Catastrophic Failure of ASEA Type IMBE-170 A4 Current Transformer

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CT Information

3 x single phase CT in 161kV substation feeding industrial load with harmonic filter

ASEA

Made in 1988 by Sweden

Type: IMBE 170 A4

Rated voltage : 170 kV

Standard : CAN3-C13-M83

4 secondary windings

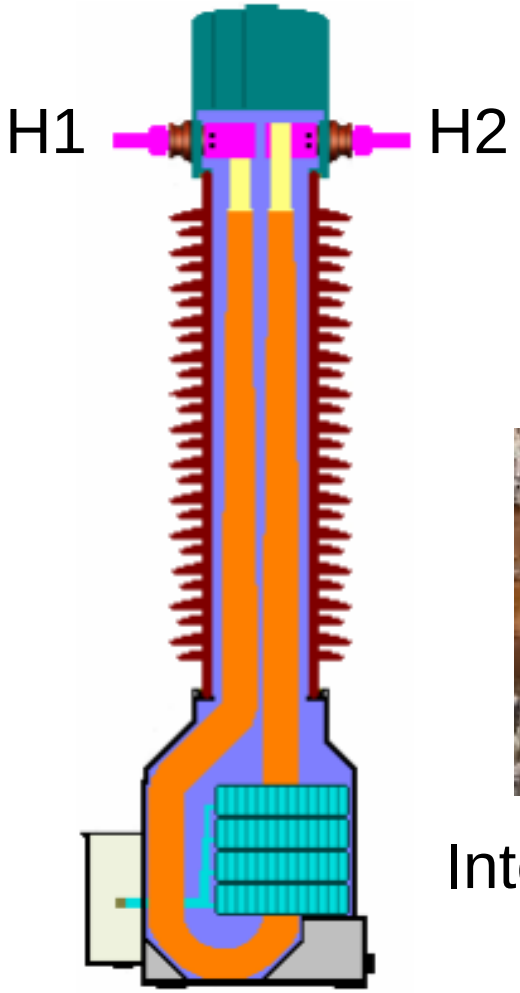
Shed porcelain insulator

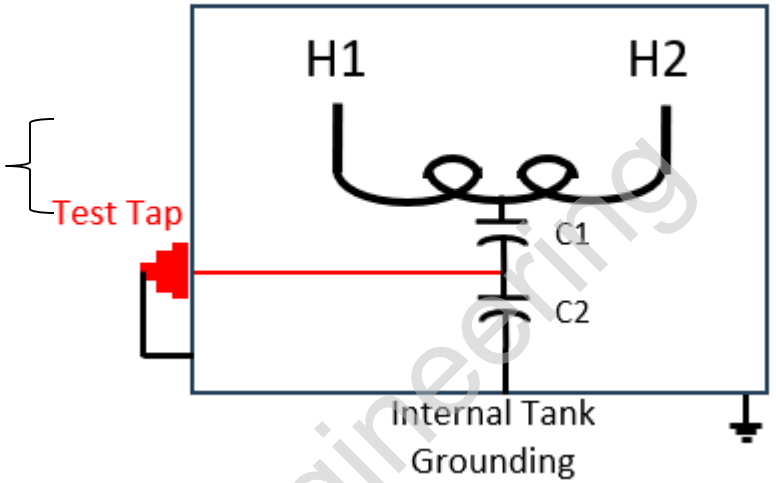
3 X SIMILARS UNITS	
PHASE	SERIAL NUMBER
A	7739539
B	7739540
C (Failed**)**	7739541

Failure Information

- ‘C’ phase unit failed June 2023
- Bottom half of housing is gone
- Collateral damage up to 250’ away & adjacent CT’s
- Burnt secondary leads and test tap ground connection
- Harmonics filter removed from service weeks before failure

CT Design





Few insulation papers between test tap and grounding layers

Internal test tap connection

Internal ground connection

Maintenance History 3 Phase CT Bank

- Insulation measurement maintenance interval of 6 years, no oil sample performed
- Phase C (Failed), no significant data change was observed from 2006 to 2017 and the PF in the latest test (2017) was within acceptable limits before event
- C2 measurement had been abandoned because of complication in selecting a correct test voltage for field testers

Date	Power factor (%PF)			Capacitance (pF)		
	PH A	PH B	PH C	PH A	PH B	PH C
7/10/2023	0.28	0.22	Failed	848	1016	Failed
10/12/2017	0.32	0.26	0.25	846	1008	954
8/29/2012	0.29	0.23	0.22	829	999	943
9/20/2006	0.51	0.41	0.40	829	998	941

PH C results 2017

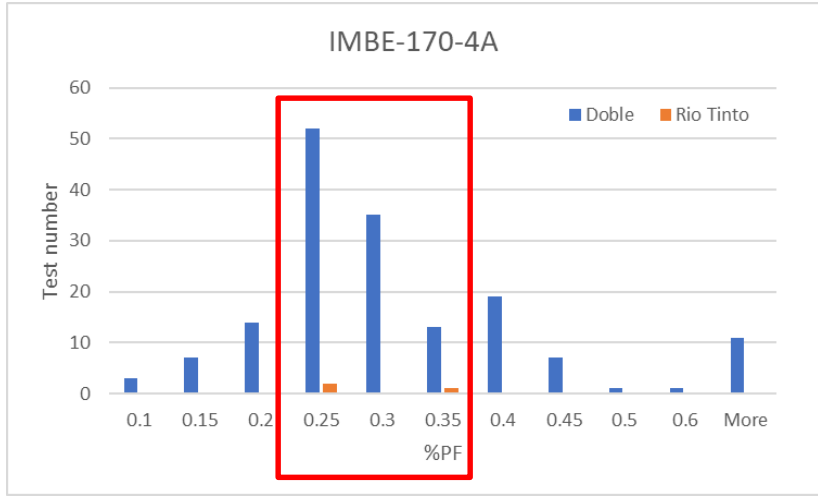
Setup						Results								...atings
#	H1	H2	Tap	Insulation System	Test kV	V [kV]	I [mA]	Loss [W]	TCF [#]	PF [%]	PF*TCF [%]	Capacitance [pF]	Ask FRANK™	Manual
1	HV			CH	10.000	10.001	3.597	0.091	1.00	0.252	0.252	954.2	G Good	Unrated U
2				CH	2.000	2.000	3.598	0.093	1.00	0.257	0.257	954.6		Unrated U
3			Red LV Lead	C1	10.000	10.001	not performed						U Unrated	Unrated U
4	Red LV Lead	HV		C2	10.000	10.002							U Unrated	Unrated U

Failure Investigation – Two Other CT Phases – PF

- Two sister units were used as benchmark for Root Cause Analysis
- Tested July 10th, 2023 – Overall, C1 & C2 insulation tests
  - PF < acceptable limit and statistically well below the data from Doble database (DTAWeb)
  - Capacitances variation from 5% to 18% suggesting some variation in the CT construction

	PH A (7/10/2023)		PH B (7/10/2023)		PH C (2017) before failure	
	%PF	Cap (pF)	%PF	Cap (pF)	%PF	Cap (pF)
Overall 10kV	0.220%	848.3	0.276%	1016.0	0.252%	954.2
Overall 2kV	0.226%	848.8	0.282%	1016.6	0.257%	954.6
C1, 10kV	0.193%	767.6	0.247%	931.4	-	
C2, 2kV	0.213%	19670	0.243%	23744.0	not performed	-

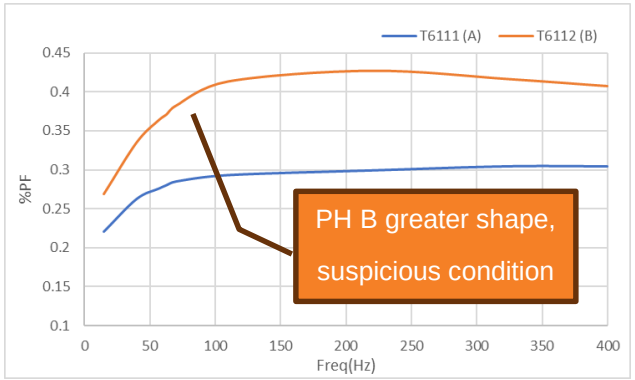
Doble database – DTA Web

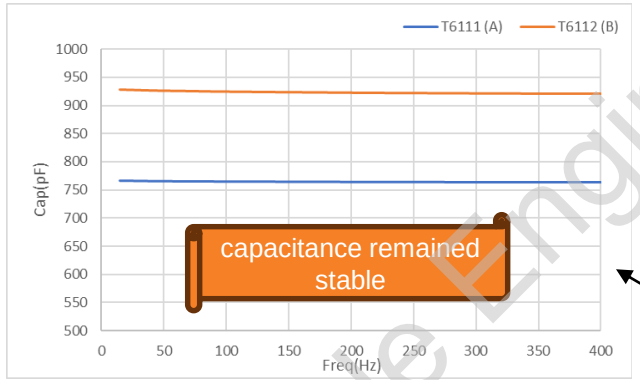


Failure Investigation – Two Other CT Phases - VFPF

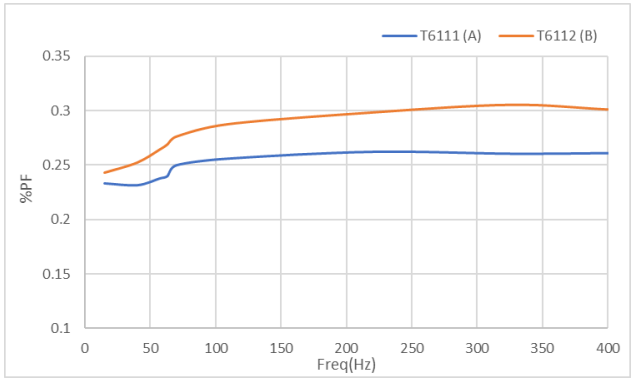
- VFPF, PF @2kV from frequency 15 to 400Hz
  - PF consistent with other standard 60Hz PF
  - Typical curve shape “fish-hook” for CT (blue)

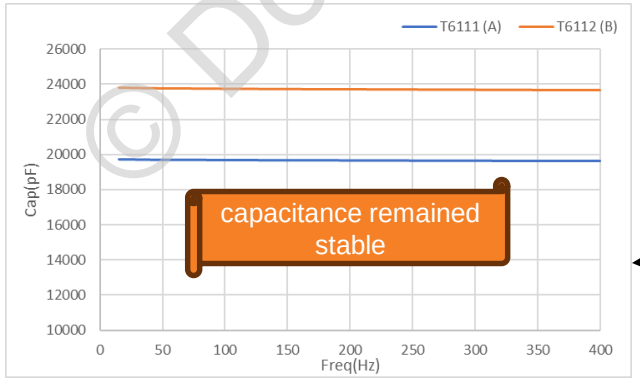
C1 main insulation



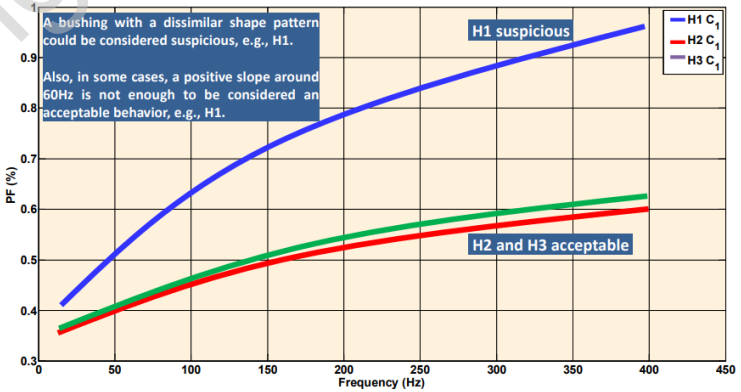


C2 test tap insulation

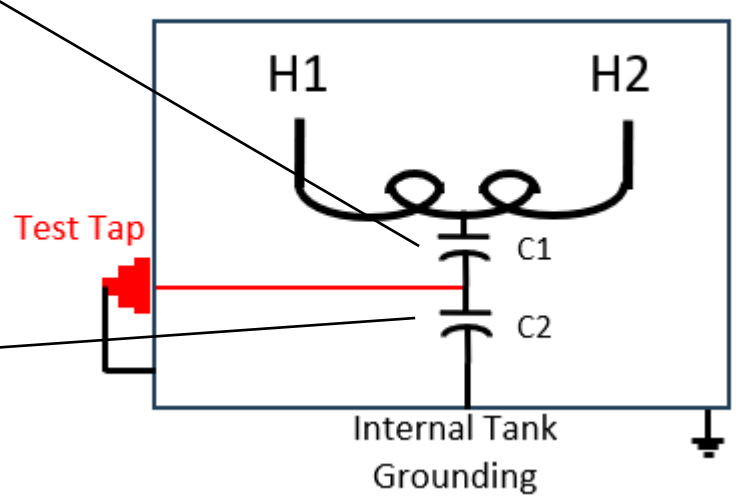




VFPF Applied to Bushings – Pattern 4



Roberto Borges, Fundamentals of Variable Frequency Power Factor (VFPF) Test and Analysis, Doble 2023



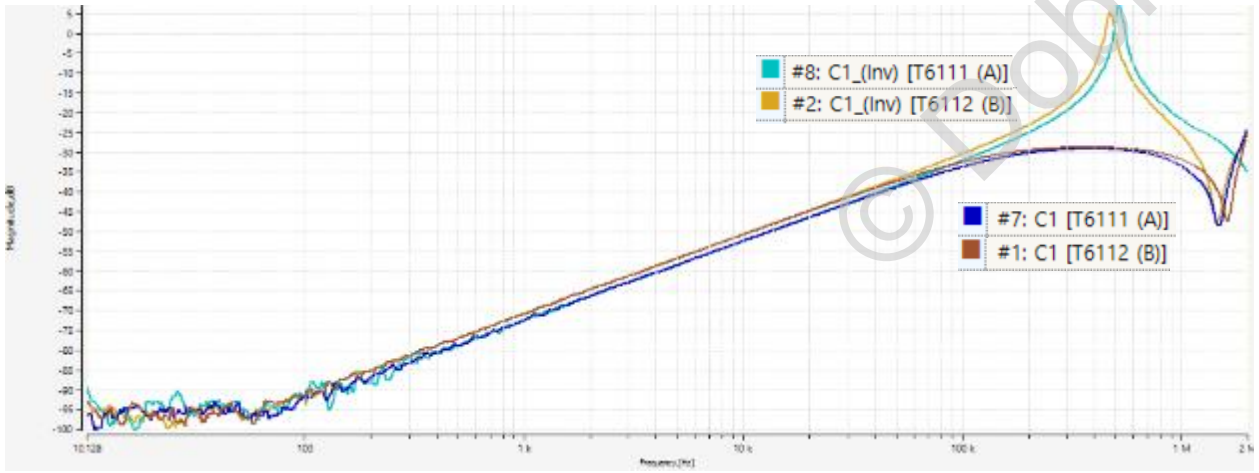
Failure Investigation – Two Other CT Phases - SFRA

- SFRA, 6 measurements, 10Hz to 2MHz
  - C1 traces different resonance frequency due to the dissimilarity of their capacitances
  - C1 (Inv) differently from the C1 trace resonance type, was probably caused by the CT magnetization reactance
  - Open-Circuit tests (Iex) classified the four secondary windings into two groups: W&X and Y&Z, suggesting that the four windings grouped into two winding structures

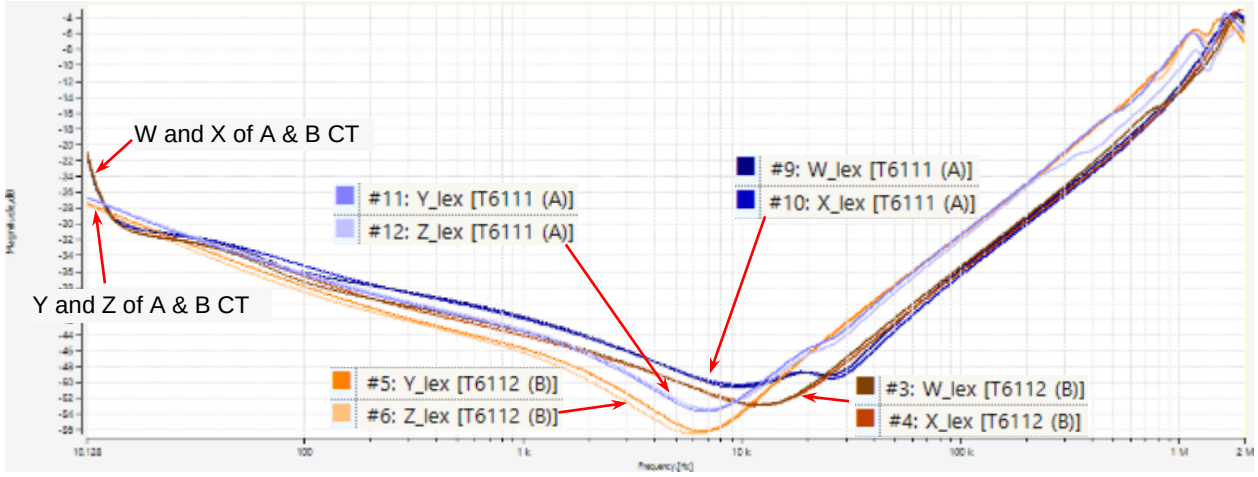
Custom Test Plan

		Setup						Results	
#	Test Identification	Preferred Start Freq. [Hz]	Preferred Stop Freq. [Hz]	Red Lead	Black Lead	Shorted	Grounded	Traces #	Test Completed
1	C1	10	2 M	H1	S0L0	none	none	1	✓
2	C1_(Inv)	10	2 M	S0L0	H1	none	none	1	✓
3	W_Iex	10	2 M	W	w	none	none	1	✓
4	X_Iex	10	2 M	X1	X0	none	none	1	✓
5	Y_Iex	10	2 M	Y1	Y0	none	none	1	✓
6	Z_Iex	10	2 M	Z1	Z0	none	none	1	✓

SFRA Test on C1



SFRA Test on secondary winding (W, X, Y & Z)



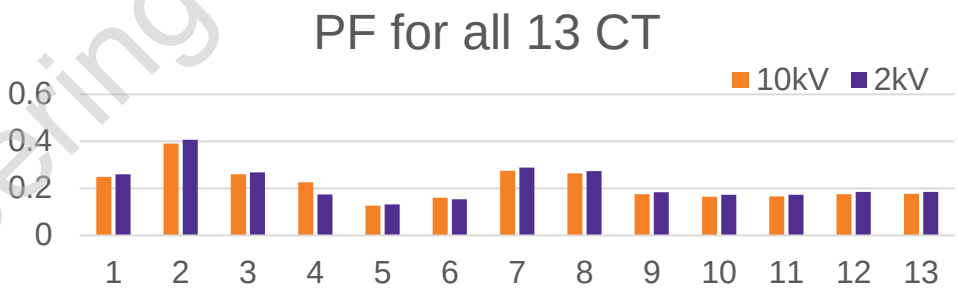
Failure Investigation – Oil Result Two Other CT Phases

- Sampling 3 CT in the failed bank before investigation (room temp)
- Hydrogen (H2) abnormal
- Various indicators confirm oil degradation:
  - kV dielectric strength
  - Power Factor are above the standards
  - H2O content is relatively high
- PH B indicated more oil degradation; PF is the worst

	PH A	PH B	PH C (fired)
H2	1644	1010	18365
CH4	6	5	6268
C2H6	1		1256
C2H4	4	3	2740
C2H2			1237
CO	180	157	860
CO2	605	610	4130
N2	71274	68964	43674
O2	9813	14080	7901
PPM H2O	20	22	15
IFT	41.58	39.54	39.72
ACID	0.008	0.010	0.003
kV, D1816-2mm	25 kV	19 kV	33 kV
PF 25degC	0.085%	0.446%	1.226%
PF 100degC	2.2312%	11.764%	18.537%
Furans (2FAL)			1715

Failure Investigation – Oil Results & PF, 13 Similar CT

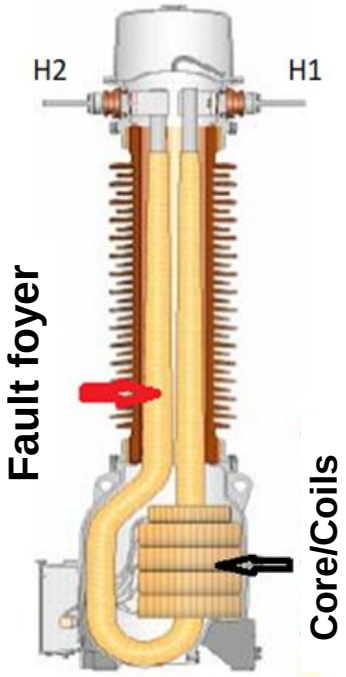
- Identified 13 CTs of the same type and proceeded with oil sampling and electrical insulation measurements
- Several CTs have relatively high hydrogen levels (H2)
- Insulation measurements within limits for all CT
- All C2 were also good (not included in this table)

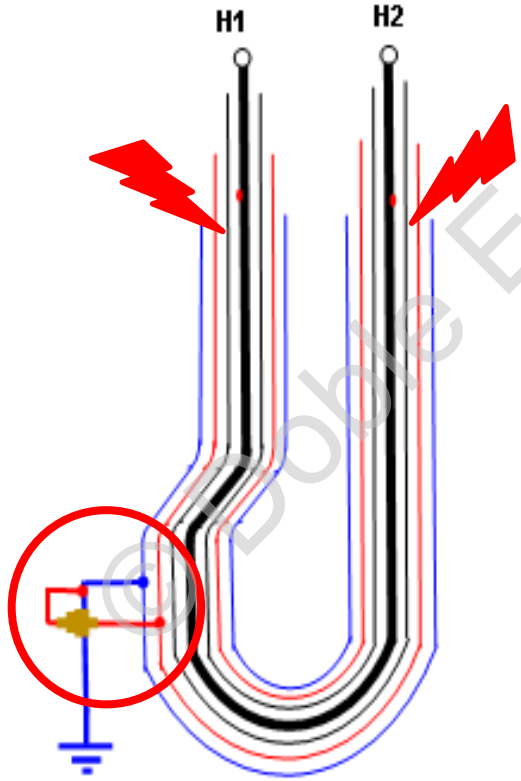


	712881	7867497	7739544	7128884	7128883	7128882	7739542	7739543	6691483	6691481	6691482	7364160	7364161
H2	666	460	528	915	1205	1183	507	396	805	1037	693	621	856
CH4	6	12	6	9	7	7	8	7	6	6	7	7	5
C2H6	1	2	2	3	2	1	1	1	2	2	2	1	1
C2H4		12		1	1	1	3	3			3	8	6
C2H2													
CO	168	427	201	226	185	216	247	222	81	110	259	338	302
CO2	339	850	497	577	437	616	713	586	190	210	431	1110	1052
N2	44633	64617	75847	49267	45764	114220	69419	79014	56449	49625	61143	77167	77582
O2	2715	1409	1605	1814	1061	19135	1826	1936	2239	1252	1206	3892	4600
H2O	7	6	7	7	6	6	9	11	10	9	7	9	10
PF – Overall 10kV %	0.249	0.390	0.259	0.225	0.126	0.160	0.275	0.263	0.175	0.164	0.166	0.175	0.176
PF – Overall 2kV %	0.259	0.407	0.268	0.174	0.131	0.154	0.288	0.273	0.183	0.173	0.172	0.184	0.184

Failure Investigation – Internal inspection

- Disassembly of the 3 CTs to detect clues about the root causes
- Layers of insulating paper were all cut at the same time to inspect internal ground and test tap measurements





Conclusion

- Catastrophic failure is a very concerning event impacting the safety, therefore maintenance and inspections are important
- Deterioration of the Overall insulation was not detected before explosion
- Remaining questions are harmonic level and C2 test
  - Whether an increase of harmonic level or resonance phenomena has affected the electrical insulation of the CT
  - Could an insulation test of C2 detected this defect that C1 test didn’t?
- The two similar CTs in the same group showed signs of oil quality degradation, which could have also affected the one that exploded but all insulation measurement were good except VFPF
- Other similar CTs all have a relatively high level of Hydrogen (H2), which seems quite common in instrument transformers. This issue is still unexplained, but according to the insulation measurements, this high level of Hydrogen does not seem to affect the insulation quality presently
- Replacement program for all IMBE-170 transformers was implemented following the explosion. The priority is based on the insulation measurements, oil analyses and production impact customer
- Safety level in a substation must remain the priority of the company's asset management group.

Acknowledgements

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Thank you.