Condition Monitoring in the Real World

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Introduction

This paper looks at the role and benefit of on-line condition monitoring. It contains real world cases that demonstrate that benefit can be accrued from the application of bushing monitoring – bushings 'saved'. It will also reveal that care must be taken to deal with sources of variability in the measured parameters: that is, the data may indicate a bad bushing, but it may not be the bushing that is bad!

Justification for Condition Monitoring

Widespread application of condition monitoring has to pay for itself – either in losses avoided or risks reduced. (Condition monitoring applications for research or evaluation purposes are intentionally omitted).

Step 1: Understand failure modes – what are the likely causes of transformer failure, how can they be detected, which systems will give information
Step 2: Return on investment – how much is the system, and what are the chances of detecting deterioration before failure.

The Doble Asset and Maintenance Management Committee has developed a cost benefit analysis spreadsheet which is available to clients.

Over the years two distinct types of failure mode have been observed: graceful and rapid onset. Graceful failures relate to slower deterioration with a clear indication from a monitored parameter allowing for several weeks to months of planning and preparation for replacement. Rapid onset failure relates to failure modes which occur over a very short time period, giving minutes to hours warning. Appropriate monitoring has to be chosen to cover either situation.

Planning Ahead: False Positives and False Negatives

In applying monitoring, it is incumbent on the owner/operator to plan ahead for whatever situation the system may be reporting and have a strategy in place on how to respond. The response plan must include the interest of all parties that have a stake in the asset – engineering, operations, and asset management.

In any monitoring system application, the owner/operator has to be prepared for both false positives and false negatives.

In the case of a false positive, or false alarm, the data collected indicates a problem when none, in fact, exists. This can be caused by a number of possible causes.

> View from the field: words of experience…
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> "False Positives are part of the costs associated with online monitoring, particularly in a market oriented network. From an Asset Management perspective however, the cost of an outage due to a false Alert is much more bearable than the cost of a failed transformer and the associated Health, Safety and Environmental consequences."

Any monitor will track parameters associated with suspected failure modes: on line DGA monitors may track hydrogen concentrations in parts per million over time. It may be that it takes some time for dissolved hydrogen to reach the sensor, and then some time for the sensor to respond. Consequently, if the failure mode is fast, the monitor may not respond in time to give appropriate warning allowing intervention. Further, variations in the parameter – in this case, hydrogen – may be caused by faults or by benign effects. It is well known that load variation on a transformer leads to significant temperature variation, which in turn leads to dissolved hydrogen variation. This is fairly well understood and is a possible cause of false positives relating to dissolved gas monitoring. Bushing monitoring relies on leakage current to indicate the status of bushing insulation. However, the current itself is also dependent on the voltage on the bushing – which may vary phase by phase, with load and with system configuration. This would likely be a benign source in monitored parameter variation leading to false positives.

In general – the only way to avoid false positives is not to have any positives at all! Unfortunately that results in more false negatives

False negatives are situations where the monitor did not respond in a timely manner, if at all. This too may be due to a number of possible causes: speed of the deterioration relative to the monitored parameter (as with the DGA example above), lack of precision in the monitor, or the failure mode being one not associated with the measured parameter.

> View from the field: words of experience…
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> "Generic settings will be capable of detecting generic failures and are the result of the manufacturer deciding on the best compromise between failure detection and false alarms (something I admit we all want). However, experience has taught us that there is value in implementing sensitive settings which can then be reviewed and changed to be less sensitive as experience dictates."

False negatives can only be avoided by having perfect monitoring equipment, complete understanding of every possible failure mode and apply monitoring with complete understanding of data being generated and causes of variation.

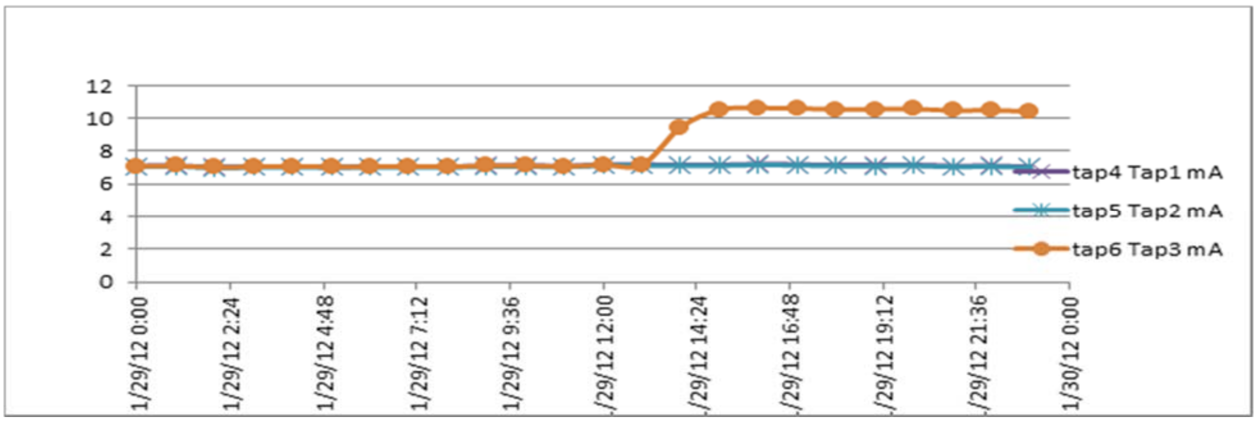
False positives and false negatives – false alarms and misses – are a reality with any monitoring system and the user has to be prepared to implement modifications to the alarm settings as experience is acquired.

View from the field: words of experience…

"False "Capacitance Alert" positives are likely to result from variations in other parameters which are verifiable (bus volts, VAR load etc). False power factor positives however, require a much more thorough understanding of both system conditions at the time of the alert AND the measuring 'philosophy' of the monitor used, combined with whatever plant information is available to you."

Case 1: Bushing Deterioration Detected: Failure averted

In this case a number of Trench COT type bushings were monitored. Over time, the monitoring system had shown variation in on-line power factor and capacitance for a number of units. In the early hours of a morning in January 2012, the monitoring system gave an alarm notification. It was considered prudent to switch the transformer out of service as a precaution. Initially it was thought this may be a false positive, relating to system voltage, or monitor performance. The data showed that a large increase in leakage current over a period of just a few hours had been detected for one bushing in a set of three.



Leakage Current Sudden Rise

Off line testing was used to confirm the on-line results, and the bushing was removed from service. Power factor had risen by a factor of more than 3, and capacitance by almost 50 %. A subsequent forensic tear down showed puncture marks and burning close to the edge of many of the foils.

Picture of Damaged Foil

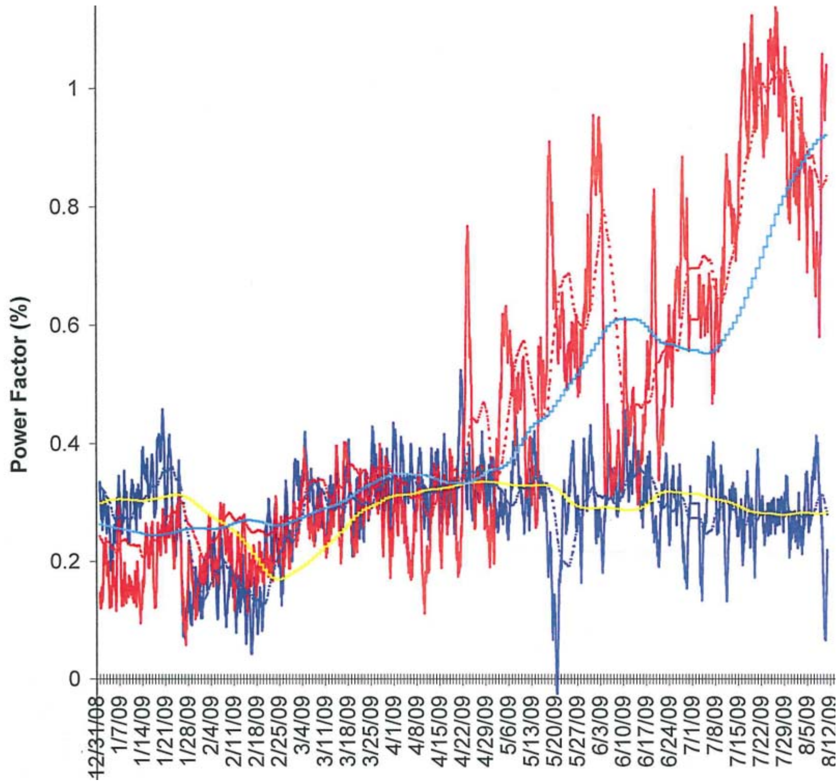
Given the status of the insulation, the time taken for the leakage current to increase and industry background on these bushings, it was concluded that this bushing had hours before catastrophic failure.

View from the field: words of experience…

"In the case of the recent Trench bushing failures seen (where it was known that the failure mechanism involved puncture of insulation sections) online monitoring was considered a useful tool to manage the risks associated with bushing failure. In one case, we configured a transformer trip using the Action Alert contacts provided by the IDD as we had no spare bushings available and had to leave the faulty bushing in place due to load/market considerations. The Action Alert levels were re-configured to be far more sensitive than other units on the Network to further control the risk of a catastrophic bushing failure. These settings were calculated from what we knew about the particular transformer temperature profile under load and using our offline insulation quality limits for Cap and Tanδ as baselines."

Case 2: Cautious Approach

In this case, variation in monitored bushing parameters showed significant variation over a several month period. The monitoring system itself gave no alarms. It was decided to remove the bushing from service – off line testing performed – and the data showed no significant issues. The bushing underwent a forensic tear down, which revealed no significant deterioration.



Hourly/Daily/Weekly variation in power factor data from two bushings in a set of three .

Variation in red shows significant excursions in power factor and a rising trend.

Variation in blue shows daily and hourly variation but no significant rising trend

Rising Trend in Bushing Power Factor

A subsequent investigation revealed that there had been significant load variation, and consequent voltage variation, at the transformer in the same period as the power factor variation was observed. This was not consistent across the phases, in that voltages could vary between phases, providing variation in leakage current and phase angle leading to variation in the power factor. Response to the variation found was highly risk averse, which may be appropriate for the station involved.

Learning Lessons

Achieving success in applying monitoring relies on three key things:

- an understanding of the need to control the measurement to produce valid results
- a context for the data so results can be analyzed in light of all impacting parameters
- actionable conclusions which permit intervention using prearranged/agreed plans

View from the field: words of experience…

“Knowledge of offline test data and phenomena are integral to applying online monitoring effectively. It is important to have an understanding of how temperature, humidity and weather patterns affect measurements… Someone in the organisation needs to be responsible for online monitoring and learning all they can about their performance within their context. “

“ The capability of application engineers to support and interpret the full range of available data is often key to getting benefit from the monitoring application.”

There must also be a mechanism in place to implement change. It may be that a target group of bushings is identified for monitoring based on measured off-line test parameters and industry knowledge. If those values or the knowledge changes, the target group will also change. The authors have expanded their monitoring and oil sampling activities after finding increasingly poor results in off line tests for bushings thought to be of a type which were acceptable.

There will always be cases of false positive – there are lessons to be learned in identifying them and sharing that knowledge within the industry at large.

Conclusions

Online condition monitoring presents certain challenges, but when applied properly, the challenges will be outweighed by the benefits. Assets can degrade rapidly, sometimes so rapidly that periodic offline testing will not detect the deterioration in time for intervention. Online monitoring can provide a means to fill the gap between offline testing, and give the asset owner more information when making important decisions.

It is important, however, to understand the data which is collected, the context of the measurement and the conclusions which may be drawn.

View from the field: words of experience…

“Online devices are intended to collect data, but the modern focus is on ‘plug and play’ where you install it and sit back and watch the benefits roll in. Online monitors collect a lot of data and that requires a lot of analysis. Tools to make this task simpler to manage and interpret are vitally important to the success of any online monitoring project. This again, is very closely related to the need to understand how the monitor actually derives its data from the quantities it measures. “

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