revealed oil leaking from the X2 bushing and running down the side of the transformer, as shown below in Figure 6. An outage was taken to address the failing X2 bushing.

Figure 6: 138kV to 69kV Autotransformer Oil Leak [5]

In both cases, the monitor data management plan proved effective in providing the right data to the right personnel at the right time, leading to two prevented bushing failures which could have caused damage to the transformer or worse, harmed personnel inside or outside of the substation.

When compared to bushing health alarms, dissolved gas analysis (DGA) alarms are typically more readily actionable. At AEP Transmission, combustible gas alarms are sent to the Transmission Operations group with two levels of criticality. The lower criticality alarms are Response Category 2, to be investigated during the next business day. This approach has led to additional failure preventions.

For example, the composite gas reading for a 345kV to 138kV autotransformer reached the lower level of criticality, causing AEP's Transmission Operations group to receive an alarm. The Transmission Operations group contacted the appropriate field personnel who performed further investigation on site during normal business hours. Their analysis found that the transformer's cooling system was ineffective due to residue on the radiators. An outage was scheduled to clean the radiators and ensure the functionality of the cooling system. Figure 7 shows that the composite gas reading dropped significantly after the scheduled outage.

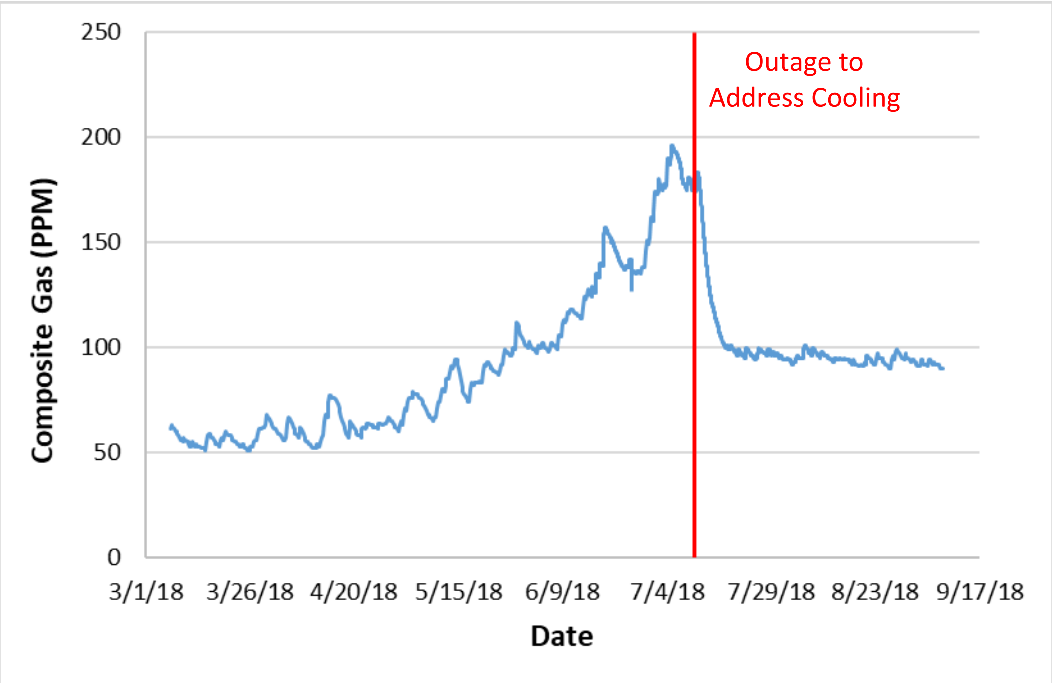

Figure 7: 345kV to 138kV Autotransformer Composite Gas Reading

Addressing this situation over a number of days was effective. The inadequate cooling was addressed before it led to a catastrophic event. These cases, like so many others, highlight the importance of understanding data and assigning alarms appropriately.

Finally, some alarms require immediate action rather than a response over a series of weeks or days. Examples include extremely high levels of combustible dissolved gas, high levels of partial discharge observed with ultra-high frequency (UHF) monitoring, abnormal pressure, mechanical pressure relief, and oil level alarms.

To identify high levels of partial discharge, AEP Transmission developed a rule set based on UHF signatures from previous transformer failures. This rule set differentiates high levels of partial discharge that require immediate action from low levels of partial discharge that require engineering analysis [6]. When the rule set requirements are met, an alarm is immediately sent to AEP's Transmission Operations group to coordinate further action.

Abnormal pressure alarms are also sent directly to AEP's Transmission Operations group. In 2018, an abnormal pressure alarm for a 345kV to 138kV autotransformer, caused by the Buchholz relay, was sent to the Transmission Operations group. The Transmission Operations group and asset monitoring personnel quickly worked with relevant field personnel to take the transformer out of service in a matter of hours.

After the transformer was removed from service, further analysis was conducted. The online DGA monitor showed an upward trend in the concentrations of multiple gases, including acetylene. The acetylene concentration trend is shown below in Figure 8. The concentration was below the warning threshold for acetylene, but the increasing trend corroborated the abnormal pressure alarm.

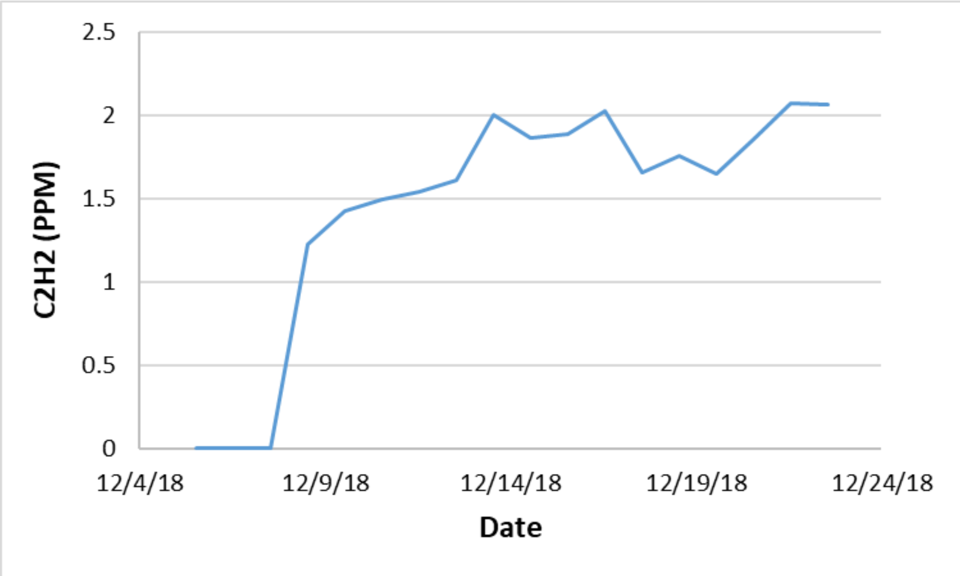

Figure 8: 345kV to 138kV Autotransformer Acetylene Reading

Additionally, an onsite inspection revealed contamination on the top pressure ring, tertiary lead exit and shipping support beam. The contamination appeared to be caused by loose nuts and washers from the shipping support beam. The onsite findings further confirmed the issue identified by the abnormal pressure alarm and the acetylene trend. Quick action by field personnel, prompted by the alarm received by the Transmission Operations group, prevented a potentially catastrophic failure, which could have damaged other assets at the station. The transformer was sent to the factory for repair.

Conclusion

Asset monitoring is extremely valuable when the data is managed properly. With an effective monitor data management plan in place, AEP Transmission has been able to respond appropriately to transformer and reactor issues and prevent numerous failures. These failure preventions result in cost savings, greater reliability, and increased safety.

Moving forward, AEP Transmission will continue to refine its monitor data management plan. AEP Transmission is focusing on automating data analysis to increase awareness. Much of this automation is facilitated by increasing the wealth of data available in the PI Historian and establishing automatic data analysis within PI. New monitoring system installations for circuit breakers, underground transmission cables, and substation thermal cameras are also following the same monitor data management plan. With the right data infrastructure, clear alarm ownership and effective training, the groundwork is established to enable the efficient integration of these systems into existing processes, providing immediate value and benefit to AEP Transmission.

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