Transformer Factory Testing

Transformer Concepts & Applications Seminar
Goldsboro, NC
September 19-21, 2023

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Reasons for Testing

- Compliance with user specifications
- Assessment of quality and reliability
- Verification of design calculations
- Compliance with applicable industry standards

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IEEE C57.12.00-2021 Table 17

Routine Tests

- Routine tests shall be made on every transformer to verify that the product meets the design specifications

Design Tests

- Design tests shall be made to determine the adequacy of the design of a particular type, style, or model of transformer or its component parts.
- Test data from previous similar designs may be used for current designs, where appropriate.
- Once made, the tests need not be repeated unless the design is changed to modify performance.

Other Tests

- Other tests are identified in product specifications and may be specified by the purchaser in addition to routine tests

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Class I and Class II Transformers

IEEE C57.12.00-2021 Sec 5.10

	Nominal System Voltage (kV)	Top Nameplate Rating (KVA)
Class I	< 69 kV = 69 kV	Any <10,000 – 1φ <15,000 – 3φ
Class II	≥115 kV ≥69 kV < 115kV	Any ≥10,000 – 1φ ≥15,000 – 3φ

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Preliminary Testing

Preliminary Testing

Tests	Class I	Class II
Voltage Ratio	Routine	Routine
Insulation Power factor	Routine	Routine
Insulation Resistance	Routine	Routine
1Φ Excitation test	GT Routine	GT Routine
CT Ratio & Polarity	GT Routine	GT Routine
Control Wiring Checks & Hi-pot	Routine	Routine
Auxiliary Losses	Routine	Routine

Preliminary Tests

Voltage Ratio Test

- Performed with ratio-meter (TTR) based on voltage comparison principle to check that windings are wound with correct turns including tapped turns
- Low voltage is applied to HV winding and voltage measured across LV/other winding is fed back to ratio-meter which displays the applied/measured voltage ratio (= turns ratio)
- Turns ratio is compared with voltage ratio requirement to meet tolerance of **+/- 0.5%**

Taps		NAME PLATE	PHASE		
HV	LV		H_1-H_2 / X_0-X_2	H_2-H_3 / X_0-X_3	H_3-H_1 / X_0-X_1
1	-	6.812	6.820	6.819	6.819
2	-	6.650	6.654	6.655	6.655
3	-	6.488	6.491	6.491	6.492
4	-	6.326	6.331	6.331	6.331
5	-	6.164	6.167	6.168	6.168

CT Ratio and Polarity Test

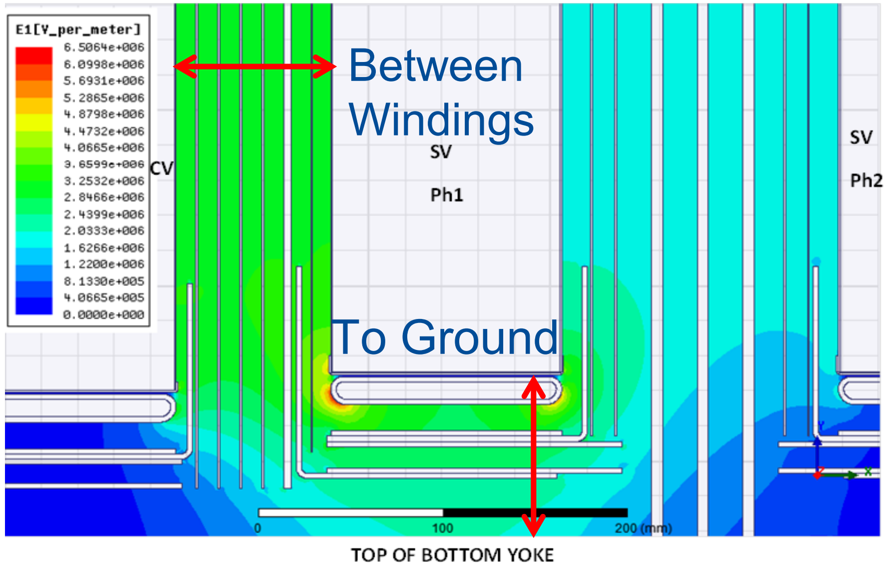
- Verify Polarity (& also Ratio) and wiring to control box

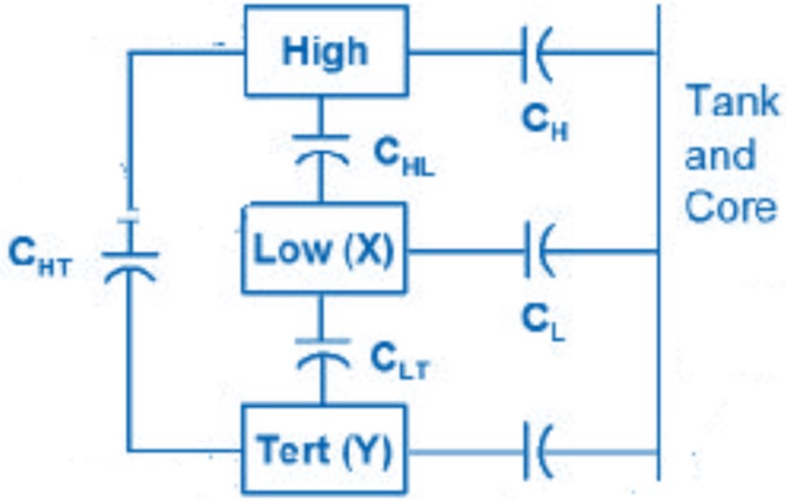
Leak Test

- 10 PSI for 10 hours minimum
- Typically Tested during Manufacturing before release to Test

Preliminary Tests (cont.)

Insulation Power Factor C57.12.90 Sec. 10.10





- Test voltage is typically 10kV
- Power Factor is affected by temperature; Recommended 10^0 to 40^0 C
- No IEEE Limit for PF, Max 0.5% good for most units

Connection	Test kV	mA	Watts	Power Factor		Cap (pF)
				Tested	@ 20°C	
CH+CHL	10	25.446	0.371	0.15	0.14	6750
CH	10	9.830	0.216	0.22	0.21	2608
CHL(UST)	10	15.601	0.128	0.08	0.08	4138
CHL	0	15.616	0.155	0.10	0.09	4142
CL+CHL	10	49.653	1.603	0.32	0.31	13171
CL	10	34.047	1.437	0.42	0.40	9031
CHL(UST)	10	15.593	0.142	0.09	0.09	4136
CHL	0	15.607	0.166	0.11	0.10	4140

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GT-07133

Report Source Two-winding Transformer

Session Test Date 9/3/2024 10:41:53 PM

Nameplate - Two-winding Transformer

Company	ONCOR	Serial Number	GT-07133
Location		Special ID	5175389
Division		Circuit Designation	
Manufacturer		Configuration	D_Y
Year Manufactured	2024	Tank Type	N2 Blanket
Mfr Location		Coolant	Oil
Phases	Three	Class	ONAN/ONAF/ONAF
Oil Volume	*	BIL	550 kV
Weight	*		
kV	138, 13.2	VA Rating	28, 37.3, 46.7, *, MVA

Administration

Test Date	9/3/2024	Test Time:	10:41 PM	Weather	Indoors
Air Temperature	20°C	Apparatus	23.9°C	Humidity	*
Tester	SMB	Work Order		Date Last Tested	
Verified	9/3/2024	Test Set Type		Date Retested	
Verification Date		Set Top Serial #		Reason	
Last Sheet #		Test Set Model		Travel Time	
Purchase Order		Ins. Book #		Duration	
Copies		Sheet #		Crew Size	

Bushing Nameplate

Designation	Serial #	Manufacturer	Type	C1 %PF	C1 Cap	C2 %PF	C2 Cap	Rated kV	Amps
H1	24-243931	PCORE Electric Co.	POC	0.31	426	0.26	3647	138	800
H2	24-243947	PCORE Electric Co.	POC	0.3	424	0.26	3621	138	800
H3	24-243937	PCORE Electric Co.	POC	0.31	424	0.26	3664	138	800
X0	24-240052	PCORE Electric Co.	POC	0.23	402	*	*	34.5	1200
X1	24-241699	PCORE Electric Co.	POC	0.23	571	*	*	34.5	3000
X2	24-241712	PCORE Electric Co.	POC	0.22	565	*	*	34.5	3000
X3	24-241708	PCORE Electric Co.	POC	0.22	567	*	*	34.5	3000

Overall Tests [M4100 Serial: 122033265]

	Insulation	V	I	Loss	PF*TCF	TCF	Cap (pF)	FRANK™
1	CH+CHL	10.001	29.060	0.490	0.165	0.981	7708.800	
2	CH	10.001	9.931	0.257	0.254	0.981	2634.055	Good
3	CHL	10.000	19.118	0.241	0.124	0.981	5071.625	Good
4	CHL	*	19.130	0.232	0.119	0.981	5074.745	Good
5	CL+CHL	10.000	83.418	1.431	0.168	0.981	22128.5	
6	CL	10.001	64.301	1.200	0.183	0.981	17056.801	Good
7	CHL	10.000	19.115	0.243	0.125	0.981	5070.440	Good
8	CHL	*	19.117	0.231	0.118	0.981	5071.699	Good
Winding without Attached Bushing Calculation								
CH-C1	CH'		9.931	0.257	0.254	0.981	2634.055	
CL-C1	CL'		64.301	1.200	0.183	0.981	17056.801	

Excitation Current & Loss [M4100 Serial: 122033265]

	Manufacturer	Type	Steps	Rated kV	Step kV	Step %	Oil Volume
DETC-1			5	138.00	3.450	2.500	*
OLTC-1			33	13.20	0.083	0.625	*

		H1 H3			H2 H1			H3 H2			
Winding : Tap	Test kV	mA	Watts	X	mA	Watts	X	mA	Watts	X	FRANK™
HV: 3 LV: 16R	10	7.040	39.880	L	3.854	19.909	L	7.708	41.461	L	Good
HV: 3 LV: 15R	10	6.855	38.821	L	3.769	19.380	L	7.472	40.238	L	Good
HV: 3 LV: 14R	10	6.682	37.794	L	3.689	18.853	L	7.248	39.067	L	Good
HV: 3 LV: 13R	10	6.527	36.803	L	3.608	18.401	L	7.025	37.986	L	Good
HV: 3 LV: 12R	10	6.379	35.939	L	3.535	17.963	L	6.825	36.952	L	Good
HV: 3 LV: 11R	10	6.242	35.125	L	3.465	17.555	L	6.634	36.007	L	Good
HV: 3 LV: 10R	10	6.117	34.386	L	3.401	17.185	L	6.461	35.154	L	Good
HV: 3 LV: 9R	10	6.000	33.710	L	3.340	16.860	L	6.300	34.362	L	Good
HV: 3 LV: 8R	10	5.894	33.099	L	3.296	16.509	L	6.156	33.647	L	Good
HV: 3 LV: 7R	10	5.794	32.588	L	3.247	16.243	L	6.026	33.018	L	Good
HV: 3 LV: 6R	10	5.710	32.112	L	3.184	15.954	L	5.893	32.476	L	Good
HV: 3 LV: 5R	10	5.634	31.703	L	3.146	15.749	L	5.794	32.038	L	Good
HV: 3 LV: 4R	10	5.571	31.360	L	3.114	15.591	L	5.710	31.667	L	Good
HV: 3 LV: 3R	10	5.519	31.086	L	3.086	15.453	L	5.642	31.351	L	Good
HV: 3 LV: 2R	10	5.479	30.885	L	3.063	15.335	L	5.591	31.141	L	Good
HV: 3 LV: 1R	10	5.451	30.755	L	3.044	15.239	L	5.557	30.993	L	Good
HV: 3 LV: 1L	10	5.484	30.858	L	3.053	15.270	L	5.577	31.116	L	Good
HV: 3 LV: 2L	10	5.511	30.983	L	3.065	15.327	L	5.604	31.231	L	Good
HV: 3 LV: 3L	10	5.552	31.179	L	3.087	15.418	L	5.653	31.435	L	Good
HV: 3 LV: 4L	10	5.605	31.454	L	3.111	15.554	L	5.716	31.752	L	Good
HV: 3 LV: 5L	10	5.667	31.793	L	3.141	15.726	L	5.794	32.124	L	Good
HV: 3 LV: 6L	10	5.740	32.189	L	3.176	15.928	L	5.887	32.560	L	Good
HV: 3 LV: 7L	10	5.826	32.665	L	3.217	16.172	L	5.996	33.084	L	Good
HV: 3 LV: 8L	10	5.923	33.201	L	3.262	16.435	L	6.119	33.687	L	Good
HV: 3 LV: 9L	10	6.028	33.819	L	3.312	16.733	L	6.254	34.386	L	Good
HV: 3 LV: 10L	10	6.145	34.485	L	3.368	17.056	L	6.404	35.158	L	Good
HV: 3 LV: 11L	10	6.272	35.233	L	3.427	17.434	L	6.565	35.991	L	Good
HV: 3 LV: 12L	10	6.408	36.030	L	3.492	17.822	L	6.736	36.896	L	Good
HV: 3 LV: 13L	10	6.556	36.909	L	3.561	18.254	L	6.920	37.876	L	Good
HV: 3 LV: 14L	10	6.713	37.846	L	3.633	18.720	L	7.119	38.959	L	Good
HV: 3 LV: 15L	10	6.880	38.856	L	3.708	19.207	L	7.325	40.082	L	Good
HV: 3 LV: 16L	10	7.049	39.925	L	3.787	19.721	L	7.540	41.297	L	Good
HV: 1 LV: N	10	5.011	27.975	L	2.820	13.925	L	5.107	28.182	L	Good
HV: 2 LV: N	10	5.219	29.315	L	2.921	14.503	L	5.329	29.541	L	Good
HV: 3 LV: N	10	5.455	30.789	L	3.047	15.347	L	5.525	30.924	L	Good
HV: 4 LV: N	10	5.690	32.379	L	3.165	16.044	L	5.763	32.487	L	Good
HV: 5 LV: N	10	5.934	34.059	L	3.295	16.870	L	6.042	34.214	L	Good

Preliminary Tests (cont.)

Single Phase Excitation Test

- Test typically performed on HV terminal and tested at 10kV
- Test is performed **1Ø** at a time and **currents** are compared
- For three phase transformers, two phases are expected to have similar and higher current compared to third.
  - Current measured on phase wound on center limb on three-legged core will have lower current due to lower magnetic reluctance
- Must de-magnetize core prior to test.

Tap Position		I (mA)		
DETC	LTC	Phase B	Phase C	Phase A
1	N	3.5	8.9	9.0
2	N	3.7	9.3	9.4
3	N	3.9	9.6	9.7
4	N	3.9	9.9	10.1
5	N	4.1	10.3	10.5
3	16R	3.9	9.6	9.7
3	15R	24.2	29.3	29.3
3	14R	3.9	9.5	9.7
3	13R	86.5	91.8	91.4
3	12R	3.9	9.5	9.7
3	11R	24.1	29.3	29.3
3	10R	3.9	9.5	9.7
3	9R	24.1	29.2	29.3
3	8R	3.9	9.5	9.7
3	7R	24.1	29.2	29.3
3	6R	3.9	9.5	9.7
3	5R	86.4	91.8	91.4
3	4R	3.9	9.5	9.7
3	3R	24.1	29.3	29.3
3	2R	3.9	9.5	9.7
3	1R	24.1	29.2	29.3

Winding Insulation Resistance C57.12.90 Sec. 10.11

- Typically tested at 1, 2.5, or 5 kV and held for 1 minute before taking reading
- Test performed high voltage to low voltage and ground and low voltage to high voltage and ground
- Acceptable values varies with design, voltage class and cooling medium - typically is greater than 500MOhms

Connection	Megger (MΩ) @ 2.5 kV
	1 min
(HV + XV + YV) - GRND	10520
HV - (XV + YV + GRND)	22500
XV - (HV + YV + GRND)	13950
YV - (HV + XV + GRND)	16570

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Performance Tests

Performance Characteristic Tests

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Tests	Class I	Class II
No Load Losses	Routine	Routine
% Excitation Tests	Routine	Routine
Load Losses	Routine	Routine
Positive Sequence Impedance	Routine	Routine
Zero Sequence Impedance	Special	Routine
Winding Resistances	Routine	Routine
Sound Test	Other	Other

Nameplate

PROLEC-GE WAUKESHA, INC.
GOLDSBORO, NORTH CAROLINA, USA

LOAD TAP CHANGING
POWER TRANSFORMER

CLASS	ONAN/ONAF/ONAF 3-PHASE	60 HZ	SER. NO.		
MVA	10.00/12.50/14.00	CONT. TEMP. RISE	65°C		
HV	115000Y/66395	VOLTS	BIL	450	KV
HV NEUTRAL			BIL	450	KV
LV	13090Y/7560	VOLTS	BIL	110	KV
LV NEUTRAL			BIL	110	KV
TV	13090 DELTA @ 3.50/4.38/4.90 MVA		BIL	110	KV
TV: BURIED FOR HARMONIC SUPPRESSION ONLY					
IMPEDANCE WITH HV SWITCH IN POSITION A	% AT 115000 - 13090	VOLTS	AND	10.00	MVA
IMPEDANCE WITH HV SWITCH IN POSITION B	% AT 115000 - 13090	VOLTS	AND	10.00	MVA

WARNING
DE-ENERGIZE TRANSFORMER
BEFORE CHANGING HV TAPS

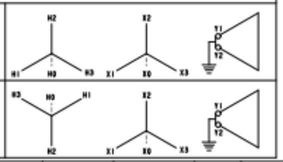
HIGH VOLTAGE TAPCHANGER DE-ENERGIZED OPERATION			
VOLTS L-L	AMPS AT 14.00 MVA	POS	CONNECTS
120750	66.9	1	21-22
117875	68.6	2	22-23
115000	70.3	3	23-24
112125	72.1	4	24-25
109250	74.0	5	25-26

FOR STEP DOWN OPERATION

APPROXIMATE WEIGHTS			LBS.
CORE & COIL (UNTANKING WEIGHT)			34160
TANK, FITTINGS, & RADIATORS			30070
RADIATORS (TOTAL)	4680	LBS.	
OIL-MAIN TANK	4160	GALS.	
OIL-TAPCHANGER COMPARTMENT	268	GALS.	
OIL-RADIATORS	190	GALS.	
OIL-TOTAL	4618	GALS.	34640
TOTAL WEIGHT			98870
SHIPPING WEIGHTS	WITHOUT OIL		WITH OIL
SHIPPING UNIT	56860		91935
SHIPPING PARTS	6935		6935
SHIPPING TOTAL	63795		98870

PHASE SHIFT DE-ENERGIZED SWITCH

POSITION	CONNECTS
(A) 0 DEGREE PHASE RELATION	34 TO 37, 44 TO 47, 54 TO 57, 38 TO 39, 48 TO 49, 58 TO 59
(B) 180 DEGREE PHASE RELATION	34 TO 38, 44 TO 48, 54 TO 58, 35 TO 37, 45 TO 47, 55 TO 57



LOW VOLTAGE	LTC POS	TAPS CONN P4	TAPS CONN P1	TAPS CONN R	AMPS @ 14.00 MVA	LOW VOLTAGE	LTC POS	TAPS CONN P4	TAPS CONN P1	TAPS CONN R	AMPS @ 14.00 MVA
11780	16L	4	4	A	617	13090	N	M	M	B	617
11860	15L	5	4	A	617	13170	1R	4	M	B	614
11940	14L	5	5	A	617	13250	2R	4	4	B	610
12030	13L	6	5	A	617	13340	3R	5	4	B	606
12110	12L	6	6	A	617	13420	4R	5	5	B	602
12190	11L	7	6	A	617	13500	5R	6	5	B	599
12270	10L	7	7	A	617	13580	6R	6	6	B	595
12350	9L	8	7	A	617	13660	7R	7	6	B	592
12440	8L	8	8	A	617	13740	8R	7	7	B	588
12520	7L	9	8	A	617	13830	9R	8	7	B	585
12600	6L	9	9	A	617	13910	10R	8	8	B	581
12680	5L	10	9	A	617	13990	11R	9	8	B	578
12760	4L	10	10	A	617	14070	12R	9	9	B	574
12840	3L	11	10	A	617	14150	13R	10	9	B	571
12930	2L	11	11	A	617	14240	14R	10	10	B	568
13010	1L	M	11	A	617	14320	15R	11	10	B	565
13090	N	M	M	B	617	14400	16R	11	11	B	561

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C800
CT:A,B,C
THERMAL RATING FACTOR = 2.0

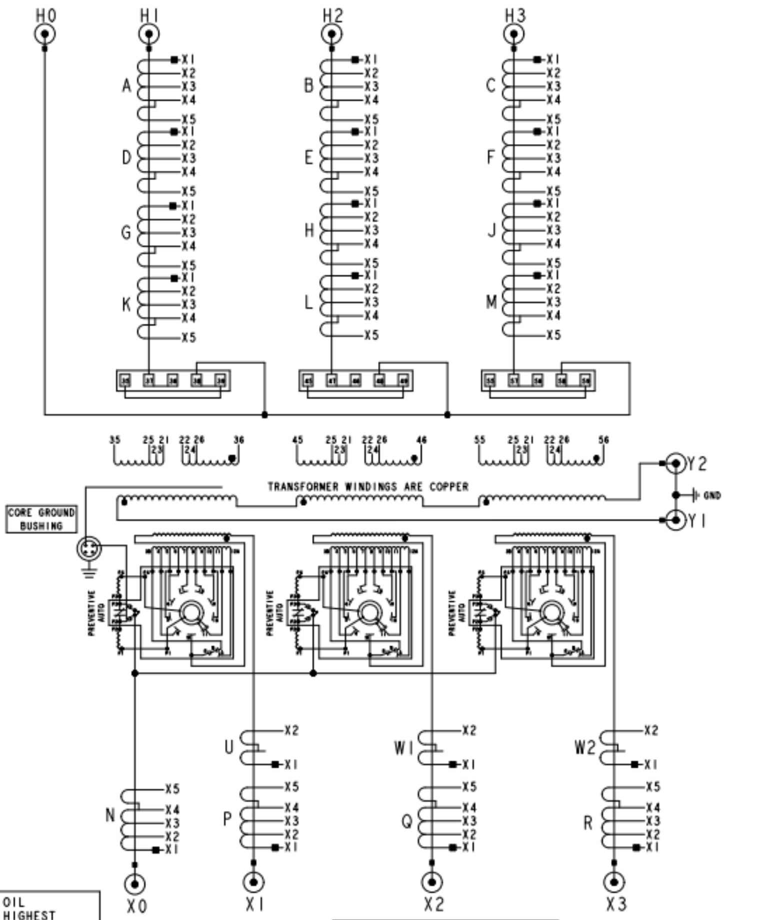
CURRENT RATIO	TAP	CURRENT RATIO	TAP
50:5	X2-X3	300:5	X2-X4
100:5	X1-X2	400:5	X1-X4
150:5	X1-X3	450:5	X3-X5
200:5	X4-X5	500:5	X2-X5
250:5	X3-X4	600:5	X1-X5

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C800
CT:D,E,F,P,Q,R
THERMAL RATING FACTOR = 2.0

CURRENT RATIO	TAP	CURRENT RATIO	TAP
100:5	X2-X3	600:5	X2-X4
200:5	X1-X2	800:5	X1-X4
300:5	X1-X3	900:5	X3-X5
400:5	X4-X5	1000:5	X2-X5
500:5	X3-X4	1200:5	X1-X5

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C800
CT:G,H,J,K,L,M
THERMAL RATING FACTOR = 2.0

CURRENT RATIO	TAP	CURRENT RATIO	TAP
300:5	X3-X4	1200:5	X1-X3
400:5	X1-X2	1500:5	X1-X4
500:5	X4-X5	1600:5	X2-X5
800:5	X2-X3	2000:5	X1-X5
1100:5	X2-X4		



TYPE OF INSULATING LIQUID: MINERAL OIL
OIL LEVEL BELOW TOP SURFACE OF THE HIGHEST POINT OF THE HIGHEST MANHOLE FLANGE AT 25°C IS 11.9 INCHES.
OIL LEVEL CHANGES 0.71 INCHES PER 10°C CHANGE IN OIL TEMPERATURE.
CONTAINS NO DETECTABLE LEVEL OF PCB (LESS THAN 1 PPM) AT TIME OF MANUFACTURE.
OIL MEETS ASTM D3487 TYPE II - INHIBITED.
OPERATING PRESSURE OF OIL PRESERVATION SYSTEM IS 5.0 LBF/IN^2 POSITIVE TO 0.5 LBF/IN^2 POSITIVE.
TANK DESIGNED FOR 10 LBF/IN^2 POSITIVE AND FULL VACUUM FILLING.
DESIGN ALTITUDE OF 3300 FEET AMSL.

BUSHING CURRENT TRANSFORMER
SINGLE RATIO RELAYING
CT:W1 FOR WINDING TEMP EQUIP.
CT:W2 FOR WINDING TEMP EQUIP.
700:5 RATIO CLASS C100
THERMAL RATING FACTOR = 2.0

BUSHING CURRENT TRANSFORMER
SINGLE RATIO RELAYING
CT:U FOR LTC CONTROL
700:5 RATIO CLASS C100
THERMAL RATING FACTOR = 2.0

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C400
CT:N
THERMAL RATING FACTOR = 2.0

CURRENT RATIO	TAP	CURRENT RATIO	TAP
100:5	X2-X3	600:5	X2-X4
200:5	X1-X2	800:5	X1-X4
300:5	X1-X3	900:5	X3-X5
400:5	X4-X5	1000:5	X2-X5
500:5	X3-X4	1200:5	X1-X5

NOTES:
1. THE HV NEUTRAL TERMINAL MUST BE DIRECTLY CONNECTED TO GROUND, OR IF LEFT UNGROUNDED, MUST BE PROTECTED BY DIRECT CONNECTION TO A PROPERLY RATED SURGE ARRESTER
2. THE LV NEUTRAL TERMINAL MUST BE DIRECTLY CONNECTED TO GROUND, OR IF LEFT UNGROUNDED, MUST BE PROTECTED BY DIRECT CONNECTION TO A PROPERLY RATED SURGE ARRESTER

LTC TYPE: REINHAUSEN RMV-II-1500-15 DESIGN NO. 5171585 A5171558590 REV. (1) DATE OF MANUFACTURE:

No-Load Test Connection – C57.12.90 Section: 8

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No Load Loss and Excitation Current

- Core Loss ~ Hysteresis Loss, Eddy Current Loss
- Hysteresis Loss ~ Flux Density & Grade of Steel
- Eddy Current Loss ~ Frequency, Temperature

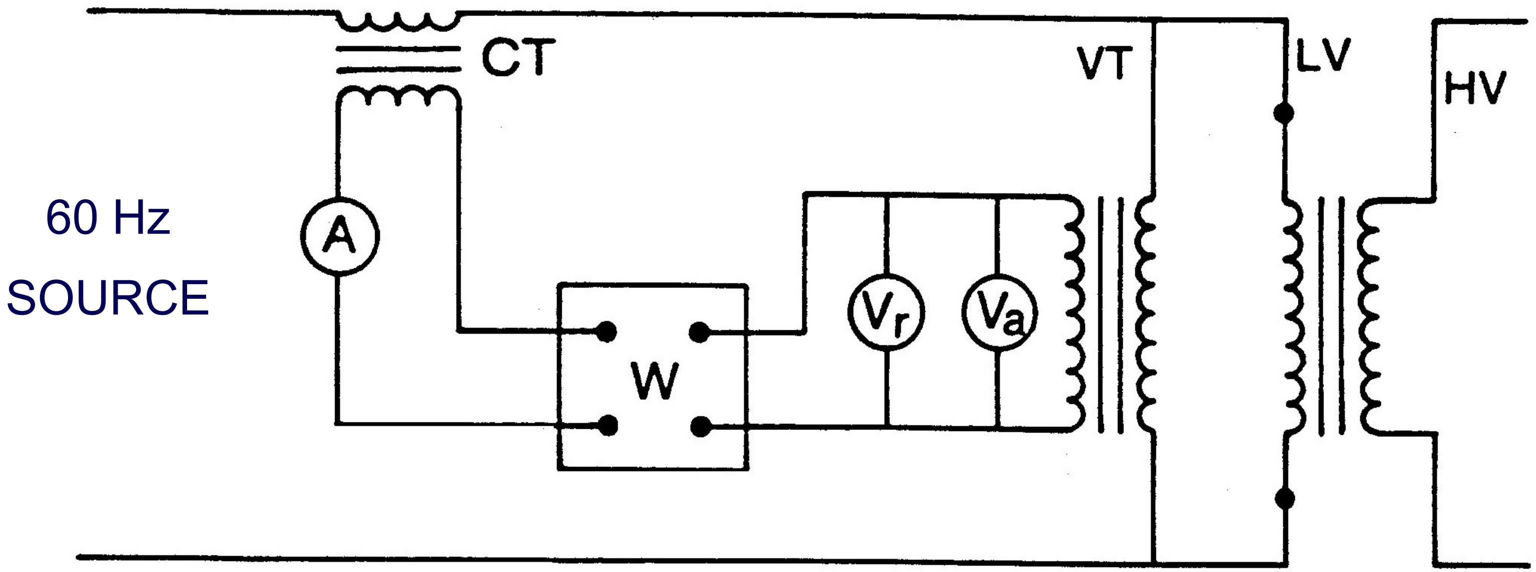
Test Circuit

- Transformer is excited from either TV/LV or HV side at 60 Hz with a variable voltage sinusoidal source
- All other terminals are left open
- Applied voltage is slowly increased to test voltage 90%, 100%, 110%

Measurement

- Require high precision loss measurement system
- Losses corrected to 20^{o}C

No-Load Test Connection



Load Loss and % Impedance

Load Loss C57.12.90 Sec. 9

- Load Losses are the losses of TRANSFORMER DUE TO LOAD CURRENT
- Load Loss = I^2R loss + Eddy loss + Stray loss
- Eddy losses depend on conductor thickness and width and leakage flux distribution
- Stray loss depends on % impedance, winding dimensions and clearance to tank and clamps

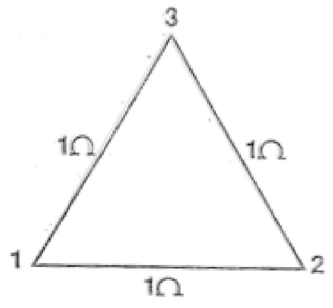
Impedance

- $\% \text{ Impedance} = \dfrac{\text{VOLTAGE FOR RATED CURRENT}}{\text{RATED VOLTAGE}} \times 100$

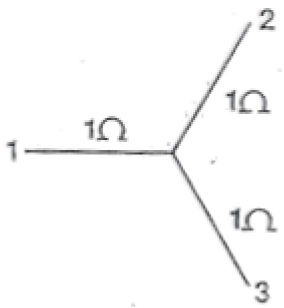
Winding Resistance Test – C57.12.90 Section: 6

- Performed with standard resistance bridge, DC current is fed to the winding and voltage developed across is measured
- Resistance = Voltage/Current is displayed and compared with design value
- Required for Load Loss calculation
- Reference for heat run winding temp rise calculation:

$$\frac{R_1}{R_2} = \frac{234.5 + T_1}{234.5 + T_2} \quad \text{for Copper}$$



1-2 = 0.6667
2-3 = 0.6667
3-1 = 0.6667
Sum = 2.0001 x 1.5 = 3



1-2 = 2
2-3 = 2
3-1 = 2
Sum = 6 x 0.5 = 3

Load Loss Test Connection

- Test Circuit

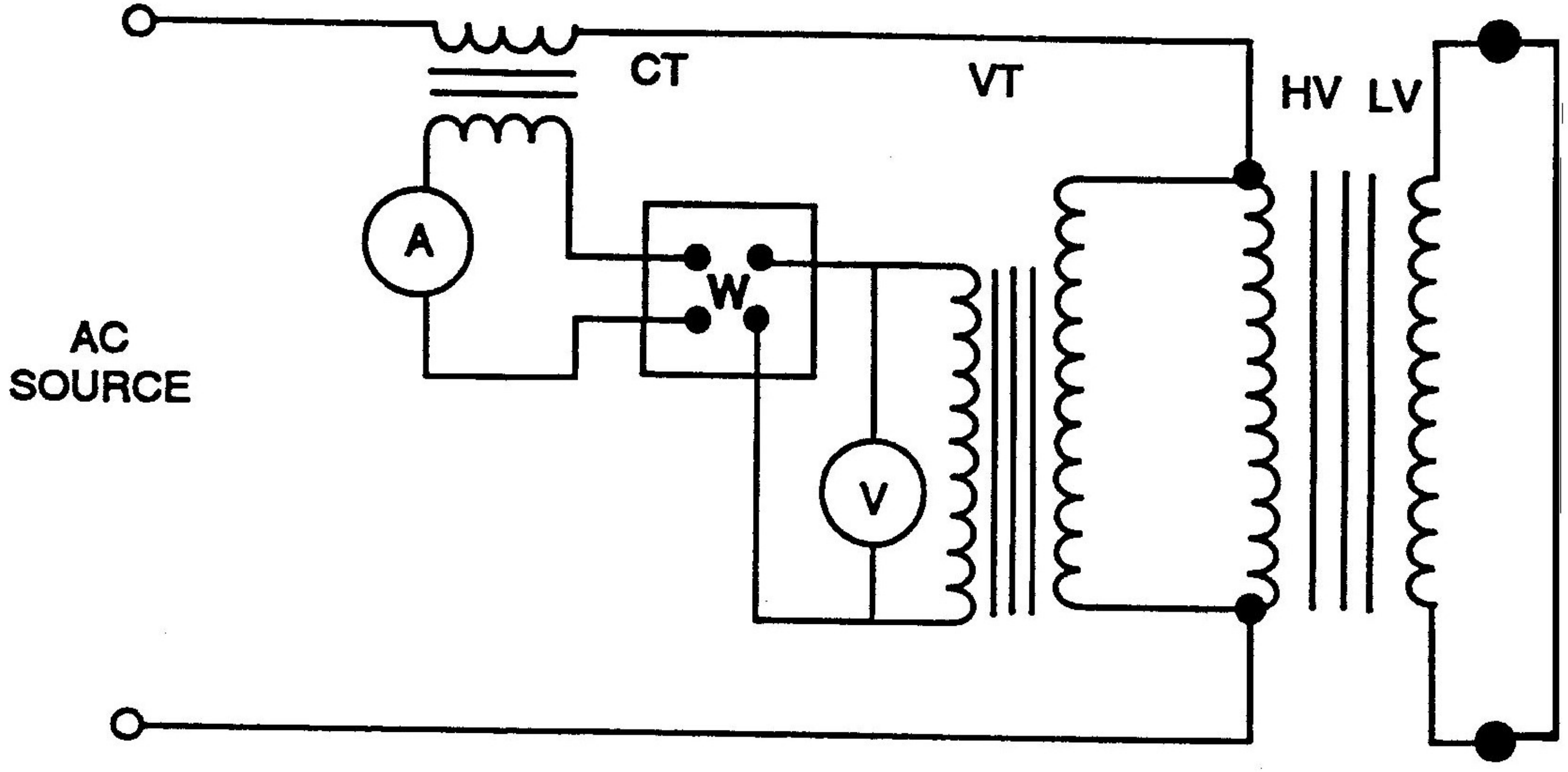
  Transformer is excited, preferably from HV side at 60 Hz with a variable voltage sinusoidal source. LV terminals are shorted. Applied voltage is slowly increased to feed the rated test current in the windings.

- Measurement

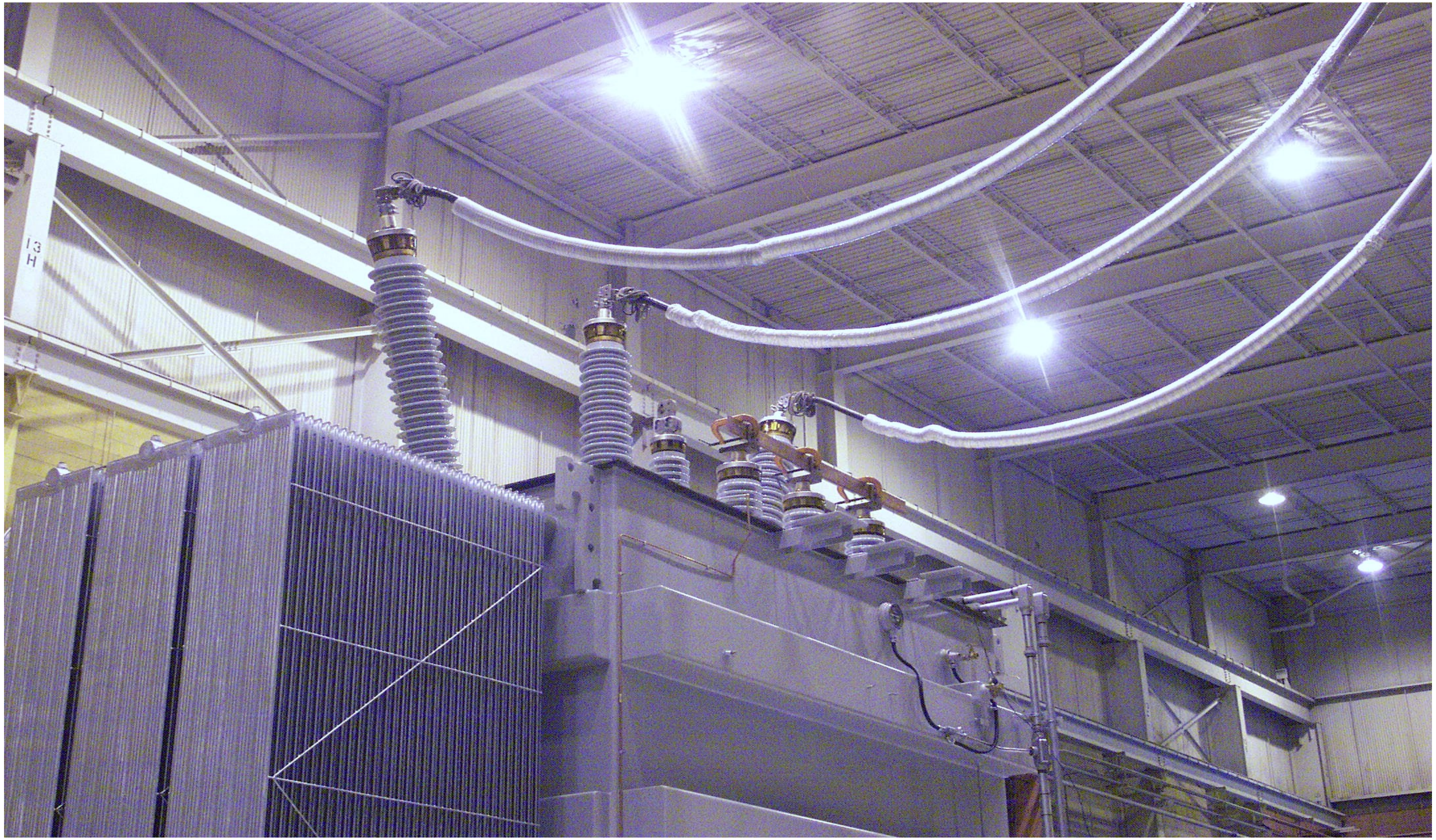
  With the help of a precision loss measurement system load current, voltage and losses are measured:

  Measured loss = $I^2 R$ Loss at ambient + stray loss
  $I^2 R$ Loss at 85ºC = $I^2 R$ Loss at ambient*(234.5+85)/(234.5 + ambient)
  Stray Loss at 85ºC = Stray Loss at ambient*(234.5+ambient)/(234.5 + 85)

Load Loss Test Connection (cont.)



Load Loss Test Connection (cont.)



Dielectric Tests

Tests	Class I	Class II
Impulse (Line)	GT Routine	Routine
Impulse (Neutral)	GT Routine	Routine
Switching Surge Impulse	Other	Routine > 345 KV
Applied Voltage	Routine	Routine
7200 cyl. Induce test	Routine GT Routine with PD	NA
1- Hr. Induce test with PD	Other	Routine

Impulse Testing – C57.12.90 Section: 10.3

- Lightning Impulse **Class II – Routine, Class I – Other**
  - Reduced Wave RFW (50 – 70% of Full Wave)
  - Full Wave *
  - Two (2) Chopped Waves
  - Full Wave
  - Full Wave *

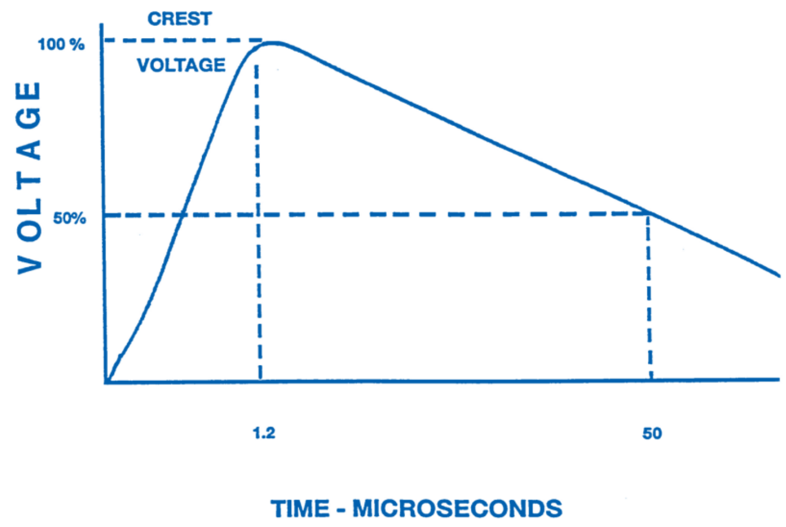
- Transformer Neutrals
  - 1 RFW
  - 2 FW
  - 1 FW*

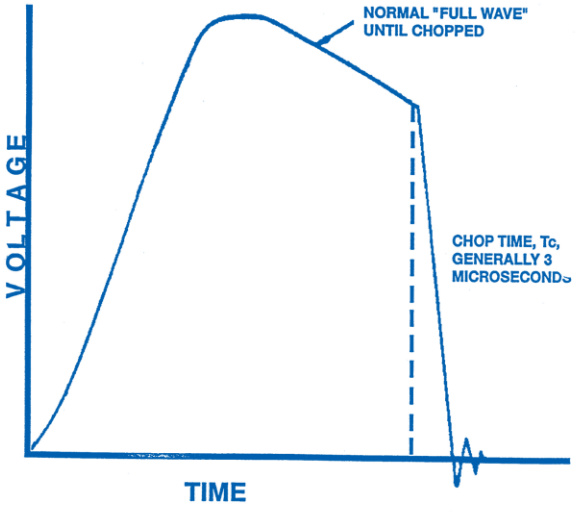
**Added in 2015 Standard*

Impulse Test

Lighting Impulse

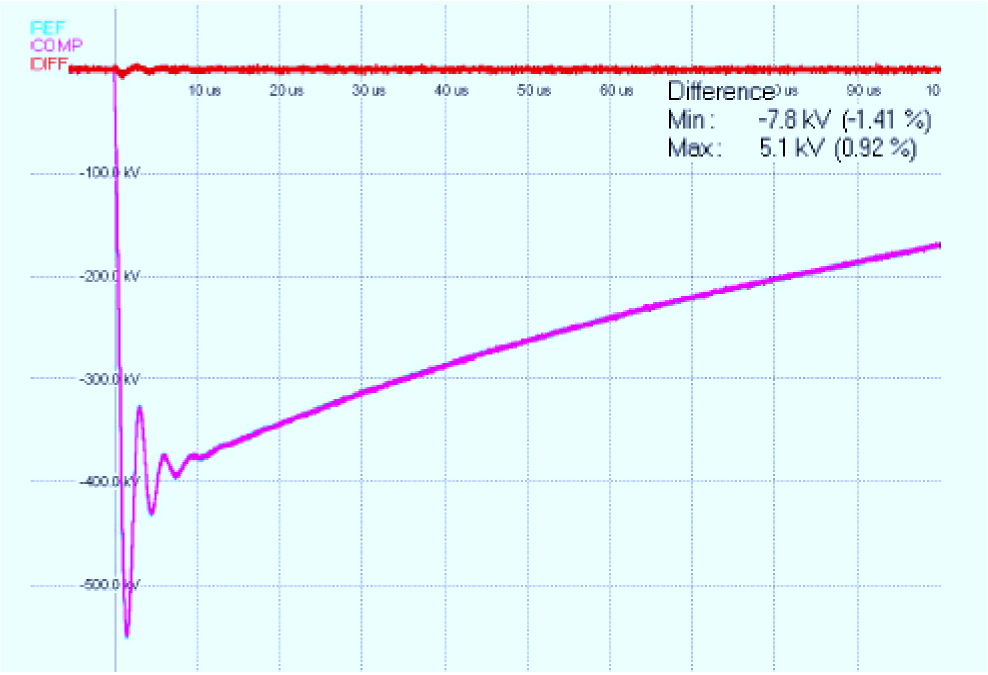
- Front Time – 1.2 microseconds + - 30% Tolerance (1.67 Times the time between 30% and 90% voltage)
- Tail Time – 50 microseconds + - 20% (Time to 50% peak voltage)
- Chop Time > = 3 microseconds for > = 150 KV
  > = 2 microseconds for < 150 KV



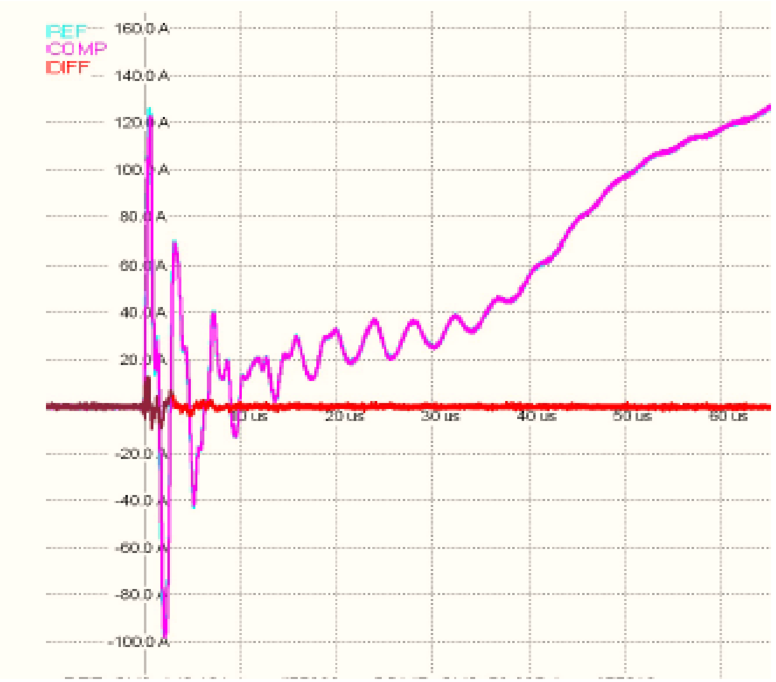


Chopped Wave

Waveform Comparisons – RFW & FW Overlay



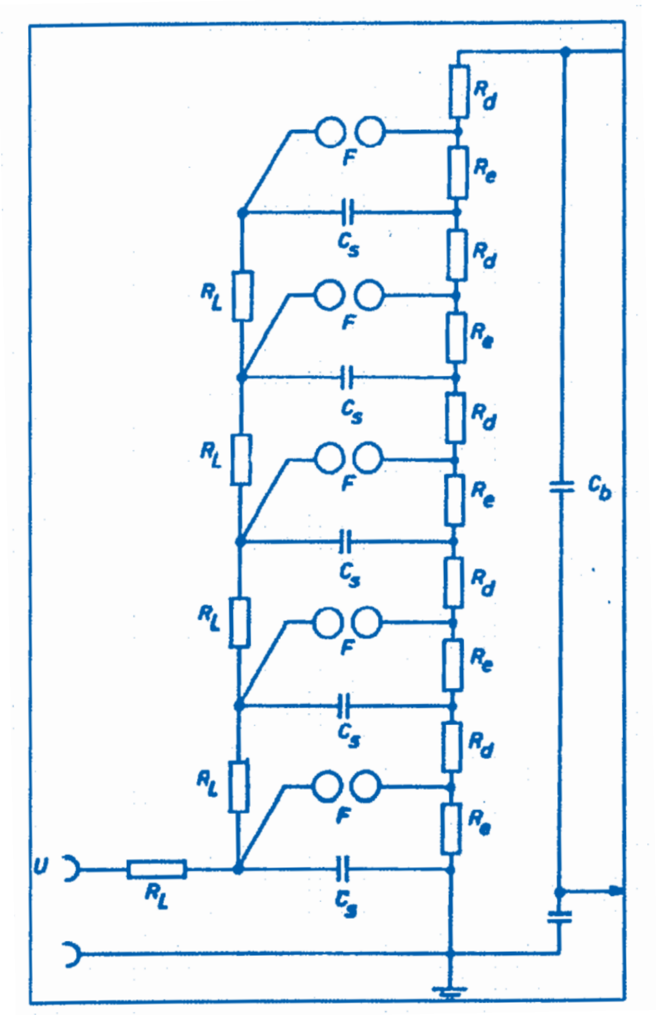
Voltage Waveform



Current Waveform

Impulse Generator (cont.)

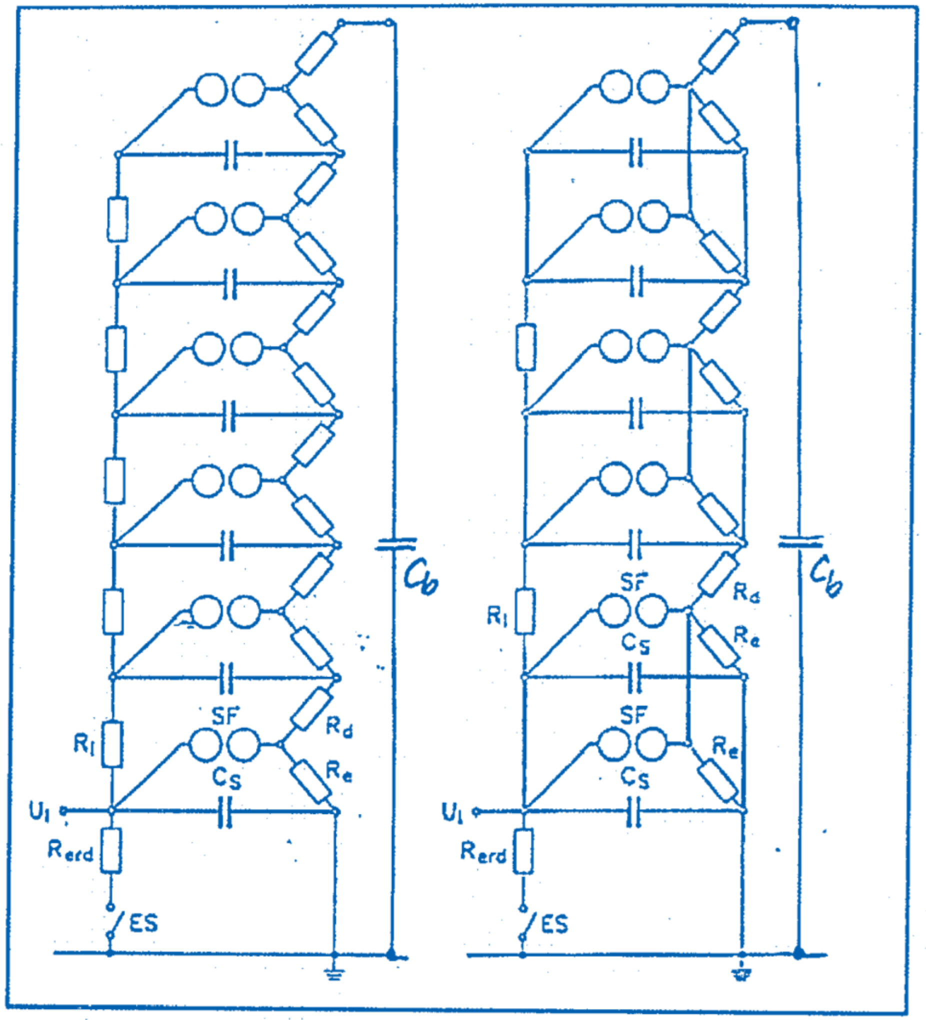
Impulse Generator (cont.)



Multiplier Circuit

- RC circuit with circuit Inductance
- Multiplier circuit introduced by Prof. Marx
- Impulse capacitor Cs are charged in parallel and discharged in series after firing the switching gaps F
- Front Time T1 is determined by Rd whereas time to half value is determined by Re

Impulse Generator (cont.)

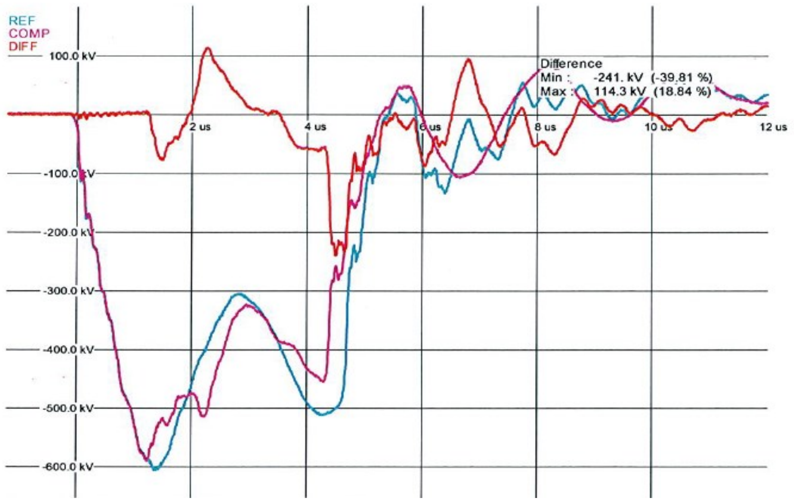


Series – Parallel Stages

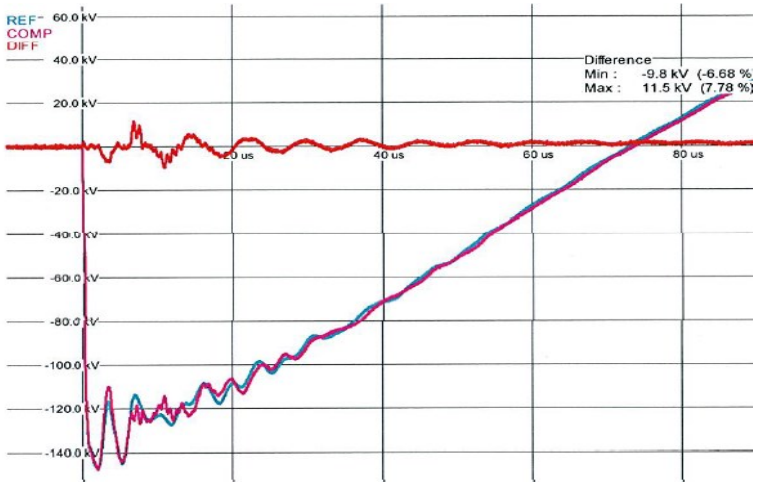
- Stages in series for higher voltage
- Stages in parallel for higher energy

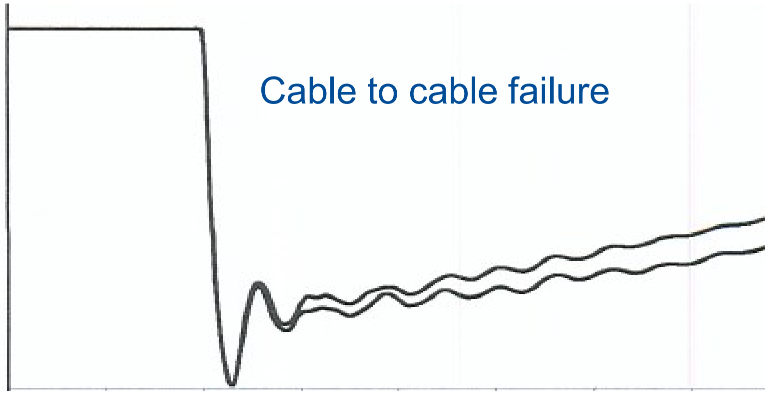
Voltage and Current Wave Shape Comparison (Reduce and Full Wave)

Chop wave failure

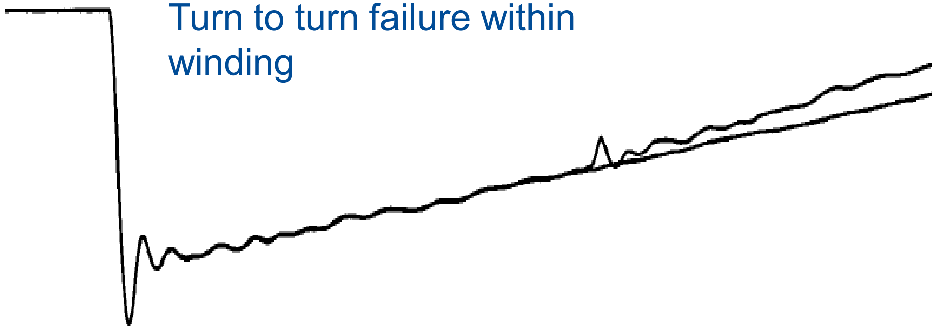


Failure between LTC Leads



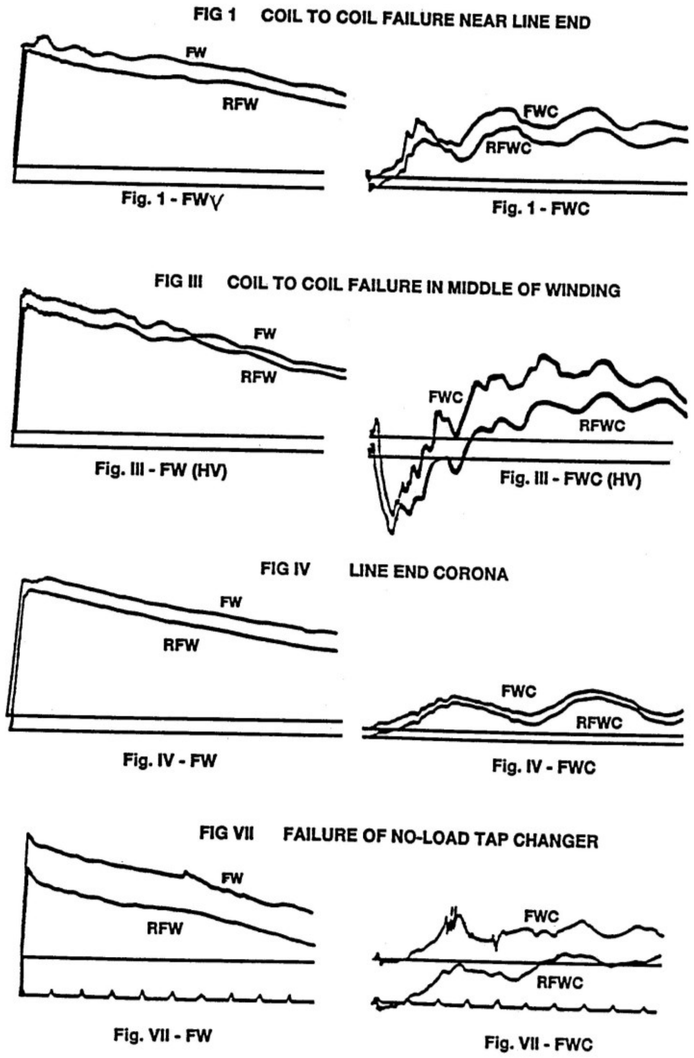


Cable to cable failure



Turn to turn failure within winding

Impulse Failure Waveforms



Switching Impulse Test

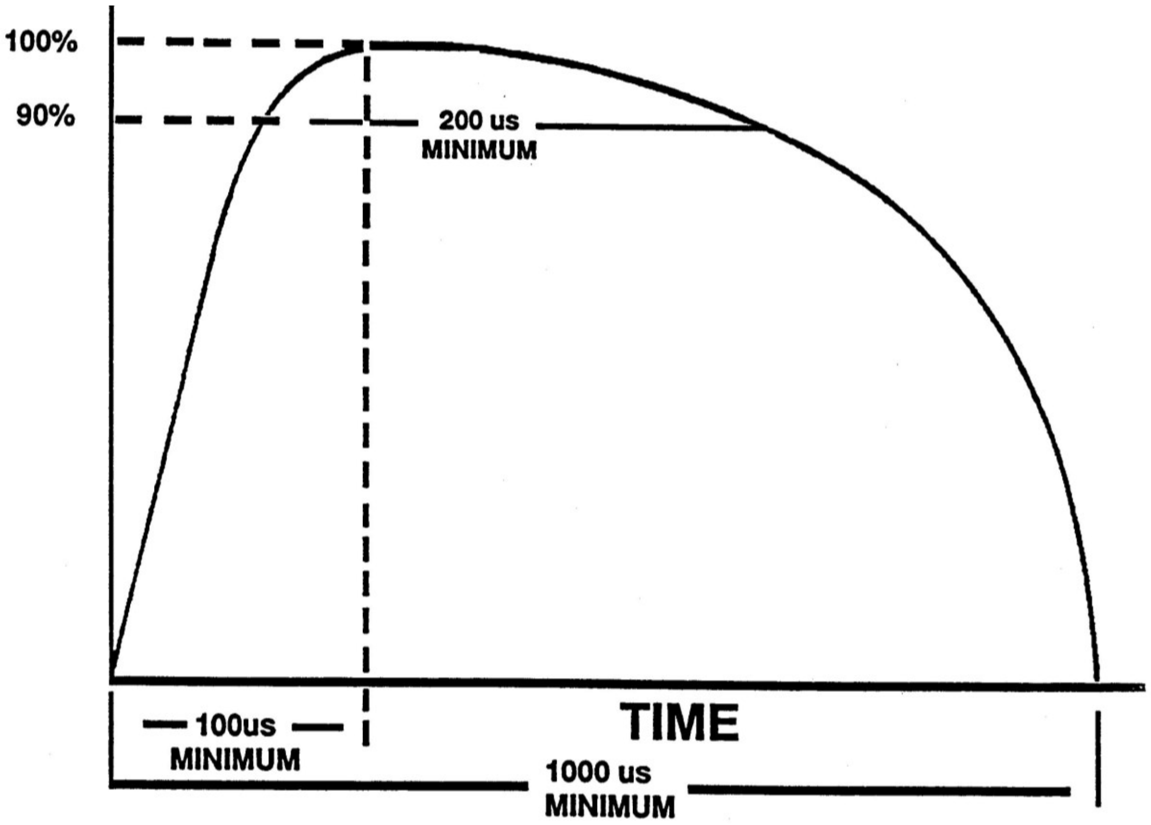
Switching Impulse Test C57.12.90 Sec. 10.2

- Time to peak value > 100 microseconds
- Time for 90 % of peak Value > 200 microseconds
- Time to first zero on tail of the wave >1000 microseconds

Test Circuit

- Test for each HV Line terminal
- Ground Neutral terminal for all Wye connection
- Ground other end of all Delta windings
- All Line terminals to be kept open except test terminal

Switching Impulse



Low Frequency Dielectric Test

Applied Voltage Test

- Transformer Connections
- Test Levels

Induced Voltage Test

- Transformer Connections
- Test Levels – Class I & Class II
- Partial Discharge

Applied Voltage Test – C57.12.90 Section: 10.6

- All terminals of winding under test are shorted together and connected to the 60 Hz supply through a high voltage test transformer. All other winding terminals are shorted together and connected to ground. Tank is also connected to ground

- During this test, as both ends of winding are connected, all parts of the winding and leads attain the same voltage level with respect to ground and all other windings

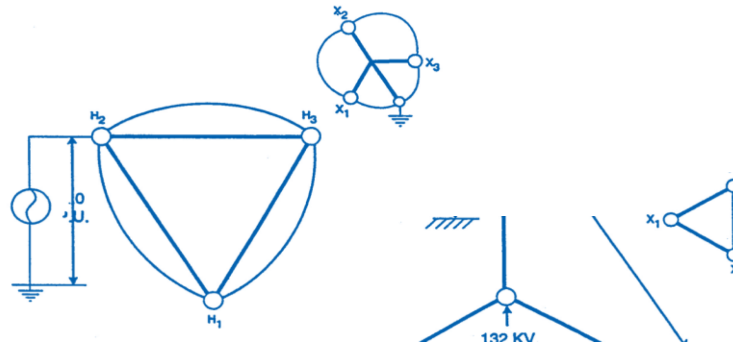
- Test voltage is raised slowly to the required voltage and held for 1 minute. The test is considered to be passed if there is no collapse of voltage or no audible internal sound

- After testing one winding, connection is changed for another windings and are tested in a similar way

Induced Voltage Test vs. Applied Voltage Test

A - Induced Test

B - Applied Test



Induced Voltage

waukesha
a prolec ge company

Prolec-GE Waukesha, Inc.
phone 919.734.8900 or 800.758.4384
fax 919.580.3254

Customer		HV	145.0	kV
Serial #	GT-07133	LV	13.2	kV
Design #	5175389			
Type	Delta/Wye	HZ	240	
BIL	550			
Config	Corona Test	ENH LV LL	22.9	kV
Tested By	KJ/EM	1 HR LV LL	19.7	kV
Date	09/04/24	Nom. x 1.05 LV LL	13.9	kV

Cycle	Time	H1 (pC)	H1 (µV)	H2 (pC)	H2 (µV)	H3 (pC)	H3 (µV)
Ambient	0:00:00	5.1	24.0	6.3	22.0	7.8	24.0
Nom. x 1.05	0:01:31	66.3	87.0	48.4	49.0	67.0	84.0
1 Hour Level	0:07:49	25.5	34.0	20.4	24.0	26.8	32.0
Enhanced	0:00:00	24.7	33.0	19.7	27.0	25.8	31.0
1 Hour Level	0:05:00	23.5	32.0	17.2	25.0	25.8	31.0
1	0:10:00	23.4	33.0	16.1	24.0	22.7	29.0
2	0:15:00	24.5	31.0	16.9	25.0	24.0	27.0
3	0:20:00	23.8	33.0	16.6	22.0	23.7	26.0
4	0:25:00	22.5	34.0	17.1	24.0	24.6	27.0
5	0:30:00	24.5	34.0	16.3	23.0	23.7	27.0
6	0:35:00	23.0	30.0	18.9	24.0	25.1	28.0
7	0:40:00	24.7	31.0	26.9	24.0	25.9	26.0
8	0:45:00	23.5	30.0	26.3	23.0	23.3	28.0
9	0:50:00	24.5	32.0	29.9	23.0	27.8	26.0
10	0:55:00	22.5	31.0	18.3	22.0	22.7	26.0
11	1:00:00	21.8	31.0	15.8	24.0	24.1	24.0
12	1:05:00	20.6	31.0	15.1	23.0	22.0	24.0
Nom. x 1.05	1:10:00	15.3	26.0	12.0	21.0	15.5	22.0

Loss

Prolec-GE Waukesha, Inc.
phone 919.734.8900 or 800.758.4384
fax 919.580.3254 info@waukesha.spx.com

ONCOR
GT-07133
Core Loss
Before Impulse

9/3/2024

Tested By:
JKC/RG

Nominal DETC Tap	OLTC Tap (NLTC=N)	% Operating Voltage	KV RMS (3 ph.avg)	KV Mean (3 ph. avg)	Amps (3 ph. avg)	Kilo Watts (3 ph. total)
C	N	90%	6.875	6.886	0.549	10.900
C	N	100%	7.641	7.650	0.772	13.897
C	N	110%	8.436	8.439	1.693	18.235
C	N	117%	8.946	8.919	4.669	23.179

Prolec-GE Waukesha, Inc.
phone 919.734.8900 or 800.758.4384
fax 919.580.3254 info@waukesha.spx.com

ONCOR
GT-07133
Load Loss
Temp 23.9ºC

9/3/2024

Tested By:
JKC/RG

Nominal DETC Tap	OLTC Tap (NLTC=N)	KV RMS (3 ph.avg)	KV Mean (3 ph. avg)	Amps (3 ph. avg)	Kilo Watts (3 ph. total)
A	16R	10.327	10.327	111.420	105.160
C	16R	9.978	9.978	117.900	109.160
E	16R	9.736	9.736	123.280	115.730
A	N	10.194	10.194	111.750	111.950
C	N	9.732	9.732	117.240	112.950
E	N	9.545	9.545	123.620	121.230
A	16L	10.117	10.117	111.630	128.900
C	16L	9.692	9.692	117.870	130.920
E	16L	9.446	9.446	123.990	137.050

Applied Voltage Test (cont.)

Test Voltage

- For Delta connected windings, applied test voltage level corresponds to NSV

  For example:
  Equivalent applied test voltage for 230kV (750,825,900 BIL) is 345kV

- For Wye connected windings, the applied test voltage is limited to the BIL of Neutral

  For example:
  If line end BIL is 550kV and neutral end BIL is 150kV, then equivalent applied test voltage is limited to 50kV (equivalent for 150 BIL)

Induced Voltage Test – C57.12.90 Section: 10.7 to 10.9

Test Connection

- Three phase voltage is applied to LV terminals at frequency ≥2 times rated frequency; all other line terminals are left open, Neutral and Tank is grounded

Test Voltage & Duration

Class I Transformers

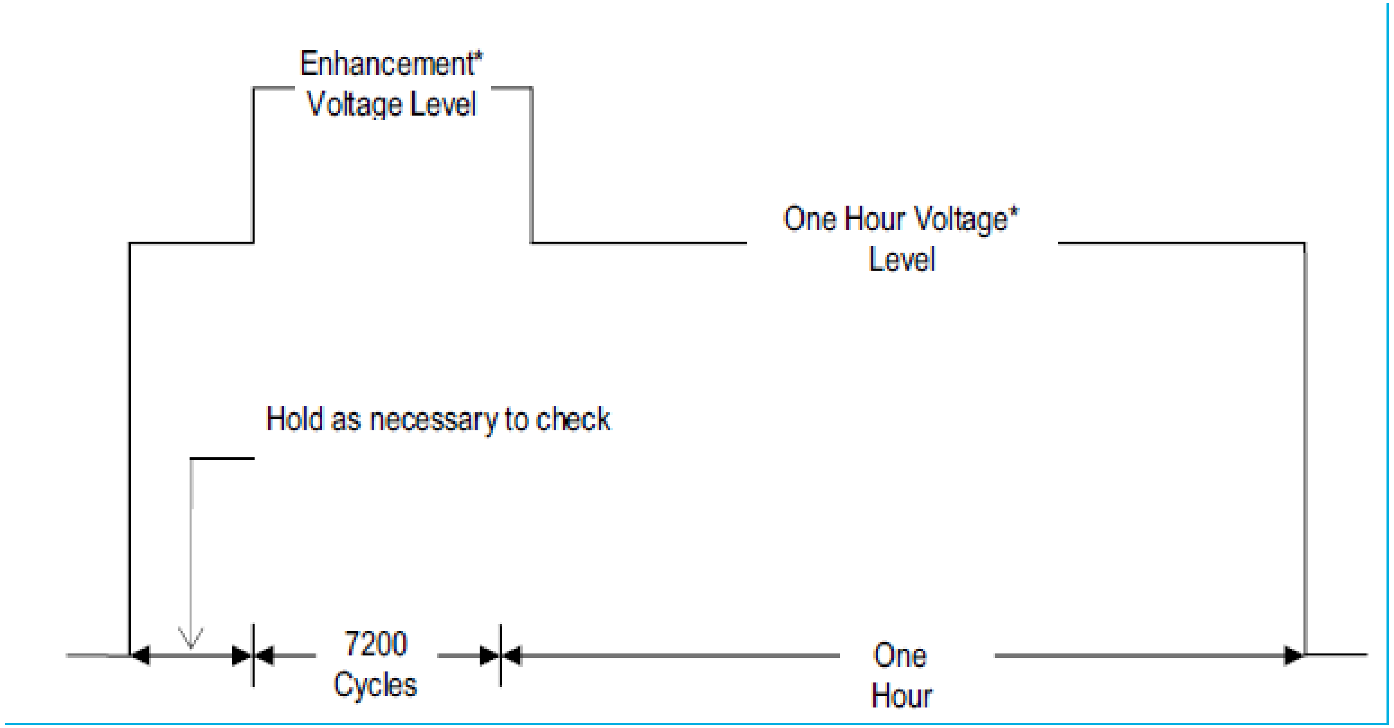
- Test voltage is equivalent to twice the volts/turn and line end is raised to achieve equivalent power frequency test voltage across phases
- Test duration is 7200 Hz; if test frequency is 180 Hz then test duration = 7200/180 = 40 seconds
- Test is considered to be passed if no collapse of voltage occurs or no audible internal sound is present

Induced Voltage Test (cont.)

Test Voltage & Duration

Class II Transformers

- Enhancement level – 173% maximum tap voltage for 7200 Hz
- One hour test voltage – 150% for 1 hour
- Partial discharge limits < = 500 pC



C57.12.00 – Table 4

Table 4—Dielectric insulation levels for Class II power transformers, voltages in kV

Maximum system voltage (kV rms)	Nominal system voltage (kV rms)	Applied voltage test (kV rms)			Induced voltage test (phase to ground) (kV rms)		Winding line-end BIL (kV crest)				Neutral BIL (kV crest)	
		Delta & fully insulated wye	Grounded wye	Impedance Grounded wye or Grounded wye with Higher BIL	Enhanced 7200 cycle	One hour	Mini-mum	Alternates			Grounded wye	Impedance Grounded wye or Grounded wye with Higher BIL
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
17	15	34	34	34	16	14	**110**				110	110
26	25	50	34	40	26	23	**150**				110	125
36	34.5	70	34	50	36	32	**200**				110	150
48	46	95	34	70	48	42	200	**250**			110	200
73	69	140	34	95	72	63	250	**350**			110	250
121	115	173	34	95	120	105	350	**450**	550		110	250
145	138	207	34	95	145	125	450	**550**	650		110	250
169	161	242	34	140	170	145	550	**650**	750	825	110	350
242	230	345	34	140	240	210	650	**750**	**825**	**900**	110	350
362	345	518	34	140	360	315	900	1050	1175		110	350
550	500	N/A	34	140	550	475	1425	1550	1675		110	350
765	735	N/A	34	140	880	750	1950	2050			110	350
800	765	N/A	34	140	885	795	1950	2050			110	350

NOTE 1- For nominal system voltage greater than maximum system voltage, use the next higher voltage class for applied test levels.

NOTE 2- Induced voltage tests shall be conducted at 1.58 X nominal voltage for one hour and 1.80 X nominal voltage for enhanced 7200 cycle test.

NOTE 3-Column 6 and Column 7 provide phase-to-ground test levels that would normally be applicable to wye windings. When the test voltage level is to be measured phase-to-phase (as is normally the case with delta windings), the levels in Column 6 and Column 7 must be multiplied by 1.732 to obtain the required phase-to-phase induced-voltage test level.

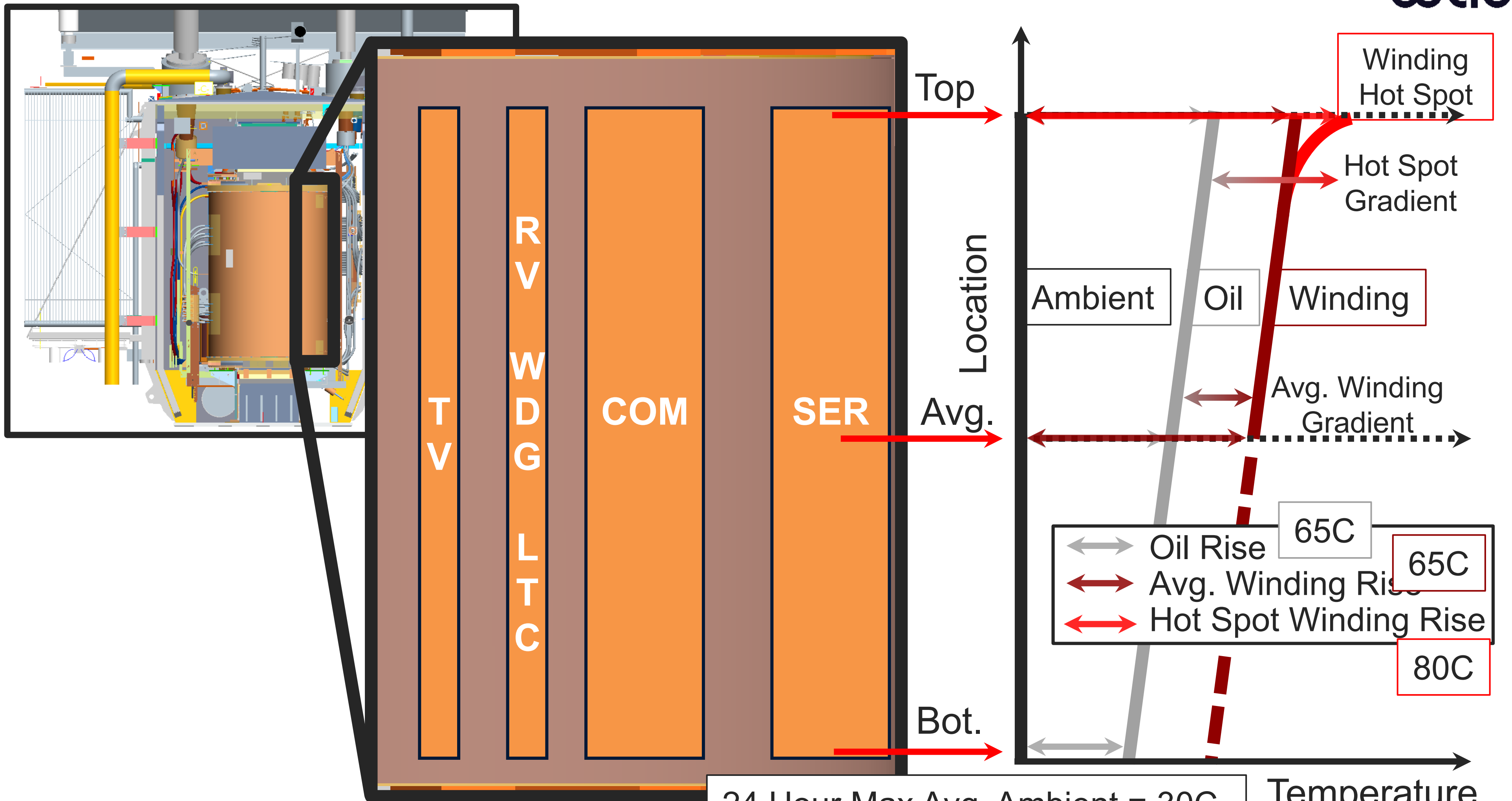
NOTE 4-Bold typeface BILs are the most commonly used standard levels.

NOTE 5-Y-Y connected transformers using a common solidly grounded neutral may use neutral BIL selected in accordance with the low-voltage winding rating.

NOTE 6-For 500kV to 765 kV nominal system voltages, induced voltage test levels do not follow rules in Note 2, and 1950 kV BIL is not a standard IEEE level.

NOTE 7- For Neutral BILs greater than 350 KV, Applied Voltage test level shall be specified by user.

Temperature Distribution Model



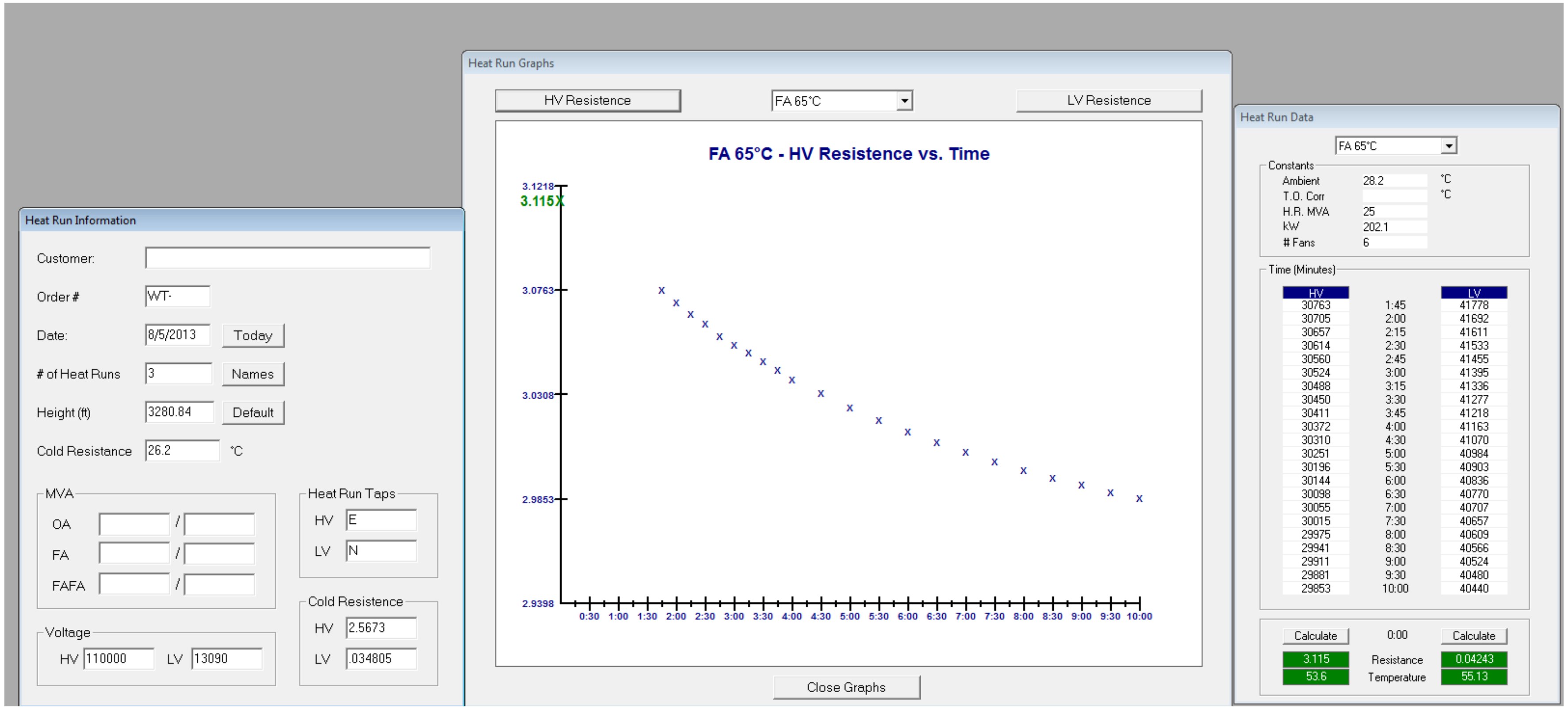
24 Hour Max Avg. Ambient = 30C
(Max Ambient = 40C)

Temperature Rise Test – C57.12.90 Section: 11

- Measurements during temperature rise test
  - Top oil temperature
  - Ambient temperatures
  - Top and bottom radiator temperature
  - Hot winding resistance at shut down
- Top Oil Rise = Top oil temperature – Average ambient
- Mean oil rise = Top oil temperature – Average of top & bottom header temp
- Average winding rise

  = { (Hot Resistance/Cold Resistance) X (234.5+ambient temp) } – Ambient
- Gradient = Average winding rise – Mean oil rise
- Hot spot Rise = Top oil rise + Hot spot gradient
- Hot spot gradient = Gradient (1 + k); k = hot-spot factor

Average Winding Rise



$$\theta_2 = \frac{R_2}{R_1}(235 + \theta_1) - 235$$

θ_2 : *Temperature of the winding when the circuit is opened*

θ_1 : *Average oil temperature at he beginning of test (cold case)*

R_2 : *Resistance at temperature θ_2 (hot case)*

R_1 : *Resistance at temperature θ_1 (cold case)*

DGA

DGA Sequence

- Before Test , After Dielectric, Before/After Temp Rise test, After all Tests
- Gassing rate depend on many factors - Winding temperature rise, Ambient Temperature, Duration of test, Design characteristics like current and flux density
- Expect significant difference lab to lab

Limits per C57.130

<table>
<tr><th></th><th>Gas Generation During Temp Rise Test PPM/ Hour</th></tr>
<tr><td>Hydrogen H_2</td><td>< 1</td></tr>
<tr><td>Carbon Monoxide CO</td><td>< 2</td></tr>
<tr><td>Carbon dioxide CO_2</td><td>< 18</td></tr>
<tr><td>Methane CH_4</td><td rowspan="3">< 0.4</td></tr>
<tr><td>Ethane C_2H_6</td></tr>
<tr><td>Ethylene C_2H_4</td></tr>
<tr><td>Acetylene C_2H_2</td><td>0</td></tr>
</table>

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Sound Test – C57.12.90 Section: 13

- **Core audible sound:** This sound component originates in the transformer core
- **Load audible sound:** This sound component is primarily produced by vibrations of the windings and tank walls when the transformer is loaded.
  - When a transformer is highly loaded, load sound can be a significant contributor to the total sound of the transformer ,especially for low no-load noise medium and large power transformers.
- **Cooling system audible sound:** typically consists of broadband fan noise, plus discrete tones (of low levels) at the fan blade passage frequency and its harmonics.

The sum of core and cooling system sound components is typically referred to as the **no-load noise** of a transformer.

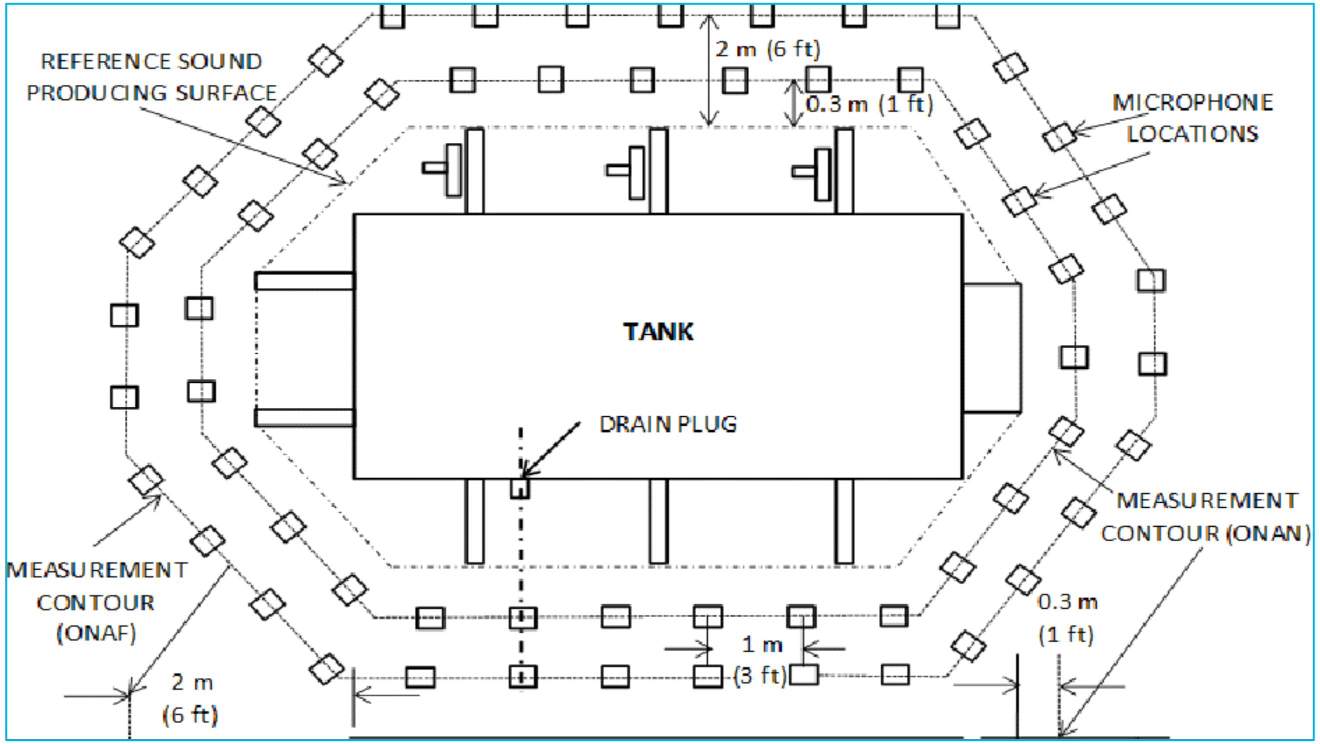
The total audible sound of the transformer, however, is the sum of all three components, 2015 standard outlines measurement methods for Load sound and calculation to arrive Total sound.

Sound levels are specified in NEMA-TR1 and that is only No-Load Sound Level

Load Sound is not significant for smaller transformers (< 100 MVA) unless No load sound required is below NEMA

Sound Test Procedure

- Measurements are generally taken on a weighted scale as per NEMA standard
- Location of measurements start at drain plug and around the transformer at approximate 3-foot intervals, 12 inches away from transformer tank/radiators as applicable at 1/3 and 2/3 heights for transformers over 9 feet
- With fans running – readings are taken 6 feet distance



Other Tests

- Bushing Cap & PF – C1/C2
- Core excitation test – typically 110% for 24 Hours
- Leakage Reactance test
- Front of Wave Impulse testing
- Frequency response analysis (FRA)
- Fast Front Switching Impulse (FFSI)
- Special Termination Lightning Impulse (STLI)
- LTC Tests
    - Operate LTC at No Load Voltage
    - Operate LTC under Load
    - Dynamic Resistances
    - DGA from LTC

Questions?