Lessons from Action Planning in Power Transformer Monitoring

CIGRE Grid of the Future 2021

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Overview/Introduction

- Overview/Introduction
- Expectations
- Identifying Anomaly
- Planning
- Lessons Learned

- “Plans are of little importance, but planning is essential.”
  — **Winston Churchill**

Presenter Background

- National Grid UK: substation tech specialist, transformers
  - Go/NoGo decisions: timescales & actions
- National Grid US: Substation Asset Mgr.
  - >2,000 power transformers, many >80 years old…
- Doble Engineering
  - Asset management and Monitoring Technology

Expectations: Lewis Carroll

"Would you tell me, please, which way I ought to go from here?"

"That depends a good deal on where you want to get to," said the Cat

"I don't much care where …" said Alice.

"Then it doesn't matter which way you go," said the Cat.

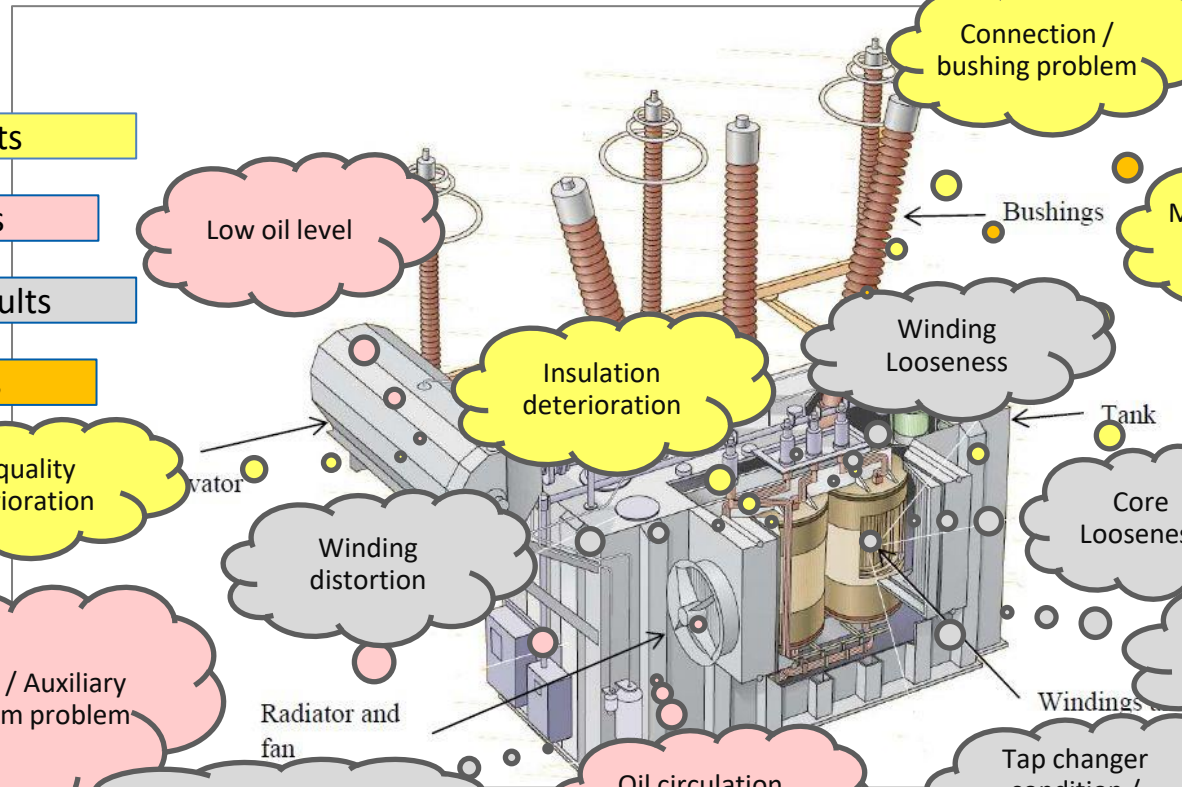
" … so long as I get somewhere," Alice added

"Oh you're sure to do that," said the Cat, "if you only walk long enough."

Expectations: ISO 18095 Transformer Failure Modes

Failure modes:

- Dielectric faults
- Thermal faults
- Mechanical faults
- External faults



Connection / bushing problem

Through fault e.g. lightning strike

Low oil level

Moisture ingress / content

Winding Looseness

Insulation deterioration

Arcing / electrical discharge

Oil quality deterioration

Core Looseness

Winding distortion

External damage/ disturbance

Overheating / Auxiliary cooling system problem

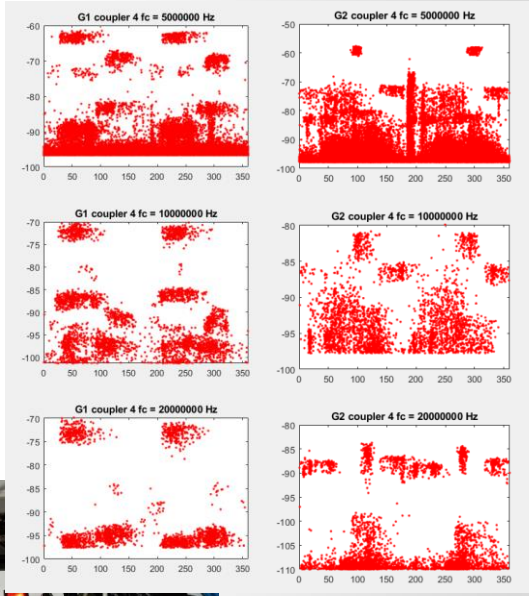
Oil leak

Oil circulation system problem

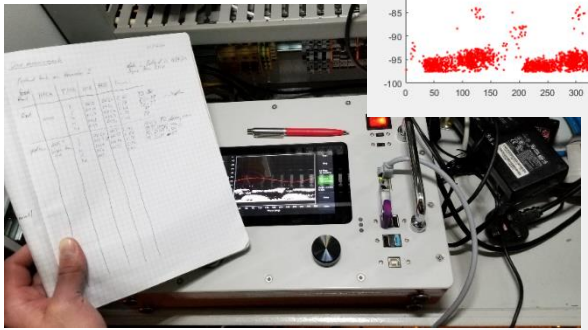
Tap changer condition / problem

Identifying Anomaly: Generator PD Couplers

- "It didn't used to do that."



- History can provide a 'normal'
- Something changed…
- Who can tell?
- Detect v. diagnose

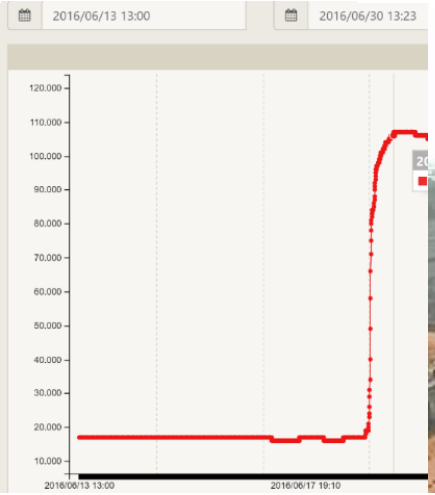


Monitoring: Were you expecting that?

Detection DGA on unit transformer: step change 20ppm -> 120ppm in ~6 hours

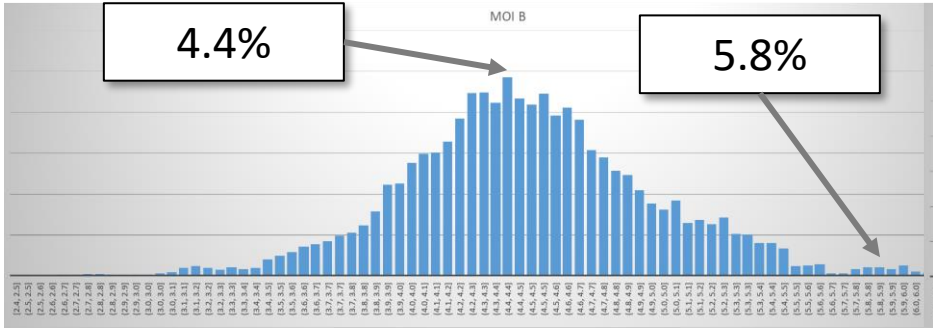
High level alert generated based on **detection** not **diagnostics**

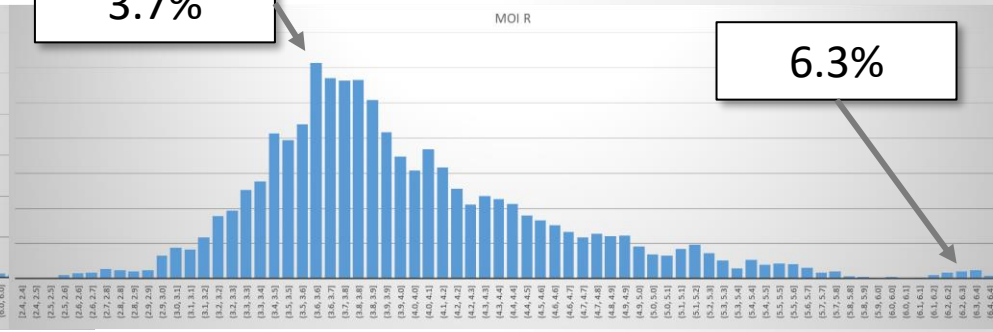
What is the action? Take a sample for lab test?

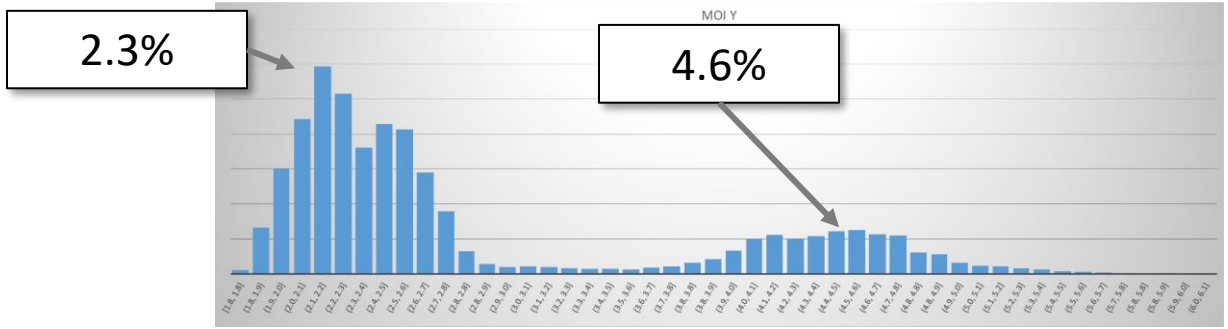


Follow the *risk analyzed* plan which was agreed when the monitor was installed!

Moisture in 3 single phase units in 3 phase bank



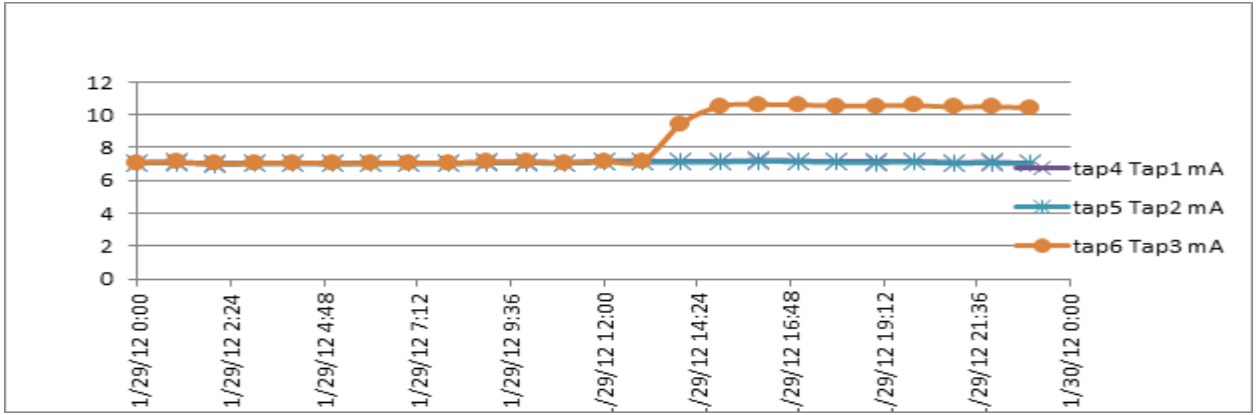




Expectation: 3 single phase units in a bank, 3 similar moisture levels…
Is this normal? At which level do we set alerts?

Planning Response to Rapid Onset Failure Mode

Monitoring Trench COT bushings, known to have a catastrophic failure mode, on >65 transmission transformers at up to 345kV[1]. Current rose rapidly for one bushing, generating a top level ACTION alert. The operators had a written and agreed policy requiring switching out and offline testing after an ACTION alert.



As a result of applying the policy a likely catastrophic failure was avoided.

1: "Condition Monitoring in the Real World", K. Wyper *et al*, 80th International Conference of Doble Clients, Boston, USA, 2013

Planning Response to Graceful Failure Mode

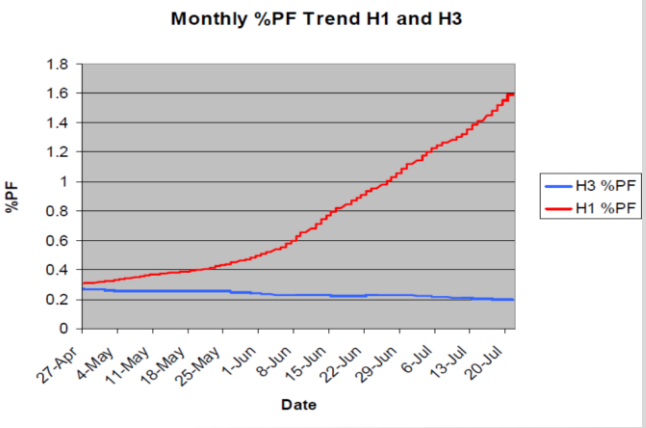
Bushing monitoring was used to identify a deteriorating bushing.

Alert limits and response plans were put in place before the bushings were returned to service after a maintenance outage.

The rise in power factor was detected and failure averted. Forensic details in the paper[1].

March 2008 Off-Line C1 Test Results

ID	Serial	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Cap(pF)
H1	1796658	.26	401	10.007	1.488	0.0410	0.28	394.74
H2	05-105312	.27	492	10.007	1.869	0.0500	0.27	495.89
H3	1797916	.26	406	10.007	1.502	0.0430	0.29	398.36
X1	96-71129	.26	377	10.011	1.421	0.0380	0.27	377.03
X2	3030410394	.24	385	10.008	1.420	0.0390	0.26	376.74
X3	96-71113	.26	381	10.007	1.431	0.0390	0.27	379.57
N	04-218906	.68	464	10.008	1.739	0.1090	0.60	461.26



1: "Chronicling the Degradation of a 345kV GE Type U Bushing", R. Wancour *et al*, 76th International Conference of Doble Clients, Boston, USA, 2009

Asset Management Case: Plans and Lessons

- Case presented by Tommy Salmon of Dominion Energy
  - Life of a Transformer 2020 “Making Condition Monitoring Matter”
  - Are you prepared for the ‘what ifs’?
  - Monitoring DGA as a detector on a power transformer

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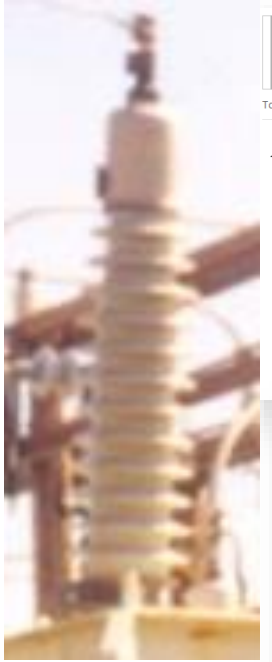
Asset Management Case: Plans and Lessons

Alarm Thresholds					
	Hydrogen (H_2) ppm	Ethylene (C_2H_4) ppm	Acetylene (C_2H_2) ppm	Sample Interval[2]	Action
Normal Condition				12 Hours	
Level 1	100	100	5	4 hrs	Increase awareness. Develop Contingencies
Level 2	1000	200	10	2 hrs	Remove from Service

Trend Thresholds	
Gas	Rate of Change
Hydrogen (H_2)	25 ppm/day
Ethylene (C_2H_4)	10 ppm/day
Acetylene (C_2H_2)	5 ppm/day

Unplanned Response: ‘Phone a Friend’



Westinghouse O+ Bushing

Wed 2018-02-21 9:18 PM
dobleARMS Notifi
[redacted] IDD306 A
To Richter, Susan

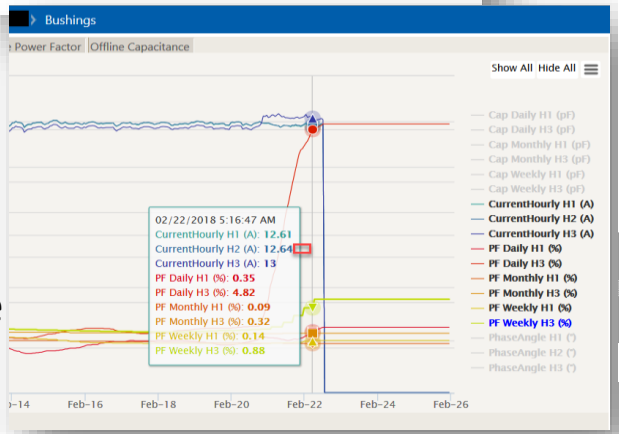
ARMS Notification

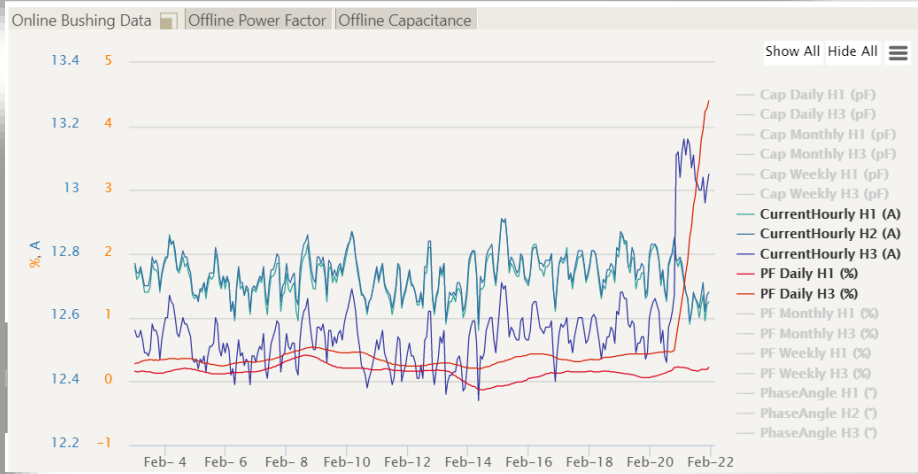
Alert: IDD Alert IDD306 ALERT has
SLL5308-1.

Alert Level: Alert
Problem: PF daily trend sever
Urgency: Investigate immedia

Asset: [redacted]T1
Source: Asset > Transformer > Digital > IDD306 ALERT
Time: Feb 21 2018 9:17PM Eastern Standard Time

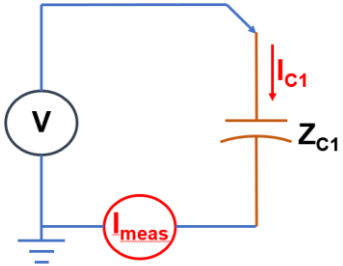
dobleARMS Notifications	[redacted] Voltage Below Limit	Thu 2018-02-22 11:24 AM
dobleARMS Notifications	[redacted] 2967 OPEN	Thu 2018-02-22 11:24 AM
dobleARMS Notifications	[redacted] -3 CLOSED	Thu 2018-02-22 11:18 AM
dobleARMS Notifications	[redacted] - IDD306 ALERT Alert	Wed 2018-02-21 9:18 PM
dobleARMS Notifications	[redacted] - IDD303 ALERT Warning	Wed 2018-02-21 2:22 PM
dobleARMS Notifications	[redacted] - IDD300 ALERT Investigate	Wed 2018-02-21 8:21 AM
dobleARMS Notifications	[redacted] C Battery back to normal	Wed 2017-12-13 10:57 AM
dobleARMS Notifications	[redacted] - DCBattery Above Limit Limits Exceeded	Wed 2017-12-13 4:20 AM

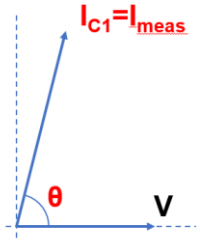


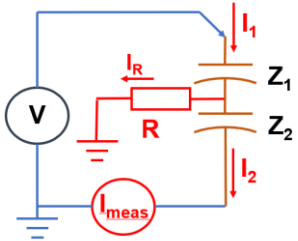


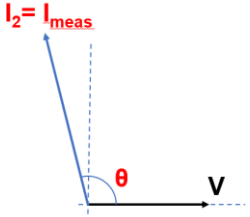
13kV Tertiary Bushing: Anomaly? Recovery?

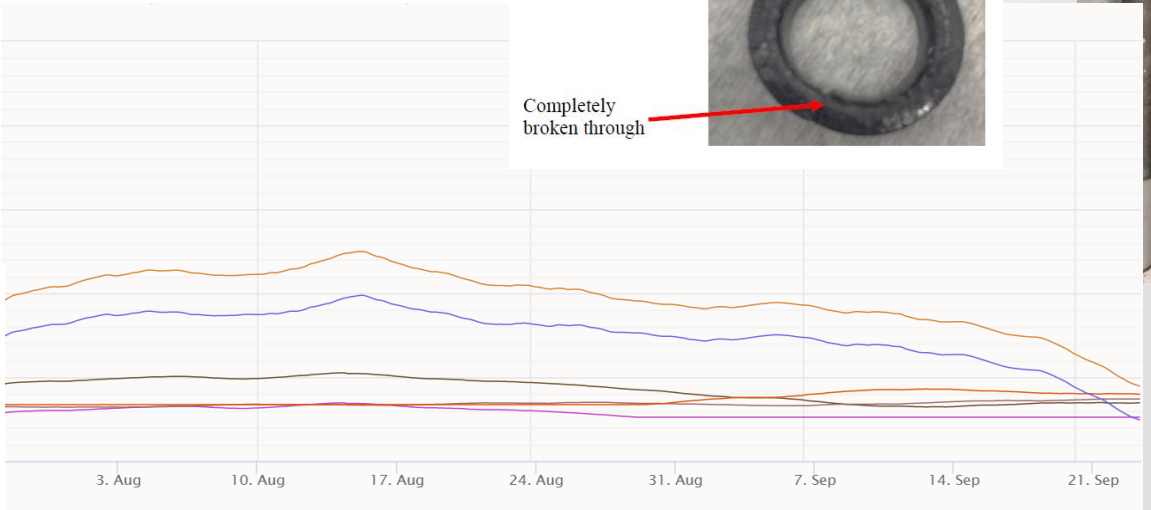
- Tertiary bushing with both Relative and True Power factor
  - Starts out going bad, then looks like it's getting better
  - Who's checking? What do they know?











1. "Negative Power Factor of Doble Insulation Test Specimens (An Analysis)", D. Kopaczynski, S.J. Manifase, 55th International Conference of Doble Clients, Boston, USA, 1987
2. "Review of Negative Power Factor Test Results And Case Study Analysis", L. Pong, 70th International Conference of Doble Clients, Boston, USA, 2002

- **Plan ahead: what to do, who to do it, when…**
- **What to monitor**, and how to monitor, are technical decisions:
  - Failure modes, Detectability, Time-scales, Likelihood, Expectations, specifications
- **Whether to monitor** is a business decision
  - Include the organization, key stakeholders, the spreadsheet guys, the money guys
- **"Mode of failure, time to failure"**
  - **When you have data: does it make sense?**
- **Plan ahead – follow the plan ('the time to fix the roof is when the sun is shining')**

"Condition monitoring is more than just a box with lights on" C. Johnstone, NG UK

Thank You!

Questions? Comments? Feedback?

Dr. Tony McGrail
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'Always appreciate the opportunity to learn new things.'