Power Transformers

Mpowering Energy

Prof.dr. R.P.P. Smeets
KEMA, the Netherlands
KEMA

- World market leader in testing and certification of HV equipment
- World’s largest high-power laboratory (8400 MVA)
- Test laboratories in
  - Netherlands
  - USA
  - Czech Republic
Short-circuit stresses transformers

• Every transformer sees several full short-circuits in its service life (CIGRE WG A2.12)
• Mechanical stresses to windings are very severe.
• Deformation of winding can reduce cooling and lifetime.

• Verification of mechanical strength can be through:
  - Short-circuit testing, most reliable, service simulation.
  - Design review, cost-wise solution, but less reliable.
• CIGRE WG12.19: From all transformers that failed because of short-circuit 1/3 passed 'design review' successfully but none underwent a short-circuit test.
Short-circuit tests

- From IEC 60076-5 (2006)
- Most important are the electro-dynamical forces due to short-circuit current
- KEMA NL performs 70 - 80 tests on power transformers per year
- Criterion to pass is change of reactance due to short-circuit current passage
What transformer for short-circuit testing?

- Key feeding transformers at power plant sub-stations or huge load centers
- Strategic intertie transformers, three-winding system transformers (tertiary), auto-transformers
- Series of transformers, one taken out for a "type" test - approach for distribution transformers
- Transformers with axially split winding connections
- Transformers in networks known for high fault incidence or high fault current levels - Track feeding transformers
Electro-dynamical short-circuit forces
(Overhead line 40 kA - 0.2 s)

this is a high-speed movie
normal condition

- Current [pu]
- Force [pu]
- Time [ms]

I_{\text{rated}}

force due to $I_{\text{rated}}$
symmetrical short-circuit current

- $I_{sc\ sym}$
- $I_{rated}$
- Short-circuit at voltage maximum
asymmetrical short-circuit current

![Graph showing asymmetrical short-circuit current and force](image_url)
relationship current - force

- Current $I_{\text{rated}}$
- Current $I_{\text{sc sym}}$
- Current $I_{\text{sc asym}}$

- Force $F - I_{\text{sc asym}}$
- Force $F - I_{\text{sc sym}}$
- Force $F - I_{\text{rated}}$

Pulsating force!
pulsating forces on winding

this is a high-speed movie
Possible damage by radial forces

- Circular winding
- Free buckling
- External bulge
- Axial supporting strips
- Compressive force
- Buckling
Possible damage by axial forces

Tilting

Normal position

Tilted conductors

limits oil flow
Transformer testing at KEMA

Matelec Certified 400 & 1000 kVA, 2010
KEMA's experience with testing power transformers

- available power 8400 MVA 3-phase 16 - 60 Hz.

- Large transformers tested on board of transporting vessel.

- Fast protection through special breaker. Limits damage in case of internal failure.
test results transformers > 25 MVA

• 157 times a large transformer > 25 MVA offered 1996 – 2010 (140 transformers in 15 years).

• largest tested object
  250 MVA 1-phase and 440 MVA 3-phase

• evaluation of performance by:
  - reactance measurement before and after test
  - visual inspection (possibly at manufacturer's site)

• 104 no short-circuit problem at test site, but further results (inspection, routine tests) may be unknown

• 36 faced problem at first access

• 17 re-tested succesfully

• initial failure rate 26%
Transformers
> 25 MVA
1996 - 2010

- Rapid rise in demand of short-circuit tests
- Failure rate not significantly depending on MVA or kV rating
test results transformers <= 3 MVA

- Period Jan 2009 - Apr 2011
  - 28 months, Netherlands
- 130 transformers tested
- 50 – 3000 kVA
- 4.16 – 33 kV
- 82% passed sc test
- 18% failed to pass
  - Mostly internal deformation. Impedance change too large.
Observed failure modes

• Axial clamping system:
  Looseness of force axial clamping, of axial compression force, of axial supporting spacers, of top and bottom insulating blocks

• Winding deformation:
  Axial shift of windings, buckling of windings, spiralling of windings (helical or layer winding)

• Cable leads:
  Mechanical movement (tapchanger to regulating windings)
  Deformed or broken leads, outward displacement of exit leads from inner windings, broken exit leads

• Insulation:
  Crushed and damaged conductor insulation, displacement of vertical oil-duct spacers
  Dielectric flashover across HV-winding, displacement of pressboard insulation, Tank current due to damaged conductor insulation,

• Bushings: LV-bushings
Conclusions

• Short-circuit testing is the most realistic tool in QA to verify withstand of electro-dynamical stresses of short-circuit

• KEMA finds failure rate against short-circuit stresses:
  - 26% transmission transformers $\geq$ 25 MVA
  - 18% distribution transformers $\leq$ 3MVA

• No common failure mode, mostly winding deformation

• Reactance change (confirmed by visual inspection), as prescribed in the standard is a very good evaluation tool