QUALITROL®

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NEW TRENDS AND USER EXPERIENCE IN ONLINE TRANSFORMER CONDITION MONITORING

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CHALLENGES IN CONDITION MONITORING

DEREGULATION CHANGED THE FACE OF THE ENERGY MARKET

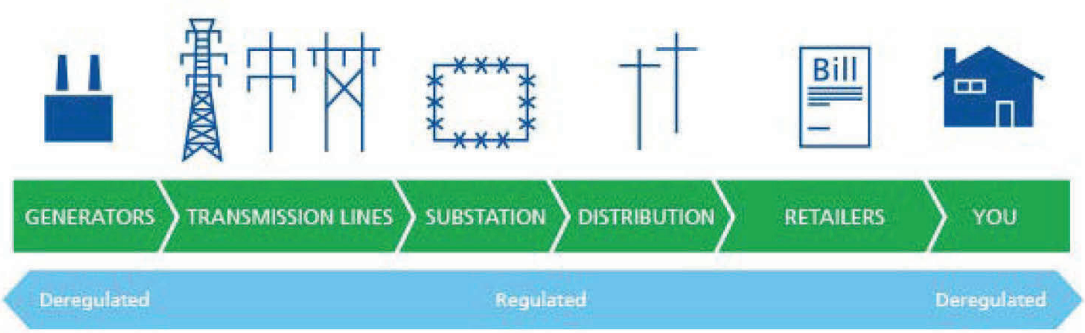
GENERATION, TRANSMISSION AND DISTRIBUTION WERE DIVIDED

MORE PROFIT ORIENTED ENTERPRISES

OUTSOURCE MAINTENANCE AND OTHER TECHNICAL SERVICES

CAREFUL INVESTMENTS IN NEW OR RENEWAL OF EQUIPMENT

SOMETIMES LIMITED TO REPLACEMENT



CHALLENGES IN CONDITION MONITORING

INCREASE

Transformer Utilization Rates
- Higher transformer loading
- Need to extend useful asset life
- Higher performance expectations

Maintenance Costs
- Higher crew costs
- Increased safety regulations
- Aging asset infrastructure

+

DECREASE

Operation and Maintenance Budgets
- Fewer resources
- Limited time constraints

Industry Expertise
- Retirement of industry veterans
- Loss of key asset knowledge

=

NEED FOR CONDITION MONITORING

- Extension of useful asset life
- Constant window on asset health
- Avoid unnecessary maintenance
- Automated data collection

CHALLENGES IN CONDITION MONITORING

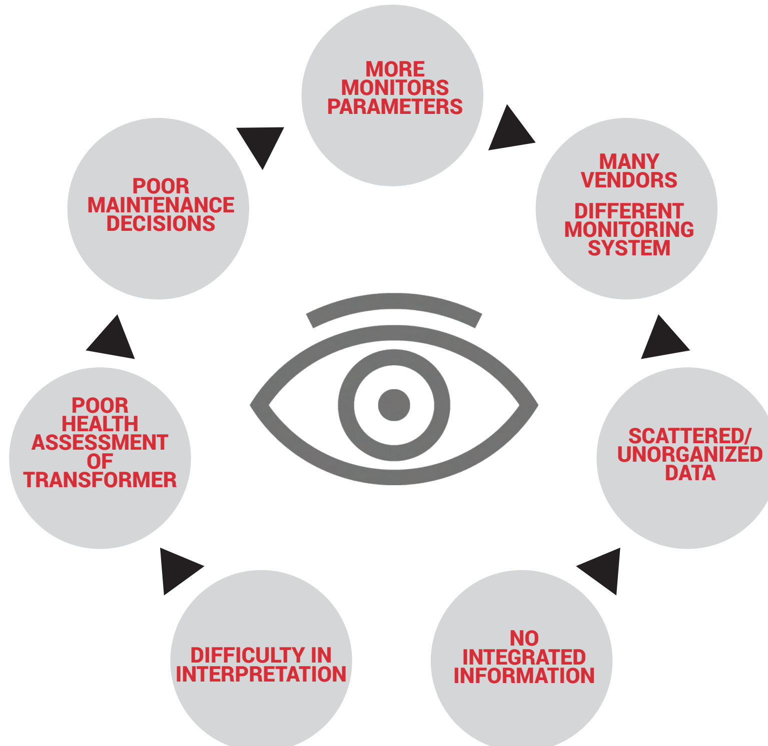
- Online monitoring was limited to some parameters
- Users struggled accessing the true overall condition of an asset
- Confusions prevailed over clear decisions

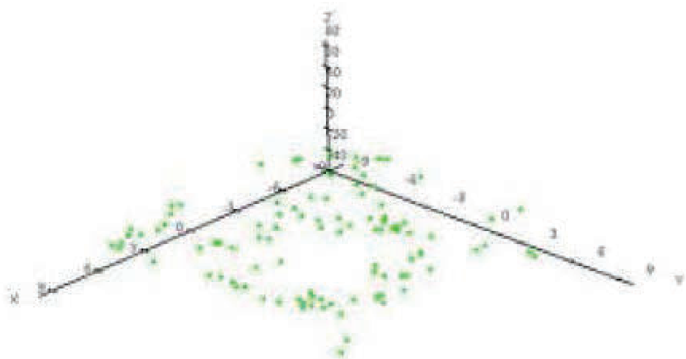
“FALSE ALARMS” LEADED AND LEAD IN NOT TRUSTING INSTALLED MONITORING SOLUTIONS

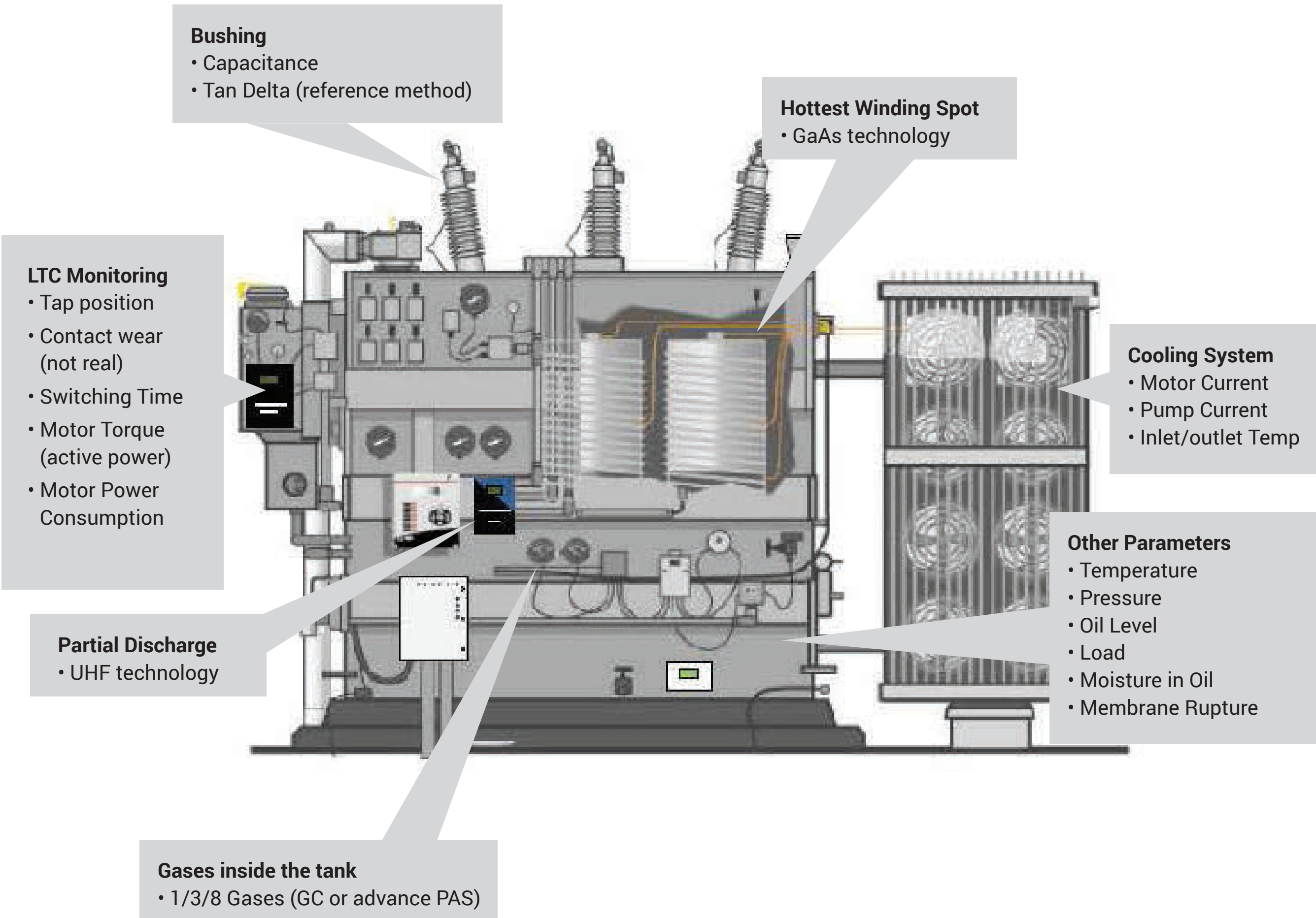
A COMMON OPINION STILL IS THAT ALWAYS THE HELP OF EXPERTS IN THAT FIELD IS NEEDED

CHALLENGES IN CONDITION MONITORING

- Presenting “only” data can mislead to:
  - Poor maintenance/ operational decisions
  - Unnecessary interventions
  - Potential to introduce new risks
- Often it is difficult to analyze the scattered data
- Data are analyzed separately in disregards of the possible relationship to other parameters or even legacy data

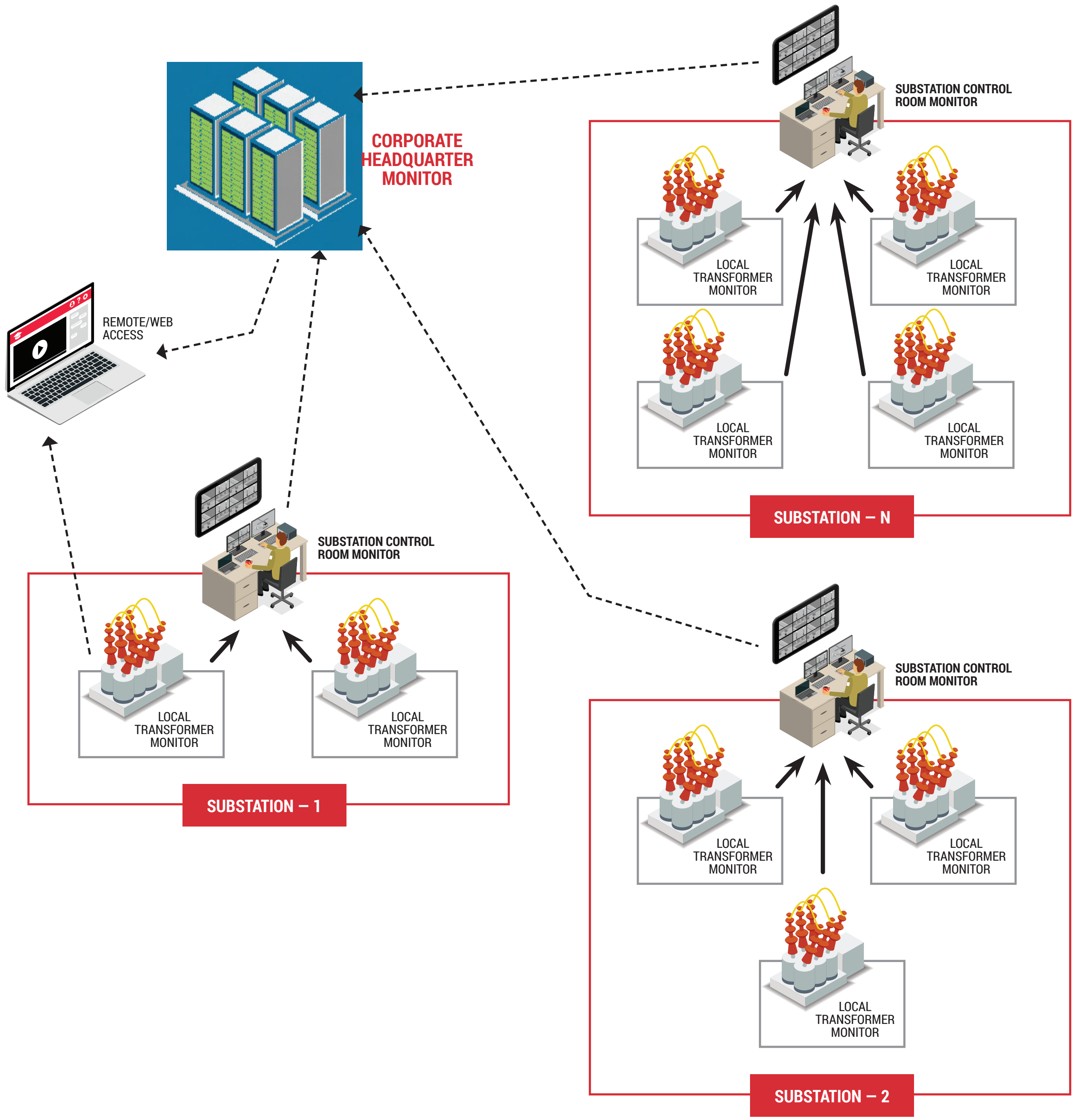






MODELS

Insulation Aging	Life time Consumption	Moisture in Insulation	Bubbling Temperature


CORPORATE HEADQUARTER MONITOR
REMOTE/WEB ACCESS
SUBSTATION CONTROL ROOM MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
SUBSTATION – N
SUBSTATION CONTROL ROOM MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
SUBSTATION – 1
SUBSTATION CONTROL ROOM MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
LOCAL TRANSFORMER MONITOR
SUBSTATION – 2

WHAT WE WANT TO ACHIEVE WITH CONDITION MONITORING?

PREVENT MAJOR FAILURES AND OPTIMIZE MAINTENANCE

- Reduce cost of sudden outages
- Avoid unnecessary maintenance visits

ACHIEVE BETTER UTILIZATION OF LOAD CAPACITY

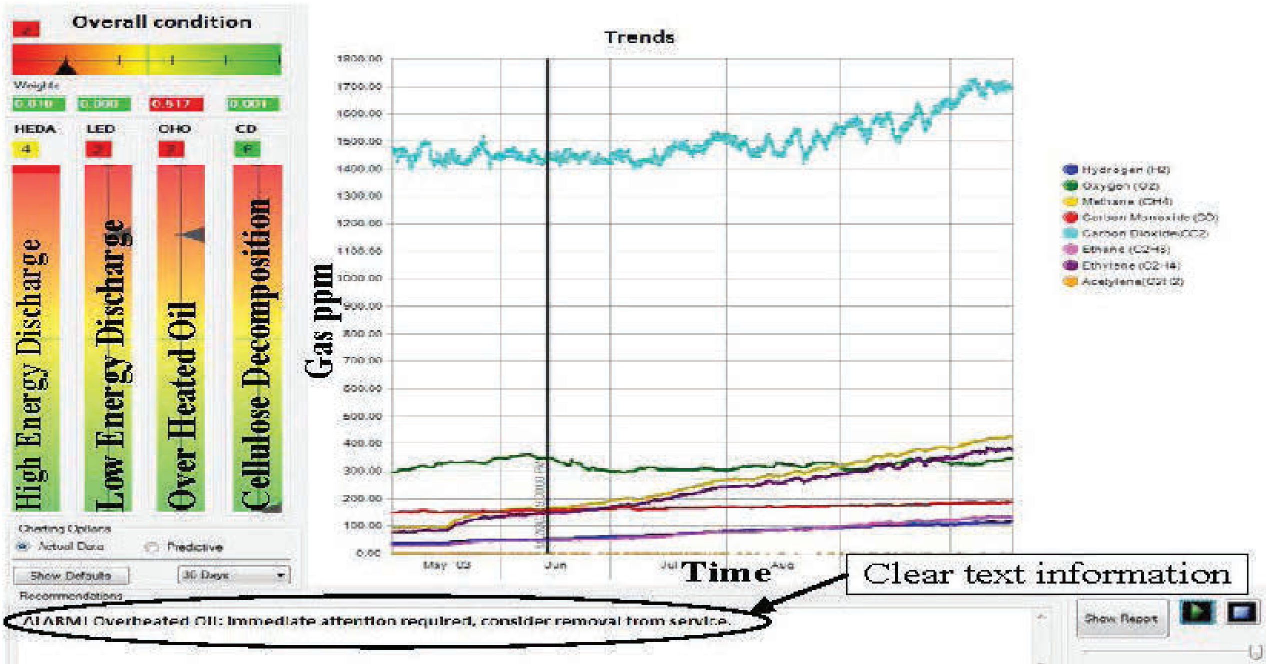
- Put closer watch on the units that has higher risk levels
- Expert Decision Support System

USING THE TRANSFORMER UNTIL ITS REAL END OF LIFE

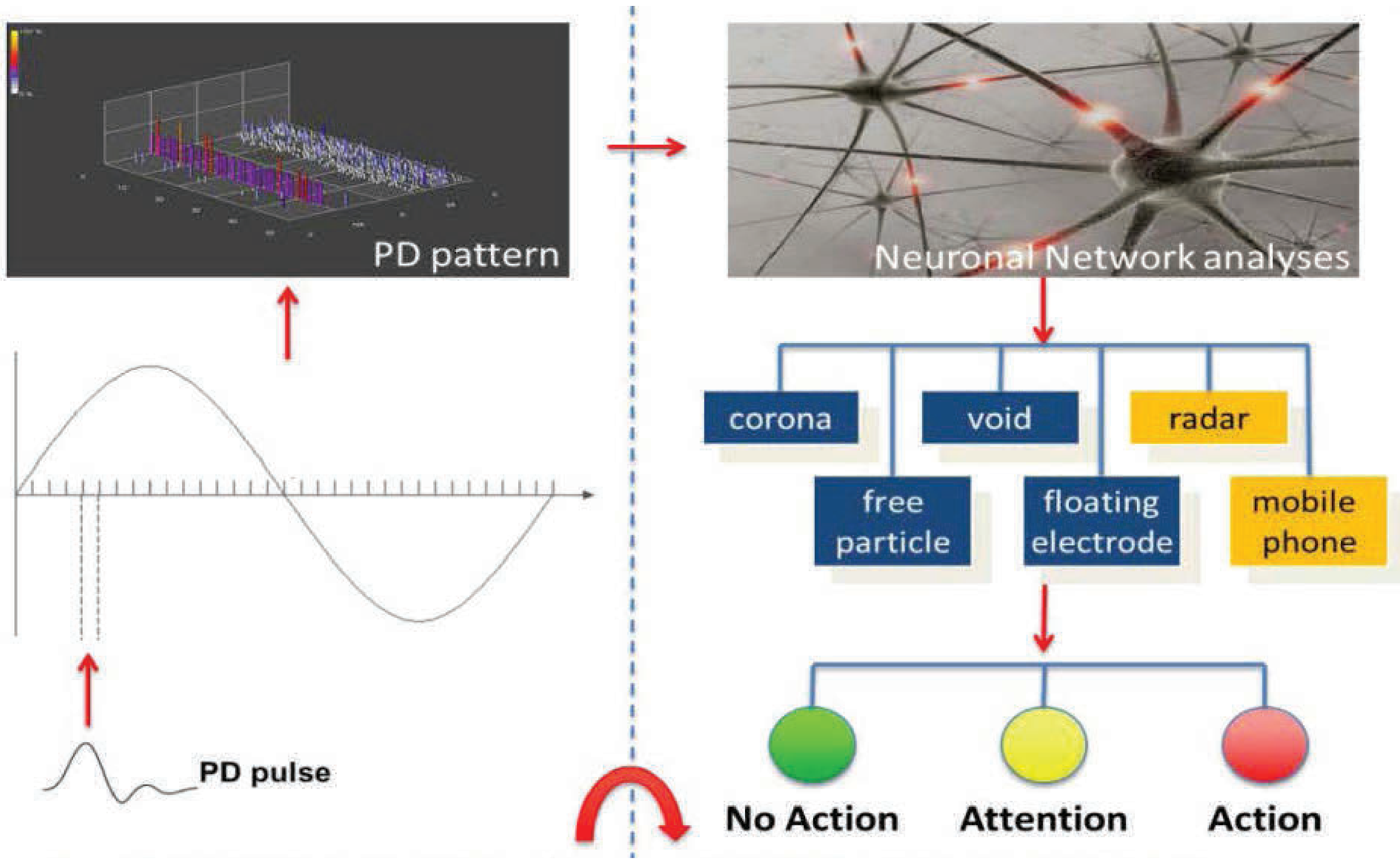
- Comparison with benchmark data
- Failure pattern analysis

CONDITION MONITORING – IT'S ALL ABOUT DATA

Analytics describes the condition of an asset based on a certain input parameters (provides the inside of the asset). To determine often neuronal networks, simple and fuzzy logic etc. will be used.



GAS IN OIL ANALYTICS WITH CLEAR TEXT INFORMATION/ RECOMMENDATIONS

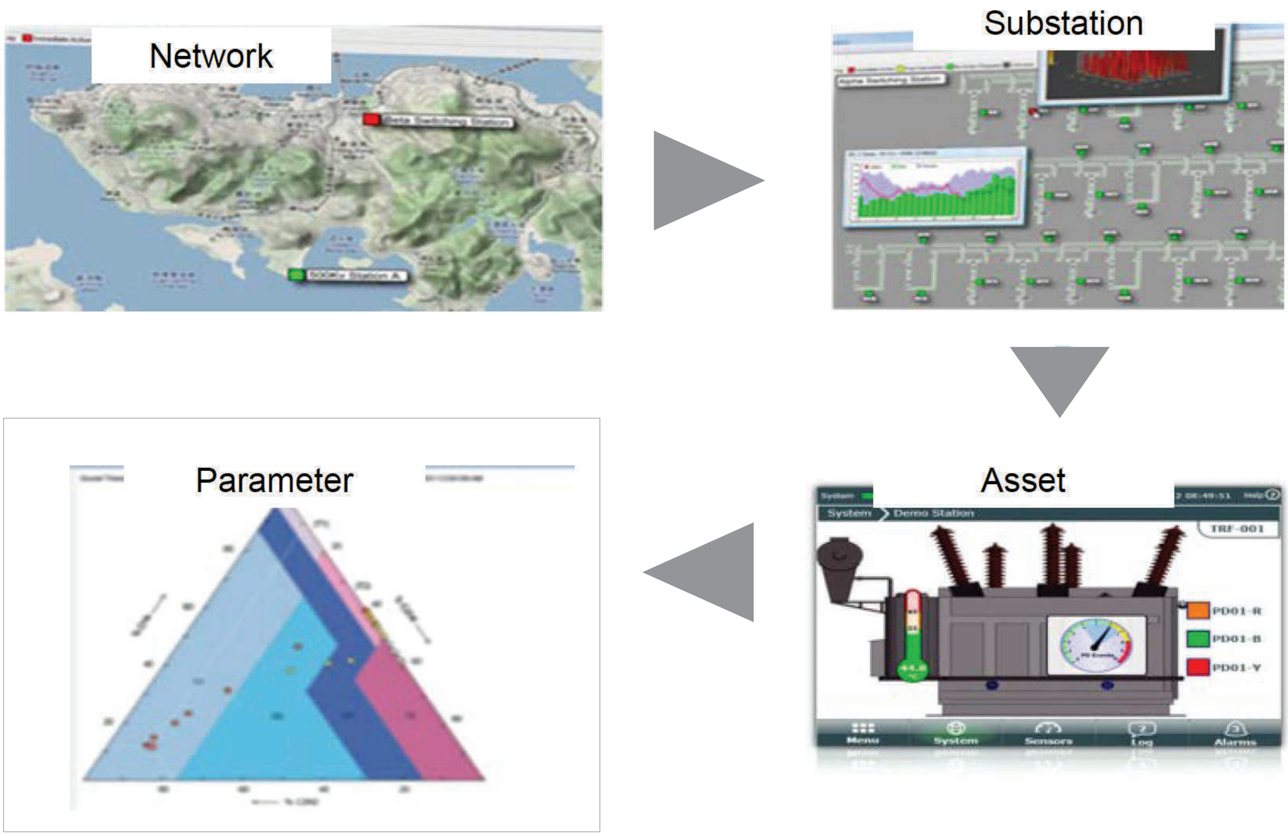


LOW ABSTRACTION LEVEL

HIGHER ABSTRACTION LEVEL

CONDITION MONITORING – IT'S ALL ABOUT DATA

Applying the abstraction levels to a utility user the user



CONDITION MONITORING – IT’S ALL ABOUT DATA

PROBLEM	MEASURED SIGNALS	ANALYTIC MODELS	CONFIRMATION	DETECTION TIME
Loss of core ground Unintentional core and shield grounds	Hydrogen or multi-gas Core ground current Gas accumulation relay PD Core hotspot (Fiber) Temperature	DGA Core Ground Current Gas Accumulation Rate PD Thermal	1 2 3 4 5	Hours Real time Hours Real Time Hours

The used type of monitoring should be always adapted to the problem which should be detected. Experiences from users are showing:

- It is important to know the history of a certain transformer/ transformer fleet
- It is important to know type and vendor specific behavior
- It is important to know the importance of a certain transformer

CONDITION MONITORING – IT'S ALL ABOUT DATA

Users today asking for:

- Analyzed data with clear recommendations (clear text preferable)
- Long-term reliable systems with low maintenance level for the monitoring system
- Immunity against disturbances in order to prevent false alarms
- Easy to use and cost-effective solutions
- Correlation of online and offline data in one central CMS (condition monitoring system)

CONDITION MONITORING TRENDS SUMMARY

In condition monitoring the trends are going of course still in using new parameters and advanced measuring principles but also into handling the data in a better way, combining and abstracting them in order to get an easy information for the user.

As there are tons of offline data available, these data going to be more and more integrated into comprehensive systems, which allows correlative analyses in order to verify certain assessment based on only one or a limited number of data.

CHALLENGES IN CONDITION MONITORING AND NEW TRENDS

- > Challenge
- > New Trends
- > What we want to achieve with Condition Monitoring?
- > It’s all about data
- > Condition Monitoring Trends Summary

TRANSFORMER MONITORING EXAMPLES

CONCLUSION

AEP TRANSFORMER FAILURE EVENT

Background (2014Q1)

> Catastrophic failure of (new) single phase 765KV xfmr

> In service 3 months (1st new 765 kV failure since 1990s)

> Fully monitored with standard EHV package

> Alarms intentionally not sent to operations (by design)

Event Analysis

> No prior warning indications received from:

- Online DGA
- Bushing health
- Temperature
- Legacy Data

> PD monitor captured activity prior to failure

> Preliminary root cause analysis – delivery transit damage

AEP TRANSFORMER FAILURE EVENT

The Failure Phenomenon

> Partial Discharge Monitor Review

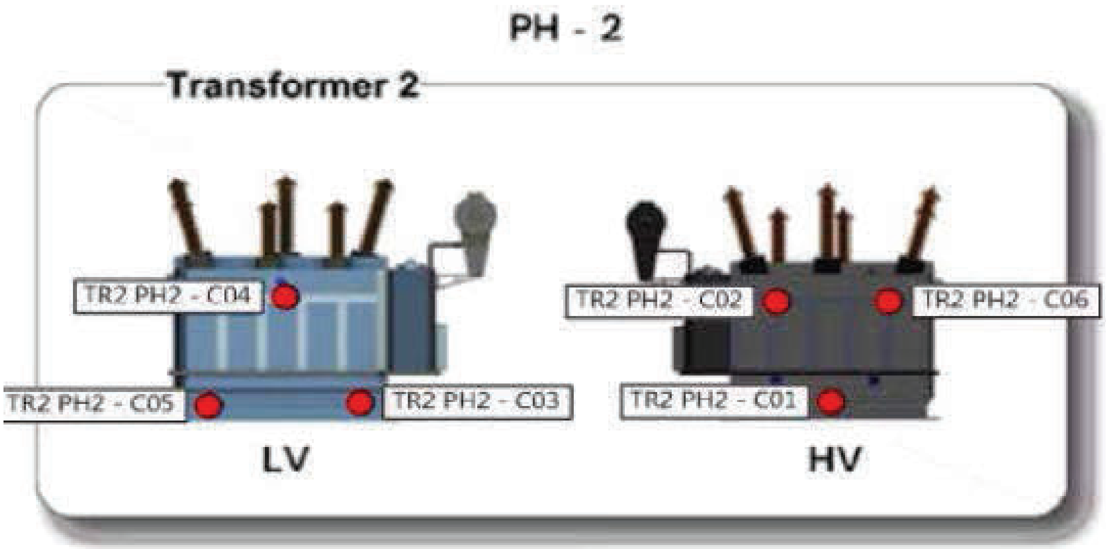
- Single phase 765 kV transformer
- UHF partial discharge monitoring system
- 6 sensors measure thru "window" in transformer wall

> Signature Found

- Partial Discharge signature found
- ~ 8 hour observed activity prior to failure
- On-line algorithms not functional @F (early deployment)

AEP TRANSFORMER FAILURE EVENT

Signature Found



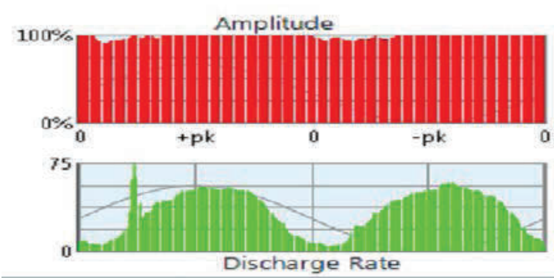


Figure 3 PHASE 2 CO1 PD POW SIGNAL

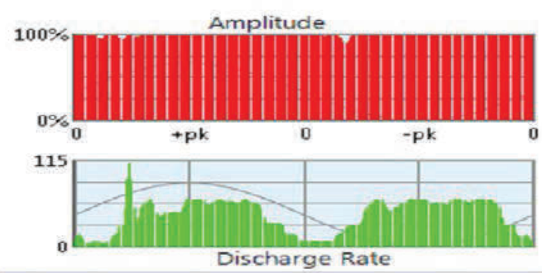


Figure 4 PHASE 2 CO2 PD POW SIGNAL

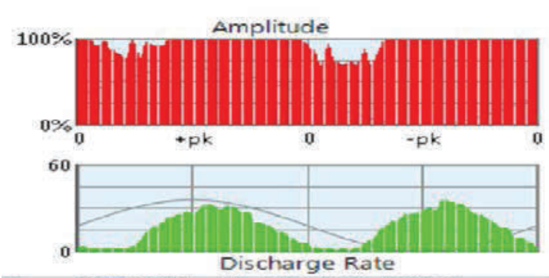


Figure 5 PHASE 2 CO1 PD POW SIGNAL

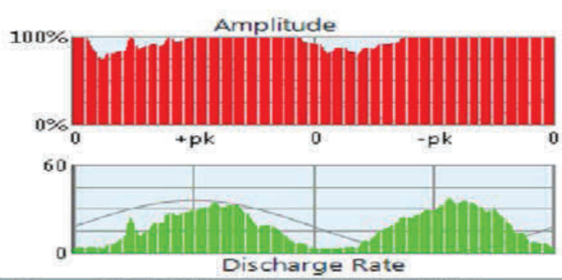
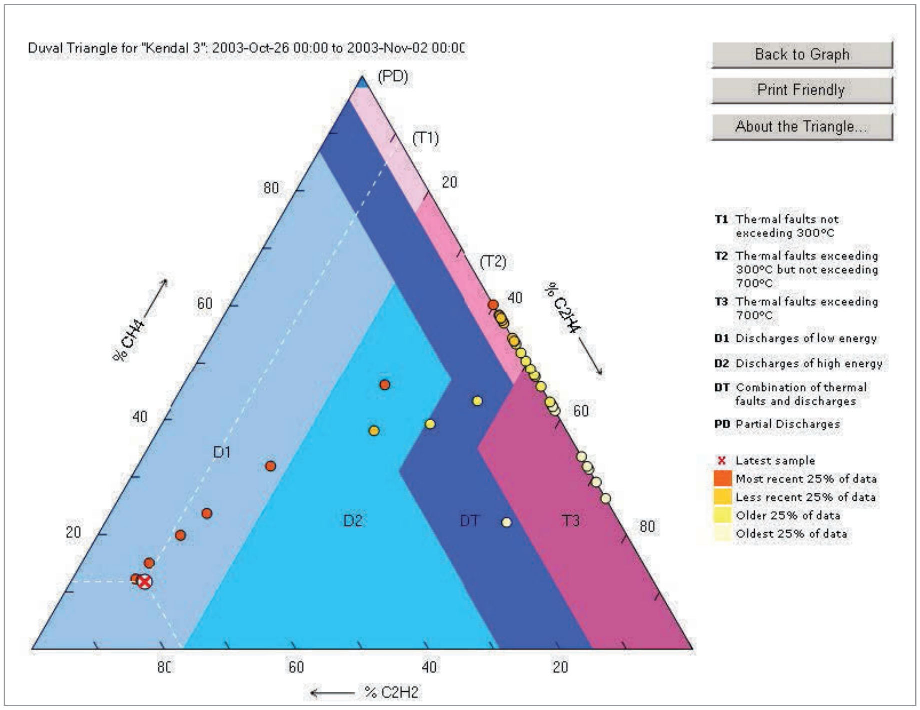


Figure 6 PHASE 2 CO2 PD POW SIGNAL

ONLINE DGA CASE #1



The Duval Triangle is a DGA tool included in the IEC 60599 Gas Guide.

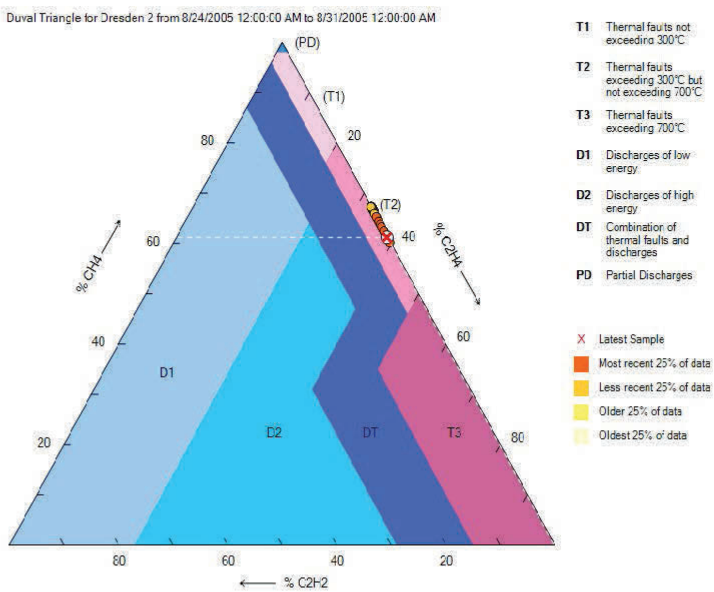
HV LEAD CORONA RING SHIELD CONNECTION

(note burn mark on corona ring material & eroded bolt)

- The Duval Triangle shows problem evolving from a T3 Thermal Fault to D1 Discharge of low energy.
- Intermittent grounding was provided by the fastening bolt causing a transient potential rise and subsequent discharges occurring between the corona ring and the main tank ground point.
- An on-site repair was performed and the transformer was returned to service.

ONLINE DGA CASE #2

Analysis

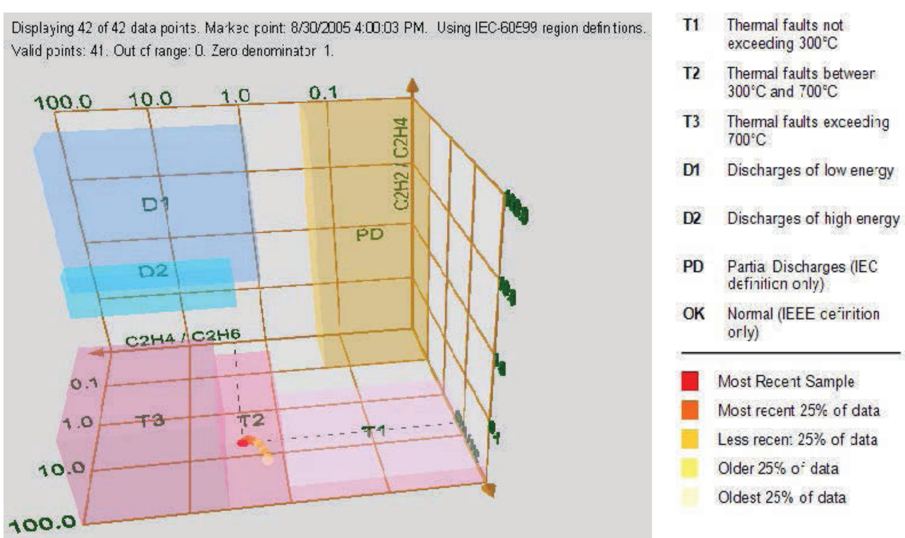


The Duval Triangle is a DGA tool included in the IEC 60599 Gas Guide.

1. Both the Duval Triangle and Rogers Ratio analysis shows the fault condition is in T2 indicating a thermal problem getting worse in the range of 300°C to 700°C

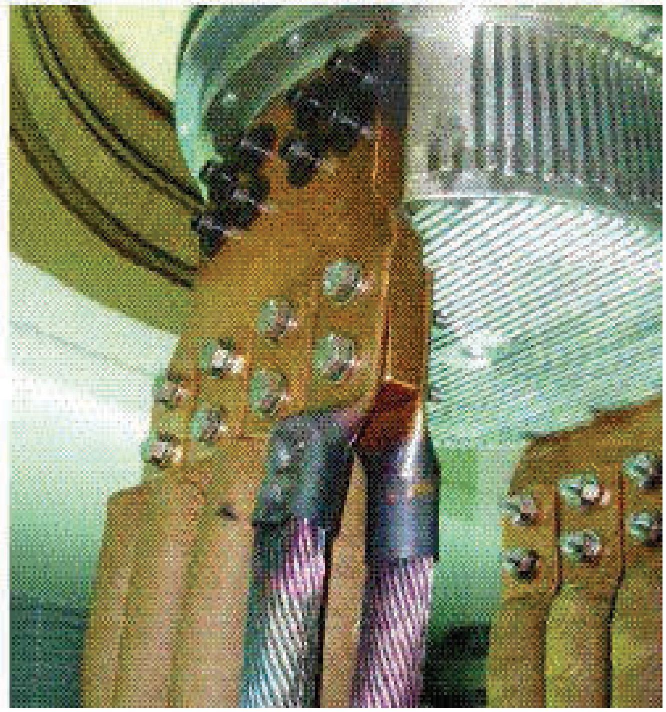
2. Combustible gas levels were rising very quickly, exceeding preset rate of change limits. Transformer load reduction began approximately 32 hours after levels began to change and was fully de-energized within approximately 52 hours

3. Root cause; Overheating of LV crimped connections caused by the combination of high eddy losses in the crimps & over-insulation + poor oil circulation in crimped bundled areas.

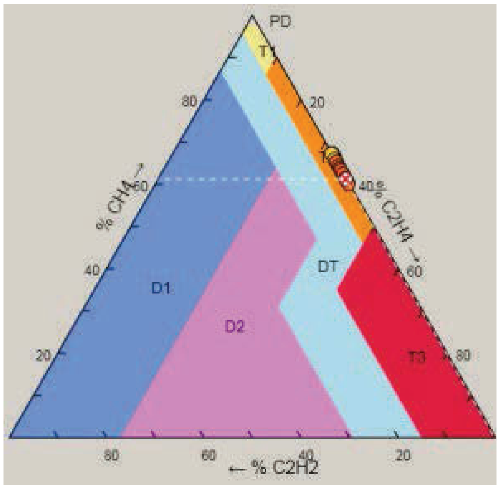


Rogers Ratios are included in IEEE 57.104 Gas Guide (similar to Basic Gas Ratios in IEC-60599)

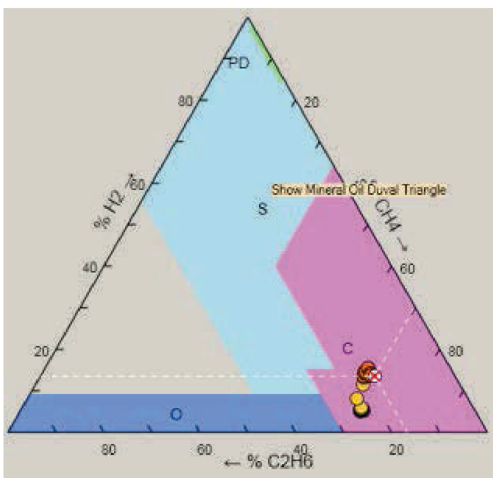
ONLINE DGA CASE #2



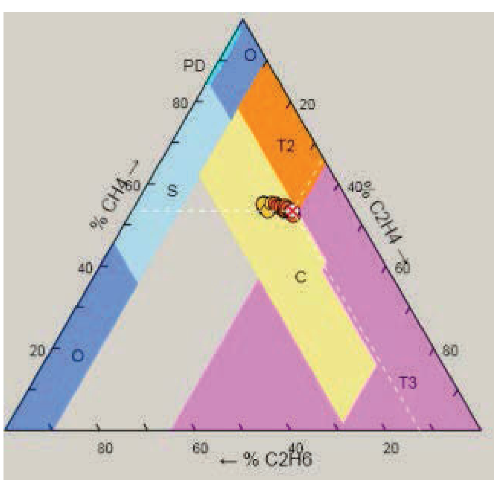
ONLINE DGA CASE #2



Triangle 1: T2 Fault



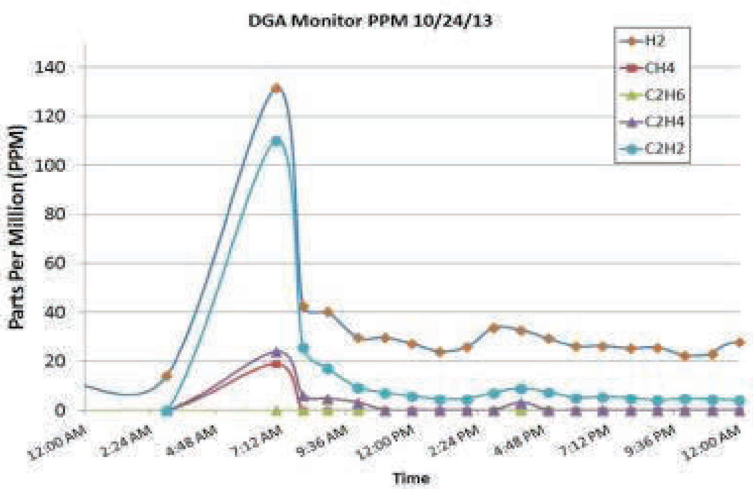
Triangle 4: Paper Fault



Triangle 5: Paper Fault

LCRA – DGA CASE #3

- Auto 345/138/13.2 kV, 480 MVA
- 4 years in service
- Loaded to about 50% of nameplate during peak conditions
- No previous issues during factory testing, field testing, or service
- At 8:33 a.m. a substation maintenance personnel reported an alarm from the multi-gas DGA monitor. C2H2 = 25.6 PPM
- At 1:23 p.m. the DGA was complete and showed no changes
- 2:21 p.m. personnel reported strange temperature readings
- Neither of the monitor alarms was perceived to be an indication of transformer failure
- 1:00 a.m. the auto tripped.
- Annunciator indicated high top oil temp and high winding temp only



LCRA – DGA CASE #3

- The station service power at this location is fed from the tertiary of the auto. No backup SS was available
- This necessitated the need to have the tertiary SS source
- 4:00 p.m. Trip contacts from the temperature monitor were bypassed and auto was energized from the low side (X) only
- 4:56 p.m. Transformer trips offline on current differential
- RPR relay, gas accumulation, pressure relief devices
- Internal inspection and diagnostic testing determined this to be a phase-phase fault likely caused by contamination or insulation breakdown

UHF PD MONITORING EXAMPLE

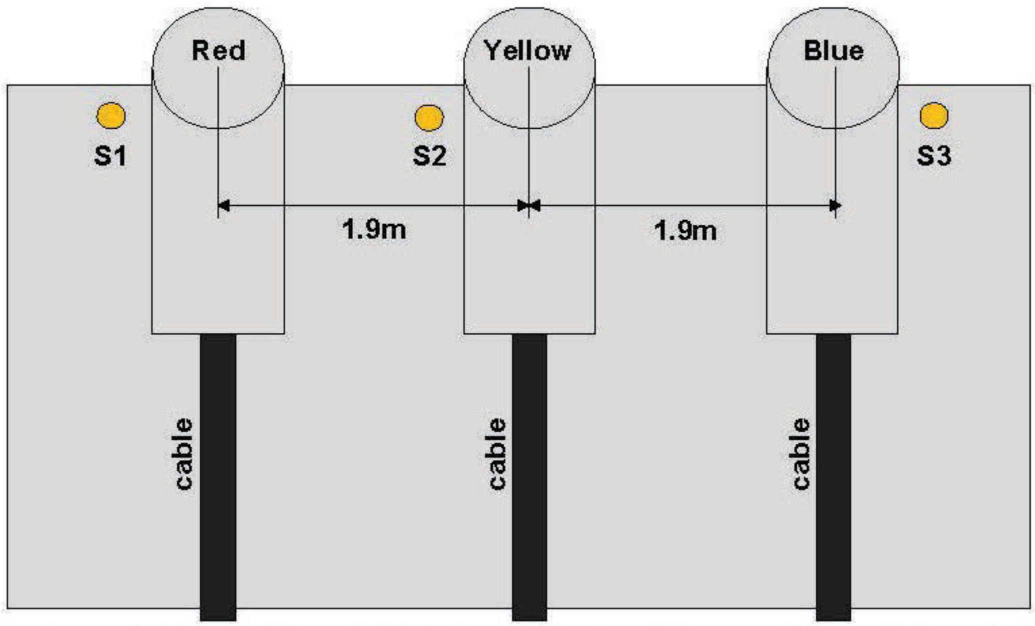
> Onsite measurement was carried out to investigate PD sources on a 230/66kV 150MVA transformer

> Situation:

- Transformer is equipped with 3 UHF PD sensors (as retrofit project)
  - Integrated into GIS PD monitoring system
  - DGA is showing constant PD activity

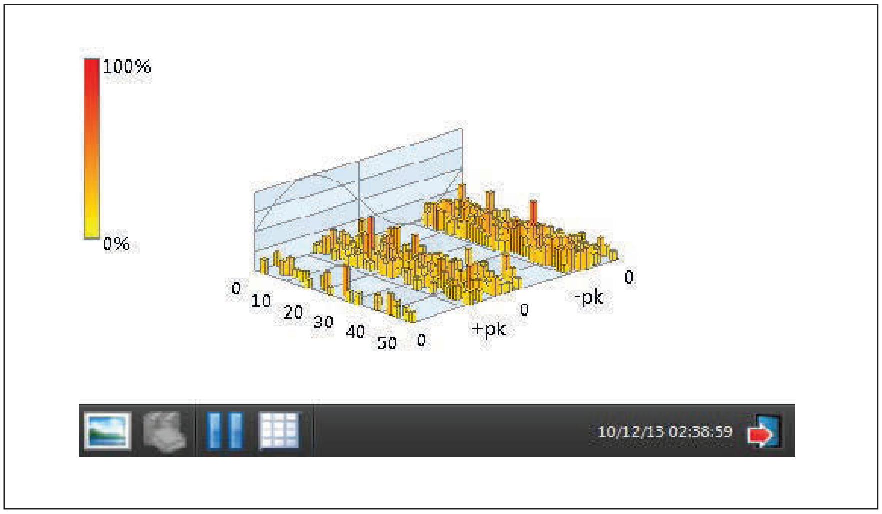
PD SENSOR LOCATION 1:
- Sensor not protruding into the main tank
- Limited sensitivity
- PD can be still detected

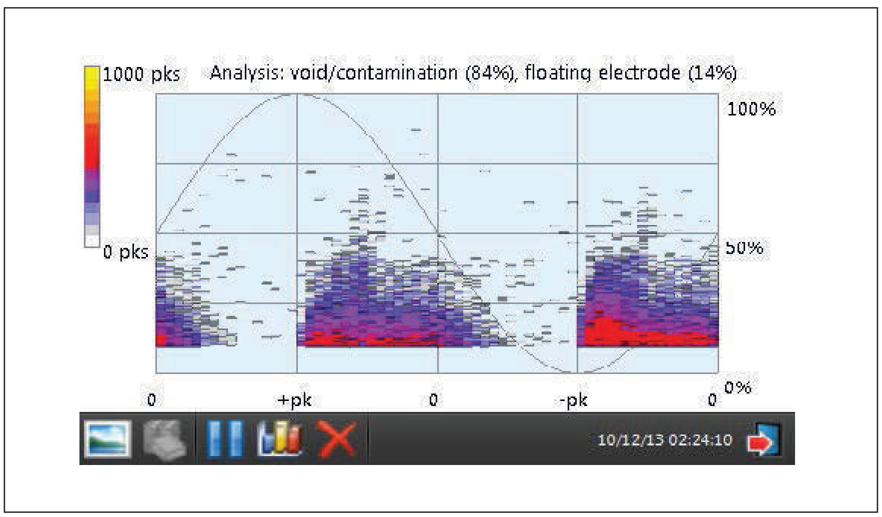
UHF PD MONITORING EXAMPLE



Transformer Layout: Sensor S1 and S2 having 1.9 meter distance.
Sensor S2 and S3 having about 2.5meter distance

UHF PD MONITORING EXAMPLE

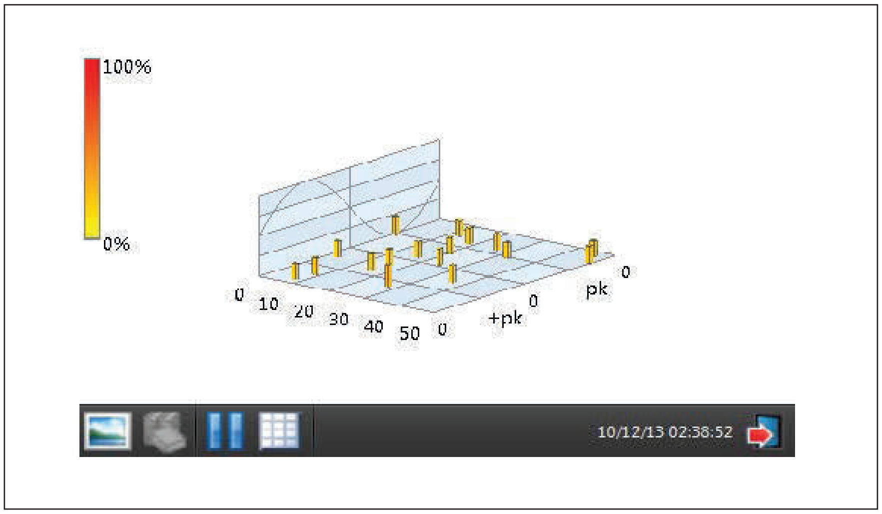


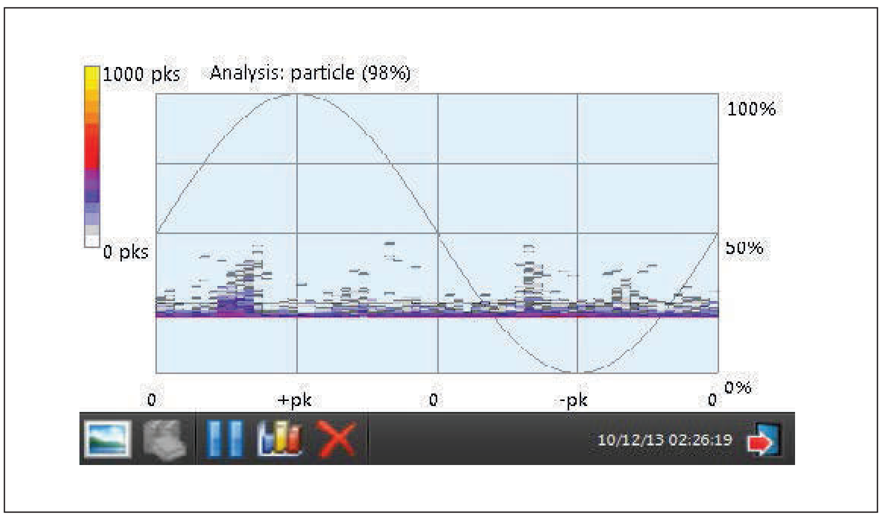


3D and PRPD pattern measured at S1 (Phase Red) with portable PDM is showing the same PD as recorded also with the connected monitoring system.

Conclusion out of that measurement:
Sensor 1 (red phase) is detecting active PD!

UHF PD MONITORING EXAMPLE

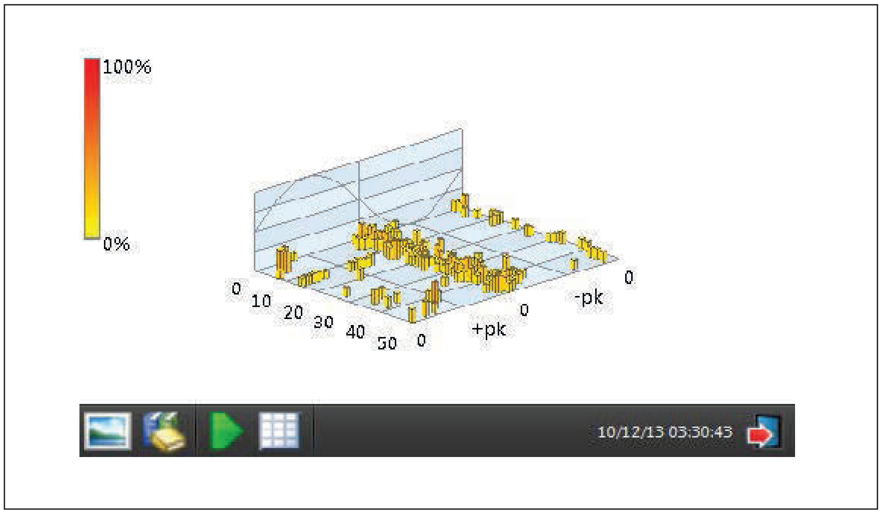


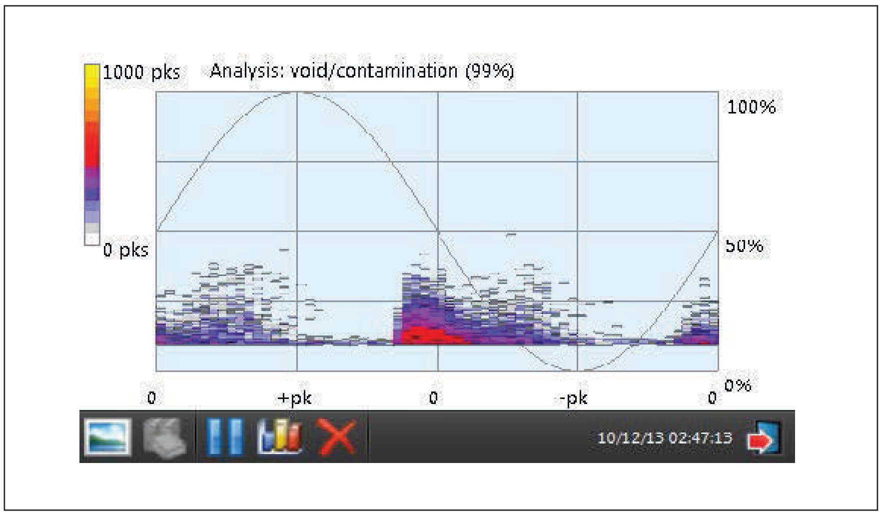


3D and PRPD pattern measured at S2 (Phase Yellow) with portable PDM is showing small phase related signals.

Conclusion out of that measurement:
Sensor 2 (phase yellow) is detecting active PD most probably from phase red and blue!

UHF PD MONITORING EXAMPLE

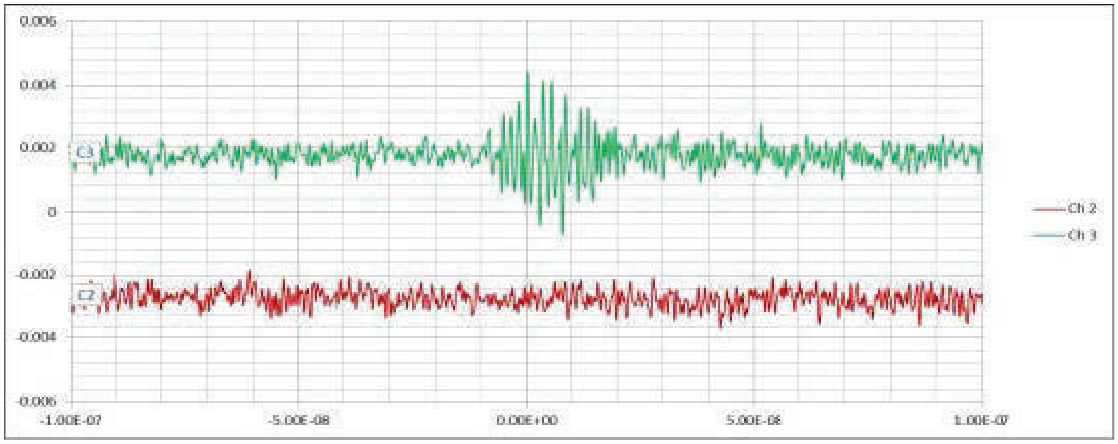


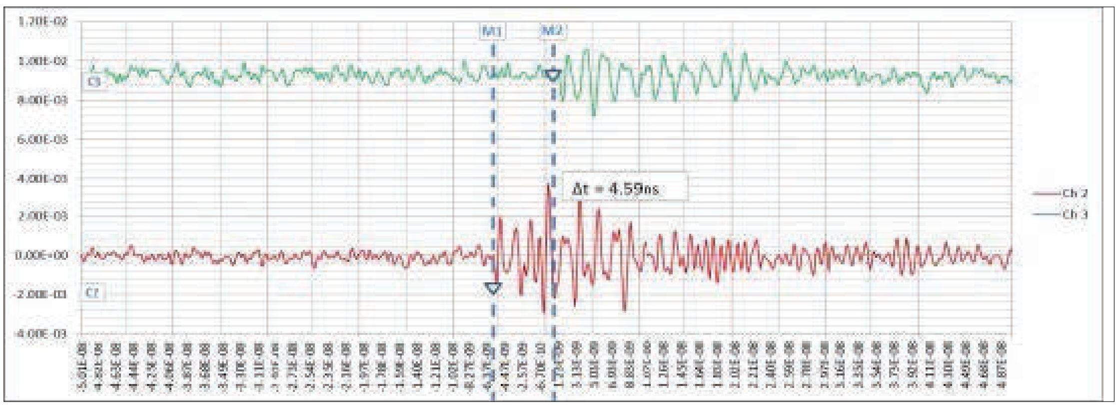


3D and PRPD pattern measured at S3 (Phase Blue) with portable PDM is showing the same PD as recorded also with connected monitoring system.

Conclusion out of that measurement:
Sensor 3 (Phase Blue) is detecting active PD!

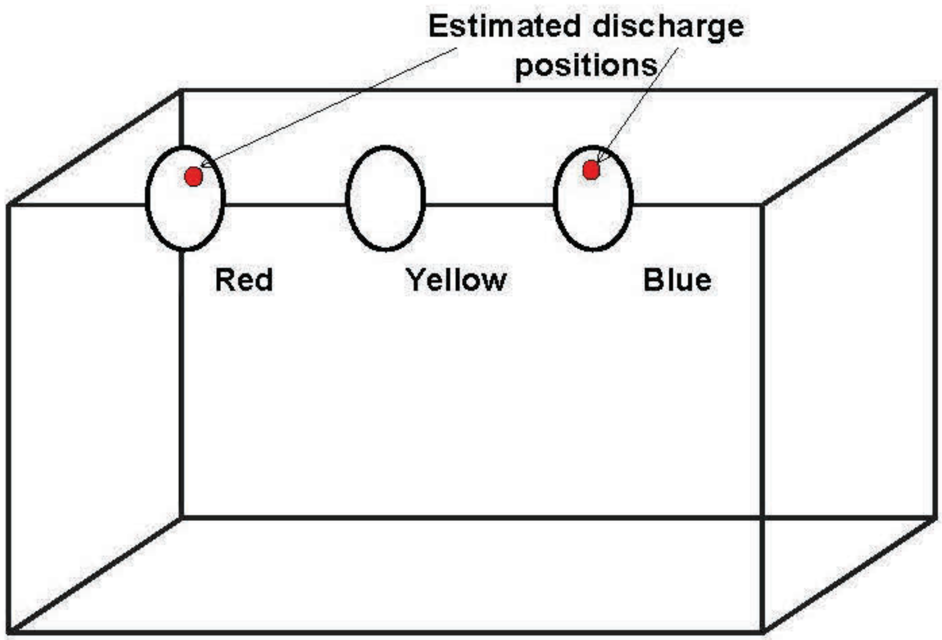
UHF PD MONITORING EXAMPLE





It was decided to conduct a time of flight measurement in order to get a better idea about the risk of the detected PD. The time of flight measurement showed that there were two independent PD sources active. The localization by using the time of flight data showed, that the discharges were originated close to the Red and Blue oil/ oil- bushing. As the discharge is stable and monitored by UHF PD and online DGA, it was decided to further monitor this discharge until a change will happen.

UHF PD MONITORING EXAMPLE



DECISION:

AS THE DISCHARGE IS NOT CHANGING AND MONITORING IS CONNECTED, NO FURTHER ACTIONS, JUST MONITOR THE TRANSFORMER

ECONOMIC BENEFITS, TEMPERATURE OVERLOADING, AN EXAMPLE (2 SLIDES)

1	Transformer rated power (MVA)	**100**
2	Overloading margin made available by monitoring (%)	**10**
3	Probability of overloading opportunity (hr/year)	**450**
4	Financial benefit from energy transmitted ($/MWh)	**80**

Yearly benefit from extra loading (1 x 2 x 3 x 4) **$360,000**

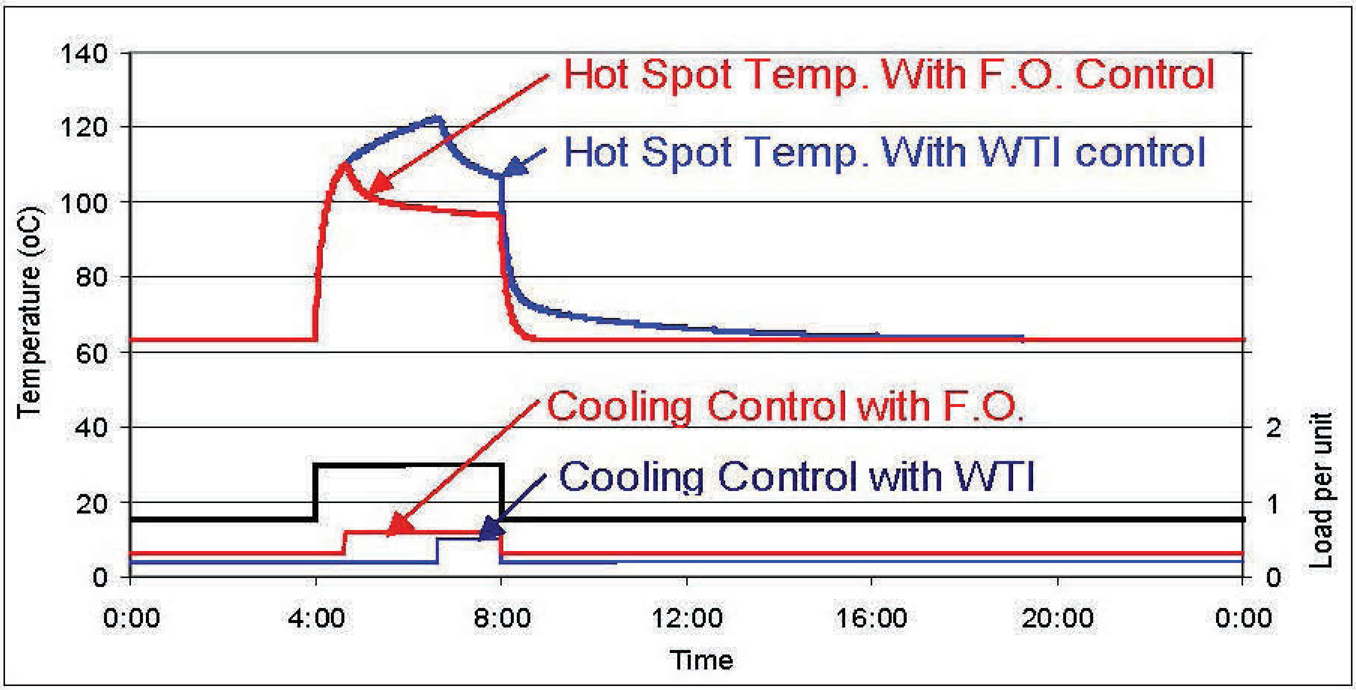
ECONOMIC BENEFITS, TEMPERATURE OVERLOADING, AN EXAMPLE (2 SLIDES)

5	Replacement cost of transformer ($)	**2,000,000**
6	Transformer normal life duration (hours)	**150,000**
7	Additional aging factor at 110% load (125°C)	**3.4**
	Cost for additional loss of life ((5 / 6) x 7 x 3)	**= $20,400**

Net yearly benefit from overloading:
$360,000 - $20,400 = $339,600

Comparison of Control Efficiency with WTI and F.O. Control

Information: Cooling control set at 110 oC

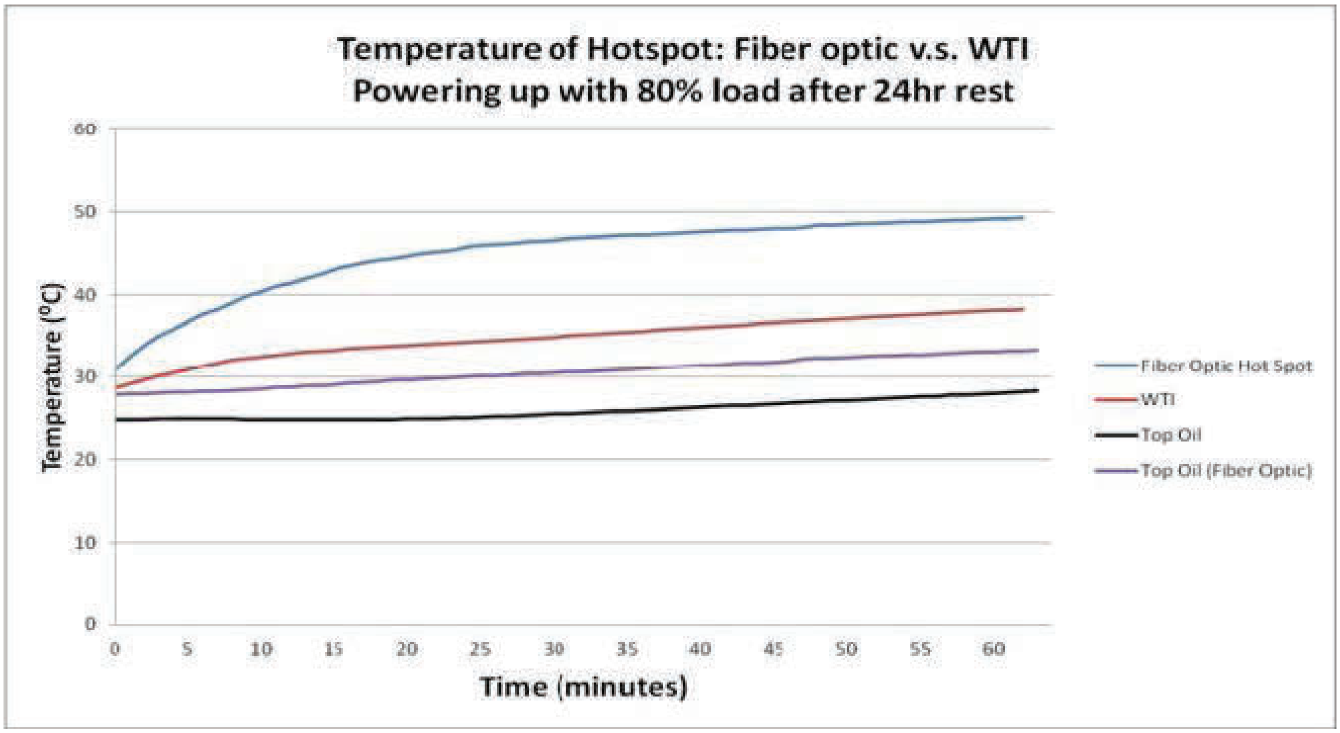


Insulation Aging, Estimation Base on Top Oil and Bottom Oil Models

POOR HOT SPOT TEMPERATURE KNOWLEDGE LEADS TO UNDERESTIMATION OF INSULATION AGING

- 3.3 hours, if cooling control is made on WTI
- 10.7 hours, if based on FO hot spot sensor

Another example of a heatrun test



Notes: These measurements were made on a phase-shifting transformer, used in a aluminum smelter. These transformers are known to exhibit very non-linear heating problems, which are very difficult to calculate or simulate. This is a good example about the usefulness of fiber sensing in power transformers !

CHALLENGES IN CONDITION MONITORING AND NEW TRENDS

TRANSFORMER MONITORING EXAMPLES

CONCLUSION

SUMMARY

> The previous cases are showing examples how and why users are using online condition monitoring (prevention of failures, prediction of overload conditions, insulation life time calculations).

> The examples also showing that the trust into online monitoring solutions needs to be increased. This can be done by:

- Using up-to-date data analyses and providing the user with easy to understand information instead of overwhelming him with a high number of scattered data and false alarms.
- Correlating online and offline data in order to increase confidence in the assessment
- Selecting parameters with respect to importance of the transformer/ asset, its failure history and the problem which should be detected.

> Upcoming and promising technologies in online monitoring are UHF partial discharge monitoring, Further above two examples are showing already the effectiveness. Further there will be a change in the technology of bushing monitoring as more accuracy is demanded. The technology will move to use voltage references from the same phase in order to increase the accuracy to enable the detection of moisture already in a very early stage.

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