Power Transformer Factory Test using IEEE Standards

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IEEE Training, Houston, Texas, Oct.8-9, 2014

Power Transformer Factory test

Topics covered

- Objective of tests
- Classification of tests
- List of tests
- Connections for test
- Details of Tests
- Sequence of tests
- Future trends

Tests for special transformers, such as HVDC converter or Phase shifting transformers are not covered

Objective of testing

- Compliance to applicable standards
- Compliance to customer specification
- Verify guaranteed parameters
- Assess quality and reliability
- Verify design
- Obtain additional performance and reference data

Classification of tests

As per IEEE standards

- Routine test
- Design test
- Other tests

As per characteristic of test

- Quality verification tests
- Performance tests
- Thermal tests
- Dielectric tests
- Mechanical tests
- Test data for future reference
- Others

IEEE standards

- **IEEE standard C57.12.00**
  IEEE Standard General Requirements for Liquid-Immersed, Distribution, Power and Regulating Transformers

  IEEE standard C57.12.90
  IEEE Standard Test Code for Liquid -Immersed, Distribution, Power and Regulating Transformers
  and
  IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers

- **CSA standard CAN/CSA-C88-M90**
  CSA standard for Power transformers and reactors

List of tests

	Routine	Design	Other	Remark
Oil quality tests	X			Quality
Resistance measurement	X			Quality
Winding Insulation resistance	X			Quality
Core/clamp insulation resistance	X			Quality
Ratio test	X			Quality and performance
Polarity and phase relationship	X			
Insulation power factor and capacitance	X			Quality and Future ref.
Control (auxiliary) losses			X	Others
Single phase excitation test			X	Future reference

List of tests

	Routine	Design	Others	Remark
No load loss and excitation current	X		X	Performance test
LTC operation with no load voltage (cycle recording)	X			Quality verification
Impedance voltage and load loss	X			Performance test
LTC operation at load current (cycle recording)	X			Quality verification
Zero phase sequence voltage			X	Future/System reference
Temperature rise		X	X	Thermal and performance

List of tests

Dielectric tests	Routine	Design	Others	Remark
Lightning impulse		X	X	Dielectric test
Switching impulse			X	Dielectric test
Applied voltage test	X			Dielectric test
Induced voltage with or without partial discharge measurement	X			Dielectric test
No load loss after dielectrics	X			CSA
Low or Power frequency test on auxiliary / control devices and current transformers	X			Dielectric test

List of tests

	Routine	Design	Others	Remark
Audible sound level			X	Performance
Short circuit capability			X	Performance and quality test
Operation tests of all devices	X			Quality verification
Dissolved gas in oil analysis	X			Quality, Thermal, Future reference
Lifting and moving devices		X		Mechanical test
Pressure		X		Mechanical test
Leak	X			Quality verification

Test system accuracy requirement

Quality measured	Accuracy
Losses	+/-3%
Voltage	+/-0.5%
Current	+/-0.5%
Resistance	+/-0.5%
Temperature	+/-1.0degC

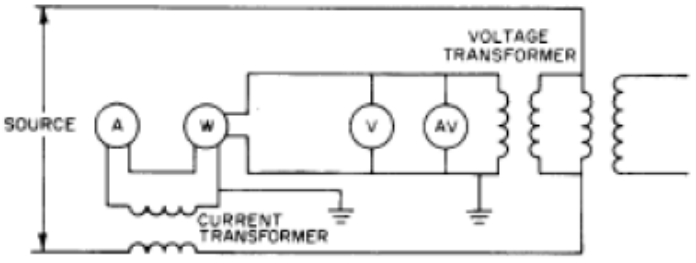
Frequency of test source to be within +/-0.5% of rated frequency

Open circuit connection

Smart solutions. Strong relationships.

Ratio test **No load loss and current test**

Sound level test **Induced voltage test**



—Connections for no-load loss test of a single-phase transformer with instrument transformers

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Measurement of no load loss and current

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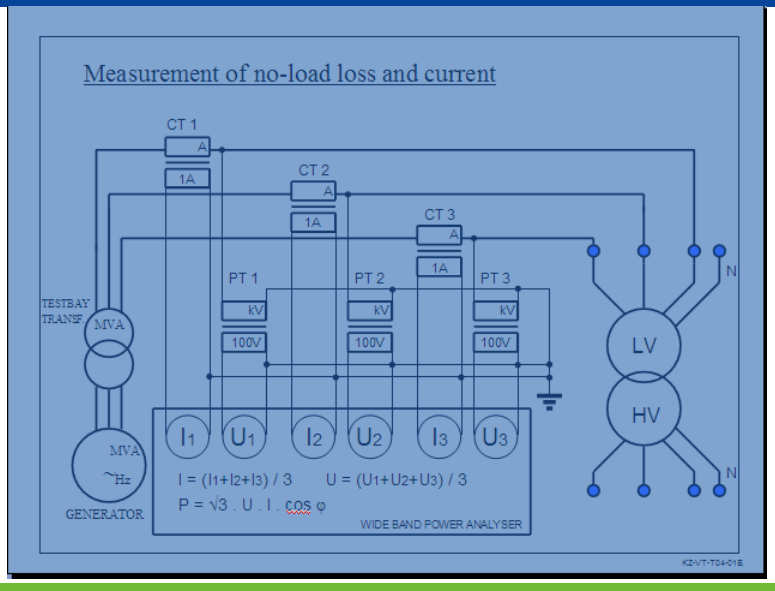

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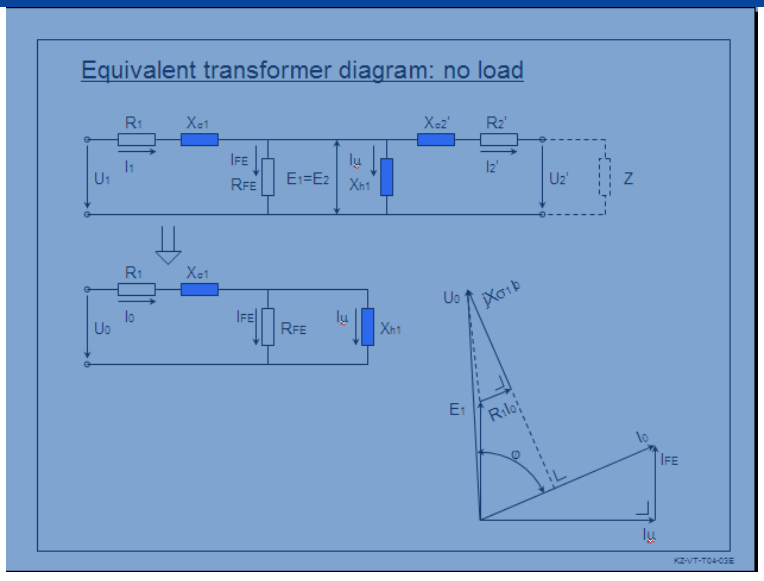
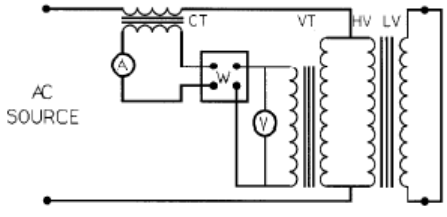
Equivalent circuit on open circuit connection



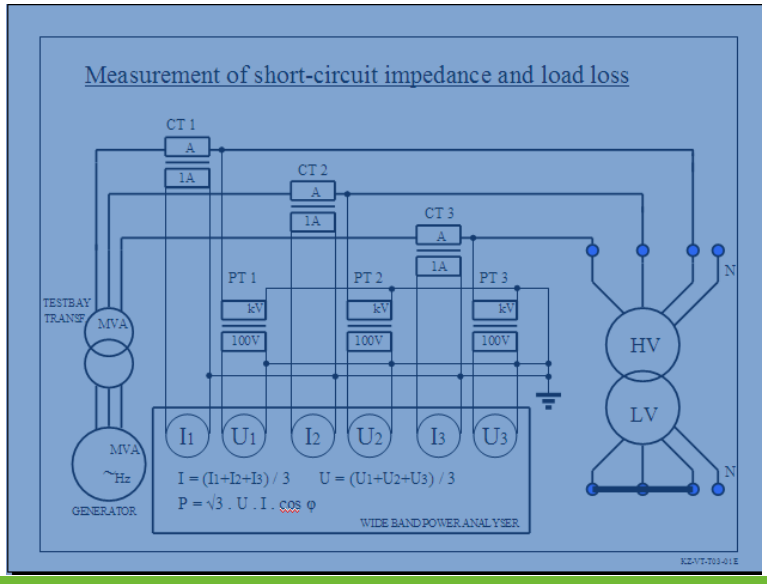
Short circuit connection

- Impedance and load loss
- Temperature rise

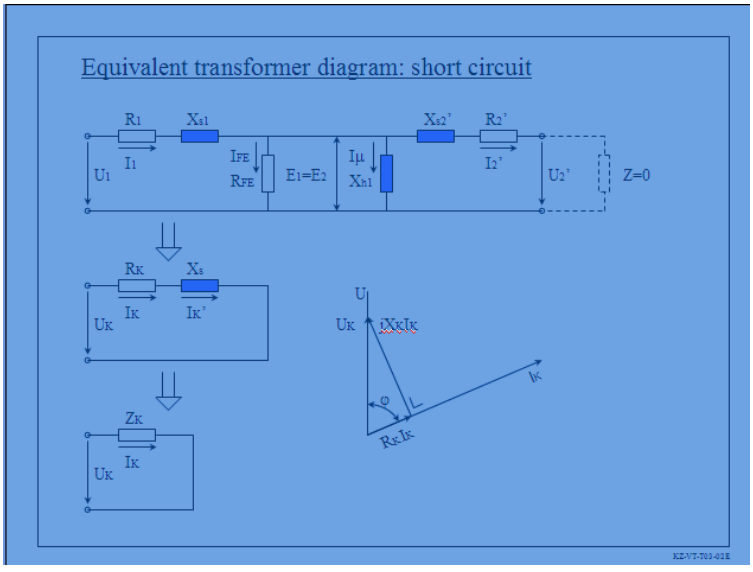


16—Single-phase transformer connections for load loss and impedance voltage tests with instrument transformers

Measurement of impedance and load loss



Equivalent circuit on short circuit connection



Special connection

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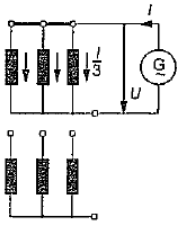
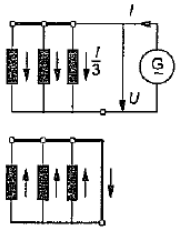
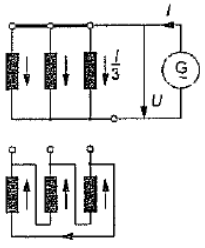
- Zero phase sequence voltage



Open circuit zero-sequence impendance of a star-star connected transformer



Short-circuit zero-sequence .mpendance of a star-star connected transformer



Zero-sequence impendance of a star-delta transformer

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Dielectric tests

Smart solutions. Strong relationships.

Withstand voltage	*Impact on design*
BIL	Bushings, lead clearances, winding internal insulation, winding clearances, stresses to ground, neutral point insulation
SIL	External clearances, Bushings, lead clearances, phase-to-phase stresses
Induced voltage	Internal winding stresses (V/T), stresses to ground, grounding, electrode configurations
Applied voltage	Stresses to ground (windings, leads). Critical for fully insulated windings

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Insulation types

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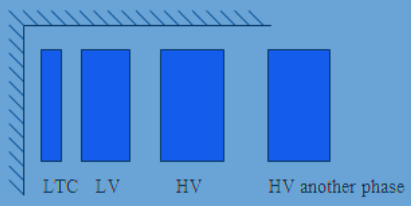
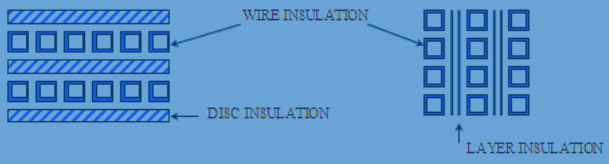
Windings

MAJOR INSULATION



INTERNAL INSULATION



CONTINUE DISC WINDING

LAYER WINDING

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Insulation stressed by different tests

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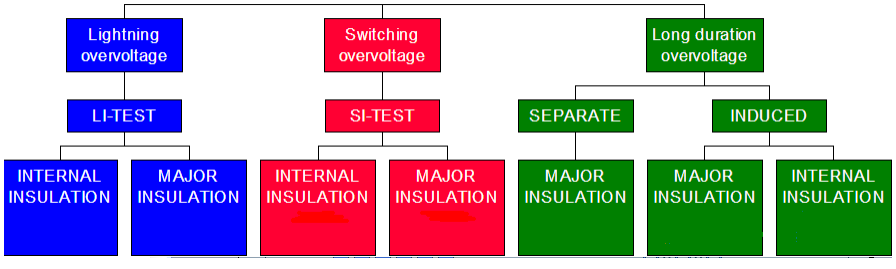

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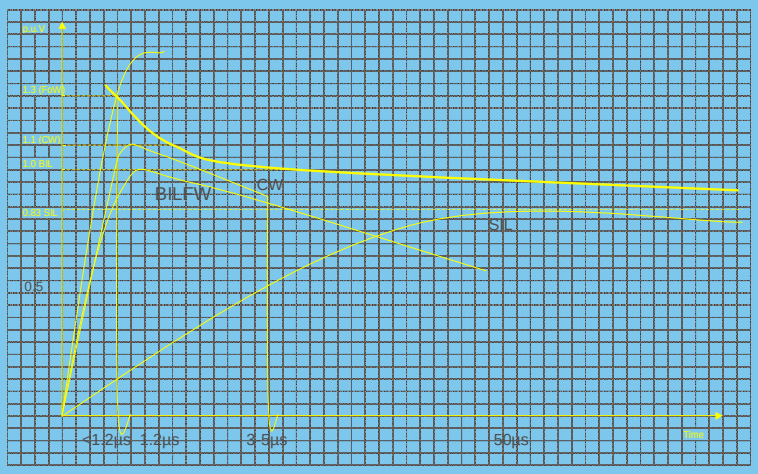
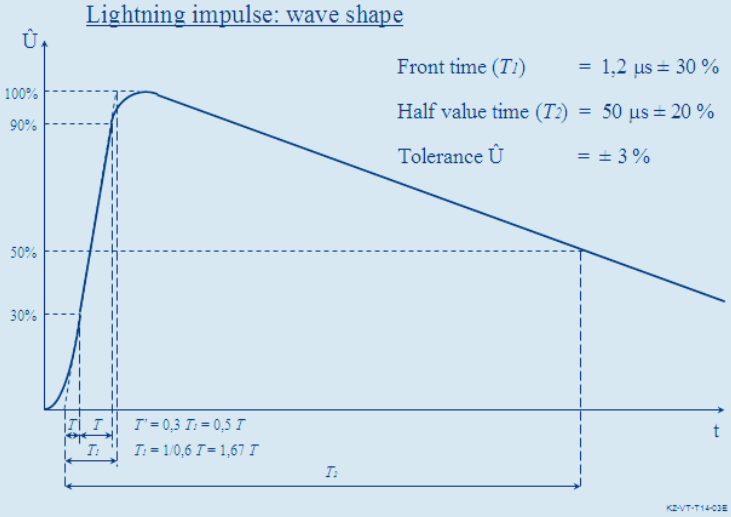
Impulse wave shapes



Lightning impulse Full wave



LI chop wave shape

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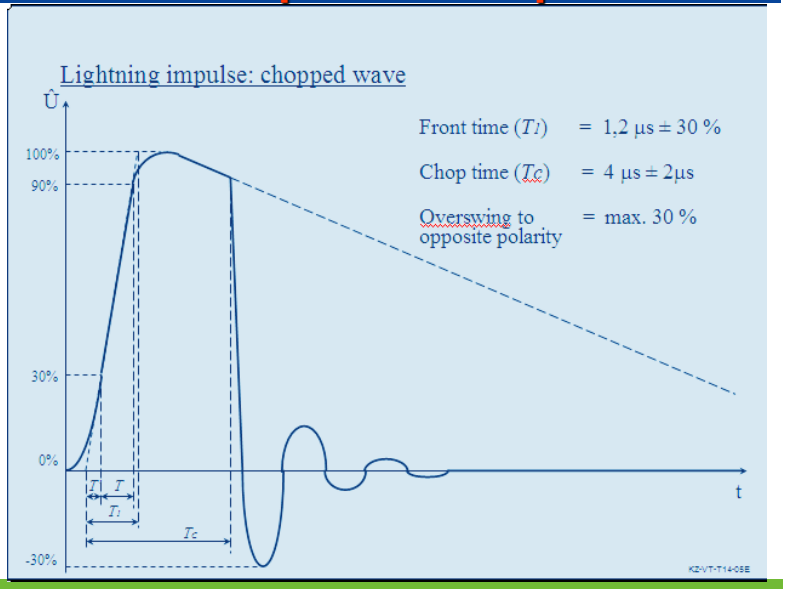
Lightning impulse: chopped wave



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LI test connections

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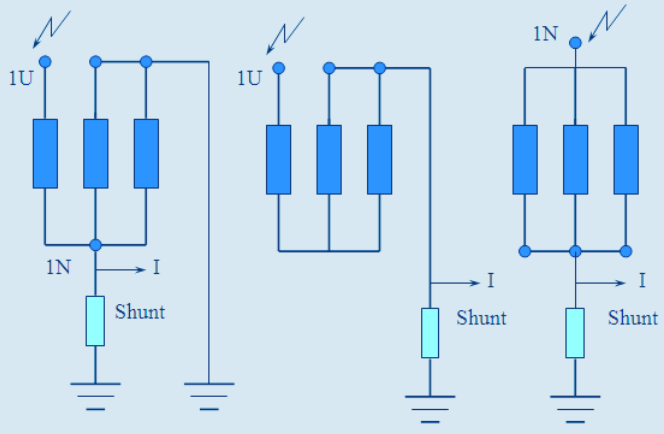
Connection LI-test star-connected windings



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LI test connections

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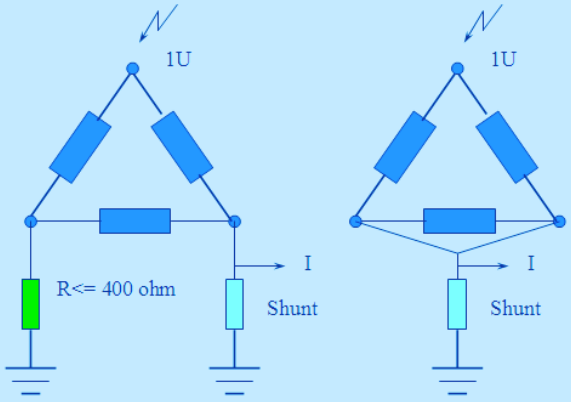
Connection LI-test delta-connected windings



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LI test connections

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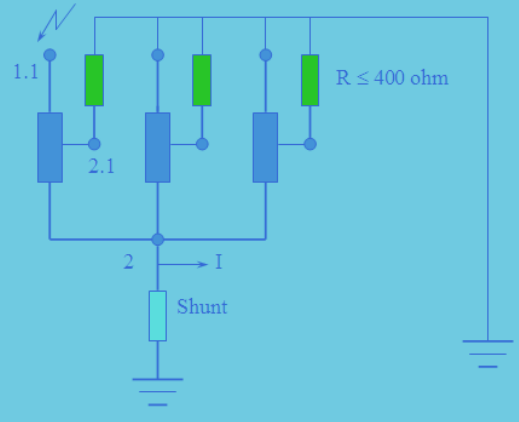
Connection LI-test star-connected auto-transformer windings



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Lightning impulse test sequence

Smart solutions. Strong relationships.

Without non linear resistors in the unit

- Reduced (50%) full wave
- 100% Chopped wave
- 100% Chopped wave
- 100% Full wave

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Lightning impulse test sequence

Smart solutions. Strong relationships.

With non linear resistors in the unit

- 50% Full wave
- 80% Full wave
- 100% Full wave
- 100% Chopped wave
- 100% Chopped wave
- 100% Full wave
- 80% Full wave
- 50% Full wave

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Lightning impulse failure detection

Smart solutions. Strong relationships.

Failure detection is by comparison of voltage and current wave shapes at reduced level and full level or between 2 wave shapes at the same level in case of non-linear resistors

Fig. XIV HV TO LV FAILURE THROUGH INSULATION

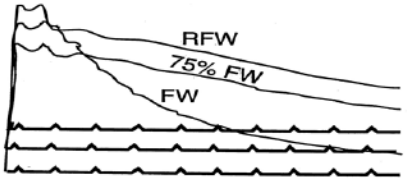

Fig. XIV - FW

Fig. XIII - FWC

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Lightning impulse test on neutral

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Wave shape:

Front time 10 micro sec

Tail time 50 micro sec

Test sequence:

- **Reduced full wave**
- **2x100% full wave**

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Dielectric tests-Switching impulse

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- **SWITCHING IMPULSE TEST**
  - 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
  - All Line terminals to be kept open except test terminal
- Sequence

Reduced Full wave followed by 2 Full waves (opposite polarity application required to demagnetize core)

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Switching impulse waveshape

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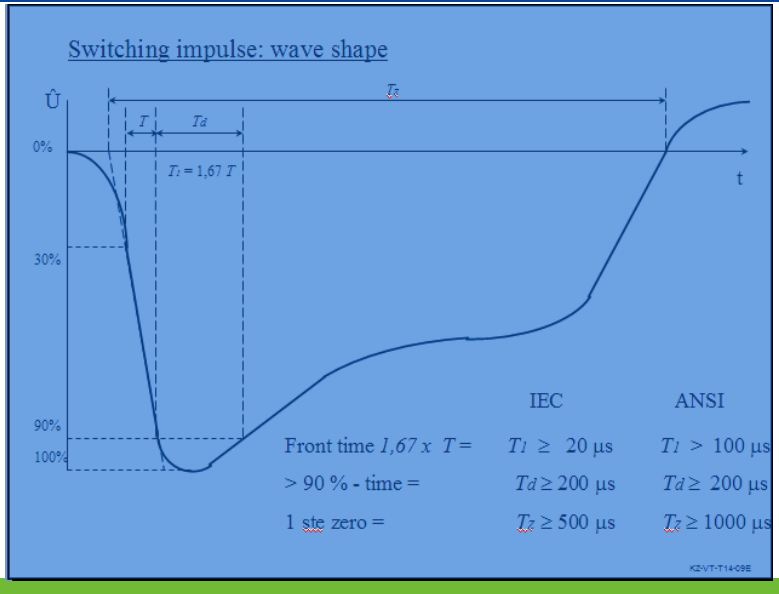

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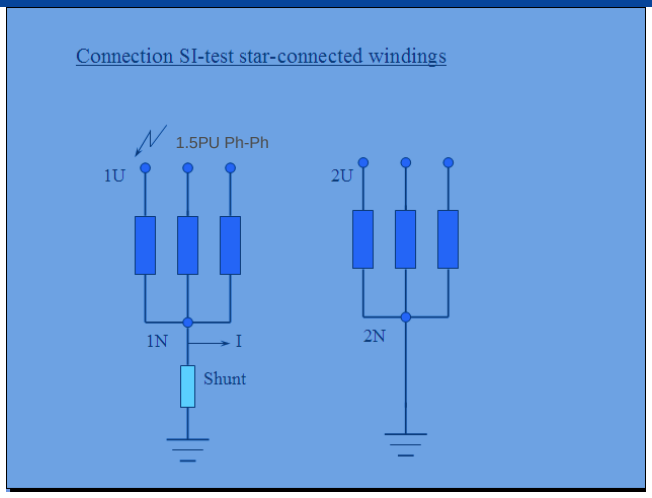
Switching impulse connection



Reduced FW and FW voltage wave shapes are compared for pass criteria

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Dielectric tests-Applied voltage

Dielectric Tests – Applied Voltage Test

- **TEST CIRCUIT:**
  - 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
  - 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

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Applied voltage test

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Dielectric Tests – Applied Voltage Test

- **TEST VOLTAGE**
  - 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
  - For Delta connected windings applied test voltage level is the voltage equivalent to BIL. For example – equivalent applied test voltage for 550 KV BIL is 230 KV
  - For Wye connected windings the applied test voltage is limited to the BIL of Neutral. For example if Line end BIL is 550 KV and neutral end BIL is 150 KV then equivalent applied test voltage is limited to 50 KV (equivalent for 150 BIL)

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Applied voltage test connection

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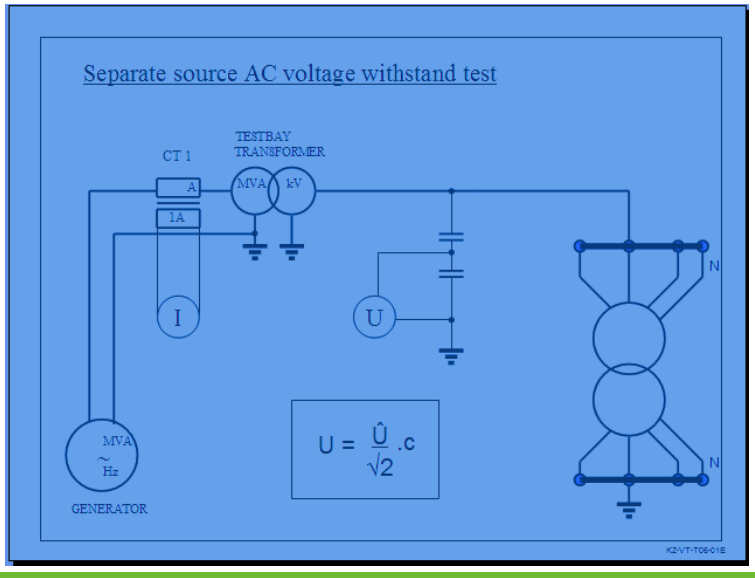

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Dielectric tests-Induced voltage

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Dielectric Tests – Induced Voltage Test

- **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 connected to ground

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Induced voltage test

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Dielectric Tests – Induced Voltage Test

- **TEST VOLTAGE & DURATION**
- **For Class I Transformers (≤ 69 KV Class) –**
  - 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 200 Hz then test duration = 7200/200 = 36 seconds
  - The test is considered to be passed if there is no collapse of voltage or no audible internal sound

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Induced voltage test

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Test voltage and duration

- For class II transformers (>69kV Class)
- Test voltage is raised slowly to 150% and held for few minutes and is raised to Enhancement level of approximately 173% for 7200 cycles and then reduced to 150% and maintained for 1 hour
- During this test partial discharge (apparent charge) in pico-coulombs is recorded every 5 minutes
- As per ANSI-IEEE standards the limit for PD level is 500pC

(Alternate measurement can be RIV in micro-volts in which case the limit is 100micro-volts. But this is not a preferred method, was moved to annex in the IEEE standard)

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Measurement of partial discharge

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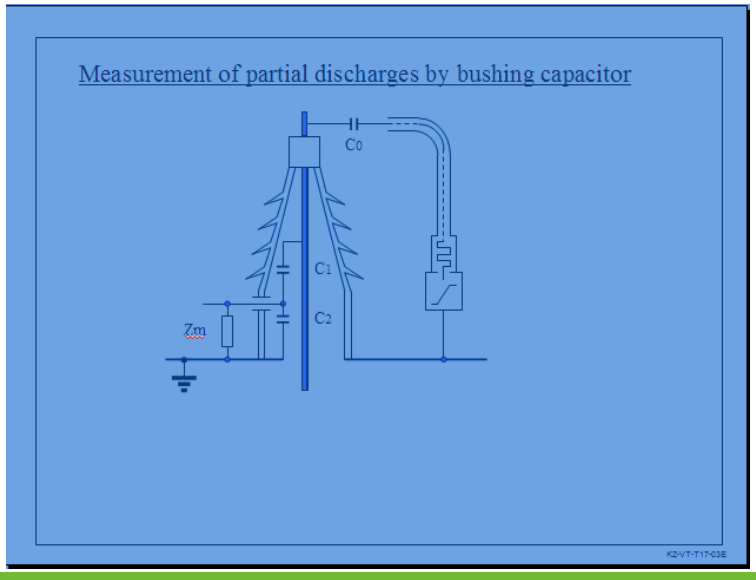

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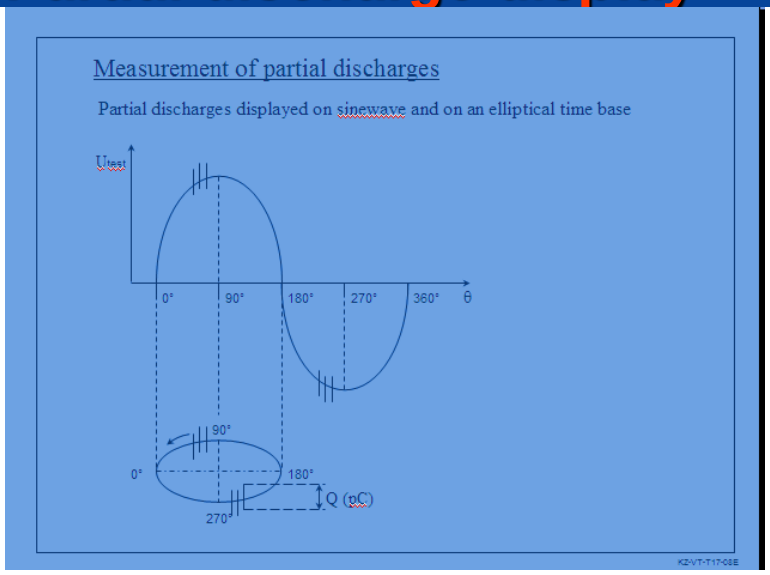
Partial discharge display



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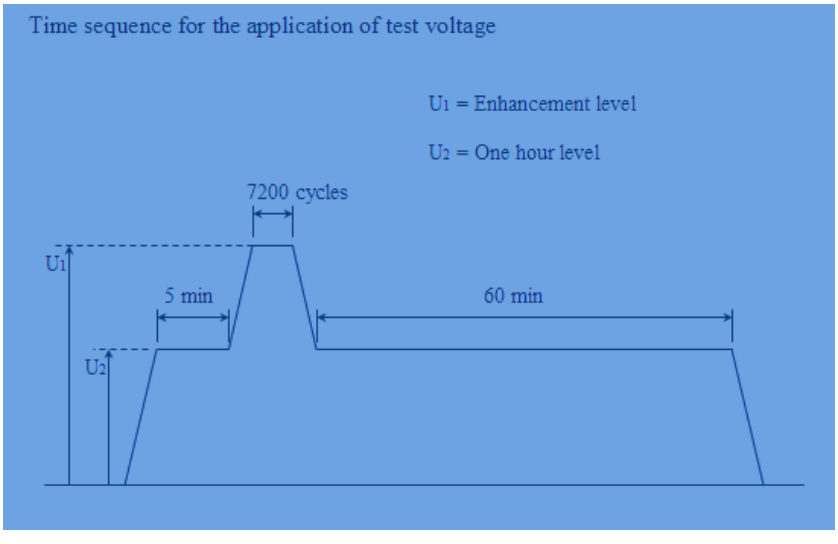
Time sequence for induced test



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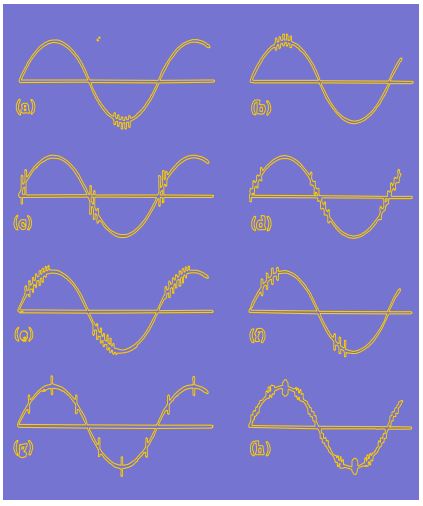
Examples of Common Discharge and Interference Patterns Encountered During Partial Discharge Tests on Power Transformers



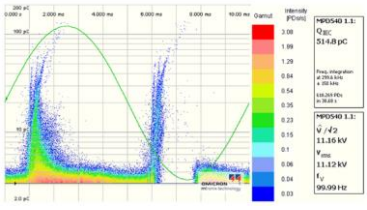
a) Corona discharge on a high-voltage electrode
b) Corona discharge on a grounded point

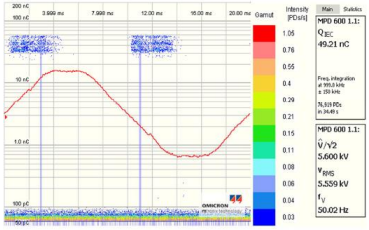
c) Unearthed conductive object near or inside the test object
d) Noise due to a bad contact (this pattern may also occur in some type of internal discharges)

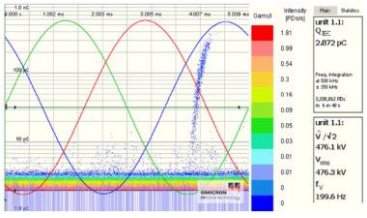
e) PD in oil-paper insulation or gas bubbles
f) Surface (creeping) discharge in oil

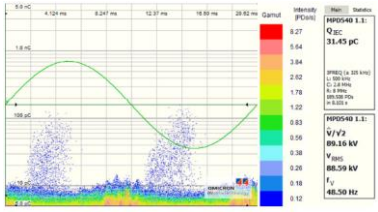
g) Interference due to thyristor pulses
h) Interference due to a modulated periodic signal

Phase-resolved PD patterns









a) Discharges in solid insulation with cavities
b) Bubbles in oil; the pattern is appearing and disappearing
c) Floating potential
d) RIP bushing problem

Temperature rise test

- Performed at Base ONAN and Maximum ONAF Rating
  - If maximum current/loss can not be fed due to test limitations, then transformer can be loaded to 80% loss levels @ 90% current as per C57.12.90
- Performed by shorting all 3 LV terminals and applying voltage from HV winding to circulate sufficient current to produce maximum total loss
- After reaching steady state oil temp. rise, current is reduced to rated value and circulated for 1 hour. Hot winding resistance is measured and curve plotted to arrive value at time of shutdown (Time zero)
- Temperature correction is applied to steady state Top-oil Rise, Mean oil Rise for total /test losses if applicable as per clause 11.5.2.2.1/C57.12.90
- Temperature correction is applied to winding gradient to correct to rated current if applicable as per clause 11.5.2.1/C57.12.90

Temperature rise test

- Measurements during Temperature Rise Test –
  - Top oil Temperature, 3 Ambient Temperatures, Top and Bottom Radiator Temperature, & Hot winding resistance at shut down
- Top Oil Rise = Top oil temperature – Average ambient
- Average oil rise = average of top & bottom header temperature
- Average winding rise = (Hot Resistance / Cold Resistance)*(234.5+ambient temp) – ambient
- Gradient = Average winding rise – Average oil rise
- Hot spot Rise = Top oil rise + Hot spot gradient
- Hot spot gradient = Gradient (1 + k)
- k = hot-spot factor calculated based on maximum eddies due to actual radial and axial field

Correction required for sites at altitudes>3300ft

Dissolved gas analysis

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- Oil sample is taken from the tank Before and After test
- Oil sampled are tested for various dissolved gasses
  - H2, CH4, C2H6, C2H4, C2H2, CO, CO2
- The change in gas levels must be within permissible limits set by customer or manufacturer's standards
- This test is also used as a diagnostic test to monitor condition of transformer in service as per IEEE Guide C57.104-1991
- PC57.130 IEEE Trial-Use Guide for the Use of DGA during Factory Temperature Rise Tests…. Will be used when it is approved and published

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Sound level test

Smart solutions. Strong relationships.

- Connection same as for no load test
- Sound pressure level measured at 0.3m(1foot) distance from sound producing surface (tank)
- Sound pressure level measured at 2 m (6feet) distance from fans when forced cooling in operation.
- Measurement done at 1/3 and 2/3 height of tank
- A weighted sound pressure level is computed
- Correction done for ambient noise

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Sound level test

- In addition to compliance to C57.12.90, HECO also spec IEC 60076-10. "Sound pressure and sound power level specifications shall apply for conditions with all ventilation fans ON, and for both no load (open secondary) and rated load operating conditions."
- **Sound pressure vs. sound power**
- **Sound measurement under load**
  - **Measure the winding sound during heat run**
  - **Measurements under load logarithmically added to core noise**

Test sequence

Low voltage/rated voltage tests

- **Ratio**
- **Polarity**
- **Resistance**
- **Core loss**
- **Load loss**
- **Zero sequence**
- **Temperature rise/overload**

Test sequence

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Dielectric tests

- Lightning impulse
- Switching impulse
- Applied voltage test
- Induced voltage/Partial discharge test
- Repeat no load test when specified

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Other tests and trends in test requirements

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- Sweep Frequency Response Analysis
  - Total assembled condition
  - Shipping condition
- Recurrent surge generator test
- Direct hotspot measurement using fiber optics
- Infrared scan during temperature rise test
- Partial discharge for 69kV class units
- Sound level using intensity meter and sound level under load
- Tests on buried tertiary winding
- Acoustic detection of partial discharge problem

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Questions

Smart solutions.
Strong relationships.

Thank you for your participation

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