Transformer Fleet Management

Asset Health Review Process

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ALTANOVA
A DOBLE COMPANY

ALTANOVA, a Doble Engineering Company, provides diagnostic solutions to utilities and industries to improve the performance of their electrical assets through portable testing equipment, advanced monitoring systems, and professional services.

Altanova History

1938 — I.S.A. Istrumentazioni Sistemi Automatici S.r.l. is established in Taino ITALY

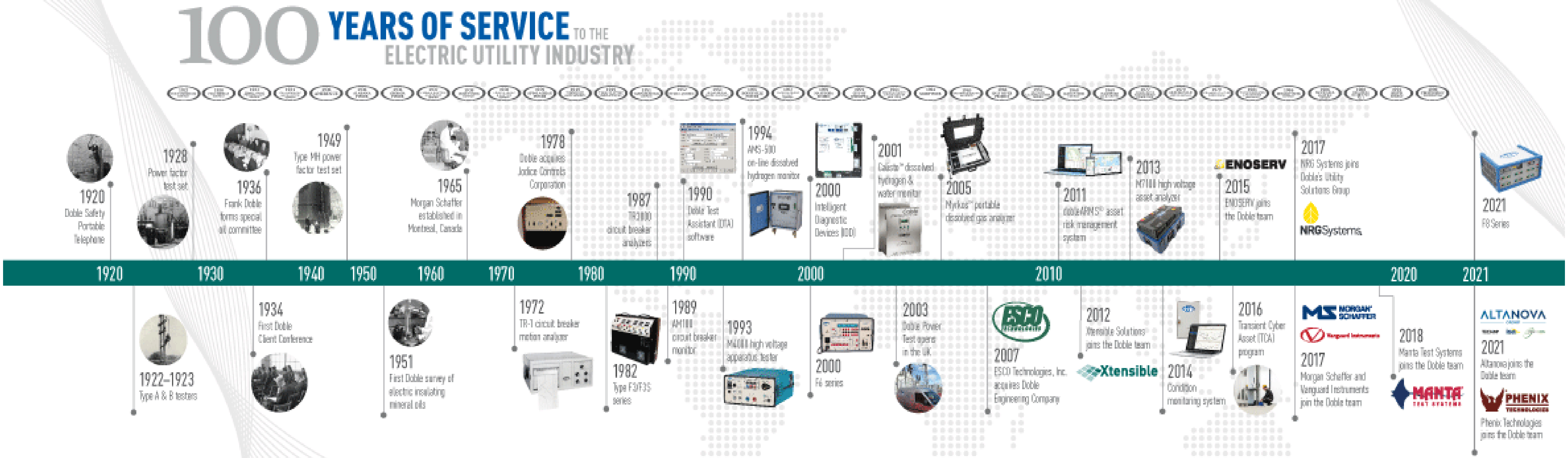
1999 — TECHIMP was born as a spin-off from the University of Bologna ITALY.

2017 — I.S.A. and TECHIMP merge giving birth to the ALTANOVA GROUP

2019 — INTELLISAW joins ALTANOVA GROUP

2021 — ALTANOVA GROUP becomes part of ESCO Technology Group and joins the Doble Engineering Company, as part of the USG division.

Doble History



Altanova Today

100

COUNTRIES

12 GLOBAL FACILITY LOCATIONS

150+

EMPLOYEES

150+

SALES PARTNERS

5550+

CUSTOMERS GLOBALLY

Part of ESCO Technologies' Utility Solutions Group

PRODUCT BRANDS

Our Solutions

Electrical Test Equipment

Essential for day-to-day maintenance tests of electrical assets. Useful in specific phases of the asset lifecycle:

- Procure
- Operate
- Maintain
- Decommission.

Professional Services

Diversified offer according to the electrical asset lifecycle:

- Installation and commissioning
- Diagnostic test
- Data analysis
- Consultancy
- Training.

Monitoring Systems

Shift from a time-based maintenance to a condition-based maintenance.

Focus on predictive maintenance and shift in focus from electric asset value cost to network outage costs.

Strong evolution of digitalization trend in the power industry.

Testing And Monitoring Solutions For:

- Power transformers
- Circuit breakers
- HV gas insulated switchgears
- MV/HV/EHV cables
- MV/LV switchgears
- Batteries
- Current & voltage transformers
- Protective relays
- Meters and transducers
- Rotating machines
- Variable speed drives
- Overhead lines



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Outline

- Importance of Fleet Management
- Purpose of Asset Health Review
- Methodology
- Process
- Case Studies
- Conclusion






Application of AHI

A previously state-owned utility after privatization

- Slowly ageing population to manage
- Increased pressure to get best value
- An improved asset management plan (AHR) was developed in response

A large independent US power producer

- 87 power plants total installed capacity of 27GW
- ~800 transformers (>250 GSU)
- 2 generator transformer failures
- “We didn’t know the overall health of our critical transformers”
- Implemented AHR: oil and electrical test results, IR scans, highlight inconsistent and missing results

Large National T&D operator in Middle East

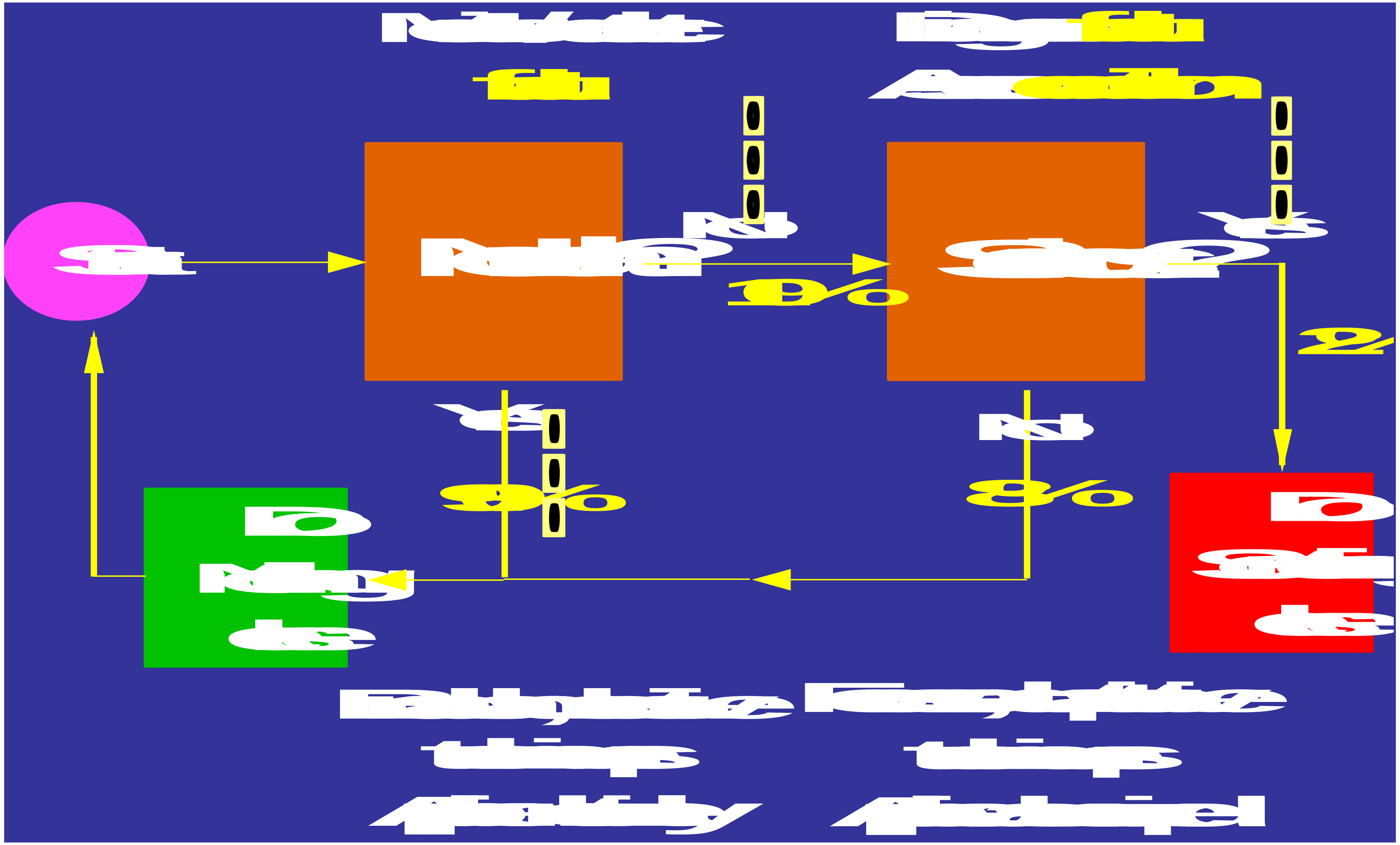
- 4 operating regions
- One region significantly higher failure rates
- Implemented AHR/CBM

Purpose of AHI System

The purpose of the Asset Health Indexing is as follows:

- Consolidate information in one place
- Assess transformer condition and performance
- Identify risks and opportunities
- Identify transformers requiring replacement in short-medium term
- Estimate long-term replacement volumes
- Trend evolution in transformer condition and replacement volumes
- Industry and insurance compliance
- Generate timely reports for management
- Is it Life Extension ?

Condition Based Methodology



Process

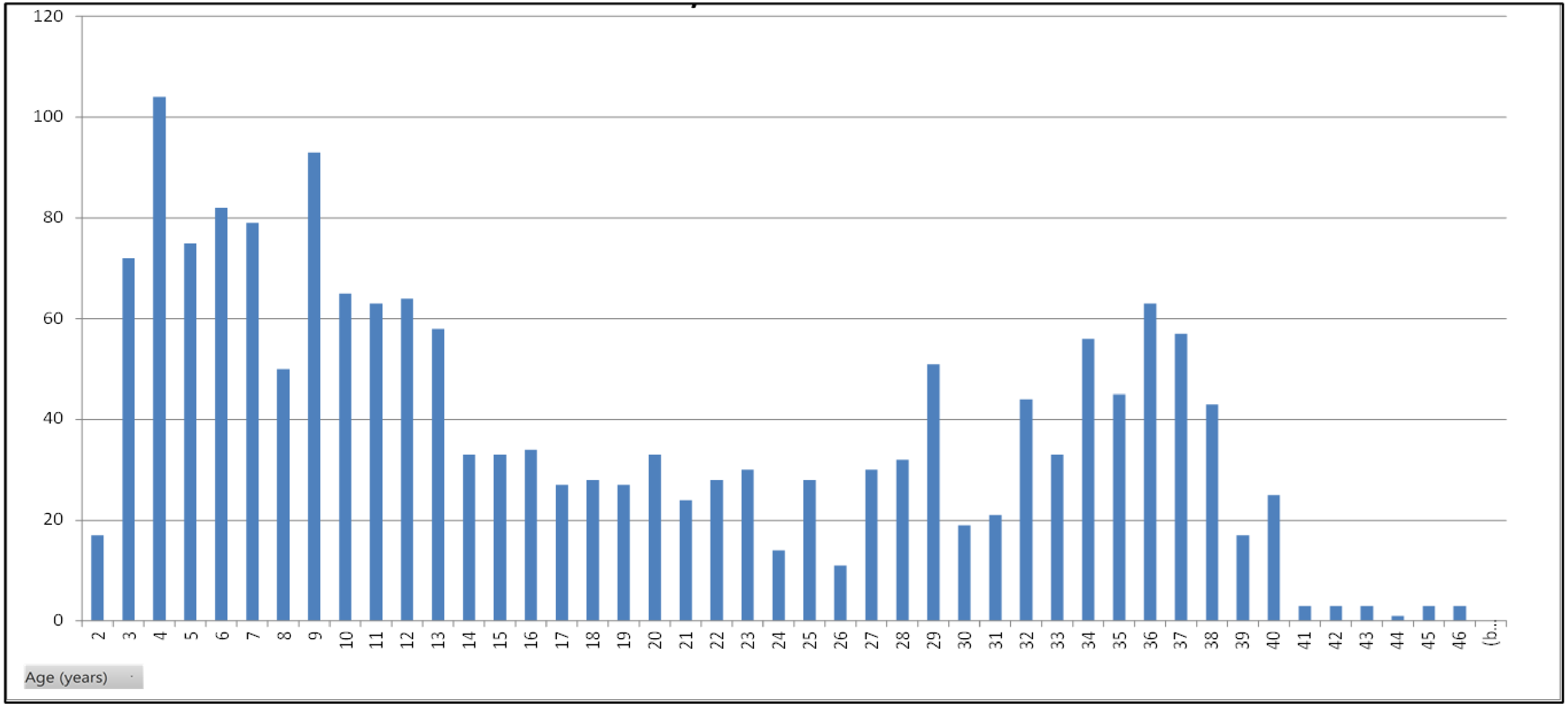
The process includes the following key elements:

1. Initial review – based on existing information
2. Second review – based on offline / online tests
3. Assess technical condition – to generate additional data for decision making
4. Assessment of designs – from forensics
5. Risk management – indexing based on risk and severity

1 – Initial Review

- Initial review is based on available data only. Quality of output depends on quality of input (such as poor oil sampling data), and therefore on quality of available data (FAT, commissioning results, lab data). Often based only on design assessment and oil test results.
- Try to assess different aspect condition of transformer, esp. *dielectric, thermal, and mechanical condition*. May include other elements, e.g. accessories or external corrosion. Convert assessment to score.
- Operational history: Service life, Loading, knowledge of maintenance done, repairs
- Event history: Faults, system events
- Monitoring data: DGA, electrical test data

1 – Initial Review



Transformer Fleet Review (age wise) 1800 units

1 – Initial Review

Typical scoring scheme:

1 Excellent - no known problems

2 Good – Minor problems only, may get worse…

3 Moderate – Likely evidence of problem requiring attention within 5-10 years.

4 Strong or likely evidence of serious problem requiring attention within 2-5 years.

5 Strong evidence of serious problem requiring attention within 1-2 years

2 – Second Review

- Second review involves gathering additional data, either to cover gaps in the available information for the initial review or to get more information about priority transformers.
- Transformers may be priority owing to condition, importance, a combination of the two, or other reasons.
- Use wide range of on-line condition assessment methods, e.g. visual inspection, IR scan, RFI survey, and especially oil tests.
- Use wide range of off-line condition assessment methods, e.g. winding capacitance and power factor, winding frequency response, and winding resistance.

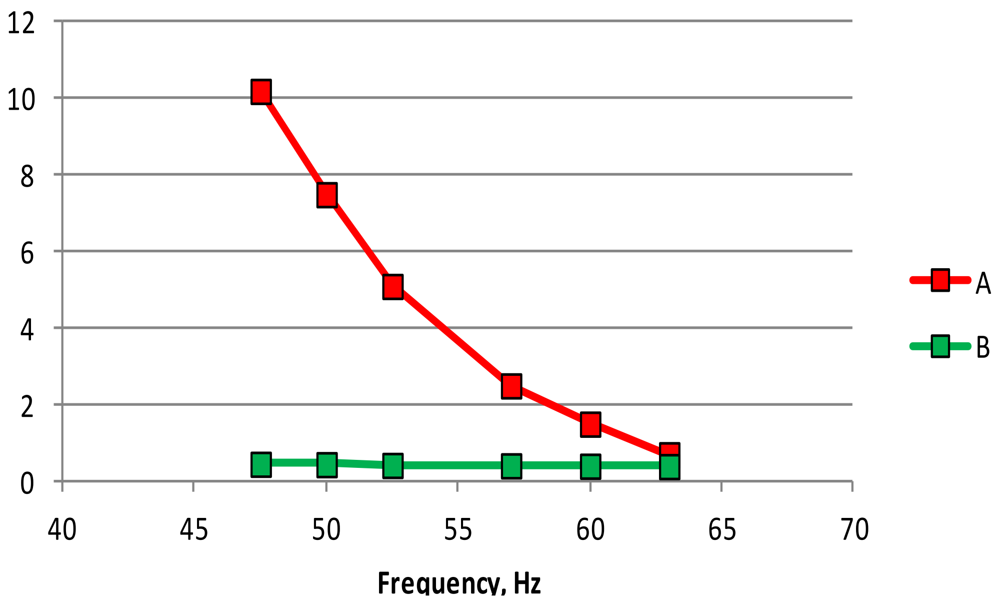
2 – Second Review

- 2-winding, 132/33 kV, 90 MVA, ONAN/ONAF, YNd11, 1964 UK OEM
- Online PD survey picked up discharge activity in the transformers

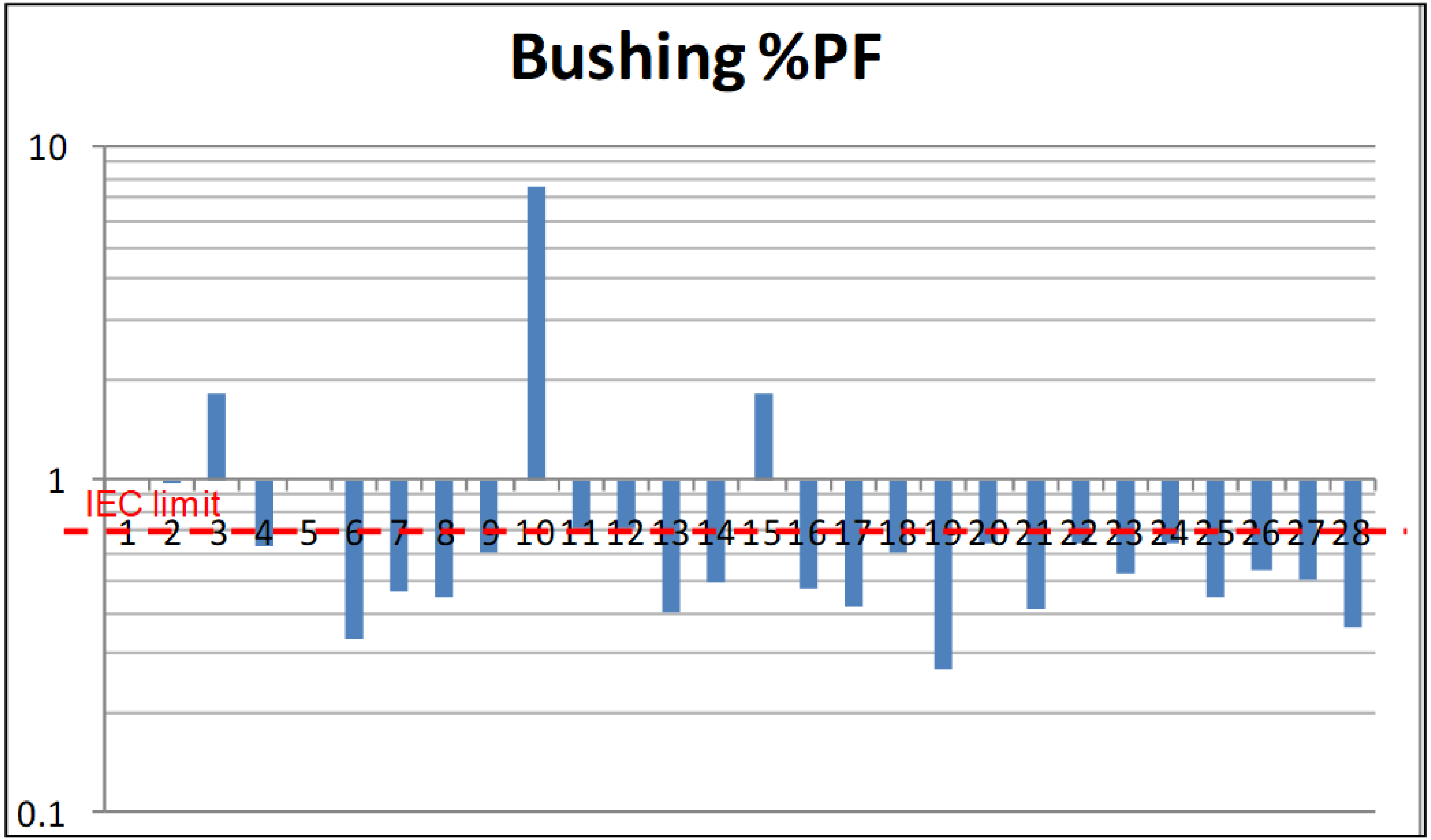
HV BUSHING CAP. & POWER FACTORS

kV	A phase	B phase	C phase
2	130 pF	130 pF	135 pF
5	133 pF 5.3 %	133 pF 5.3 %	137 pF 5.3 %
10	133 pF 4.4 %	134 pF 4.3 %	151 pF 3.5 %
12	129 pF 7.5 %	129 pF 10.5 %	146 pF 5.8 %

CURVE A: B PHASE BUSHING OF A2T (Tested Bushing with High PF)
CURVE B: B PHASE BUSHING OF A1T (Reference)



2 – Second Review



Bushing Contribution in Fault Development

3 – Assess Technical Condition

- Arrange a technical condition assessment for priority transformers using outcome of first review, and second review, and design assessments. May be able to extend to remainder of population by analogy/extension.

- Often used to determine need for refurbishment or replacement. May also be used to assess suitability for redeployment or change of use.

- Occasionally used to determine requirement for spare transformers.

Case Study – 1

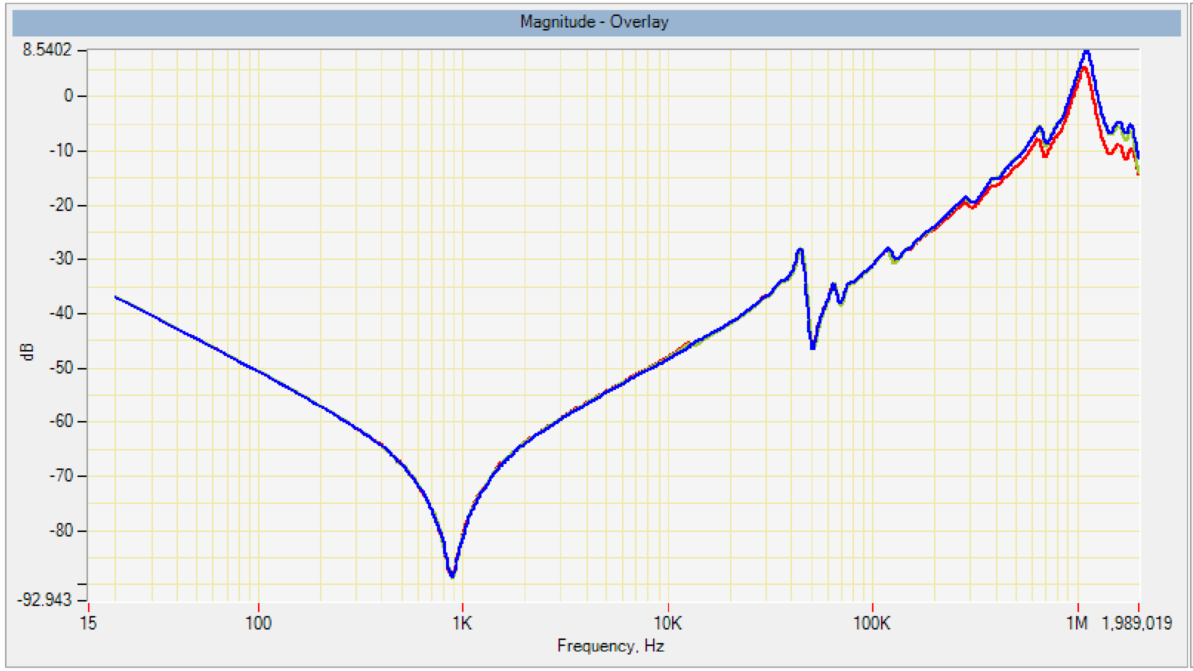
- It is about Selector Flash Over and Tapchanger (Partial) Damage during service, transformers T1 & T2, 400kV, 800MVA, YNd1, 2-winding units, manufactured in 1960s in England
- Reasons for Fault Investigation:

  - Transformer **T1** & **T2** were tested for fault finding in OLTC. Electrical Testing and DGA carried out to investigate the cause
- Conclusion:

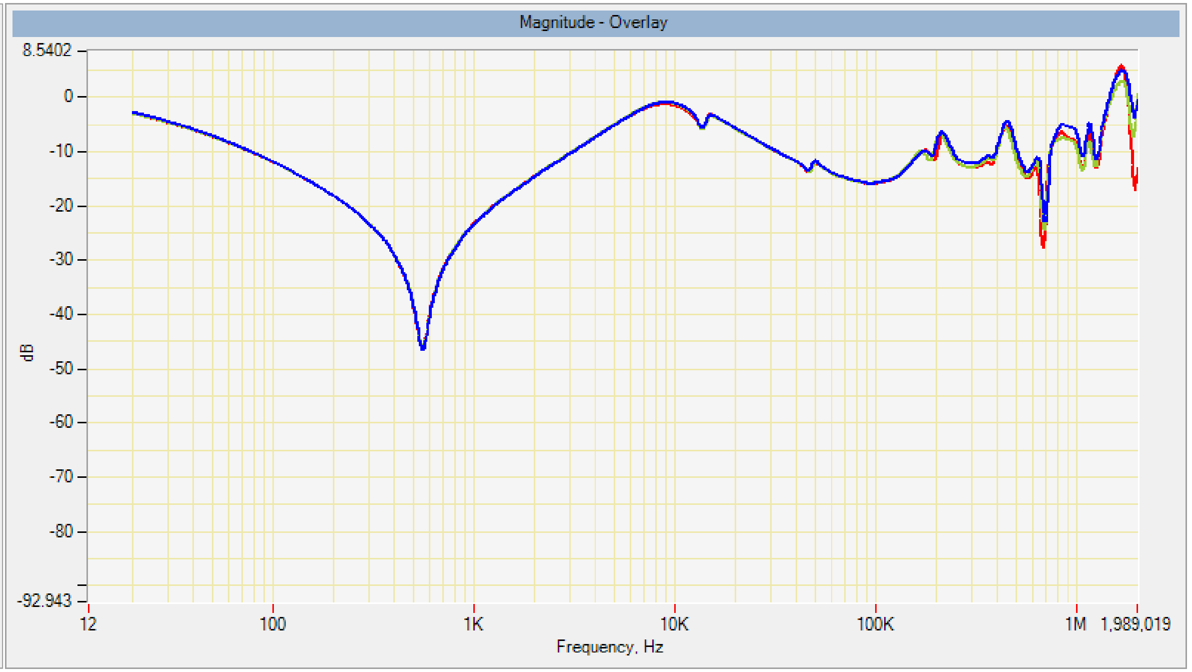
- Transformer **T1** marked for Regular Oil Analysis / RFI Survey / Offline test in 3 yrs

- Transformer **T2** was unreliable for further service and scrapped

Case Study – 1



HV Winding - Y

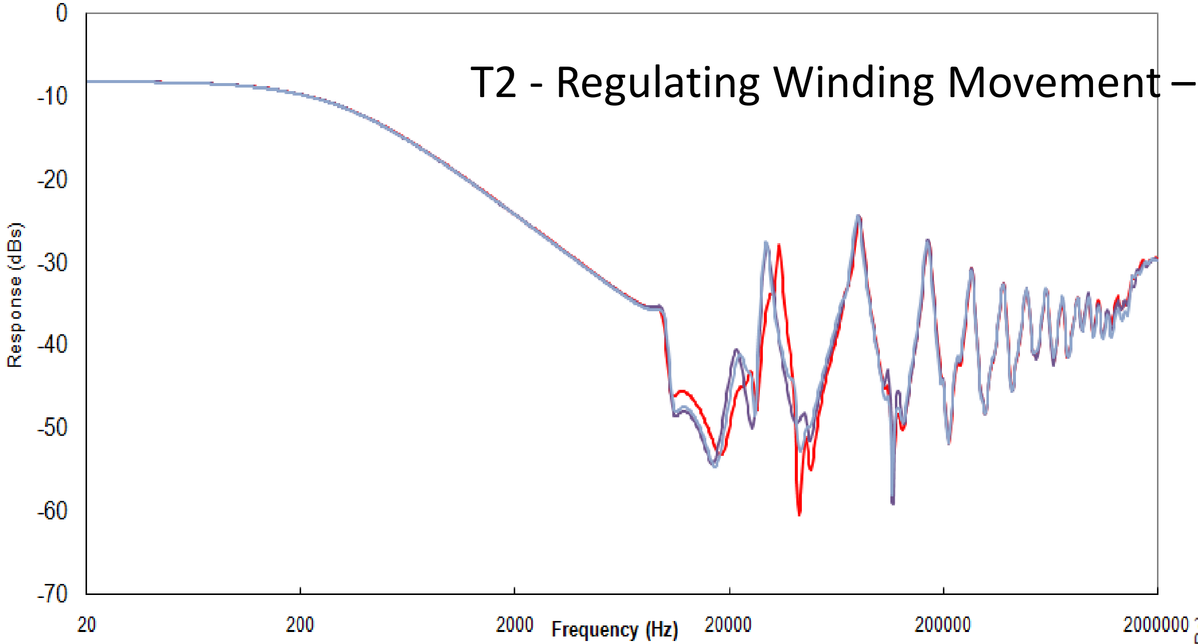


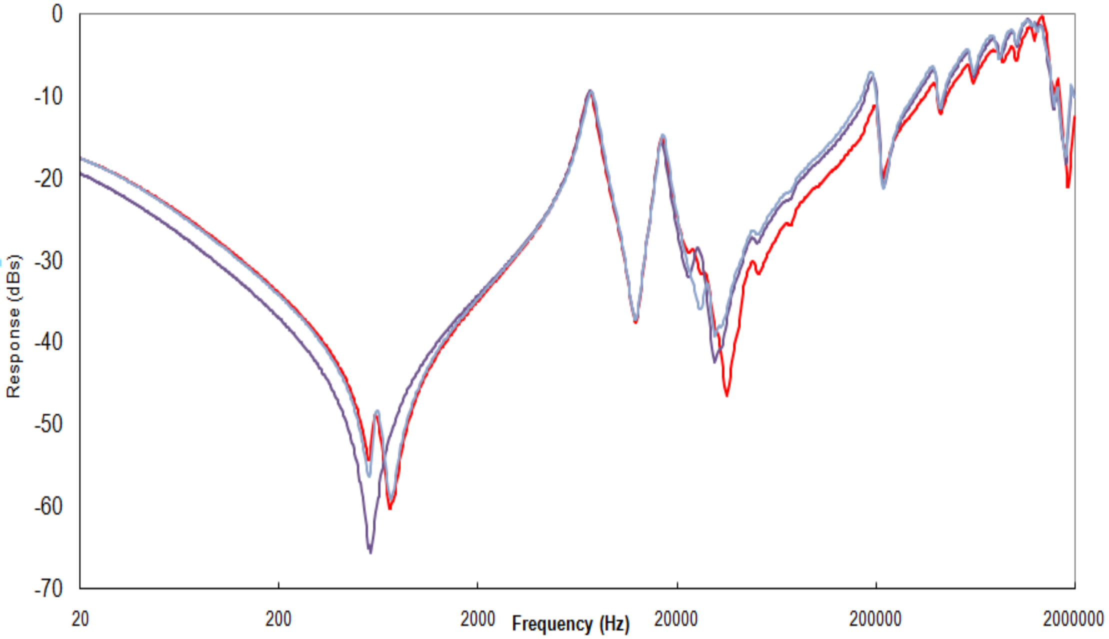
LV Winding – Open Delta

T1 with no signs of winding movement (HV & LV winding)

Case Study – 1

T2 - Regulating Winding Movement – SFRA Detected Fault at Tap 19





Case Study – 1

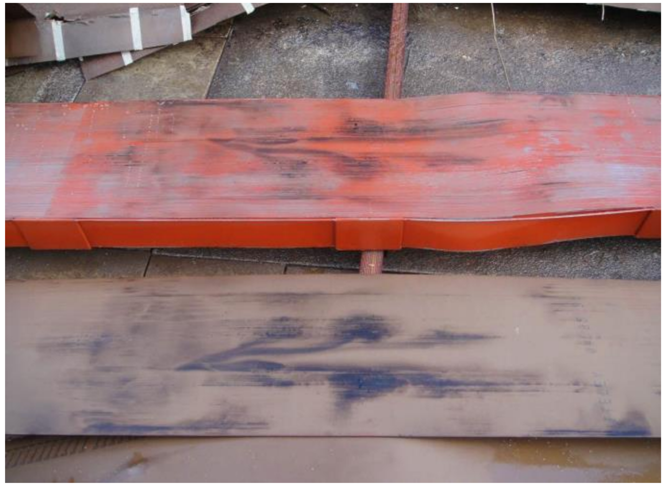
- Forensic Analysis confirmed winding movement




4 – Design Assessment

- Not the same as design review, although design review data may be useful. Info from nameplate is useful (kV, MVA, %Z, OEM, Year etc.)
- Involves assessing how different designs perform in service, e.g. rate of solid insulation ageing, short-circuit withstand capability, thermal problems developing in service.
- Often involves feedback from transformer forensics, which is often more helpful for assessing how design perform in service. And good for determining actual causes of failure. Also good for investigating solid insulation ageing.
- CIGRE brochure 529 – WG A2.36 (Guidelines for Conducting Design Reviews for Power Transformers)

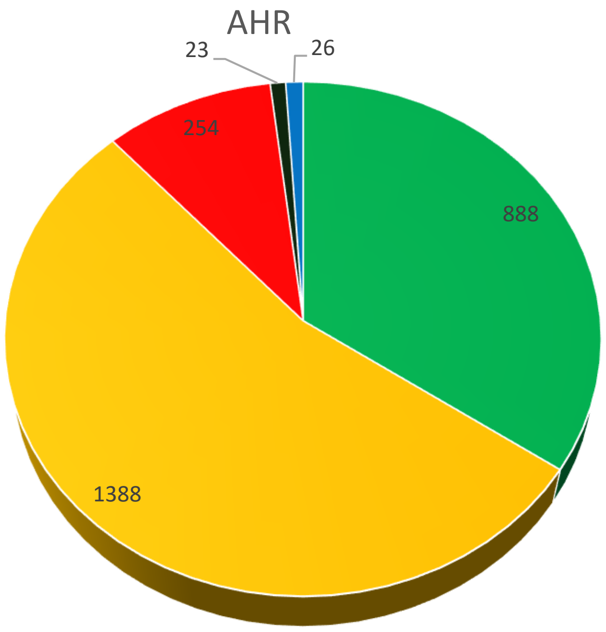
4 – Design Assessment (from forensics)





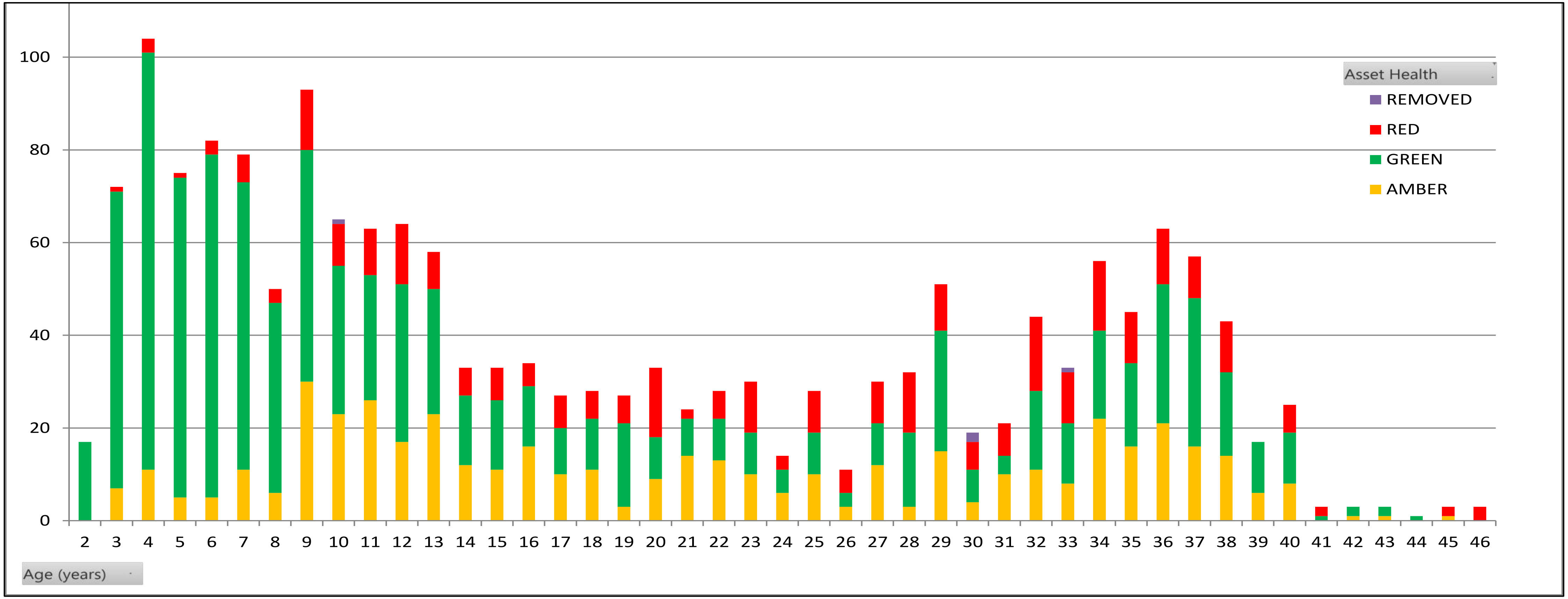
5 – Risk Management

- Risk of failure – low/medium/high
- Safe Access for continued (enhanced) monitoring
- Continuous Online & Offline surveys/condition monitoring
- Decision to change the category level based on available information
- Plan for Replacement(s)



Transformers Profiling w.r.t. Condition

5 – Risk Management



Transformers Profiling w.r.t. Service Life

Outcome

EXECUTIVE SUMMARY SHEET ASSET HEALTH REVIEW							
Transformer Numbers	No. of Units Analysed	Assigned Asset Health Categories					Individual Trf AHR Reports Completed
		GREEN	AMBER	RED	BLACK	REMOVED	
North	940	189	615	133	0	3	919
East	876	279	464	92	23	20	875
West	251	87	149	12	0	3	244
South	510	333	160	17	0	0	510
GRAND TOTAL	**2577**	**888**	**1388**	**254**	**23**	**26**	**2548**

Asset Health categories

Outcome

League table for transmission operator – sorted by worst overall condition score

Design/Manufacturer

Current and Mitigated Condition

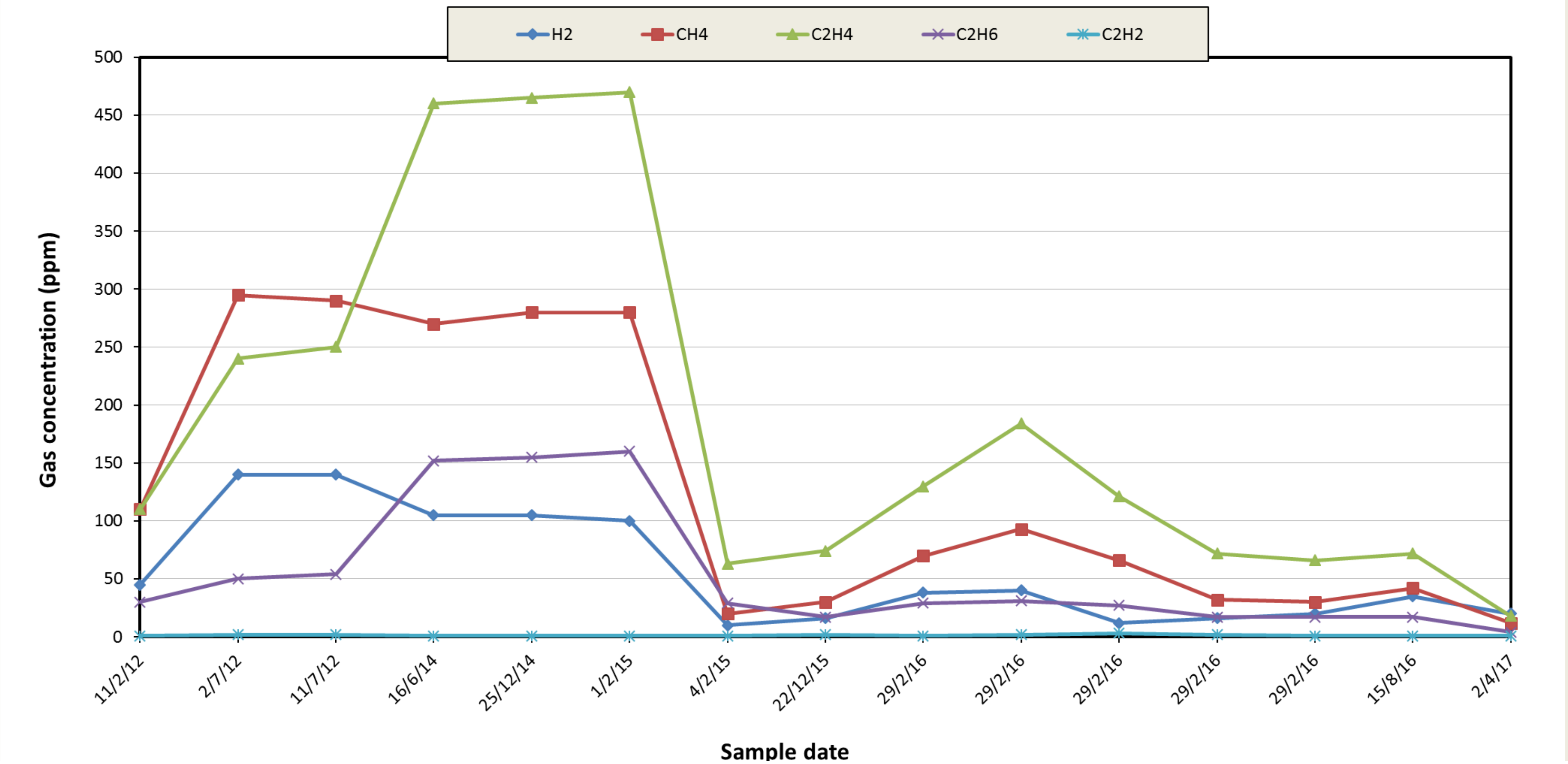
Possible improvement in score*

Component score based on sub-components

							Overall Condition			Core and Windings			Oil		OLTC	Exterior
T-N	Ratio	Rated P	Manufact	Design	sign	Year	Now	Mitigated	Possible Ir	Dielectric	Thermal	Mechanic	Ageing	Contamina n		
T4315	400/132 kV	240 MVA	AEI Wythen	A04a	32	1965	221	213	8	100	100	1	13	10	3	10
T3040	275/132 kV	120 MVA	EEC	E11b	32	1959	170	103	68	30	60	1	190	10	10	10
T6975	400/275 kV	1000 MVA	GEC	G02b	104	1994	170	135	35	30	60		36	100		1
T3039	275/132 kV	120 MVA	EEC	E11b	32	1959	154	143	11	30	100	1	23	10	10	3
T4259	275/66 kV	180 MVA	CP	D07	12	1965	152	126	26	60	60	1	70	10	1	
T2370	275/132 kV	120 MVA	MVE	M01	5	1957	151	94	57	30	60	1	160	10	3	10
T5961	400/275 kV	750 MVA	HHE	H02	111	1971	147	100	47	3	60		140			3
T6201	275/33 kV	100 MVA	PPT	P21	104	1972	144	139	5	1	3	100	13		1	10
T5566	400/132 kV	240 MVA	CAP	C04	32	1968	138	85	54	10	60	1	140	30	1	
T4409	275/132 kV	240 MVA	HHE	H07a	12	1964	133	107	26	1	100	1	70	10	3	
T5581	400/132 kV	240 MVA	AEI Wythen	A04b	102	1967	132	106	26	10	60	1	70	10	3	
T4686	400/132 kV	220 MVA	PPT	P06a	131	1967	131	107	24	1	60	1	63	10	1	10
T4406	275/132 kV	240 MVA	HHE	H07a	12	1964	129	106	23	1	100		63	10	1	
T2300	275/132 kV	120 MVA	EEC	E11a	102	1955	129	105	24	10	60	1	70		1	10
T4258	275/132 kV	240 MVA	HHE	H07a	12	1966	129	106	23	1	100		63	10	1	
T3041	275/132 kV	120 MVA	EEC	E11b	32	1959	129	107	22	30	60	3	43	30	10	
T2521	275/132 kV	120 MVA	FER	F08	120	1956	124	105	19	3	60	1	50	10	1	
T3583	275/132 kV	180 MVA	FUL	L05	111	1962	122	99	23	1	60		63	10	1	
T5434	400/132 kV	240 MVA	AEI Wythen	A04b	102	1967	122	96	26	1	60		70	10	3	
T3139	275/66 kV	120 MVA	AEI Rugby	A10	3	1960	122	106	16	100	3	1	40	10	1	

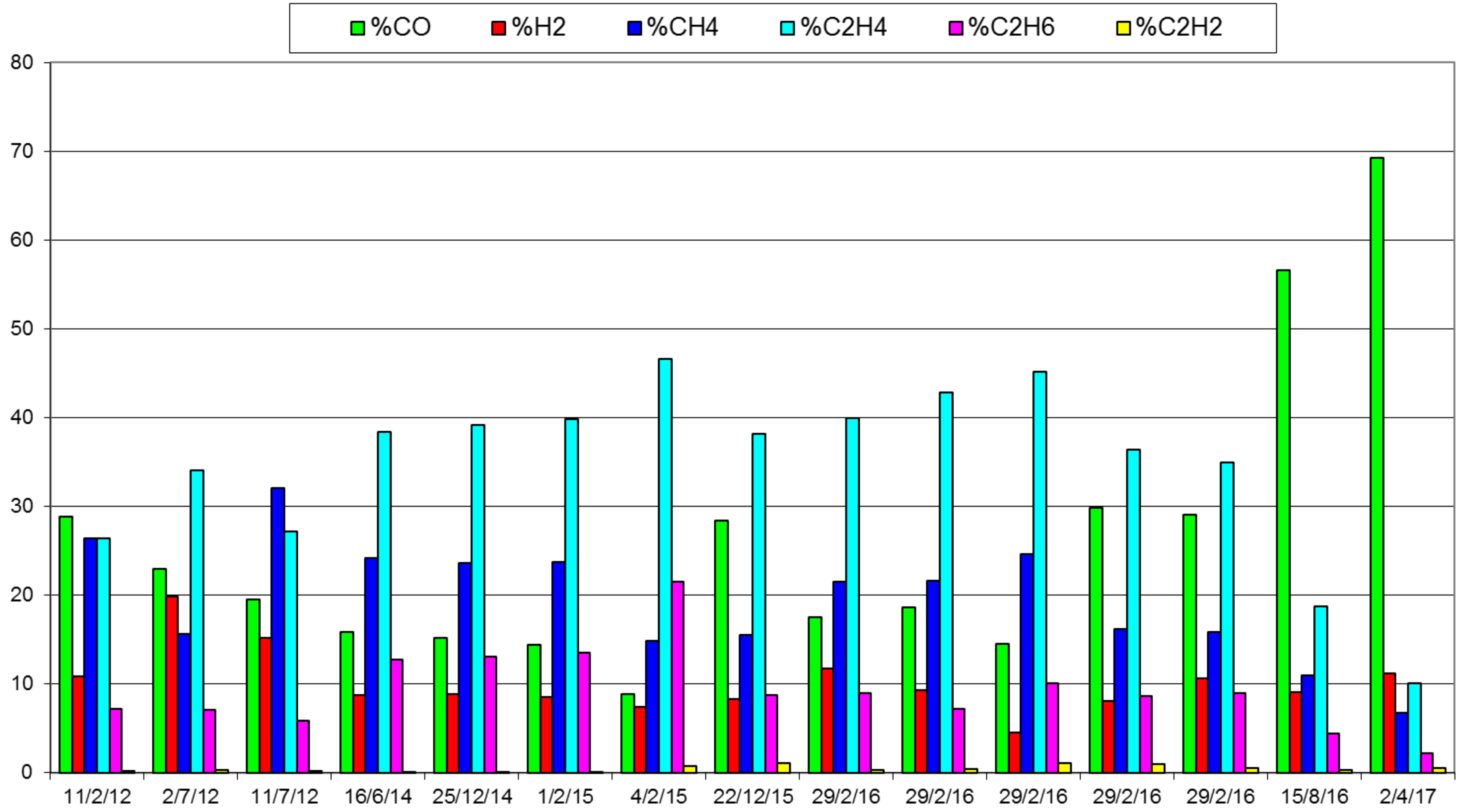
*some categories are irreversible or cannot be improved, such as aged solid insulation etc.

Case Study – 2 Transformer Core Earthing



DGA gas levels of large transmission unit 2-winding, 220kV, 3-phase

Case Study – 2 Transformer Core Earthing



DGA gas signature of large transmission unit 2-winding, 220kV, 3-phase

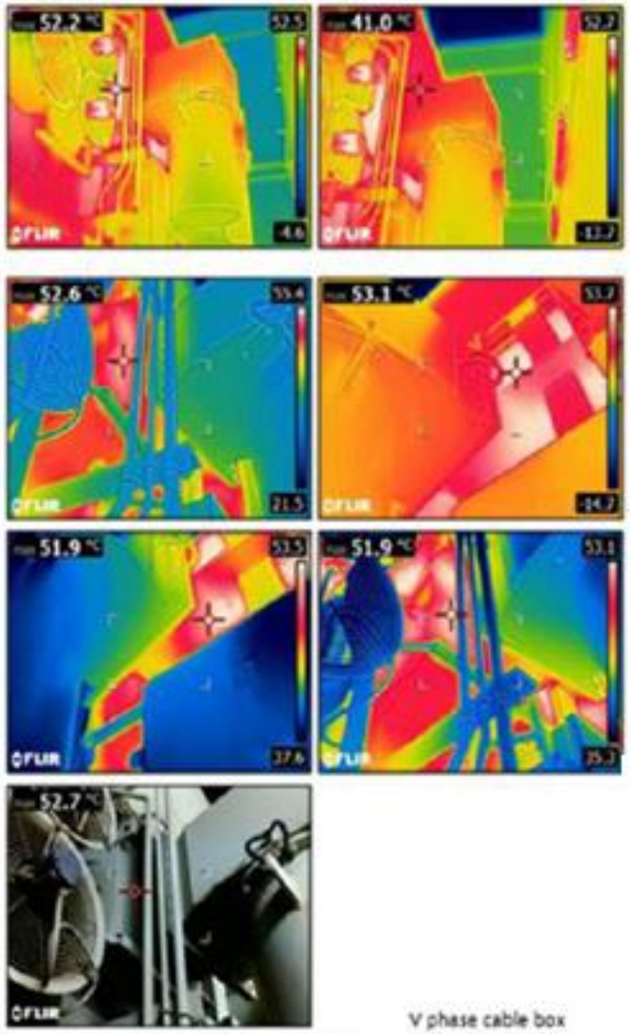
Case Study – 2 Transformer Core Earthing

(courtesy of Rick Youngblood – Doble Engineering)

Core-Frame Inspection and Resistor Installation (Aug 2016)

Case study – 3 380kV Cable Boxes Failure in Service

Case Study – 3 Lessons Learned from Failure

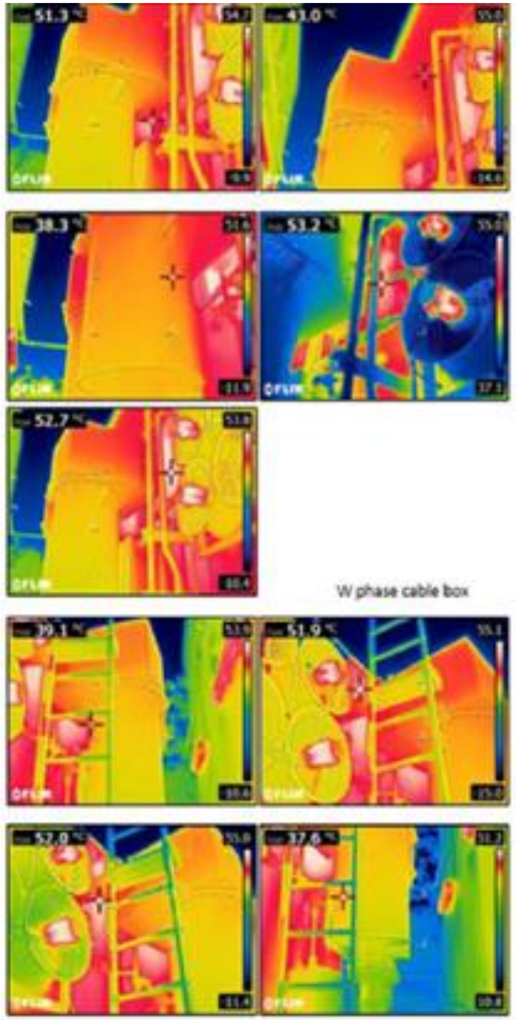


V phase cable box

V phase cable box

V phase cable box

V phase cable box



W phase cable box

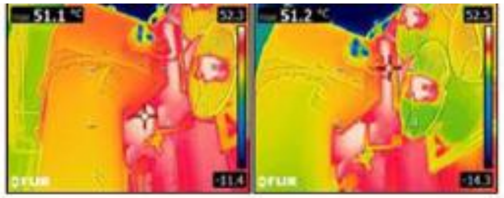
W phase cable box

W phase cable box

U phase cable box

U phase cable box

Faulty Joint!



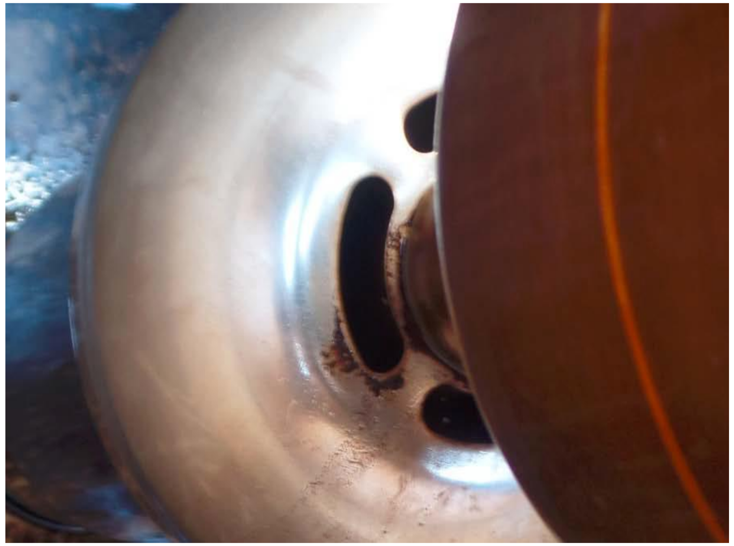
Neutral phase cable box

Sister Tx Cable Boxes IR scans revealed hotspots

Case Study – 3 Lessons learned from Failure

N phase – heat decolourisation markings of corona shield with some pitting

N phase – Heat decolourisation markings of corona shield with some pitting. Brittle paper pieces seen plus paper has voids from incorrect laying.



Signs on pitting on corona shield

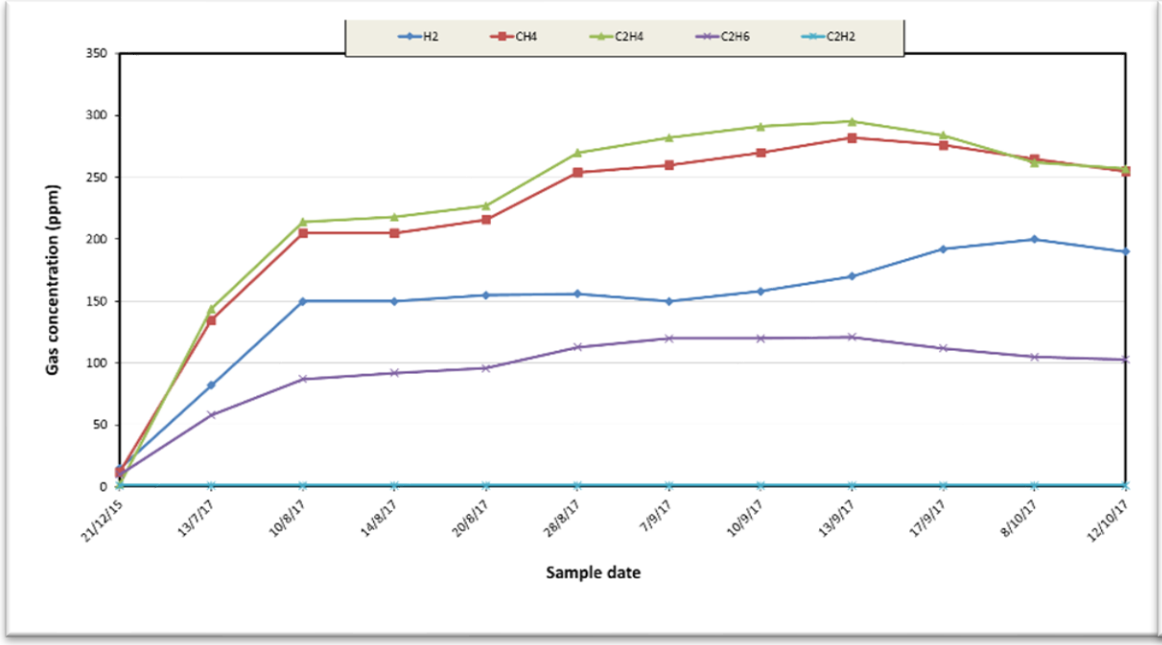
Sister Tx Cable boxes were inspected

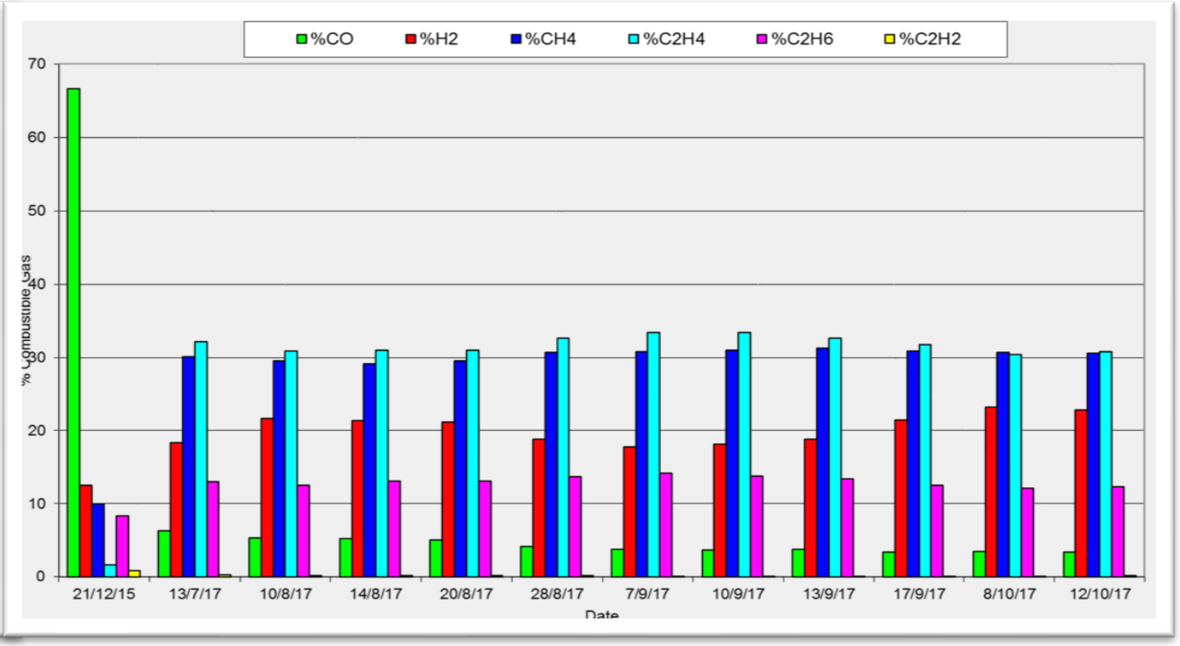
Case Study 4 – 2FAL Criteria

EQ.ID	Preserv.	Man Year	MVA	CO (2013-17) ppm	2FAL	Est DP	%age Life	est. life yrs.
TR01A	Gel Breather	1982	40	319	9.74	146	0	0
TR04A	Gel Breather	1981	40	283	8.66	161	0	0
TR02A	Gel Breather	1982	40	551	7.78	174	0	0
TR02B	Gel Breather	1981	46	646	5	228	10	3.5
TR02C	Gel Breather	1981	40	1002	4.96	230	11	3.85
TR01B	Gel Breather	1981	40	1116	4.46	243	14	4.9
TR01C	Gel Breather	1982	40	616	4.33	247	16	5.44
TR02D	Gel Breather	1982	40	696	3.55	272	23	7.82
TR01D	Gel Breather	1982	40	364	2.38	321	34	11.56
TR03A	Gel Breather	1968	31.5	423	1.34	393	49	23.52
TR03B	Gel Breather	1968	31.5	472	1.25	401	51	24.48

Case Study – 5

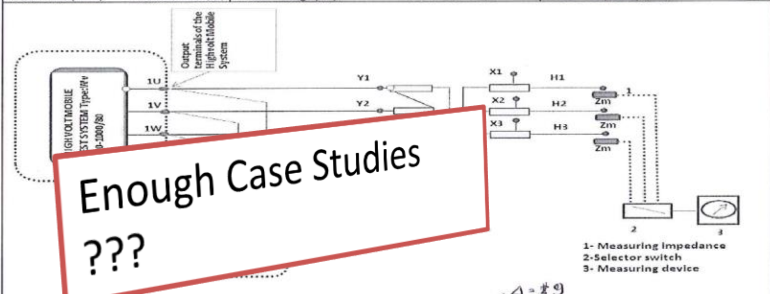
- A 380kV, autotransformer, believed to be failed due to Partial Discharges
- DGA results confirmed the myth
- Back energization confirmed PD in the sister unit





Case Study – 5

Rated Power(MVA):	452,5/602,5/752,5/(2,5)	Rated Voltage(kV):	380 / 230 / 13,8	Rated Frequency (Hz):	60



Test Frequency(Hz): 120 | Measuring frequency(kHz): 450 Δ = ±9

Temperature: (24 ± 2) °C | Shunt reactor : 1

*) phase to phase voltage

Measuring points:	Circuit Calibration: with 100 pC H1	H2	H3
H1 - Tank:	100		
H2 - Tank:		100	
H3 - Tank:			100
Correction factor: k	1,0	1,0	1,0

Duration	% Um	Up*(V)	H1 pC	H2 pC	H3 pC		TV Supply Voltages Ph. To Ph.	Ph to Earth
Correction factor : k			1,0	1,0	1,0			
		Rem.	< 21	< 25	< 25			
	100	420000	22	27	26		14526	8387
	110	462000	22	28	27		15979	9225
5'	110	462000	22	28	28		15979	9225
	150	630000	25	30	30		21789	12580
5'	150	630000	25	30	30		21789	12580
	170	714000	29	32	32		24695	14258
60"	170	714000	30	32	32		24695	14258
	150	630000	25	28	27		21789	12580
5'	150	630000	25	30	30		21789	12580
10'	150	630000	25	30	30		21789	12580
15'	150	630000	25	30	28		21789	12580
20'	150	630000	28	29	30		21789	12580
25'	150	630000	920	500	110	The test	21789	12580
30'	150	630000	→	→	→	is stopped for	21789	12580
35'	150	630000				investigation.	21789	12580
40'	150	630000					21789	12580
45'	150	630000					21789	12580
50'	150	630000					21789	12580
55'	150	630000					21789	12580
60'	150	630000					21789	12580
	110	462000					15979	9225
5'	110	462000					15979	9225
			<	<	<			

Measuring instrument : OMICRON MPD600 ; Serial no : FM050E , FM085E , FM063E / MCU 502 ; Serial no : HA128B
HV/LV/TV :399.000 / 230.000 /13.800 V ; Tap Pos :1

Tested by:	Witnessed by:	CUSTOMER OR REPRESENTATIVE:
DATE: 21.03.2016	DATE:	DATE:

Back Energisation PD test of sister tx




Sister tx damaged insulation causing PD (design issue) – leads out 1 & 3 (before & after repair)

AHR Summary Code Sheet

Substation	Overall Transformer Code	Oil Code	Electrical Code	Mechanical Code	Most Recent Sample date Oil	DGA Code	Paper Aging Code (FAL and CO	Oil Quality Code	Moisture Code	Corrosive Sulfur Code	Most Recent Electrical Test Dat	Overall Power Factor Cc	Overall Capacitance Code	Bushing Code	Winding Insulation Resistance Code	Core Insulation Resistance Code	Winding Resistance Code
B	4	4	5	5	9/22/15	5	3	4	4	0	2014	5	5	0	5	0	0
C	1	1	3	5	9/22/15	1	4	4	4	0	2014	3	5	0MP	5	0MP	0
D	4	4	5	5	11/13/2015	4	4	4	3	0	2015	5	5	0	5	0	0
E	3	3	3	3	9/22/2015	4	3	4	3	0	2015	3	3	0	5	0	0
F	4	4	5	5	9/22/2015	4	4	4	3	0	2014	5	5	0	5	0	0
G	2	2	3	5	5/26/2016	4	3	2	3	0	2014	5	5	3	5	0	5
H	3	3	5	5	3/25/2015	3	3	4	4	0	2014	5	5	5	5	0	5

Easy to group and prioritize
Drill down to sectional codes
Gap analysis data needed

Fleet Activity Report

dobleARMS World Wide Energy > North America Grid — 3 Days — 10 — Hendrik

IM Report

W...	Division	Location	Asset	Special Id	Serial Number	KV	MVA	Manufactur...	Last Sample Date	AHI	IM Assessment Score	Arcing	Partial Discharge	Anomalous Water Indication	Thermal Fault Oil	Thermal Fault Paper	Thermal Cellulosic Decompositio	DG - AI	DobleLab TRF	IEC DGA	IEEE DGA	Oil Qua Evalua
	Central	NA Station 15	TR 1	M1004401	A5685T	230	30		06/06/2012	1	1	1	1	1	1	1	1	1	1	1	1	
	Central	NA Station 16	TR 4	M1006701	8167653	345	560		10/04/2012	3	3	2	2	1	2	4	10	10	1	5	1	
	Central	NA Station 16	TR 2	M1006601	8167651	345	560		05/01/2013	6	5	5	5	1	6	8	10	30	1	5	1	
	Central	NA Station 17	TR 1	M1006501	5382851	67			04/04/2013	1	1	1	1	1	1	1	1	1	1	1	1	
	Central	NA Station 18	TR 1	M1007701	C0540551	115	30		10/17/2012	1	1	1	1	3	1	1	1	1	1	1	1	
	Central	NA Station 19	TR 1	M1000201	RAR69034	110	25		04/26/2013	4	4	2	7	3	2	2	1	10	1	2	8	
	Central	NA Station 20	TR 1	M1001301	18226527701	110	30		02/06/2013	1	1	1	1	1	1	1	1	1	1	1	1	
	Central	NA Station 20	TR 3	M1001201	6538975	110	20		02/06/2013	2	1	1	1	1	1	1	1	1	1	3	1	
	Central	NA Station 23	TR 3	M1007901	SLL56502	230	30		07/18/2012	1	1	1	1	3	1	1	1	1	1	1	1	
	Central	NA Station 23	TR 2	M1006701	SLM54245	230	30		07/18/2012	1	1	1	1	1	1	1	1	1	1	1	1	
	Central	NA Station 23	TR 1	M1009201	137341	230	50		07/18/2012	2	1	1	1	1	1	2	10	1	1	4	1	
	Central	NA Station 24	TR 1	M1007701	RDP32431	115	25		03/07/2013	1	1	1	1	2	1	1	1	1	1	1	1	
	Central	NA Station 25	TR 1	M1006701	G851798B	115	30		04/11/2013	1	1	1	1	1	1	1	1	1	1	1	1	
	Central	NA Station 25	TR 2	M1004801	RHP39152	110	30		08/01/2012	1	1	1	1	1	1	2	1	1	1	1	1	
	Central	NA Station 25	TR 3	M1009501	RHR22433	110	25		08/01/2012	2	1	1	1	1	1	1	1	1	1	3	1	
	Central	NA Station 27	TR 1	M10052601	C0469751	44	1.2		10/22/2012	4	3	1	1	1	1	19	1	1	4	3	1	
	Central	NA Station 39	TR 3	M1001901	A2043T	115	30		02/10/2013	1	1	1	1	3	1	1	1	1	1	1	1	
	Central	NA Station 39	TR 1	M1001601	C0668551	115	30		02/10/2013	1	1	1	1	3	1	1	1	1	1	1	1	
	Central	NA Station 39	TR 4	M1005001	6996996	110	25		05/02/2013	2	1	1	1	3	1	1	1	1	1	3	1	
	Central	NA Station 39	TR 2	M1008001	C658432	110	20		02/10/2013	8	7	1	1	1	1	62	1	1	13	1	1	
	Central	NA Station 46	TR 1	M1003302	1984359	13.2	5		02/20/2013	1	1	1	1	2	1	1	1	1	1	1	1	
	Central	NA Station 46	TR 3	M1003306	2215476	13.2	5		02/20/2013	1	1	1	1	2	1	1	1	1	1	1	1	
	Central	NA Station 46	TR 2	M1002901	C0577751	43.8	1.2		08/23/2012	2	1	1	1	1	1	1	1	1	1	3	1	
	Mexico	Guadalajara	TR 2		6533291				01/08/2008	1	1	1	1	5	1	1	1	1	1	1	1	
	Mexico	Guadalajara	TR 3	M1005101	HC19367001	44	11.2		08/23/2012	1	1	1	1	1	1	1	1	1	1	1	1	
	Mexico	Guadalajara	TR 1	M1002201	H888460	43.8	5.2		08/23/2012	33	32	71	15	3	19	19	1	100	38	12	35	
	Mexico	Mexico City	TR 2	M1003701	A5435T	44	11.2		04/18/2013	1	1	1	1	1	1	1	1	1	1	1	1	
	Mexico	Mexico City	TR 1		C859395	44	0.00...		07/20/2005	1	1	1	1	3	1	1	1	1	1	1	1	

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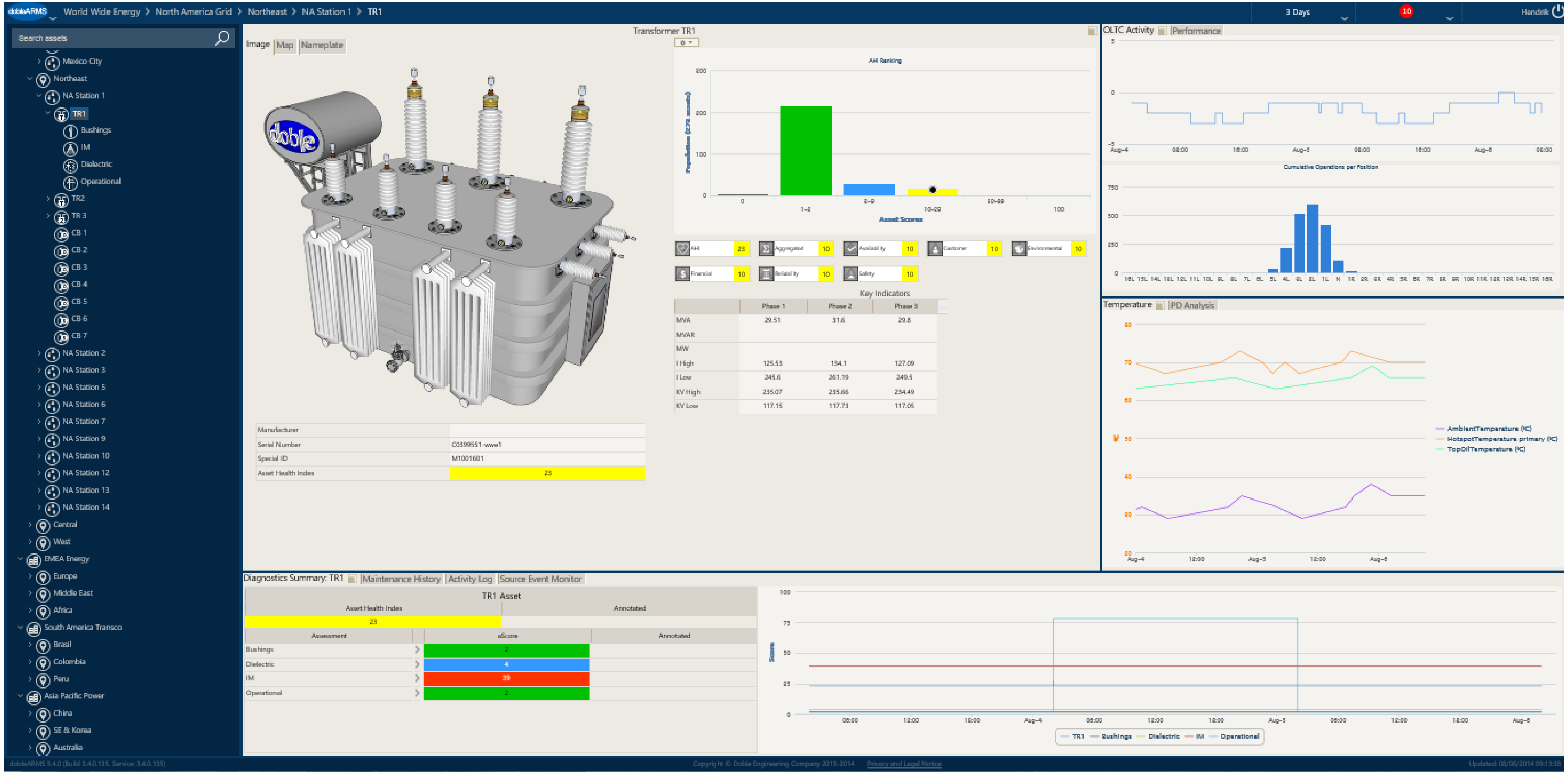
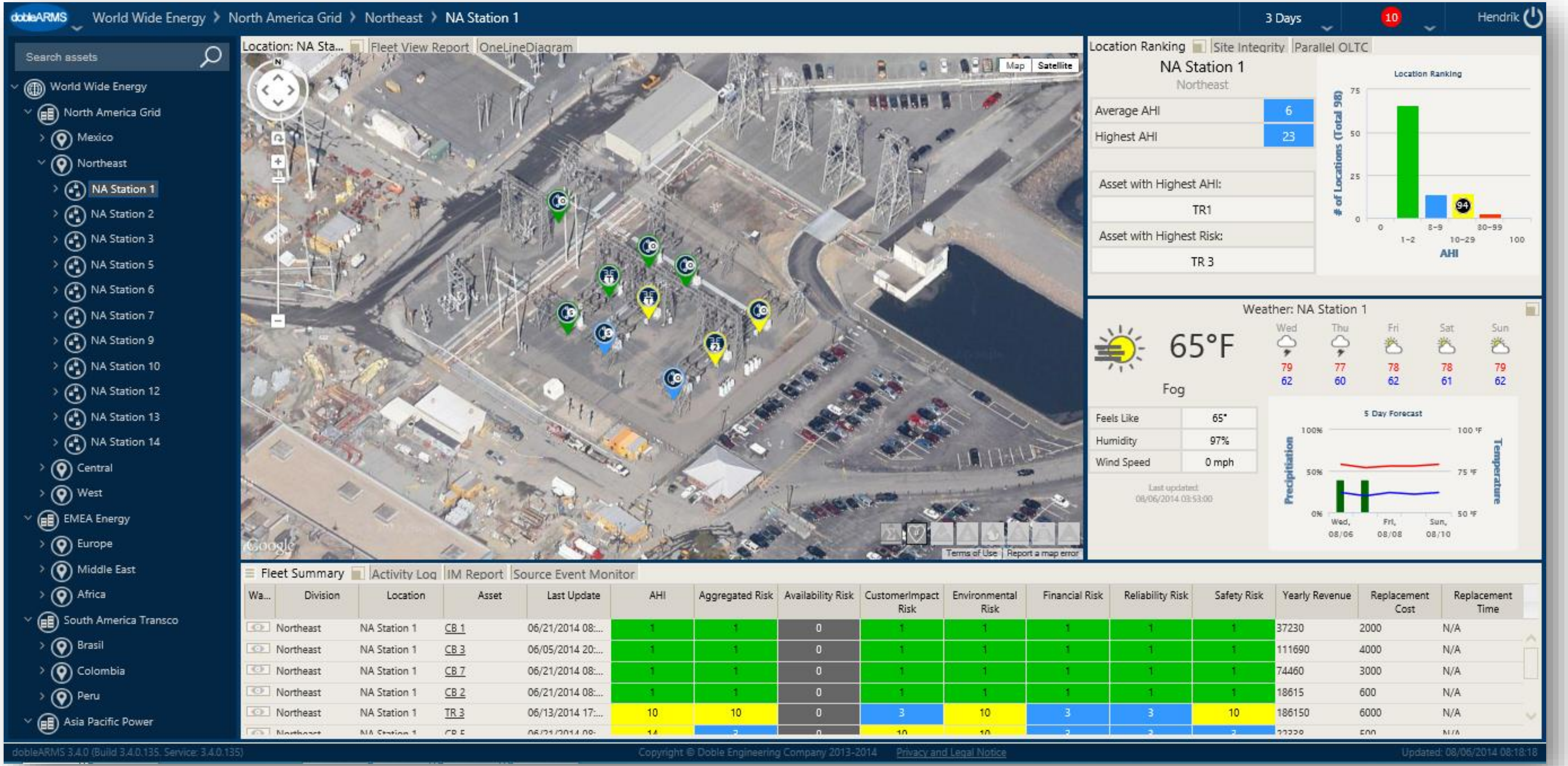
Transformer Assessment Methods

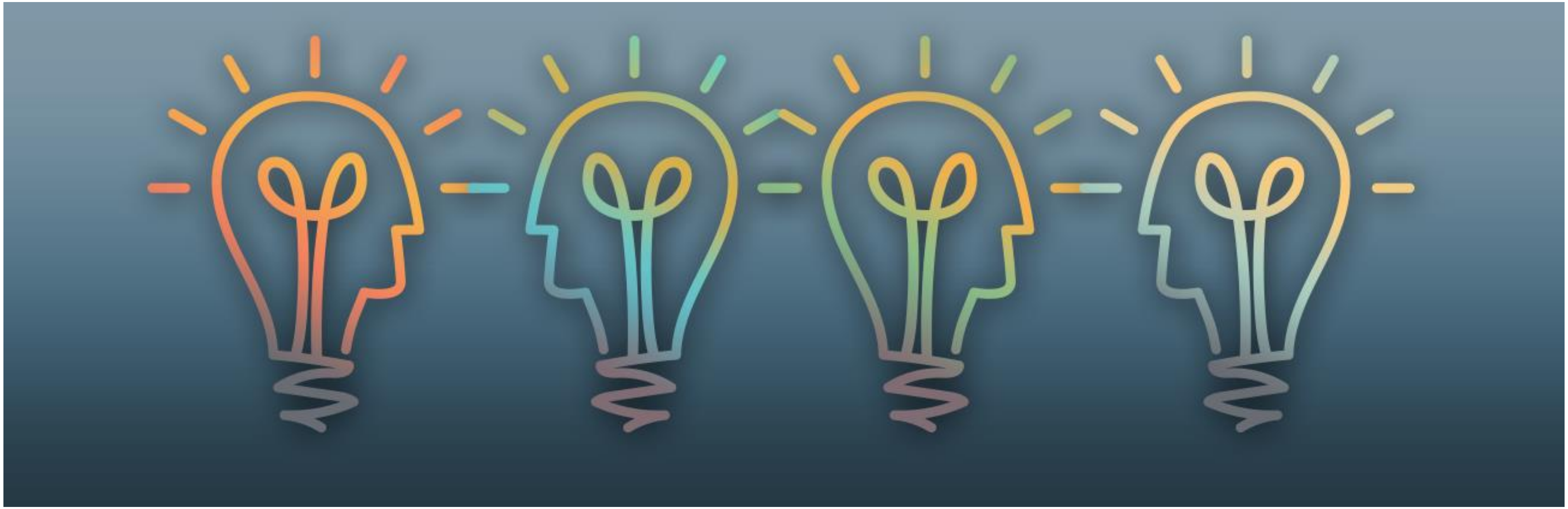


Substation Asset Overview

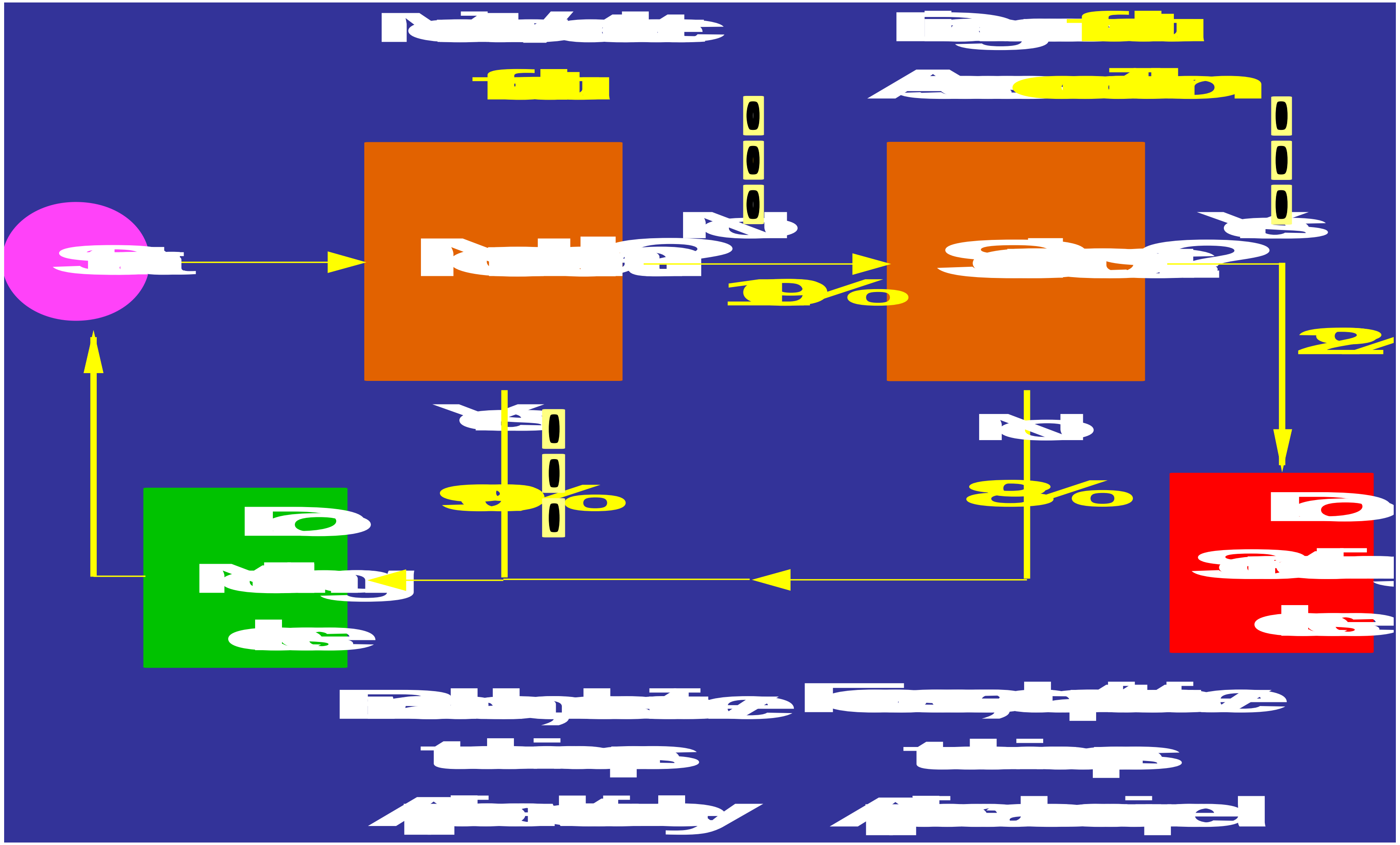


Wa...	Division	Location	Asset	Last Update	AHI	Aggregated Risk	Availability Risk	CustomerImpact Risk	Environmental Risk	Financial Risk	Reliability Risk	Safety Risk	Yearly Revenue	Replacement Cost	Replacement Time
	Northeast	NA Station 1	CB 1	06/21/2014 08:...	1	1	0	1	1	1	1	1	37230	2000	N/A
	Northeast	NA Station 1	CB 3	06/05/2014 20:...	1	1	0	1	1	1	1	1	111690	4000	N/A
	Northeast	NA Station 1	CB 7	06/21/2014 08:...	1	1	0	1	1	1	1	1	74460	3000	N/A
	Northeast	NA Station 1	CB 2	06/21/2014 08:...	1	1	0	1	1	1	1	1	18615	600	N/A
	Northeast	NA Station 1	TR 3	06/13/2014 17:...	10	10	0	3	10	3	3	10	186150	6000	N/A

Finished ???



Condition Based Methodology



Asset Health Review Coding

Code 1: Immediate Attention

Code 2: Action in near future

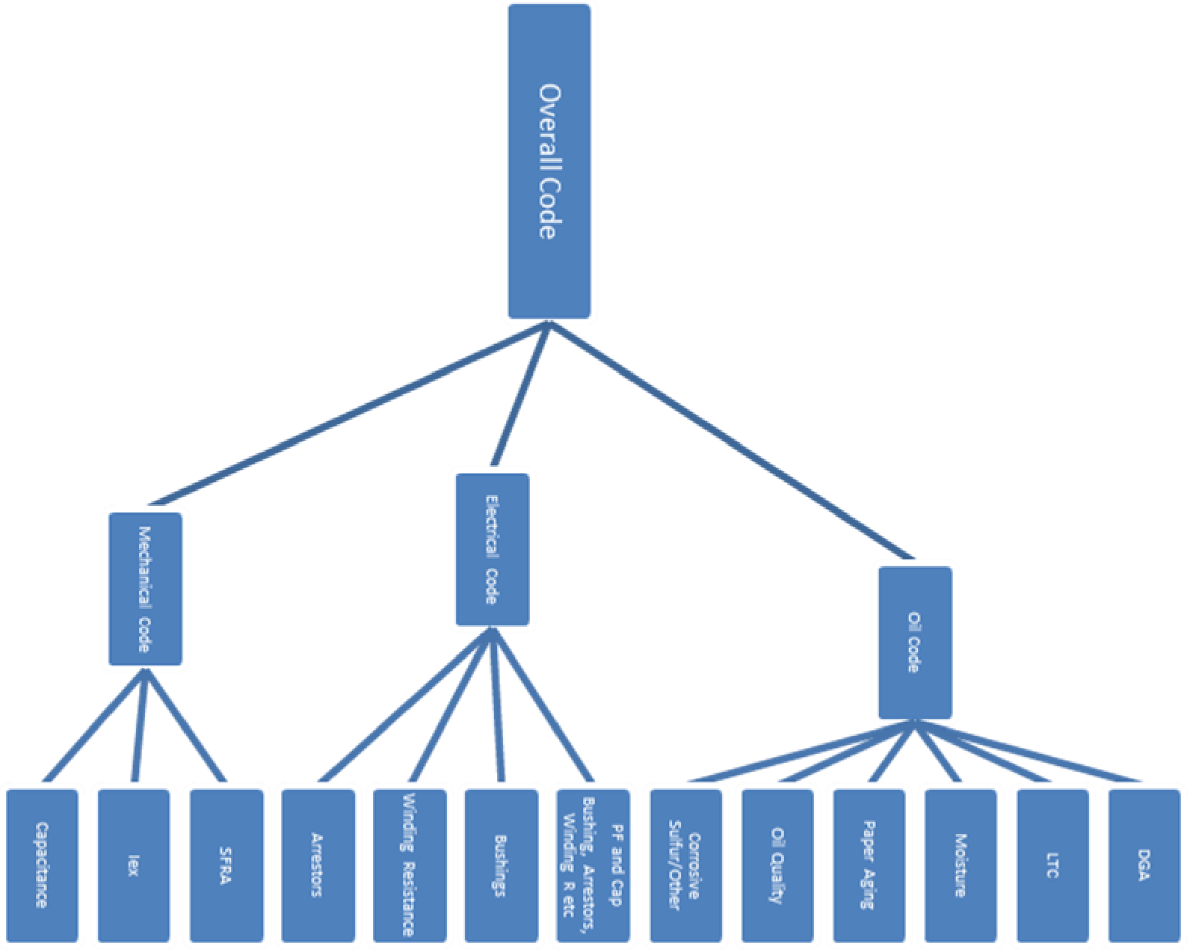
Code 3: Monitor data-possible issue

Code 4: Normal aging-normal sample schedule

Code 5: No problems detected-normal sample schedule

Code 0: No Data

Code 0MP: Incomplete Data



Asset Register

Create a transformer asset register listing with consistent nomenclature:

Design parameters
- Manufacturer, Family, Year

Functional parameters
- kV, MVA, % Z, etc.

Operational history
- Service life, Loading

Event history
- Faults, system events

Monitoring data: DGA, electrical test data
- Database/integrated to permit evaluation trends

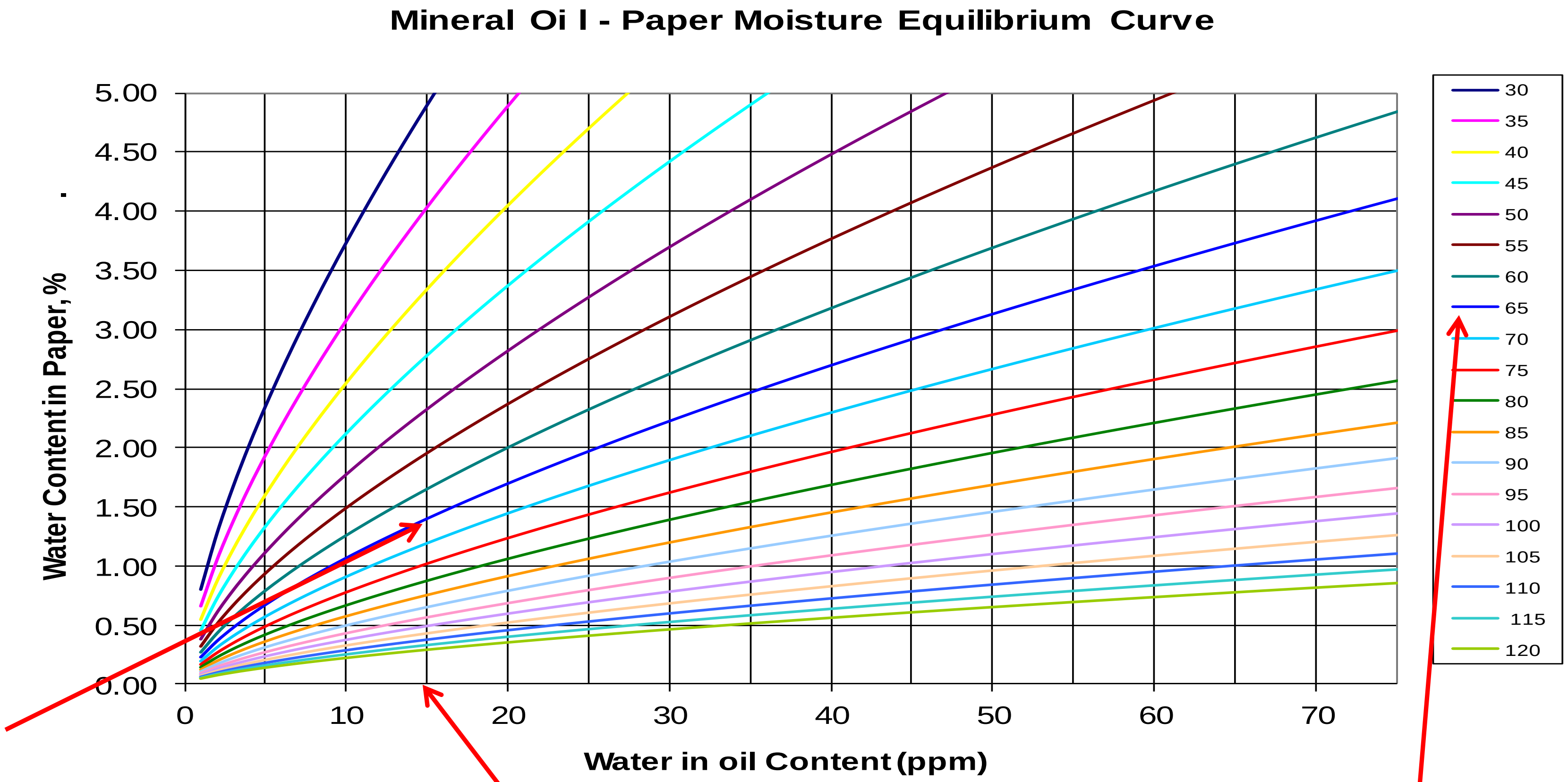
Oil Laboratory Testing

DGA	Furanic -MeOH/EtOH -DP	Moisture -%RS -Water in Paper -Dielectric BDV	Oil Quality -IFT -Acidity or NN -PF	-Corrosive Sulfur -Passivator -Foaming -Metals -Stray Gassing
Active Fault Indication!	Solid insulation	Insulation wetness	Oil condition	Special tests
Incipient fault conditions	Condition/aging rate	Operation/aging rate	Condition/aging rate	Contamination, Compatibility issues, Pump operations

IEC 60599:2015
IEEE C57.104:2019

IEC 60422

Moisture-in-Paper Estimation (Doble Oil Labs)



3. Estimated 1.4% water in paper

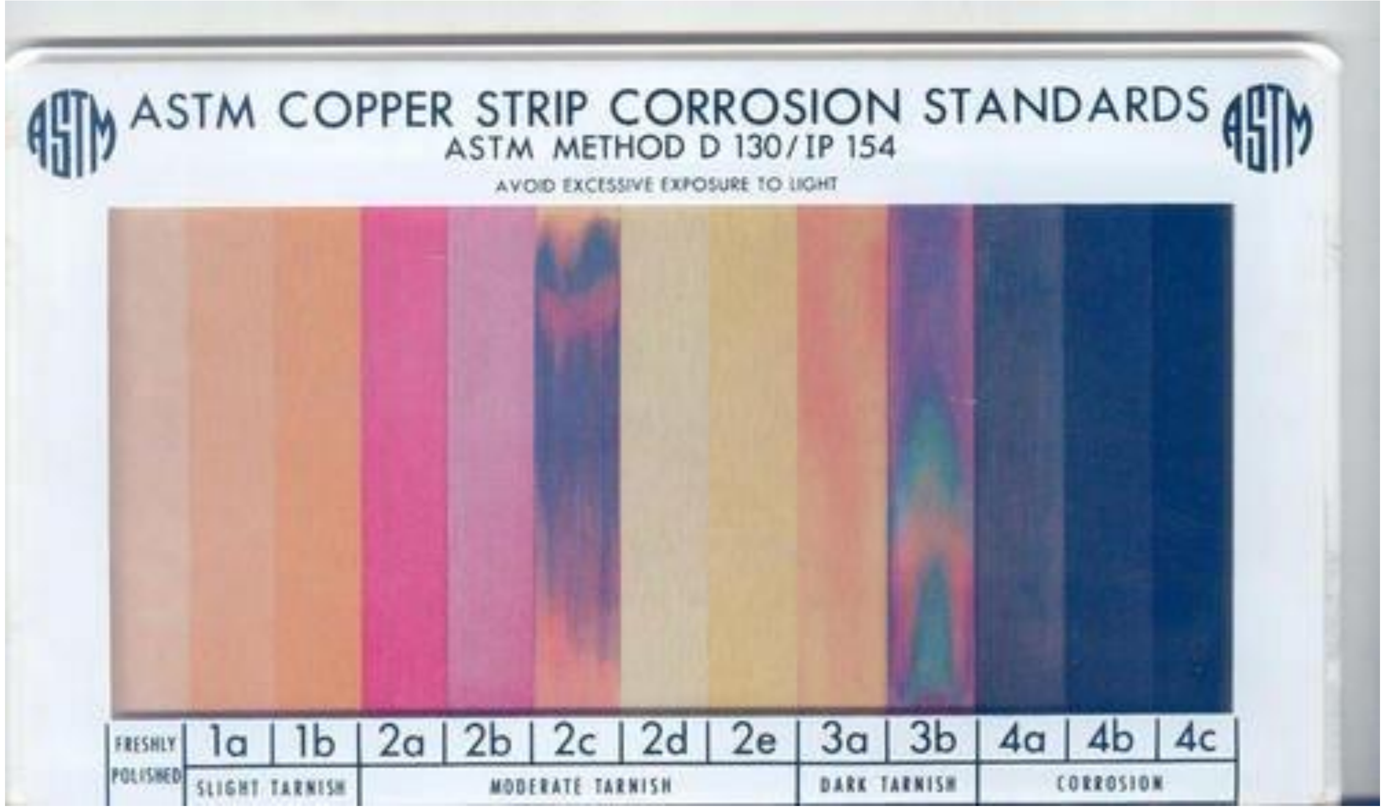
1. Water in oil content of 15 ppm

2. Top oil temperature at time of sampling 65C

Oil Contamination with DBDS - Corrosive Sulfur

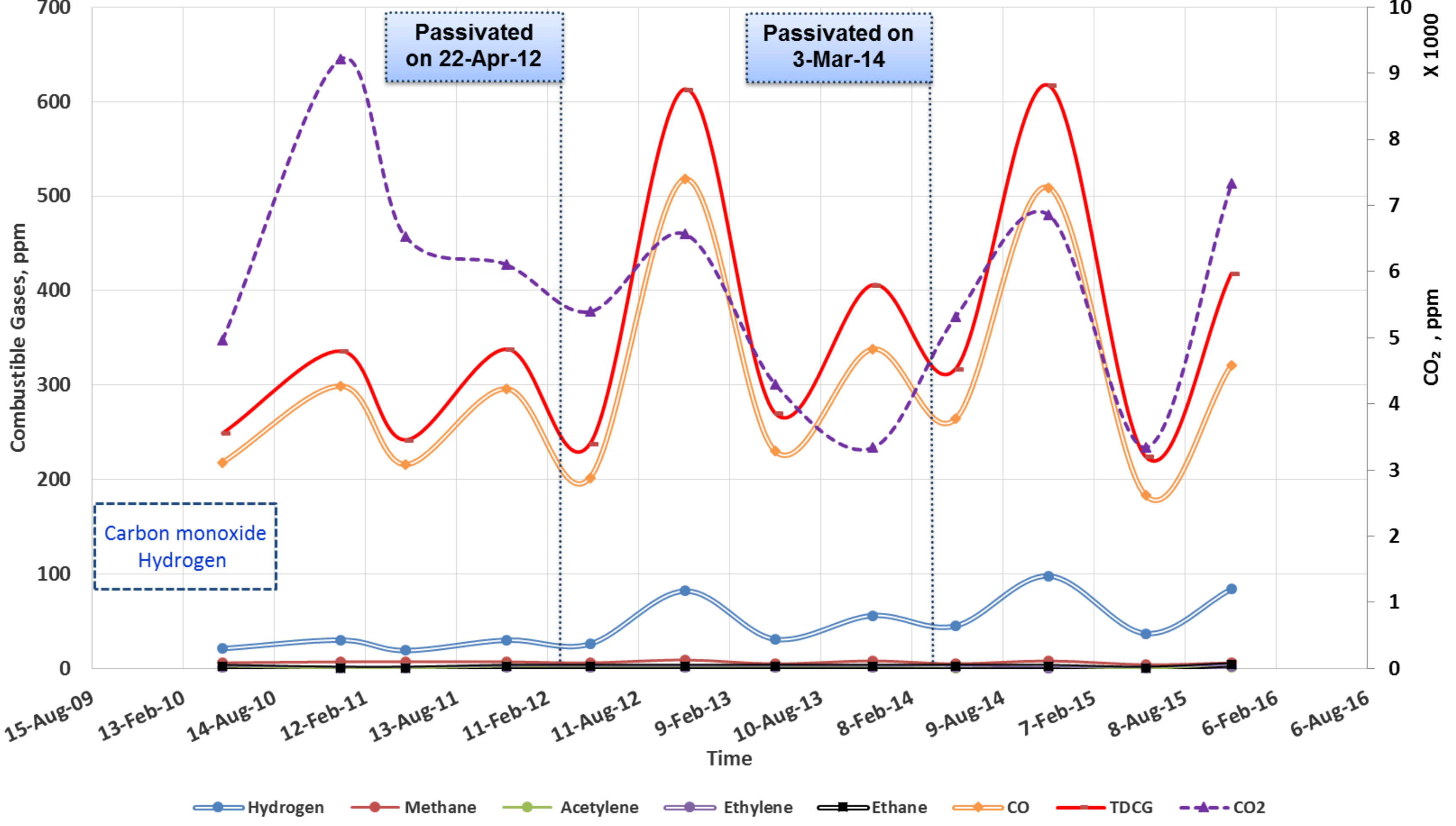
ASTM D1275A

ASTM D1275B



Doble CCD Tests

FALSE NEGATIVES - STRAY GASSING AFTER PASSIVATION



External Inspection: In-service Examination

- Visual inspection of the transformer and components
- Leaks, corrosion
- Bushings – discoloration, mechanical
- Conservator and bladder
- LTC
- Surge arrestor counter
- Cooling operating properly
- Infrared thermography – overheating, bad connections

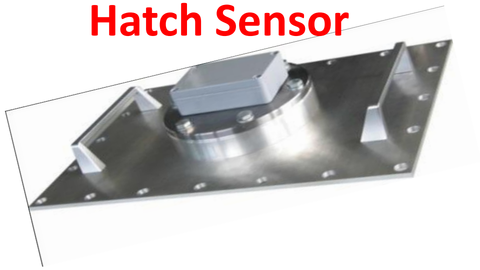
Loss of nitrogen can have dramatic effect on loss of insulation life, oxygen and moisture

Additional In-Service Testing: Online Partial Discharge

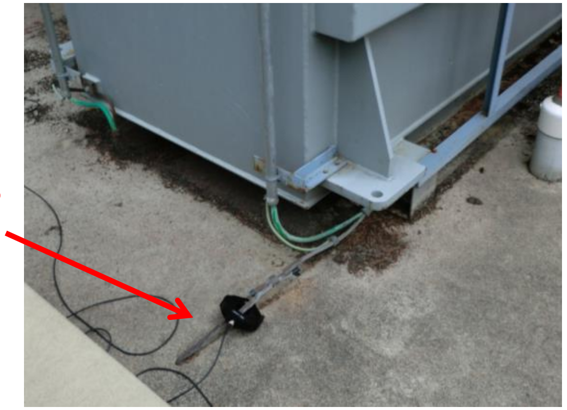
UHF and HFCT PD Measurements - Detection

UHF Antenna

Hatch Sensor

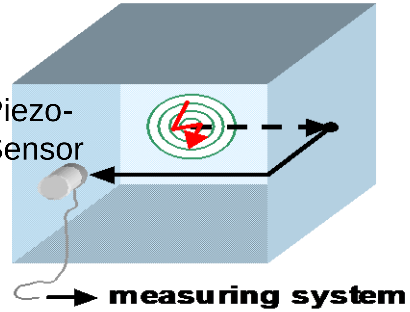


HFCT

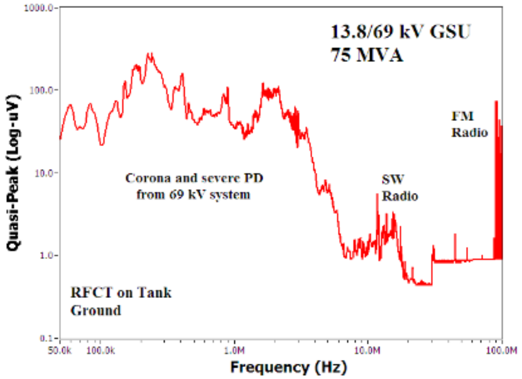


RFI

Acoustic Measurements - Location



EMI



TEV Probe

List of Offline Electrical Tests

- Present and historic data, including factory acceptance tests
- To detect dielectric/thermal, mechanical and magnetic circuit problems
  - » Overall Power Factor & Capacitance: to check bulk insulation quality
  - » Bushing Power Factor & Capacitance: to detect insulation quality of bushing (externally & internally), can detect shorted layers / damaged test tap and loss of insulating oil
  - » Core/Frame Insulation Resistance: to check poor insulation between core-frame-ground
  - » Winding Resistance: to detect electrical discontinuities or resistive contacts/joints
  - » Exciting or Magnetising Current: to detect Shorted turns in winding, welded lamination in core
  - » Leakage Reactance: to detect gross Winding deformation
  - » Sweep Frequency Response Analysis: to detect any change in RLC geometry (winding integrity)
  - » Transformer Turns Ratio (TTR): to detect Shorted turns or to confirm the correct ratio after tap-changer repair

List of Relevant IEC Standards

- **IEC 60076-1:2011**
  Power transformers - Part 1: General
- IEC 60076-2:2011
  Power transformers - Part 2: Temperature rise for liquid-immersed transformers
- IEC 60076-4:2002
  Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing - Power transformers and reactors
- IEC 60076-5:2006
  Power transformers - Part 5: Ability to withstand short circuit
- IEC 60076-6:2007
  Power transformers - Part 6: Reactors
- IEC 60076-7:2018
  Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers
- IEC 60076-10:2016
  Power transformers - Part 10: Determination of sound levels
- **IEC 60076-11:2018**
  Power transformers - Part 11: Dry-type transformers
- IEC 60076-14:2013
  Power transformers - Part 14: Liquid-immersed power transformers using high-temperature insulation materials
- **IEC 60076-16:2011**
  Power transformers - Part 16: Transformers for wind turbine applications
- **IEC 60076-18:2012**
  Power transformers - Part 18: Measurement of frequency response
- **IEC 60076-16:2018**
  Power transformers - Part 16: Transformers for wind turbine applications
- IEC 60076-57-129:2017
  Power transformers - Part 57-129: Transformers for HVDC applications
- IEC/IEEE 60076-57-1202:2017
  Power transformers - Part 57-1202: Liquid immersed phase-shifting transformers
- **IEC 60599:3.0 2015**
  Mineral oil-filled electrical equipment in service – guidance on the interpretation of dissolved and free gases analysis

Conclusions

- The concept of AHI for Fleet Management allows customers to get the best value from ageing populations of transformers / reactors
- A successful program in place, relies on a wide range of data to gain a good understanding of the performance of different designs in service. It is able to identify both *risks* and *opportunities*, especially for 'life extension'.
- All information is consolidated in one place in an easily accessible format.

Thank You for Your Keen Interest and Attention

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ALTANOVA
A DOBLE COMPANY

Next ALTANOVA **WEBINARS**

15 Mar — Transformer fleet management - The Asset Health Review (AHR) process (APAC)

22 Mar — Manejo de transformadores de potencia: análisis de salud de activos para evaluación de riesgos

7 Apr — Introduction to power transformer testing

12 Apr — Offline testing of underground cables