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Condition Monitoring and AI in an Asset Management World

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SUMMARY

The electric transmission system is stressed beyond what it has seen historically, and we rely on it more today than ever before. Changes in technology, weather, and lifestyles have presented new and unique challenges to operating the grid. Luckily, the changes in technology have also presented new opportunities to gather information and process that information in ways that weren't possible even fifteen years ago. This paper and presentation will aim to discuss these challenges and opportunities, using examples seen and overcome in recent years.

KEYWORDS

Condition Monitoring, Asset Management, DGA, Analytics, Artificial Intelligence, Internet of Things

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Recent years have seen an increase in online condition monitoring and the use of analytics and artificial intelligence to detect problems within electrical assets at the early stages. This paper reviews some of those cases and shows that there is a need to not only rely on the monitors and analytics for the early detection, but that the owner/operator still will need to understand what the information means, what is expected, what an anomaly might look like, and how to determine if the variation is in fact a true detection of deterioration.

Quality & Standards

The grid system is already stressed and often operates with overload condition, which means we need to strengthen or harden the grid. However, we need to make sure we are using quality equipment for the improvements required – otherwise we may be forced to repeat 'improvements' on a short timescale, which is not a sustainable approach. To ensure the quality required is achieved, asset owners and operators should look to standards published via industry bodies such as CIGRE and IEEE for guidance in the design and maintenance of the transmission system. For instance, the IEEE loading guide for transformers can be used to identify nodes on the system that may be able to be overloaded to move load around the system, and also identify limits that the transformers can be subjected to for short periods of time. In addition, we need to look at how standards need to evolve: the interoperability of microgrids, for example, using renewables is covered by several standards and guides from both IEEE and IEC (1,2,3). The rate at which these standards need to be reviewed and updated is only likely to increase over time, requiring people who are knowledgeable in both the technical aspects and the environmental influences.

Data Collection and Knowledge Management

Data becomes a key tool to identifying where the weak spots might be on the transmission grid. Data can be collected from a number of places, including thermal sensors and on line DGA and moisture sensors across a range of transformers which can be used to make sure that the asset is providing its full capability in terms of loading in a safe and reliable manner.

Anomaly Detection – Statistical Approaches

In any analysis to detect a data anomaly there will be a number of approaches available. Let's look at some anomaly detection we worked out with a large southern Californian utility.

They worked with us extensively on transformer load and ageing algorithms and, in parallel, identifying data spikes and other anomalies in PI data for load on transformers caused by data transfer errors and noise.

We implemented several different 'anomaly indicators' in spreadsheet form so that they could see the pro's and con's of each one – sensitivity to variation, hysteresis, application of mean and standard deviation combinations, running cross and auto-correlation. The more sensitive the approach, the more likely it was to pick out a false positive.

One application of the algorithms was to identify poor LTC operation – where parallel transmission transformer split a load, a deteriorated LTC tap position may alter the way the load splits and provide an imbalance. Detecting a spike in the differential of the two loads could indicate a bad LTC. It could also indicate a data spike based on noise – as was determined where a reactive step change of 40 MVAr was identified but deemed to be data noise as the actual imbalance would not be supported by the physics of the transformer banks. Someone has to know what the data anomaly discovered actually means.

Data and Analysis

Asset owners collect asset data to understand the nature of the asset groups we have – by manufacturer, by design, by location, by impact or criticality. Condition data is collected as part of an iterative process to identify actions – maintain, replace. Condition and operational data may require both short term intervention and longer term investment.

Data may be used in several ways:

- By itself and with reference to its own history, as with the operating time on a breaker, looking for variation against ‘expected’ values
- In synthesis/combination with other available data – transformer load and top oil temperature, noting that a correlation may be time delayed
- In aggregation with other individual units – does one unit stand out? Does one unit have an operating time within specification but which is slower than others in the same family? Is the relationship between two parameters not one of cause and effect, but one of two effects deriving from a common cause?

Case 1: Follow the Plan

A temperature monitoring system detected a rising trend on one sensor compared both to its own history as well as compared to other sensors installed on a generator at a critical facility. The monitoring system had been commissioned and checked, such that all alarms were being sent back to the control center, and when an alarm came in, depending on the severity level, a plan was agreed upon to take action. The levels of action, again, were dependant on the level of alarm, and could be as basic as notifiying operations that an alarm had been recieved, but could include de-energizing the asset.

The alarm results on the monitor indicated a failing asset, and an alert was automatically generated. The alert was acknowledged by the control room, but they failed to pass the information along to operations, and the asset failed. The simple act of acknowledging the alert is where the response plan should begin, but in lessons learned, it is important that everyone understands why the response plan was put in place, and that each step is critical to saving the asset, and keeping everyone safe.

The importance of having an agreed upon plan, and executing the plan when needed, can be the difference between catastrophic failure, and saving a multi-million dollar asset. The next few case studies show examples where the plan was in place, acted upon, and success was achieved.

Case 2: Dissolved Gas Analysis Response

An online transformer oil dissolved gas monitor, a composite gas detector, gave a low level alert on a previously 'stable' 48 MVA transformer. Organizational response was to confirm the monitor readings through a sample taken for laboratory analysis after the transformer was de-energized.

This led to confirmation of the increase in gassing, and further electrical testing was performed, which showed poor results for the winding resistance testing, seen here :

Date	Ambient	a-n	b-n	c-n
April 2016	n/a	3.80	3.84	3.88
Dec 2018	9°C	3.64	3.65	3.67
1st Feb 2020	10°C	4.54 / 4.90 / 4.77	4.43 / **8.85** / 4.78	**5.75** / 4.53 / 4.38
2nd Feb 2020 – @ internal inspection	10°C	6.384	**6.326**	6.247

With this additional knowledge in hand, a subsequent internal inspection of the transformer was scheduled. Upon investigation inside the transformer tank, it was discovered that one internal connection was falling apart, causing arcing within the unit. The transformer was likely to fail catastrophically, possibly within hours considering the deterioration found.

Repairs to the connection were implemented, and the transformer was saved. Follow up actions from this discovery included checking sister units for a similar condition, which was confirmed and fixed.

Case 3: Dissolved Gas Analysis Response, part two

A multi-gas dissolved gas monitor was installed on transformers at a critical 500-250 kV transmission substation located in the northeast United States. The transformers are two sets of three single phase 500-250 kV transformers, with one spare unit between the two, for a total of seven transformer tanks being monitored. The unit in question had the DGA monitors installed and commissioned in December of 2022, and very low levels of gassing were recorded by the units, and nothing above the default alarm thresholds.

On January 14, 2023 after a recent switching operation, an increase in "metal" gases, such as hydrogen, methane, ethane, ethylene and acetylene were detected, with a step change seen within 4 hours, then all the gases remain steady. Another switching operations a few months later (April 2023) led to a more significant increase in these gases, which were confirmed with oil samples sent to a lab.

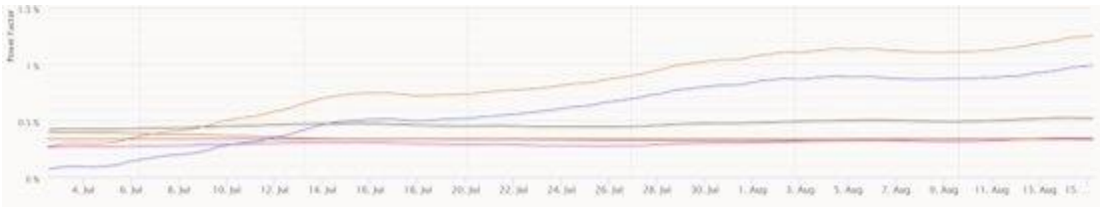
A third switching operation in May of 2023 again led to a direct increase in gas levels, including acetylene increasing from 2.8 ppm after the April 2023 switching event to 19 ppm in May. Another DGA sample was taken and sent to a lab for analysis, and after ruling out one bad sample, another good sample confirmed the readings from the DGA monitor.

When the increases in gassing levels were confirmed, the utility decided to take the transformer out of service on May 10, 2023, two days after the last switching event. The transfomer was de-energized, oil emptied, and a manufacturer’s representative was brought on site for an internal inspection. It was found that the low voltage corona shield was loose, creating arcing inside the transformer. The shield was fixed, and the transformer was returned to service. The utility feels that had this problem not been detected using online DGA monitoring, this critical transformer would have failed catastrophically while still in service. Instead, the problem was detected early on, fixed, and the transformer was saved.

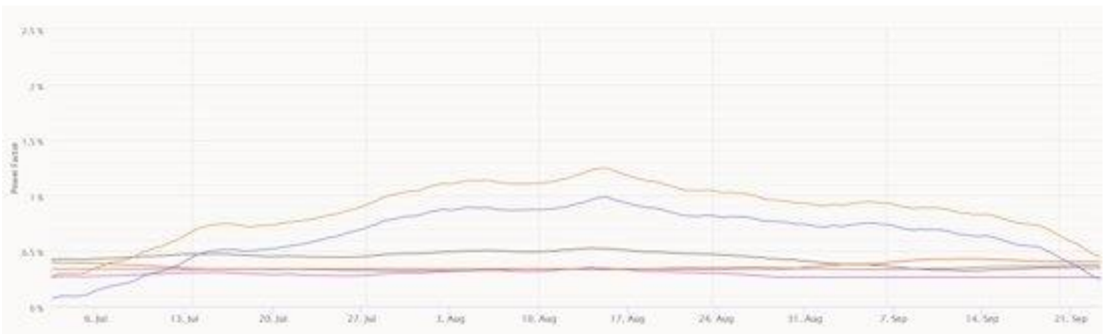
Case 4: Bushing Power Factor Variation

An online bushing monitor showed rising power factor for the main C1 value on a 14 kV tertiary bushing. When the power factor of a bushing rises, typically we expect that the insulation system is deteriorating, and depending on the failure mode and type of bushing, we may have upwards of a few months time to locate a replacement bushing, and plan the outage. It appeared that this bushing was failing in the ‘graceful’ deterioration method, so it was decided to leave the bushing in service, and keep an eye on it. Over a period of several weeks, the figure below shows that increase in power factor, when compared to the other two bushings.

The following trend shows that using both the relative and true power factor methods, the bushing deterioration was detected, and is following the same deterioration pattern.

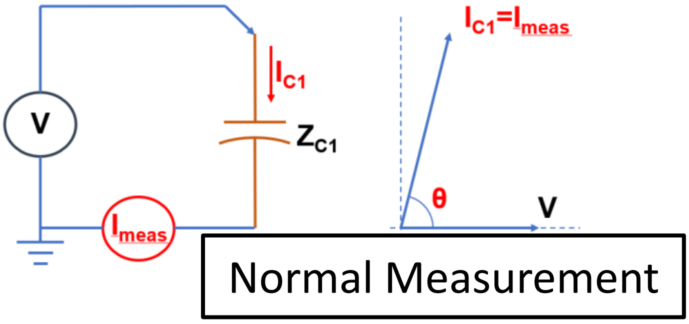


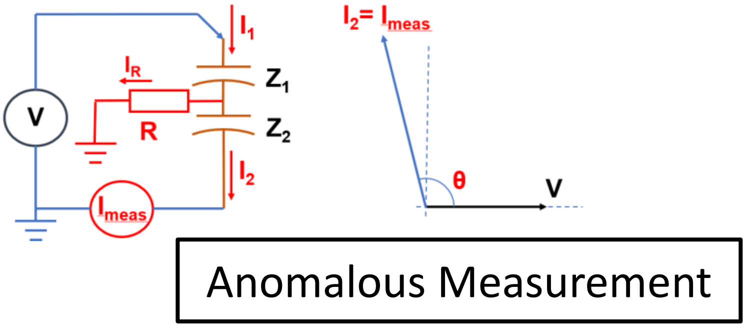
Subsequently, and somewhat surprisingly, the power factor started to fall, eventually going negative. This is not a typical turn of events, as insulation systems that start to deteriorate don’t heal themselves, and decide to improve, which is what a lower power factor would initially indicate. The initial rise in power factor, and subsequent ‘improvement’ in the results are shown below.



At this point, after lots of discussion about what could be causing this phenomena, the transformer was taken out of service to test the bushings as a precautionary measure. The bushing power factor was measured using offline test equipment, and measured at 0.98% power factor, almost four times the nameplate value. It was decided that this bushing should not be re-energized, and would be replaced.

The bushing was also torn down in the lab, to see if it could be determined what was happening with the online readings, and why it appeared that the power factor was improving. It was suspected that a resistive path to ground had developed somewhere in the online test circuit, such that current was being shunted around the meter, therefore it looked like there was less leakage current coming from the bushing. The theory behind the measurement circuits can be seen in the images below.





If contamination gets into the oil, it could in fact cause the initial rise in deteriorating power factor. If that contamination moves around inside the oil, it is possible that it could get into a spot where it would provide an alternate path to ground for the leakage current, which would look like the insulation system was improving.

The bushing was torn down, and it was found that there was a crack in the fill plug gasket, which was allowing moisture to get into the bushing and mix with the oil, creating sludge. All three bushings were replaced, and the transformer remains in service (4).

Prediction

It isn't sufficient just to know the present condition of assets, we need to know how they will perform in future under a variety of possible conditions. In simple terms we need not only to know how close to the cliff edge we are, but also which way we are facing, how fast we are moving, and what the world around us is doing.

Resilience

The more data and information that can be collected and turned into knowledge, the better the transmission grid can be supported and the more reliable it becomes. Utilities are going to greater lengths to understand the performance of their systems, using digital twins to fully model their grid, and simulate historic weather events to determine where they are vulnerable, and what can be done to become more resilient. With appropriate monitoring, elements of the Grid which deteriorate or become vulnerable may be addressed automatically, leading to a more 'self aware' and 'self healing' grid. Application of AI has great promise, but as can be seen with autonomous cars, human oversight is needed as we don’t necessarily know everything that may happen.

Discussion

To be of value, condition monitoring has to be understood and embedded within the organization: managing data, alert settings, alert response planning all need to be agreed by appropriate stakeholders, and subsequent ‘lessons learned’ developed and applied.

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