Understanding offline testing and condition monitoring results for bushings

Dr. Tony McGrail
Solutions Director: Asset Management & Monitoring Technology
Doble Engineering

Bushings

When bushings go bad

Introduction

- The aim of this presentation is to review
  - The basics of bushing offline testing
  - Motivations for bushing condition monitoring
  - Examples of bushing saves
  - Some of the features which appear in good monitoring applications.
- We have successful bushing saves from many locations, some of which have been presented at the International Conference of Doble Clients; full papers available on request.

Motivation: Industry Experience

- A technical paper by Sokolov and Vanin at the 1997 International Conference of Doble Clients[1] noted results of a survey:
  - *…irrespective of their geographical location or differences in design, high-voltage bushings remain one of the weakest components and may have been the cause of up to 30% of all of the large transformer failures.* ***Because of preventive maintenance, the number of defective bushings removed from service annually is ten times the number of failed bushings.***
- CIGRE Working Group A2.43:
  - *A failure of any of the bushings results in a transformer failure as well. According to various researches,* ***bushings cause 5 to 50 % of the total number of transformer failures****, often followed by transformer damages, fires, huge collateral damage and ecological incidents[2].*

1: "Evaluation and Identification of Typical Defects and Failure Modes in 110-750 Kv Bushings", V. Sokolov & V. Vanin, 64th International Conference of Doble Clients, Boston, USA, 1997
2: CIGRE Technical Brochure 755 "Transformer Bushing Reliability" 2019

Motivations: safety, financial, reliability, management

- All assets will fail – it's a matter of 'when' not 'if':
  - We can prevent failures if we have adequate warning of deterioration
  - Regular offline testing *could* give such warning
  - But if you only test every 6 or 10 or 12 years, you may miss a few failures
- Bushing failure *usually* leads to transformer failure[1,2]:
  - The results may be catastrophic – safety impacts severe
  - Business interruption costs and environmental clean-up costs may greatly exceed asset replacement costs
- Appropriate monitoring may prevent failures:
  - Detect and diagnose failure modes and have a planned response!
- ISO 55001 (2014): Asset Management
  - Section 9: **Performance Evaluation**
  - Monitoring, measurement, analysis, audit, review, improve

1: "Evaluation and Identification of Typical Defects and Failure Modes in 110-750 Kv Bushings", V. Sokolov & V. Vanin, 64th International Conference of Doble Clients, Boston, USA, 1997
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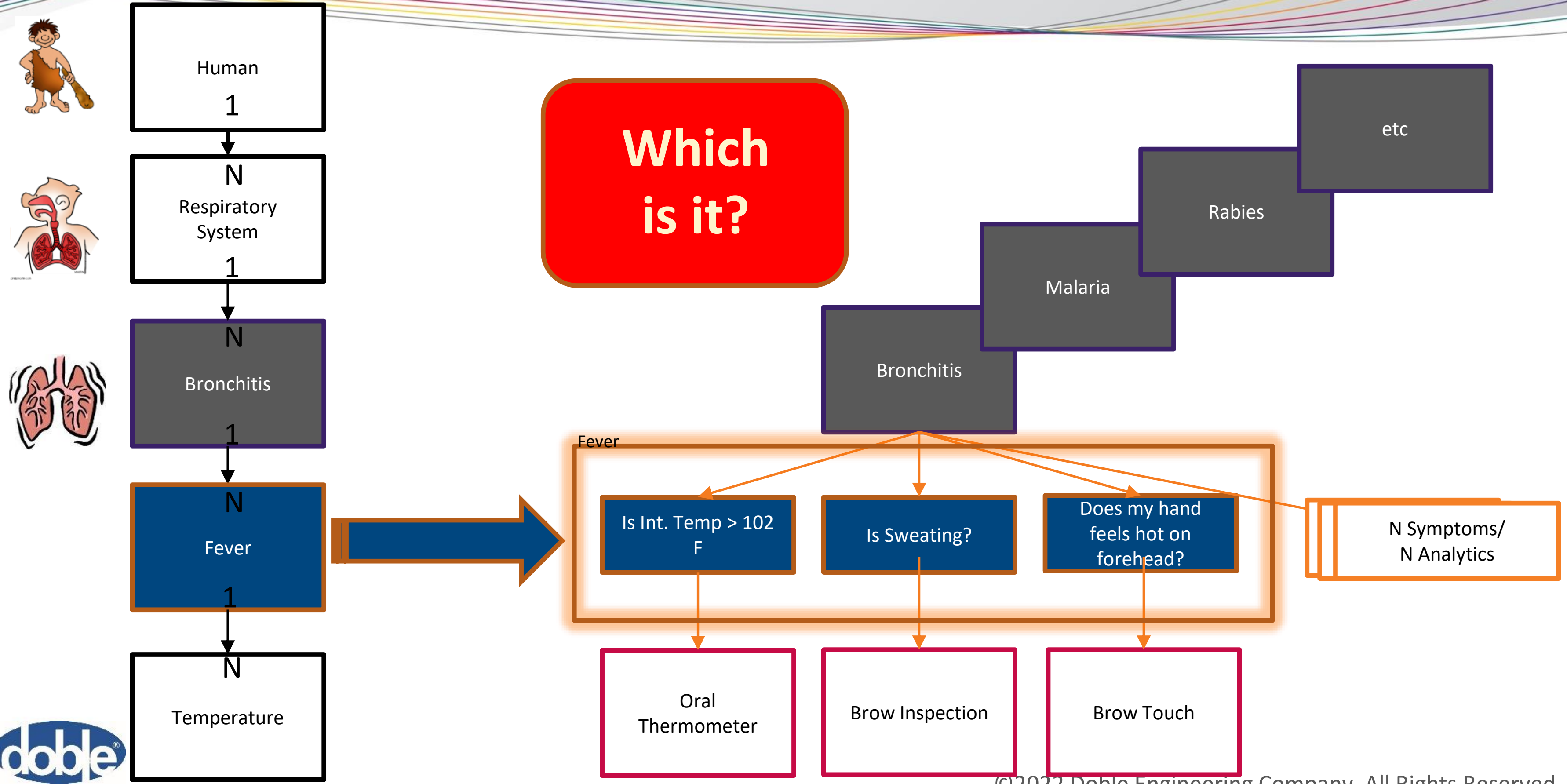
Motivation: some failure modes

- As the insulation deteriorates, the bushing will eventually fail
  - Electrical stress will accelerate ‘natural’ deterioration
- What can cause deterioration? Some modes include:
  - Moisture/contamination ingress through seals, filler caps or flanges
  - Damaged outer covers (porcelain or other material) allowing ingress of moisture/contamination
  - Damage during storage, from animals, vandalism etc
  - Manufacturing defects which provide uneven electrical stress
  - Overheating, leading to?
- Symptoms?
  - What can we measure and what do the measurements mean?

Symptoms? Symptoms of what, exactly?



Motivation: Bushings and Timescales to Failure

- Bushings generally have two distinct failure mode ***timescales***:
  - ‘Graceful’: exemplified by GE Type U bushings where deterioration may take place over several weeks to months[1]
  - ‘Rapid Onset’: found in Trench COT(A) bushings where deterioration may become evident over a few hours[2]

1: “Chronicling the Degradation of a 345kV GE Type U Bushing”, R. Wancour *et al*, 76th International Conference of Doble Clients, Boston, USA, 2009
2: “Condition Monitoring in the Real World”, K. Wyper *et al*, 80th International Conference of Doble Clients, Boston, USA, 2013

Motivation: Identify Failure Modes to Prevent Failure

- A bushing allows a current to pass through a barrier
  - Usually, a conductor at elevated voltages and a grounded barrier
- If the insulation deteriorates, the bushing may be compromised and then fail
  - And transformers, breakers etc may fail as a consequence[1]

- Check 2019 Doble Client Conference paper:
  - "Bushing Monitoring – What We Can Measure And Implications For Deterioration Detection"
  - Paper discusses thermography/IR, PD, current/phase, power factor and capacitance etc
- **Measuring parameters which relate to the deterioration <u>makes sense</u>**
- As we're interested in the deterioration of insulation,.
  - We can measure currents/voltages and then derive other parameters

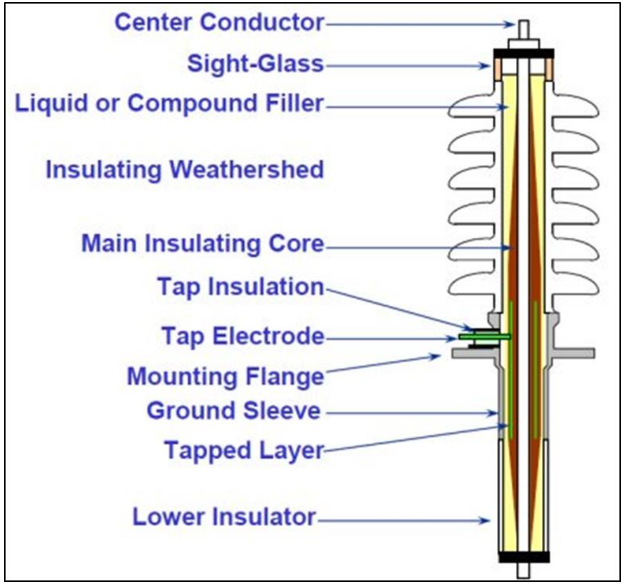
1: CIGRE Technical Brochure 755 "Transformer Bushing Reliability" 2019

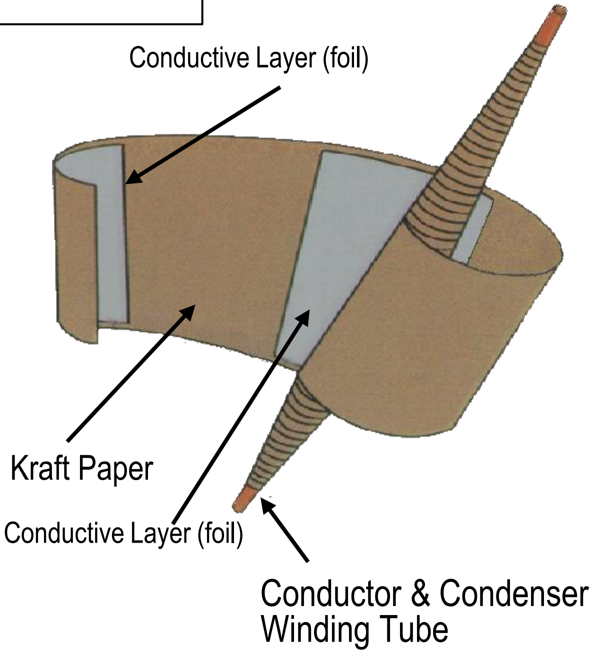
IEEE Standards

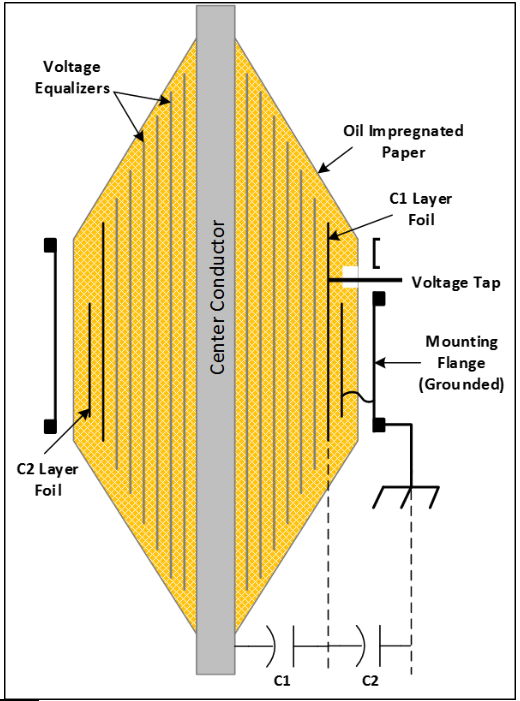
- **IEEE Std C57.19.00™** - IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings
- **IEEE Std C57.19.01™** - IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.
- **IEEE Guide C57.19.100™** - IEEE Guide for Application of Power Apparatus Bushings.
- **IEEE Std 4™** - IEEE Standard Techniques for High Voltage Testing.
- **IEEE C57.143™ -** IEEE Guide for Application for Monitoring Equipment to Liquid-Immersed Transformers and Components

Inside a bushing… much can go wrong

Bushings are complex devices!





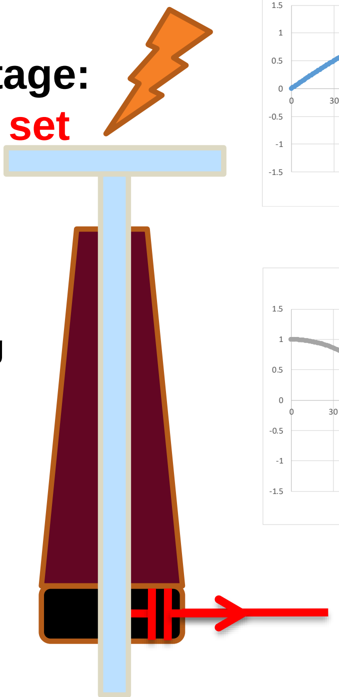


The conductive layers even out the voltage stress

Power Factor: Offline applied voltage & measured current

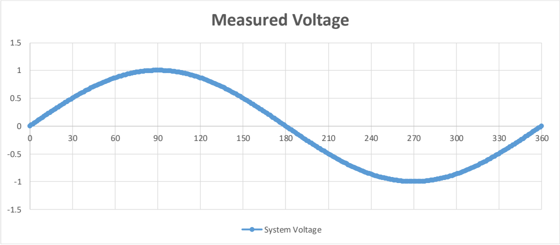
We measure applied voltage and leakage currents very accurately: magnitude & phase.

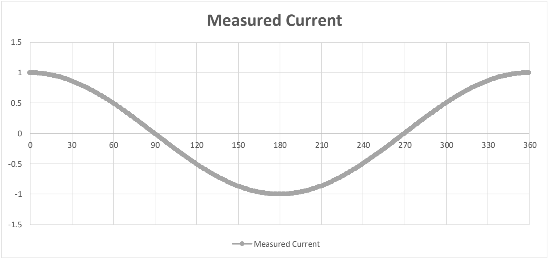
Applied Voltage: from a test set



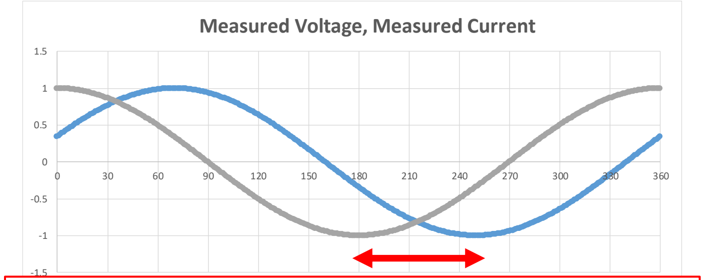
Bushing

Leakage Current





Pure inductors/capacitors have a phase difference of 90º between current & voltage



Current/Voltage phase difference

The variation from 90º is a measure of insulation quality: the power factor. A variation of 0.1º is **significant** change.

Leakage Current

- Bushing insulation is not perfect:
  - There is a capacitive/resistive leakage which flows to ground
  - Each bushing will have its own leakage current depending on:
    - System voltage driving the current
    - Bushing characteristics
- Variation in the leakage current may thus indicate:
  - Variation in applied voltage
  - Variation in bushing characteristics
- We need to identify the root cause of variation!
  - Which we can do – and thus save bushings from failure

Interpreting offline bushing test results

- Measurement data and derived data

Transformer - Bushing C1 Tests

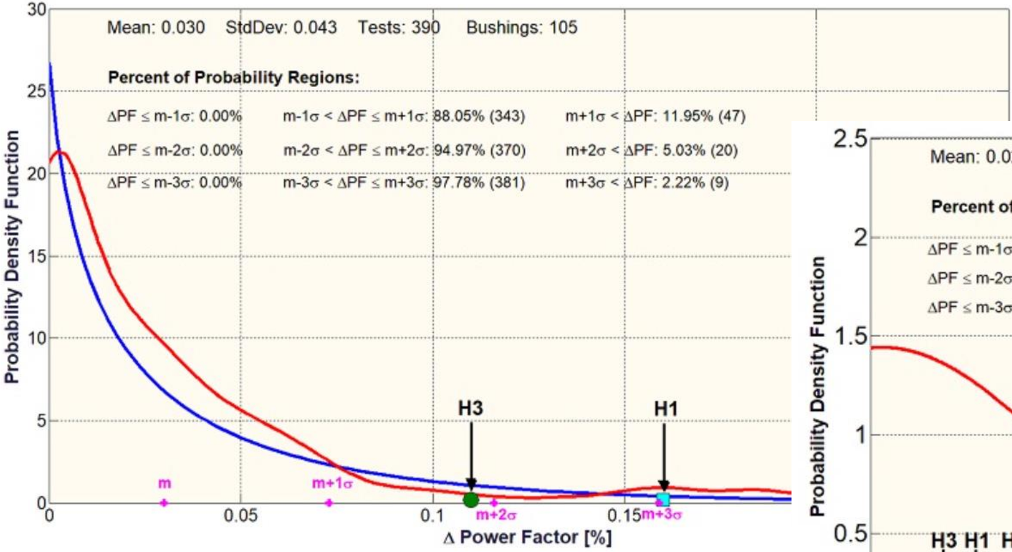
☐ Apply C1 Correction Factor from First Bushing to All Bushir

☐ ITC ☑ Temp Corr. Table

Test No	Bushing Nameplate					Test Mode	TEST kV	Capacitance C (pF)	POWER FACTOR %			DIRECT		IR
	Dsg.	SERIAL #	CAT. #	PF	Cap. (pF)				Measured	@ 20°C	Corr Factor	mA	Watts	
11	H1	K728058		0.26	426.00	UST-R	10.01	416.76	0.29	0.29	1.000	1.5710	0.0450	G /
12	H2	K7282187		0.25	425.30	UST-R	10.00	416.24	0.28	0.28	1.000	1.5690	0.0440	G /
13	H3	K7296687		0.30	402.80	UST-R	10.01	420.10	2.41	2.41	1.000	1.5840	0.3810	I /
14	X0	41445787		0.29	621.70	UST-R	10.00	624.24	0.32	0.32	1.010	2.3530	0.0750	G /
15	X1	41446287		0.30	618.60	UST-R	10.01	620.66	0.34	0.34	1.010	2.3400	0.0800	G /
16	X2	41445387		0.30	613.30	UST-R	10.01	623.86	0.34	0.34	1.010	2.3520	0.0800	G /
17	X3	41444287		0.30	615.80	UST-R	10.01	617.60	0.34	0.34	1.010	2.3280	0.0780	G /
18						UST-R								
19						UST-R								

Interpreting offline bushing test results

- Population analysis: does it look bad?



https://www.transformer-technology.com/community-hub/technical-articles/1541-managing-bushings-from-statistics-to-singularities-where-to-focus-tony-mcgrail-byline-transformer-technology.html

Offline v. Online

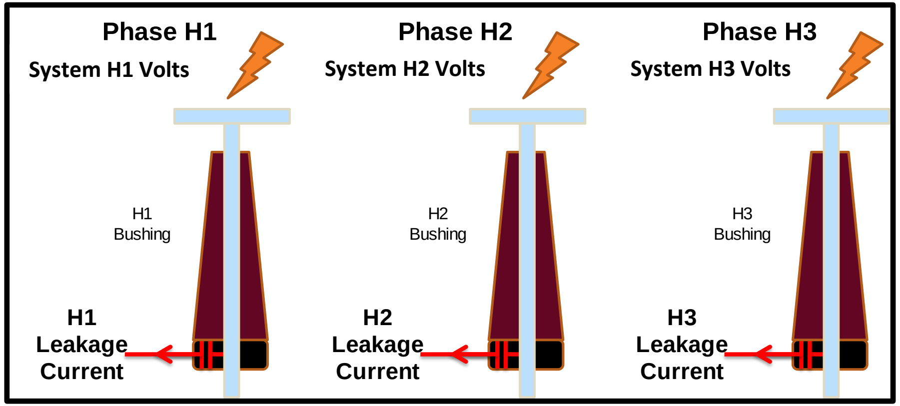
IEEE C57.143: “IEEE Guide for Application for Monitoring Equipment to Liquid-Immersed Transformers and Components”

Abstract: Identification of the key parameters that can be monitored for obtaining an indication of the condition of liquid-immersed transformers is covered by this guide. It also covers risk/benefit analysis, sensor application, and monitoring systems application. *This guide does not cover interpretation of monitoring results*

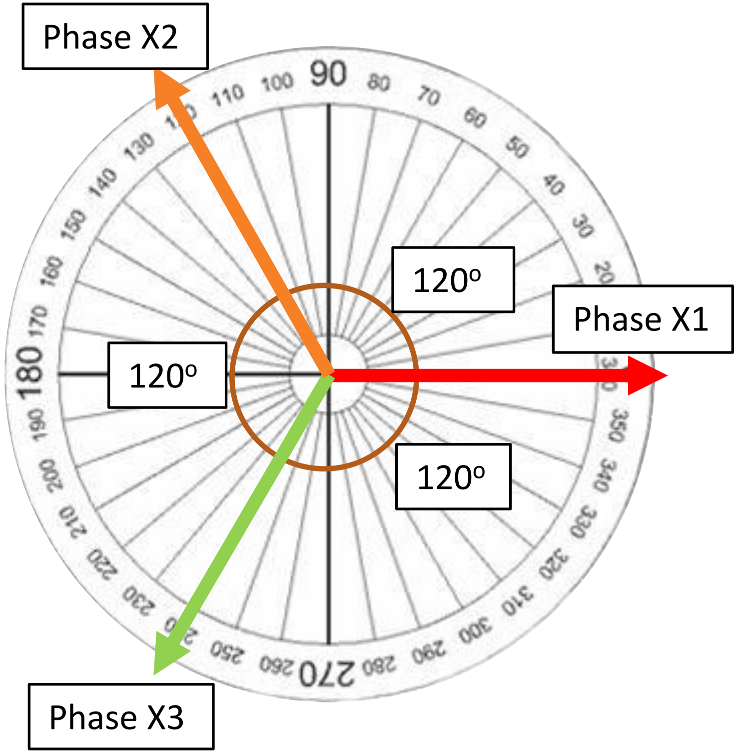
Keywords: IEEE C57.143, liquid-immersed transformers, transformer monitoring

Monitoring: Parameters

- There are several parameters which may be monitored to indicate deterioration:
  - Leakage current: which allows ***derivation*** of power factor, capacitance and harmonic content
  - Temperature – but at which point(s) on the bushing?
  - EMI/RFI: allows detection and diagnostics of partial discharge (PD): this may be a complex analysis as PD signals propagate extensively



Ideal 3 phase system – balanced voltages, currents etc

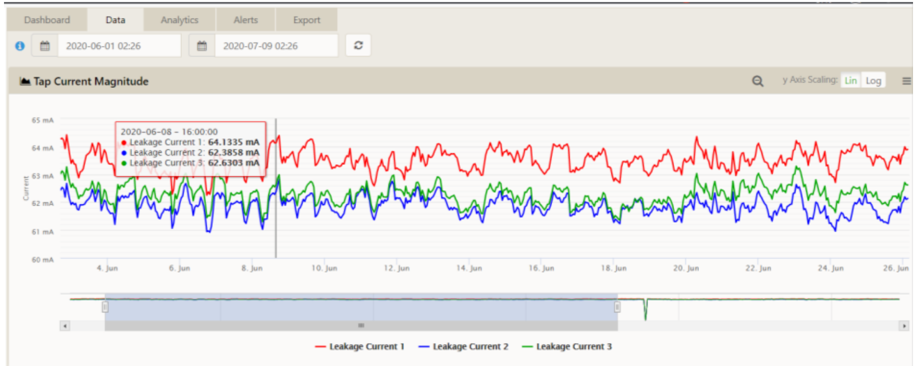


- **Relative phase angles** all equal
  - X1->X2 = 120°
  - X2->X3 = 120°
  - X3->X1 = 120°
- **Magnitudes all equal**
  - |X1| = |X2| = |X3|
- Applies to system voltages, currents including leakage currents
- Sum of currents/voltages is, *in theory*, zero

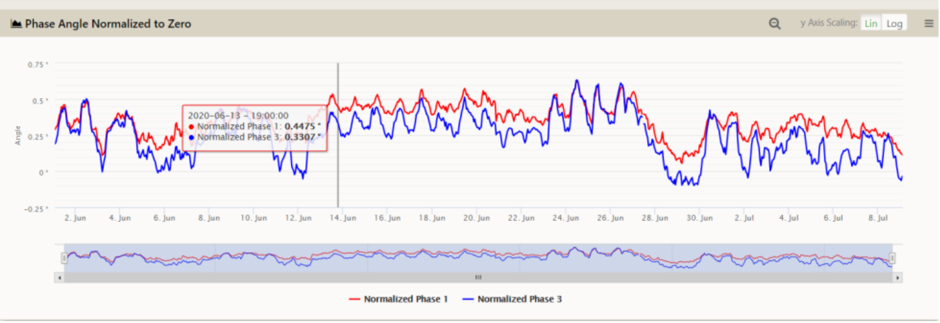
In a perfect world: leakage currents are identical

The world is not perfect… system voltage magnitude and phase variations are usually present.

This chart shows leakage current magnitude for each of three bushings in a set: the magnitudes vary over time, and also vary relative to each other



This chart shows relative phase of currents for two of three bushings in a set: each should be 120º. We have normalized to 0º so we can easily measure variation from 'ideal'.

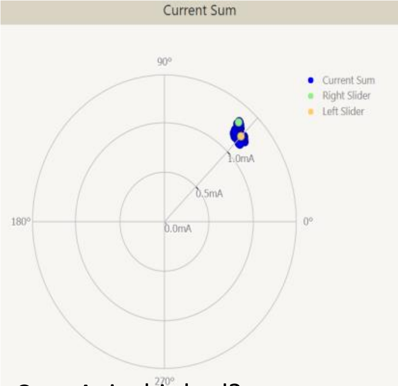


The three relative phase angles sum to zero – all information is available in any 2 values. A chart with three angles is also to be made available.

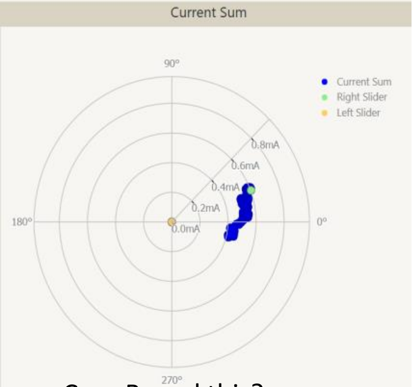
In a perfect world – 3 balanced Phases Sum to Zero

- Sum Current can be a detector, but system variations mean **too many false positives**
- Doble moved on from this ~20 years ago: look at individual currents

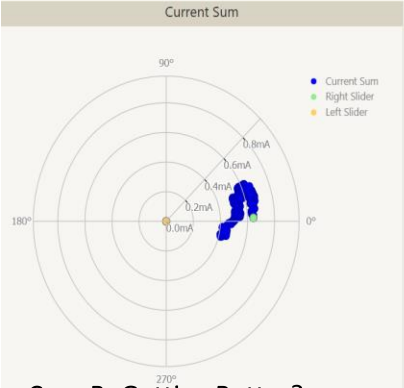
The sum current chart is available in Doble PRIME for ‘old time sake’…



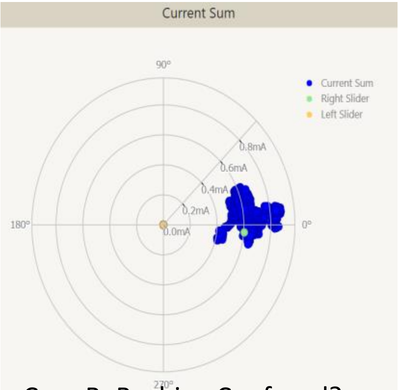
Case A: is this bad?



Case B: and this?



Case B: Getting Better?

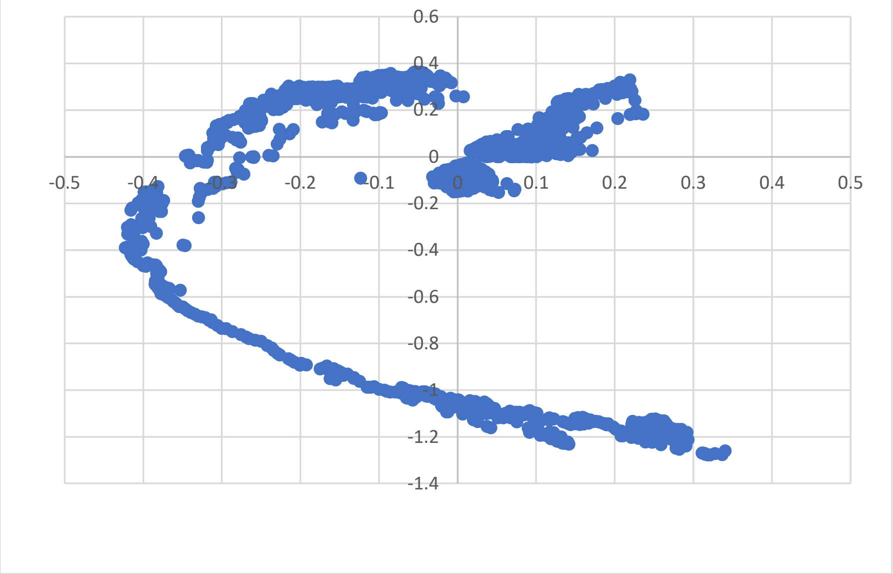


Case B: Bushing Confused?

The sum should be zero: the cases here are false positives!

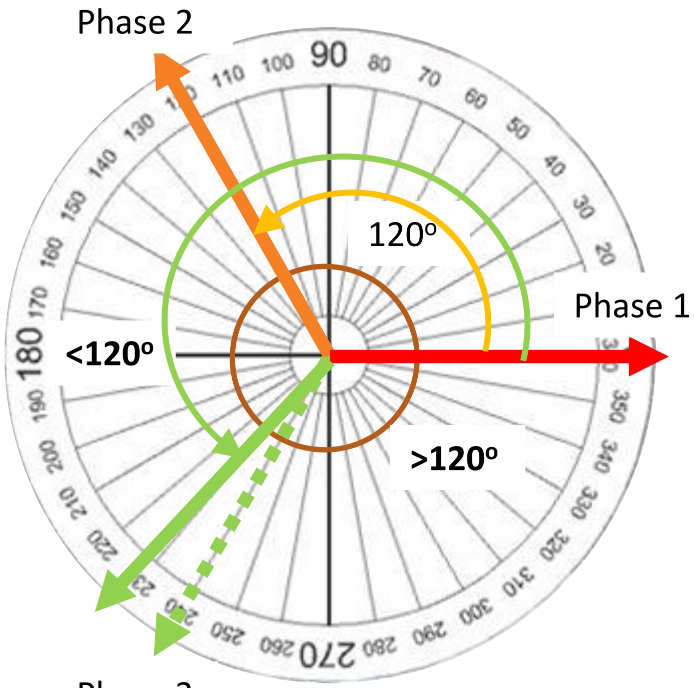
In a perfect world – 3 balanced Phases Sum to Zero

The sum current chart is available in Doble PRIME for 'old time sake'…



What does this mean?

How much phase change would a 'bad bushing' give?



- Relative phase angles **NOT** all equal
  - X1->X2 = 120°
  - **X2->X3 = <120°**
  - **X3->X1 = >120°**
- A variation of 0.2° or less would indicate a bad power factor

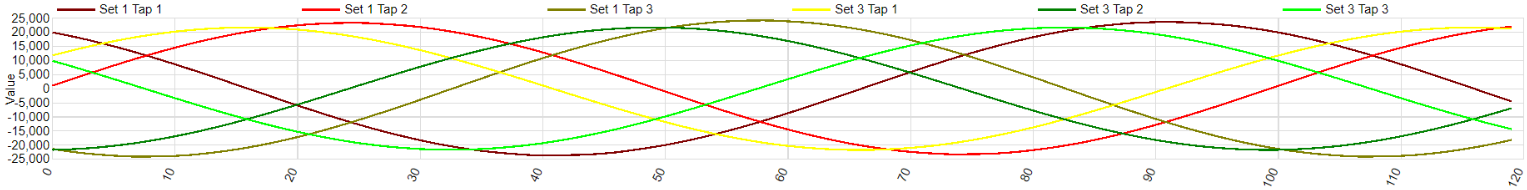
How do we find this against the 'noisy' system voltage variation?

A simple way is to use averaging.

Power Factor: Offline, Online Relative and Online True

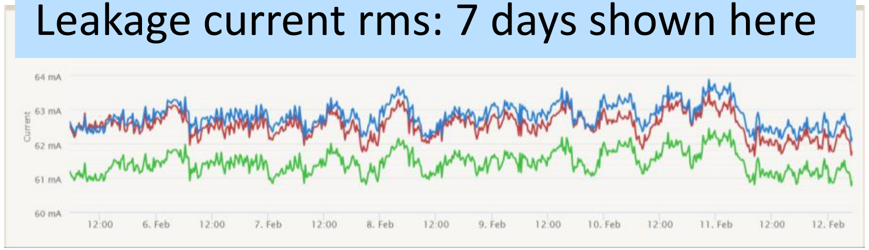
- Three measurements – why are they not all the same?
  - In offline tests we supply the voltage and can control it very precisely
  - In online measurements we have to find a way to find the voltage
  - The instrument transformer (voltage transformer) is ALSO in the measurement
- We measure both relative power factor (**RPF**) and true power factor (**TPF**) **simultaneously**
- **We can identify either bad bushings or bad IT/VTs**

What to measure?

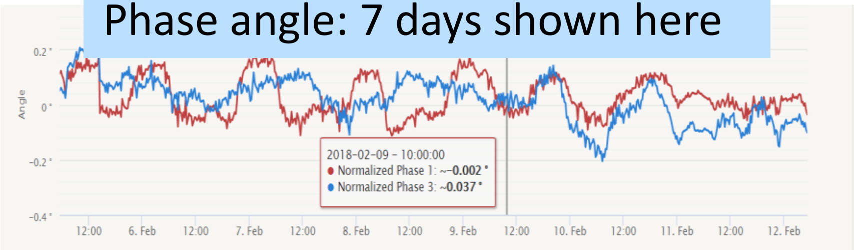


Capture raw sine-waves for every current/voltage reading - these are then used to calculate:

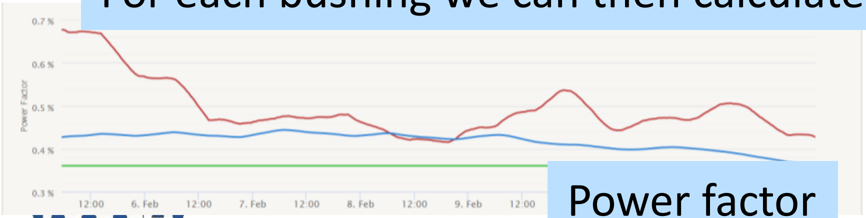
Leakage current rms: 7 days shown here



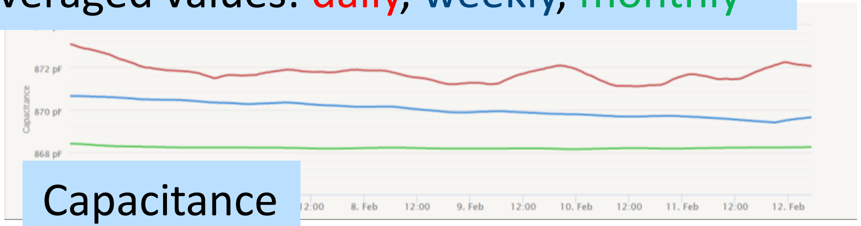
Phase angle: 7 days shown here



For each bushing we can then calculate averaged values: daily, weekly, monthly



Power factor



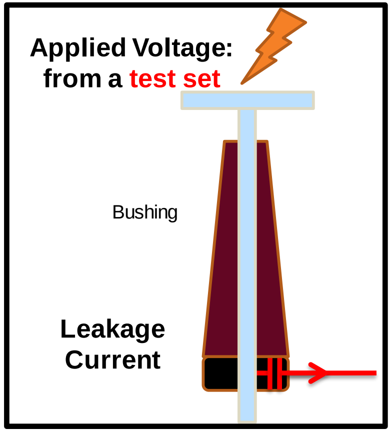
Capacitance

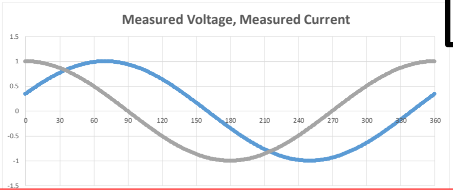
What alerts do we need?

- For each parameter we expect 3 levels of alert:
  - INFO, WARNING, ACTION
- That means 3 alerts for each parameter:
  - RMS current
  - Phase angle
  - Daily, weekly, monthly Capacitance
  - Daily, weekly, monthly Power factor
  - Total Harmonic Distortion (calculated with current RMS and Phase)
- Plus an 'instant' alert on any parameter should it exceed a specified value – removes any averaging effects which could delay an alert

Power Factors: Offline v. Online Relative (RPF) v. Online True (TPF)

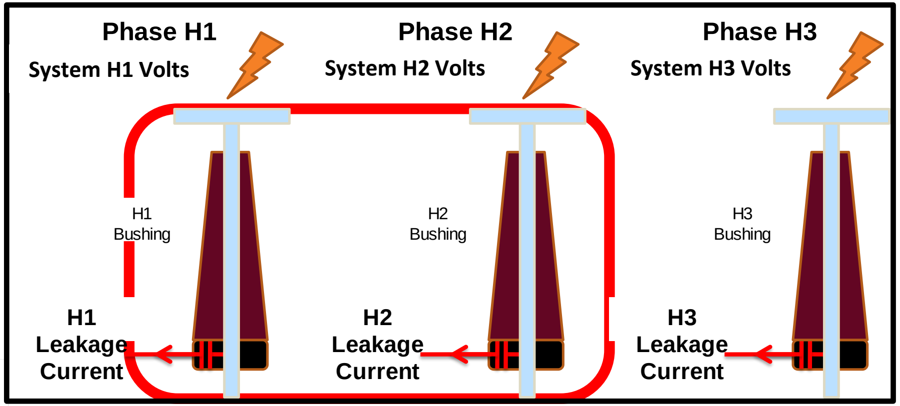
Offline test





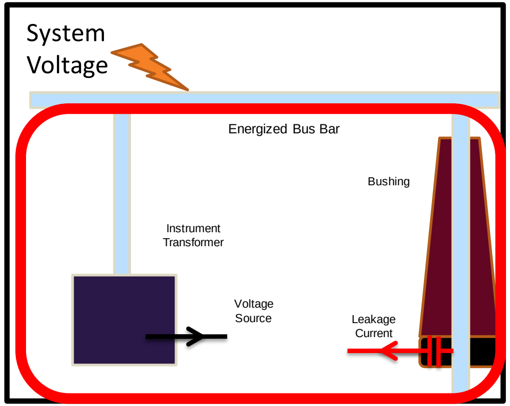
Current/Voltage phase difference

Online monitoring – we do not control the voltage: it becomes a source of variation



We measure both RPF and TPF together so can identify a bad bushing or a bad IT

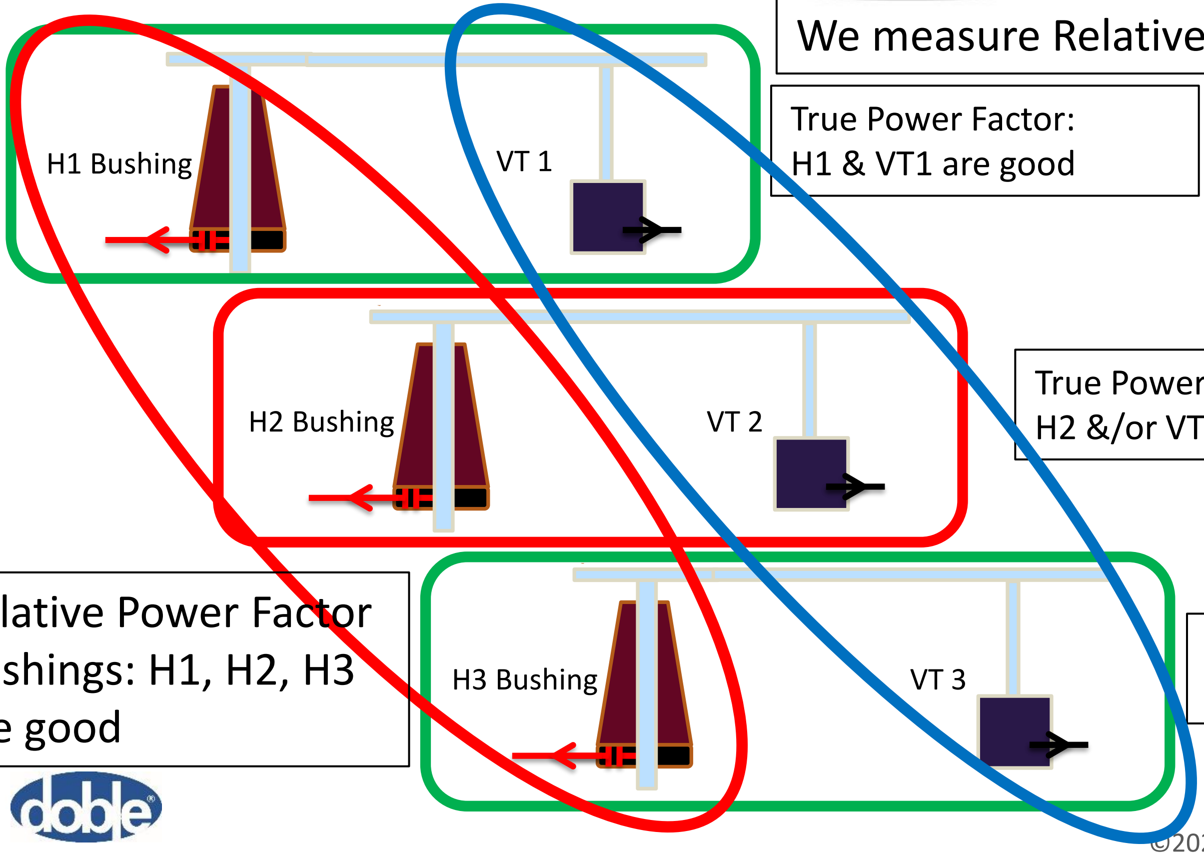
True Power Factor: Bushing and Instrument Transformer both included



https://www.transformer-technology.com/community-hub/technical-articles/1306-power-factor-offline-relative-and-true-tony-mcgrail-byline-transformer-technology.html

True Power Factor: is it a bad bushing or bad VT?

We measure Relative and True simultaneously



True Power Factor:
H1 & VT1 are good

TPF: Bushing H2 or VT2 bad
RPF: Bushings are good
So: bad VT

True Power Factor:
H2 &/or VT2 is bad

True Power Factor:
H3 & VT3 are good

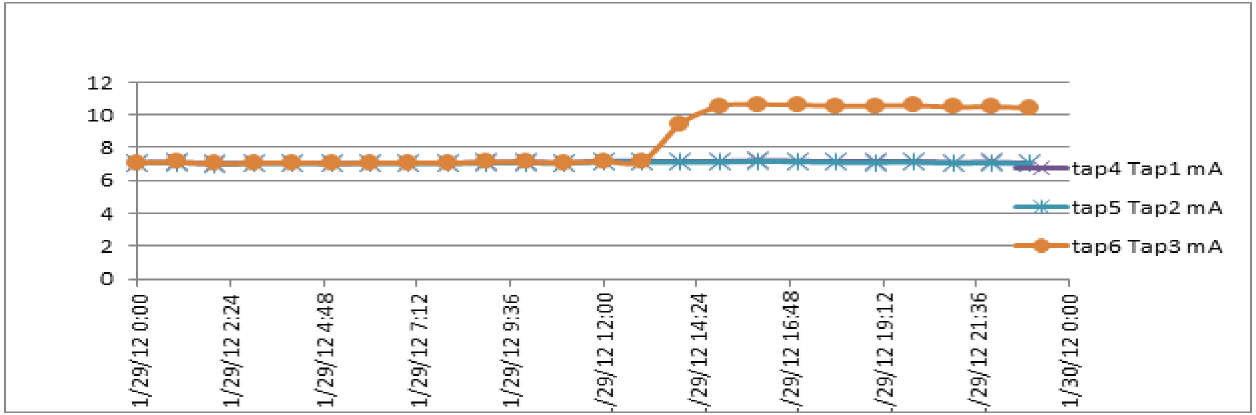
Relative Power Factor
Bushings: H1, H2, H3
are good

Cases

- We have had many cases over the years, several of which have been shared at the Doble Client Conference and elsewhere.
- The cases presented here are examples of different bushing designs and failure modes
- They follow the three C's of condition monitoring:
  - **Control** the measurement
  - Understand the **context**
  - Draw appropriate **conclusions**

Trench Bushing: learning from the past

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.**

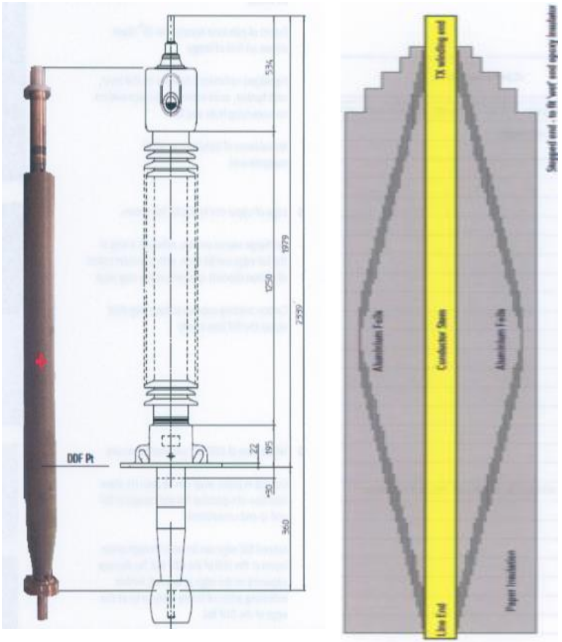


As a result of applying the policy a likely catastrophic failure was avoided. (Detailed analyses on next slide.)

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

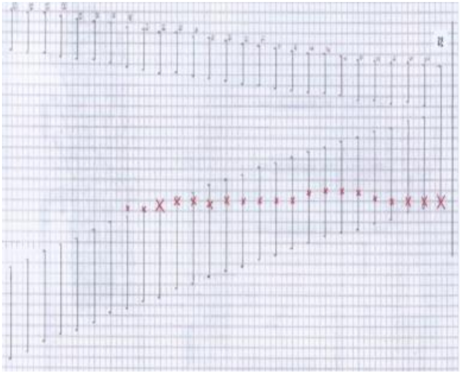
Trench Bushing: close the feedback loop - forensics

Bushing construction and foil layout.



Burning at a foil edge at a point corresponding to the red x in the construction.

A map of how far through the foils the deterioration had progressed. Offline tests confirmed the incipient failure.



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GE Type U Bushing: Graceful failure

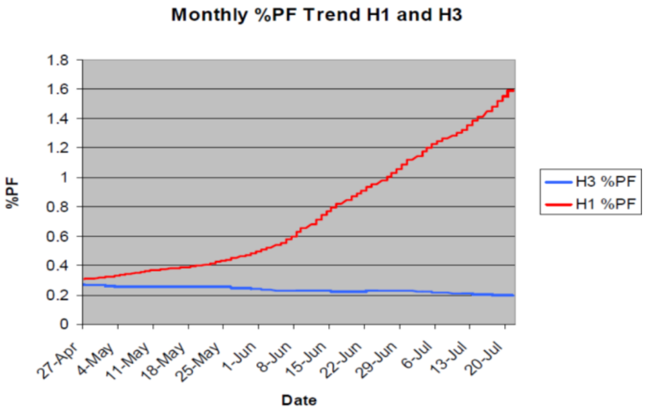
Bushing monitoring was used to identify a deteriorating bushing.

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

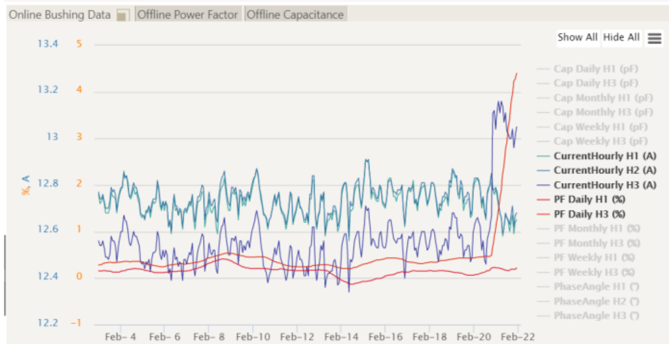
ID	Serial	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Cap(pF)
H1	1796658	.26	401	10.007	1.488	0.0410	0.28	394.74
H2	05-105312	.27	492	10.007	1.869	0.0500	0.27	495.89
H3	1797916	.26	406	10.007	1.502	0.0430	0.29	398.36
X1	96-71129	.26	377	10.011	1.421	0.0380	0.27	377.03
X2	3030410394	.24	385	10.008	1.420	0.0390	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

Westinghouse O+ Bushing

A Westinghouse O+ Bushing generated alerts showing rapid deterioration. The ACTION alert followed ~13 hours after the INFO alert.



[redacted]

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

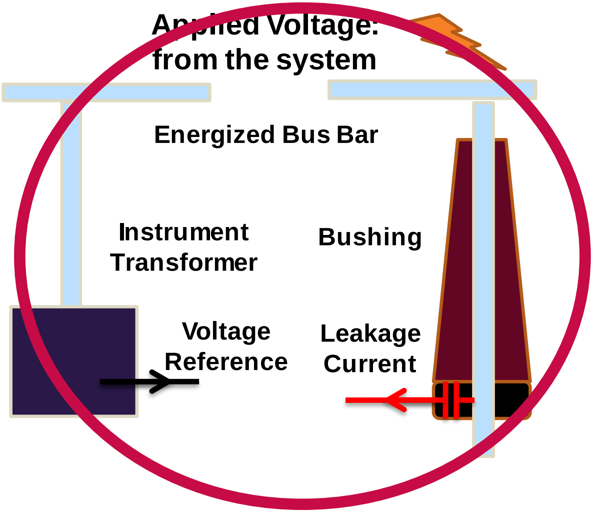
Power factor for one bushing rose sharply, and its leakage current rose by ~0.6mA, or about 5%. Offline tests were performed confirming the deterioration: a 9x rise in power factor.

Test No	Bushing Nameplate					Test Mode	TEST kV		Capacitance C (pF)	POWER FACTOR %		
	Dsg	SERIAL #	CAT. #	PF	ap (pF)					Measured	@ 20°C	Corr Factor
11	H1	K728058		0.26	426.00	UST-R	10.01		416.76	0.29	0.29	1.000
12	H2	K7282187		0.25	425.30	UST-R	10.00		416.24	0.28	0.28	1.000
13	H3	K7296687		0.30	402.80	UST-R	10.01		420.10	2.41	2.41	1.000

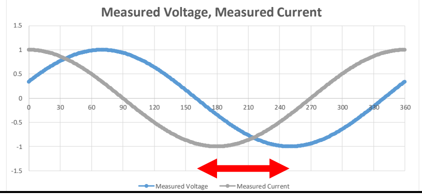
An incipient failure was thus avoided.

True Power factor: Phase by phase

The Instrument Transformer is part of the measurement



Actual Reference Voltages and Measured Current

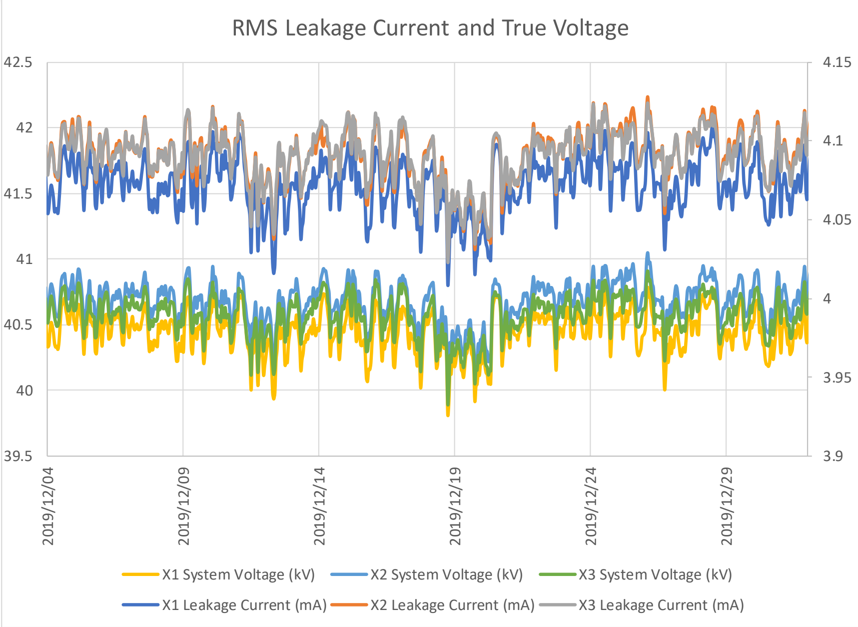


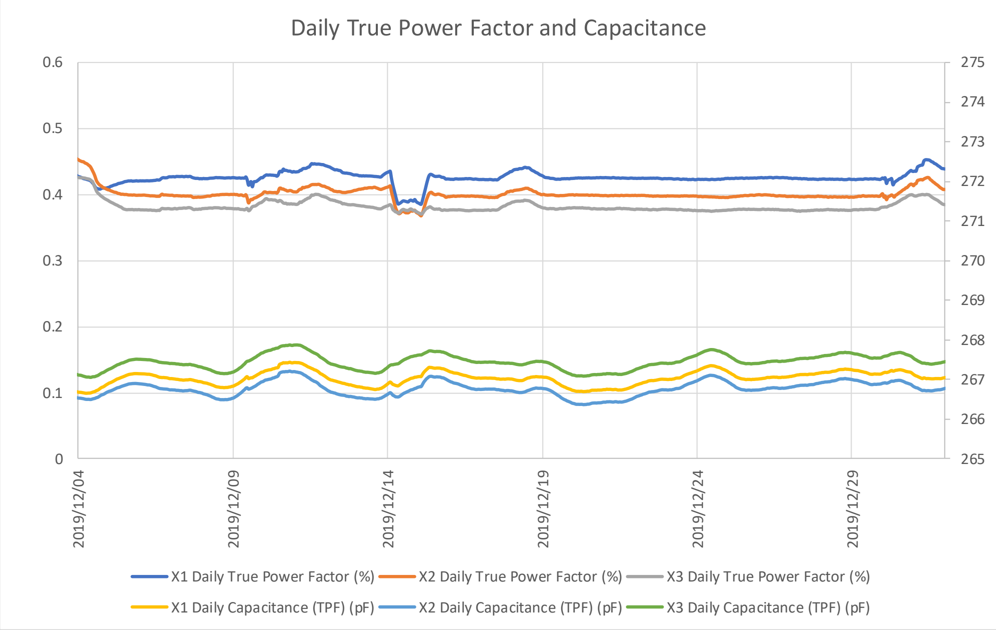
We measure the overall PHASE SHIFT

The resulting phase shift *we measure* is a combination of the phase shift of everything between the voltage test point and the bushing test tap.

The power factor is a **true representation** of everything between the measurement points

Using a voltage reference helps remove doubt

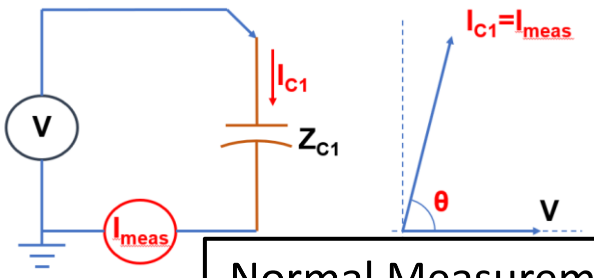




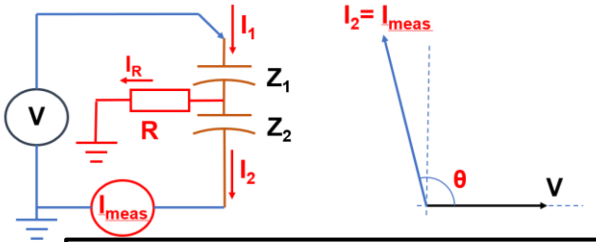
True Power Factor is calculated for the bushing/IT combination on individual phases

Anomaly? 13kV Tertiary Bushing: gets better?

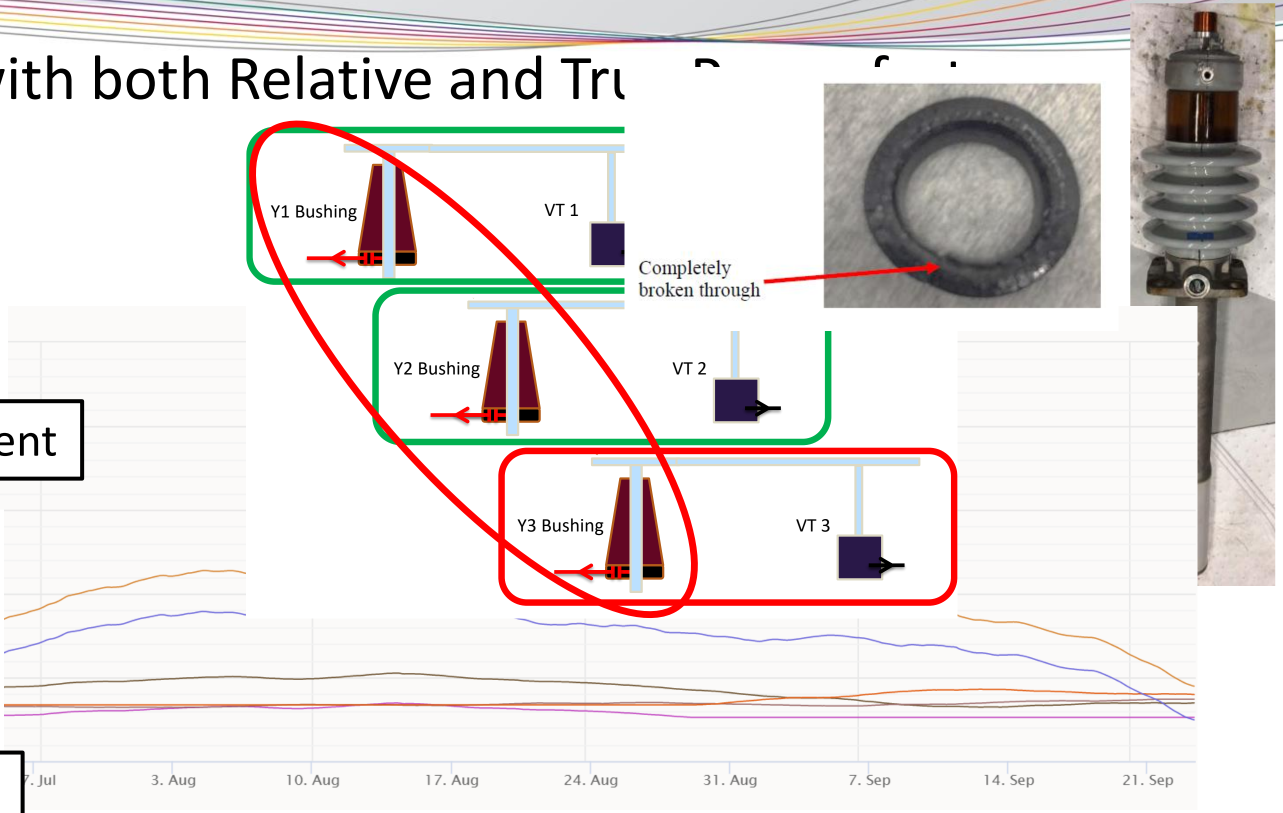
- Tertiary bushing with both Relative and Tru



Normal Measurement



Anomalous Measurement



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

RPF and TPF (Relative and True Power Factors)

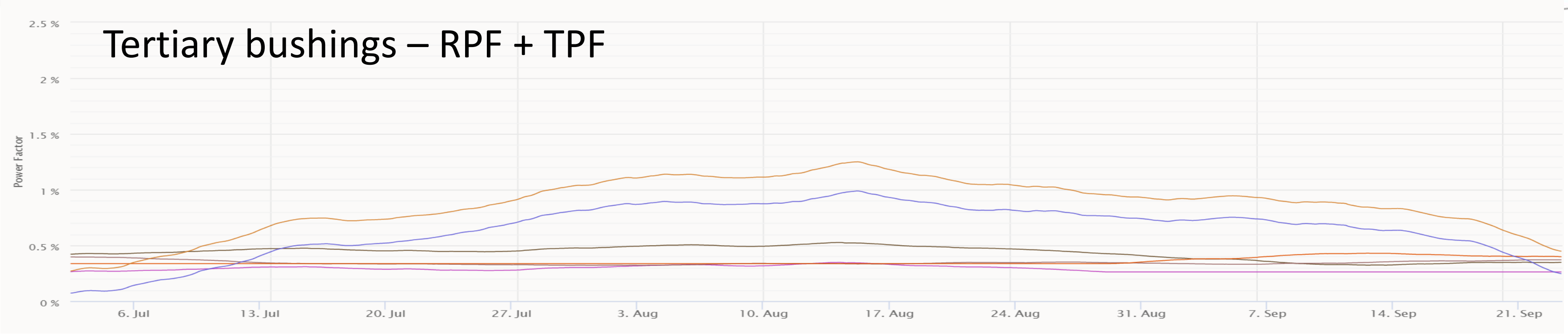
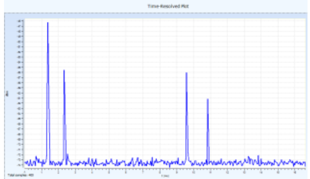
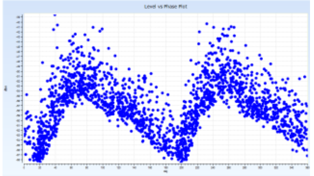
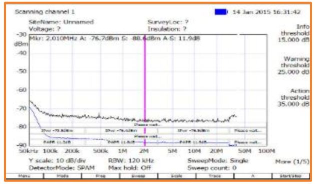
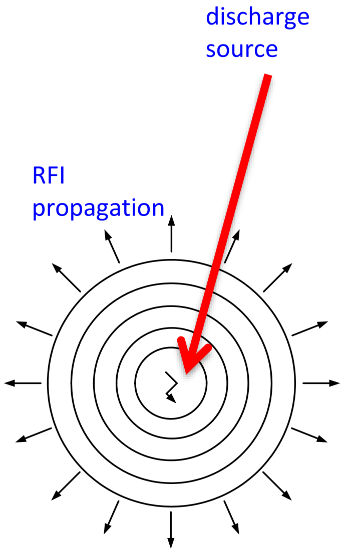


Chart has 6 traces: RPF and TPF for each tertiary bushing

- The two which rise then fall are for the same single bushing
- The offset between the RPF and TPF traces is due to the original TPF set up
- **Both** RPF and TPF showing a rise and fall means that the bushing is the source of variation
- Scenarios for possible bushing deterioration were identified – moisture ingress being most likely
- Forensic analysis of the bushing confirmed moisture ingress through a cracked oil fill-plug gasket
- All three bushings were replaced as a set

PD: Partial Discharge - basics

- Partial Discharge is a consequence of insulation deterioration
- Early **detection** and trending allows for appropriate intervention in transformers, rotating machines and other assets
- Detection and trend over time – statistics of PD severity
- Use advanced **diagnostic** tools to support decisions

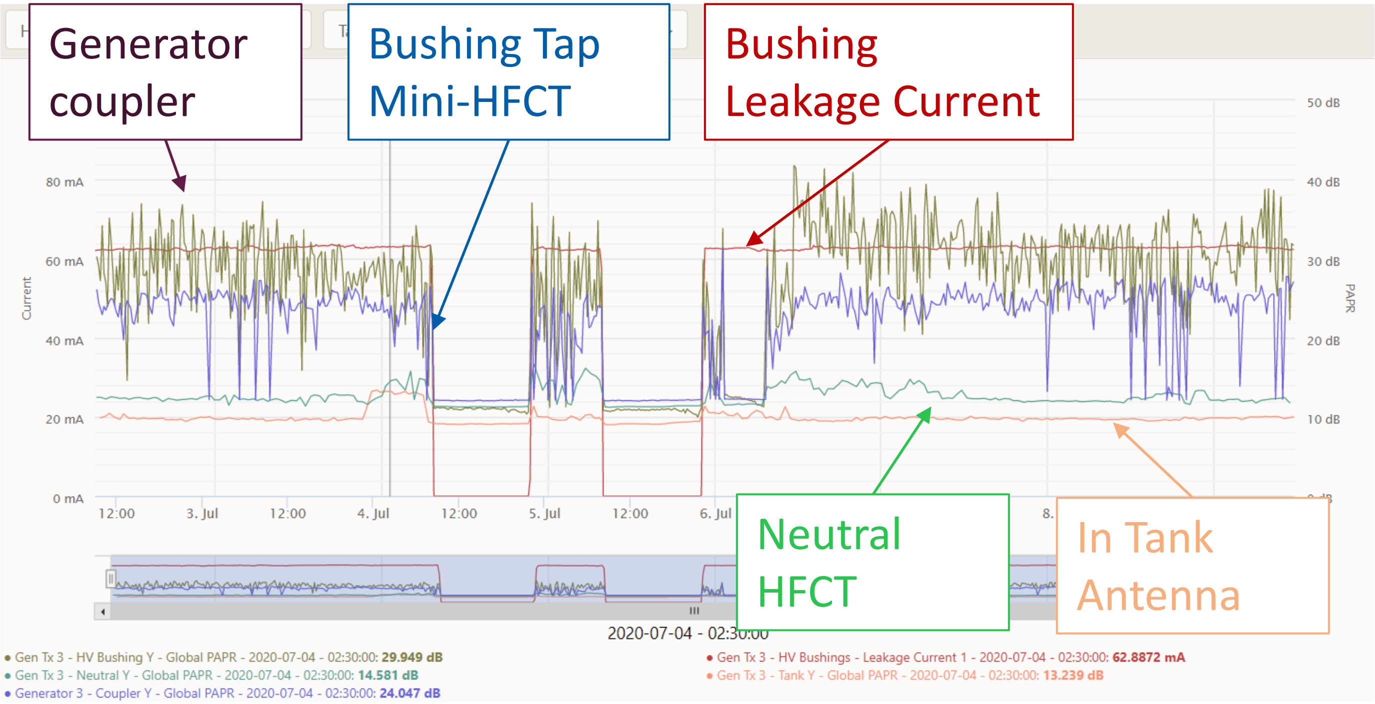
‘Detailed diagnostics may require context for analysis and expert support’ CIGRE TB 660

“There is desire to use PD… but also fear.” Utility Engineer

Bushing PD

- Measuring PD via the bushing test tap is useful – if you can make sense of the data:
  - Statistical analysis to indicate severity of PD and support trending
  - Time resolved and Phase resolved patterns to support diagnosis
  - Detailed PD analysis can get expensive for multichannel synchronous
- PD signals propagate easily and can be detected far away from the source
- Who will be looking at the data? Check to avoid false positives?
- Who will set alert levels? Who will respond? Who will verify veracity?
- Example at a generator/GSU set with multiple sensors… PD is on the iso-phase bus, nothing to do with the bushings

Bushing PD


Generator coupler
Bushing Tap Mini-HFCT
Bushing Leakage Current
Neutral HFCT
In Tank Antenna
80 mA
60 mA
40 mA
20 mA
0 mA
Current
50 dB
40 dB
30 dB
20 dB
10 dB
PAPR
12:00
3. Jul
12:00
4. Jul
12:00
5. Jul
12:00
6. Jul
8.
2020-07-04 - 02:30:00
Gen Tx 3 - HV Bushing Y - Global PAPR - 2020-07-04 - 02:30:00: 29.949 dB
Gen Tx 3 - Neutral Y - Global PAPR - 2020-07-04 - 02:30:00: 14.581 dB
Generator 3 - Coupler Y - Global PAPR - 2020-07-04 - 02:30:00: 24.047 dB
Gen Tx 3 - HV Bushings - Leakage Current 1 - 2020-07-04 - 02:30:00: 62.8872 mA
Gen Tx 3 - Tank Y - Global PAPR - 2020-07-04 - 02:30:00: 13.239 dB

Monitoring Successes: Common Theme

- What we see in successful condition monitoring cases includes:
  - **Setting expectations**: for the monitor, the measurement to be made and the organization
  - Understand: Control, Context, Conclusion
  - **For each bushing in each individual application**, identify what to expect for leakage current magnitude, for power factor and for capacitance
  - Identify/set limits for each level of alert
  - Have a **planned response** for each alert on each bushing
  - Ensure **the plan is agreed** and ‘written up’ – names, timescales, actions
  - When an alert comes in: FOLLOW THE PLAN!

In Conclusion

Bushing Testing is useful – but highly intermittent!

- Standards exist for analysis of data

Bushing Monitoring provides benefits:

- Bushing ‘saves’
- Transformer ‘saves’

Needs some understanding of what the numbers mean:

- Failure modes likely to be found in a bushing
- Symptoms of failure modes
- Data for detection of anomaly (not all anomalies are bad)
- Analyses to alert: who, why, what to do, by when

Need the organization to embed monitoring in daily activities

What is common in successful cases is an agreed response plan and decisive action!

THANK YOU!

Questions? Comments? Feedback?

Tony McGrail
tmcgrail@doble.com

"Always appreciate the opportunity to learn new things."

Bonus case… Incoming alerts

- Legacy IDD installed ~2008; c
- Some DAQ & BTA issues addr
- 3 Levels of escalating Alert:
  - Info, Warning & Action

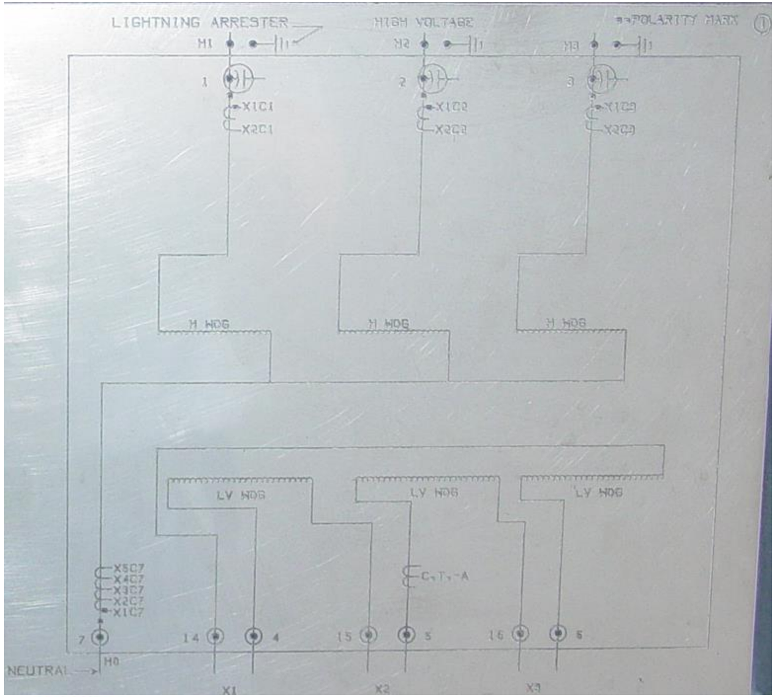
ALERT! CODE	BUSHING ID OR SET NAME	ALERT! LEVEL	RECEIVED DATE/TIME
24-6010	4	WARNING	12/14/2020 12:00
14-6010	14	WARNING	12/14/2020 10:00
22-5010	4	INFO	12/14/2020 5:00

Table 7-1 IDD Expert System States

State	Description
2998	First recording after learning has been initiated when the apparatus is de-energized.
2999	First recording after learning has been initiated when the apparatus is energized.
3000	Normal completion of the recording with no learning milestones.
3001	Normal completion of the recording with daily learning baseline.
3002	Normal completion of the recording with weekly learning baseline.
3003	Normal completion of the recording with monthly learning baseline.
3409	The bushing set is de-energized.
4000	Abnormal recording NO RESULTS.
4001	INFO Abnormal Recording NO RESULTS after 5 attempts.
5010	Exceeded daily Power Factor INFO limit
5011	Exceeded daily Capacitance INFO limit
5070	Exceeded weekly Power Factor INFO limit
5071	Exceeded weekly Capacitance INFO limit
5280	Exceeded monthly Power Factor INFO limit
5281	Exceeded monthly Capacitance INFO limit
6010	Exceeded daily Power Factor WARNING limit
6011	Exceeded daily Capacitance WARNING limit
6070	Exceeded weekly Power Factor WARNING limit
6071	Exceeded weekly Capacitance WARNING limit
6280	Exceeded monthly Power Factor WARNING limit
6010	Exceeded daily Power Factor WARNING limit
7010	Exceeded daily Power Factor ACTION limit
7011	Exceeded daily Capacitance ACTION limit
5010	Exceeded daily Power Factor INFO limit
7280	Exceeded monthly Power Factor ACTION limit
7281	Exceeded monthly Capacitance ACTION limit

Transformer Nameplate & History

- 1972, GE Pittsfield, 980 MVA, 345-23.75kV, 3phase, Y-delta



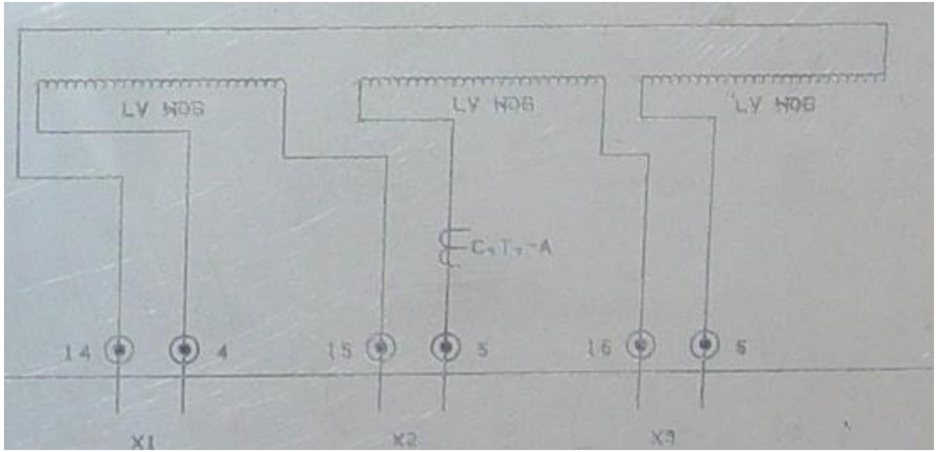
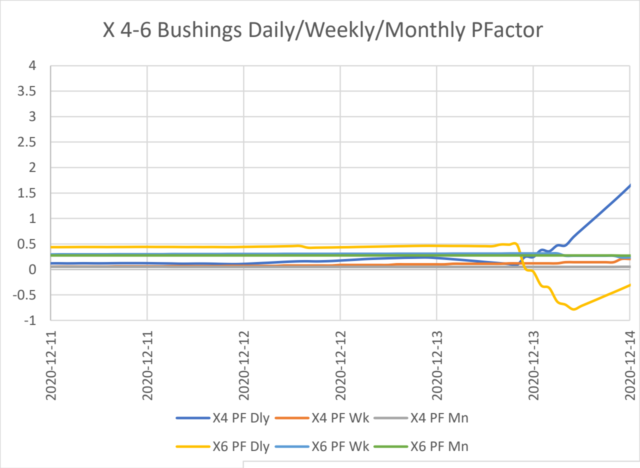
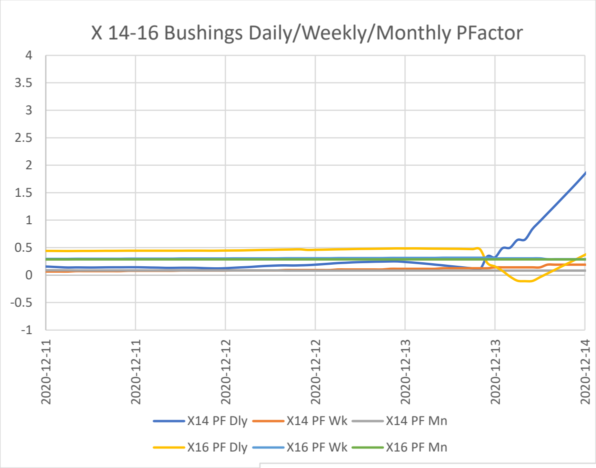
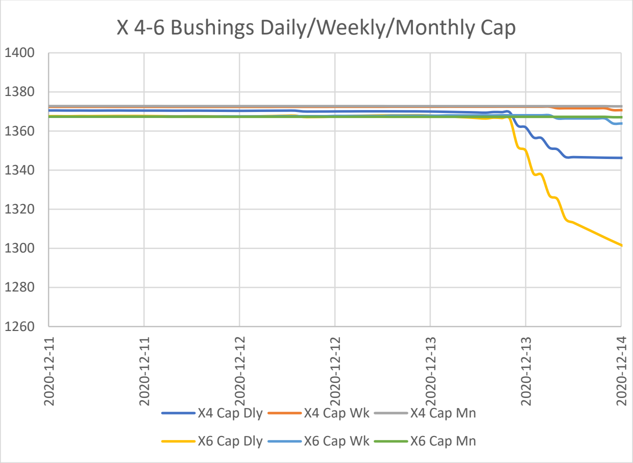


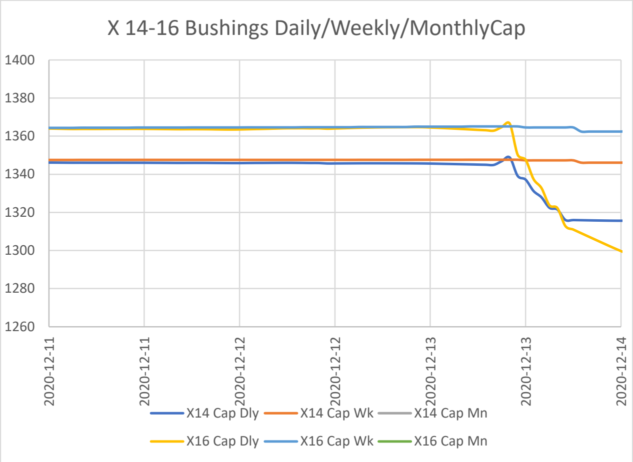
ABB Type T	Bushing 4		Bushing 5		Bushing 6	
	Cap	%PF	Cap	%PF	Cap	%PF
Nameplate	1381	0.32	1351	0.31	1379	0.31
Measured	1374.9	0.3	1336.1	0.31	1371.5	0.3
ABB Type T	Bushing 14		Bushing 15		Bushing 16	
	Cap	%PF	Cap	%PF	Cap	%PF
Nameplate	1355	0.33	1361	0.33	1375	0.32
Measured	1349	0.32	1353.8	0.31	1368.5	0.3

Data: Power Factor and Capacitance

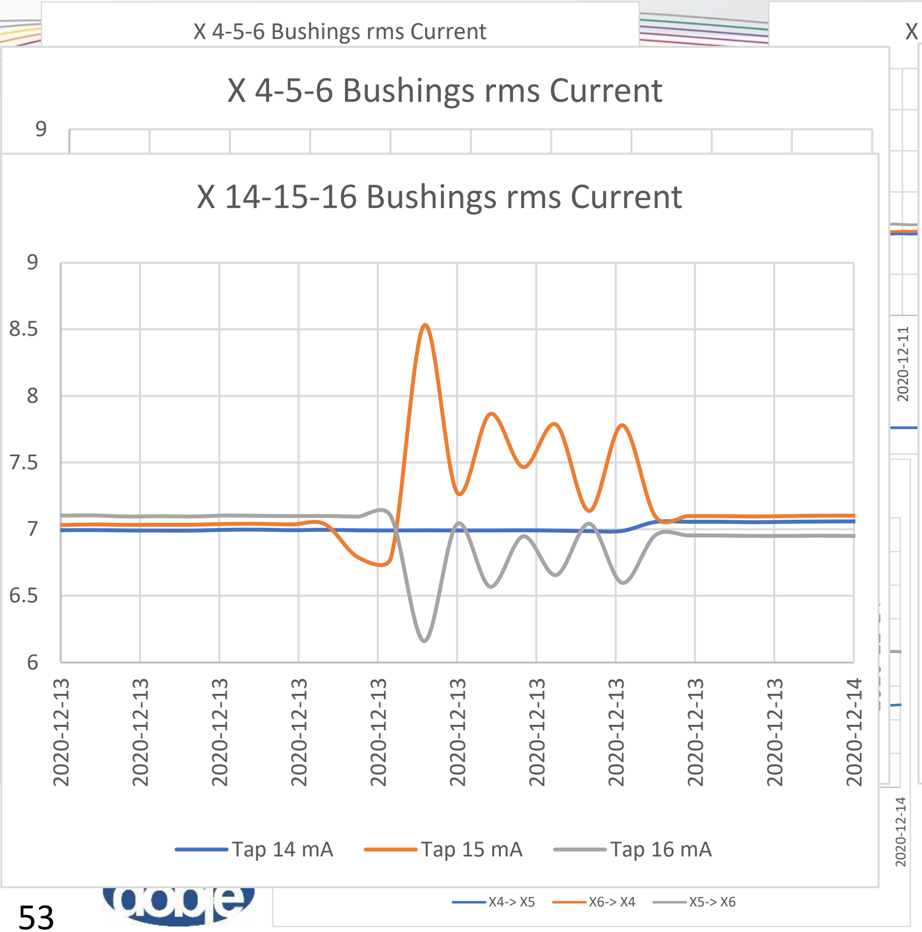


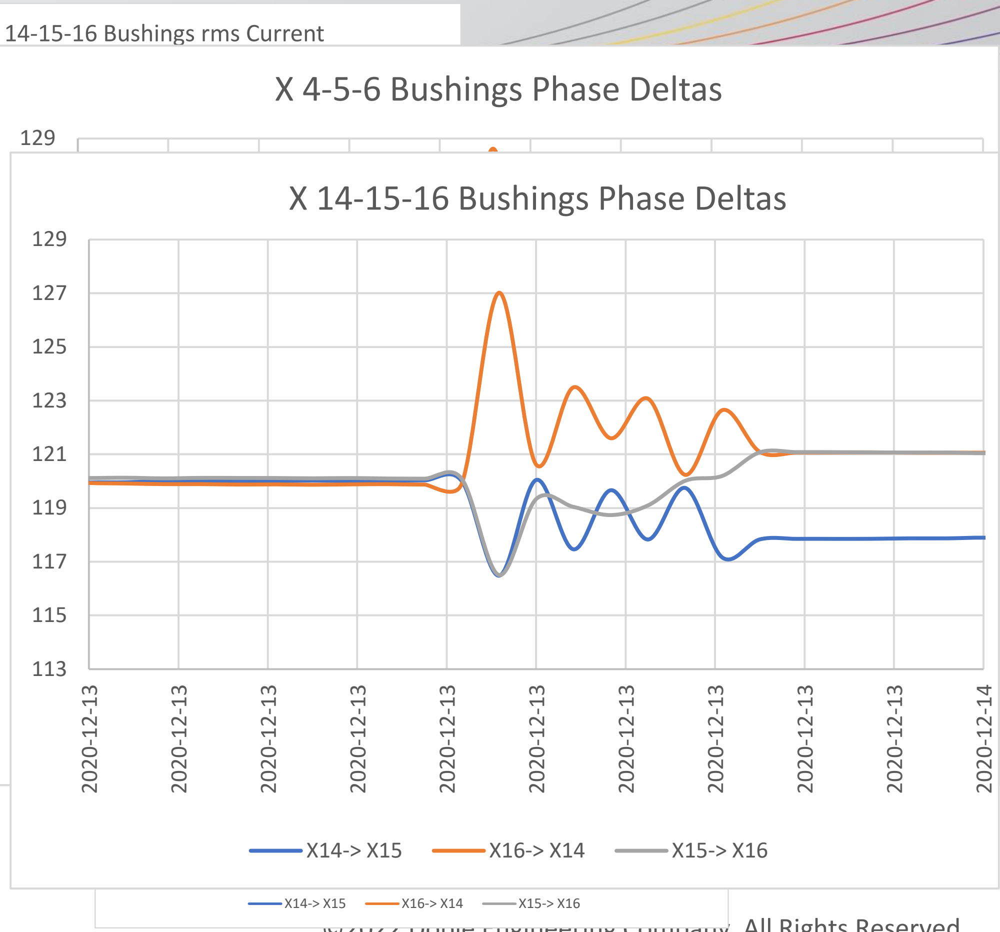






Data: Leakage Currents and Relative Phase





Discussion

- What questions to ask?
  - Is it the bushings?
- Any other relevant data?
  - Temperature, load, protection operation, weather, other…
  - Any maintenance data or family history?
- What's the action???

DGA Data

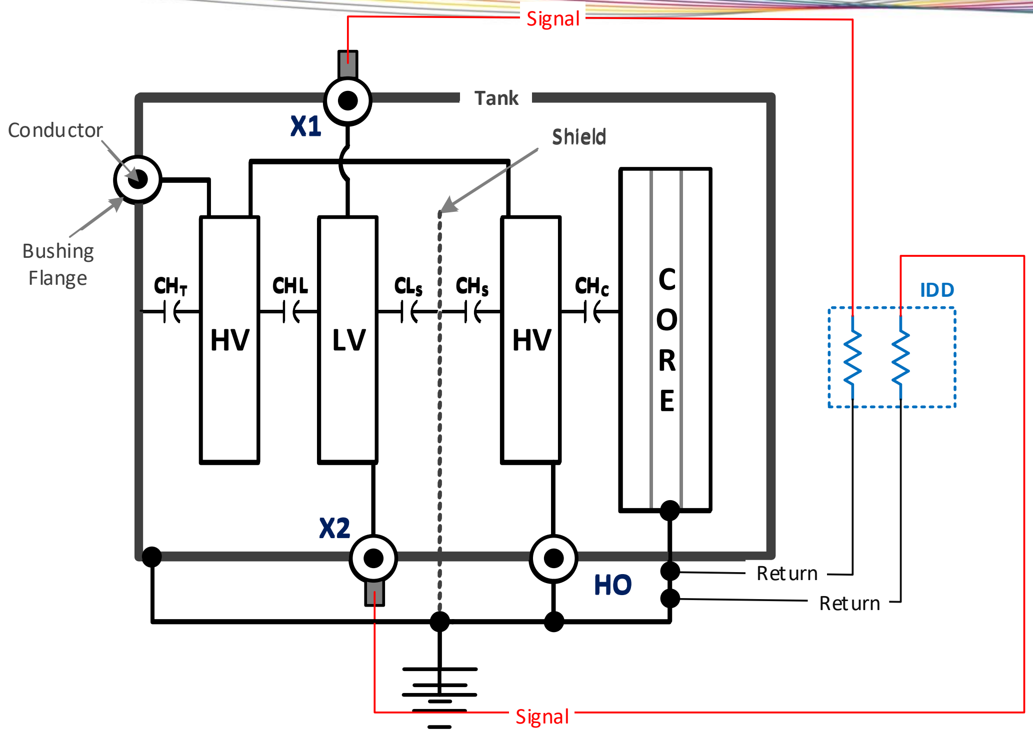
GAS-IN-OIL ANALYSIS GAS CHROMATOGRAPHY EXPRESSED IN PPM

DATE	HYDROGEN	OXYGEN	NITROGEN	METHANE	CARBON MONOXIDE	CARBON DIOXIDE	ETHANE	ETHYLENE	ACETYLENE	TOTAL COMBUST.	TOTAL GAS
07/30/18	10	6,713	19,862	26	88	1,412	15	2	ND	141	28,128 *
01/15/19	24	7,695	23,719	48	127	1,270	28	3	ND	230	32,914 *
07/01/19	15	1,909	18,730	67	163	3,052	43	4	ND	292	23,983
07/24/19	9	847	11,798	44	96	2,019	27	3	ND	179	14,843
12/18/19	ND	608	15,678	80	172	3,770	43	5	ND	300	20,356
06/01/20	ND	4,191	22,964	26	72	1,540	18	2	ND	118	28,813
11/16/20	2	415	11,778	56	135	2,754	36	3	ND	232	15,179
12/14/20	31	648	12,104	65	145	2,736	35	7	12	295	15,783

RECOMMENDATION INVESTIGATE

E-THE LEVEL OF ACETYLENE INDICATES AN ARCING/SPARKING CONDITION OR SEVERE HOT SPOT WITH TEMPERATURES MOST LIKELY EXCEEDING 700 DEGREES C. POSSIBLE CAUSES INCLUDE DETERIORATED TAP CHANGER CONTACTS, INTERNAL CONNECTIONS, OR THE CORE ASSEMBLY.

More discussion



Bonus case… What does this mean?