High-Power Testing of Circuit Breakers

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categories of tests

development tests
type-tests (for certification)
acceptance tests
1 development tests

product development

testing of prototypes

ordered by: manufacturer
standard: according clients instructions
laboratory: mostly at manufacturer’s site

2 type tests

provide confidence that a duly indentified product conforms with requirements of a specific standard

ordered by: manufacturer
standard: (Inter)national standard
aim: certification
laboratory: independent testing institute
recognized group of manuf. labs
3 acceptance tests

verify that a certain product complies with a specific application specified by the user

ordered by: user of the equipment
standard: agreement manufacturer - user
laboratory: independent testing institute, recognised group of manuf. labs

test methods

direct testing
- on the grid
- generator fed
- capacitor bank fed

synthetic testing
direct testing

pros
simple
cheap
representative
high-power available

cons
poor flexibility
difficult to adjust

laboratory supplied by power grid

pros
adjustable
flexible
no influence on local grid

con
huge investment

generator supplied laboratory
direct test lay-out

generator
master breaker
transformers
test object
current measurement
test object
current measurement
voltage measurement

slamecka 1966
making switch

current limiting coils
TRV generating circuit

increase of capacity per break

GVA / break


1 5 10 15 20

SF6

Air blast
electra 2003

highest lab-
power available
synthetic testing

example: short-circuit test of a CB (three-phase)
420 kV - 63 kA - 50 Hz
⇒ necessary power: 420 x 63 x √3 = 45830 MVA

greater than any laboratory's direct power
(Max: 8400 MVA)
other methods must be sought:
- single phase test: necessary power 45830/3 = 15277 MVA
- half-pole testing (if possible): 15277/2 = 7638 MVA
this still does not match the power-voltage characteristics of the most powerful labs.

solution

before interruption a sufficiently large power must be available to maintain the full (arc) current at moderate voltage (< 60 kV)
- from generators

after interruption there is only the need for a sufficiently high voltage
- from precharged capacitor

special circuit needed to reignite the arc
synthetic tests

generator circuit

capacitor circuit

synthetic testing

Synthetic circuit (parallel current injection)
synthetic testing

three-phase synthetic testing
synthetic testing in practice

**test methods:**
- current injection
- voltage injection

**ratings to be tested synthetically:**
- 1100 kV - 63 kA - 60 Hz - 1Ø (experimentally)
- 550 kV - 63 kA - 60 Hz - 1Ø (routine)
- 245 kV - 63 kA - 60 Hz - 3Ø

2 x cap. bank
720 kV - 1.7 MJ

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high-power test of 1100 kV CB
Test-circuit should represent the service conditions of equipment as much as possible

Standards prescribe inherent behaviour of test-circuits. Inherent means 'naked' circuit only, without test-object.

This can be different when a real test-objects interacts with the test-circuit

Then, the representation must still be realistic.

But: test are possible with test-circuits that show inherently adequate behaviour in accordance with standards, but do not reflect realistic service conditions
**circuit breaker testing**

- Many arcs in series: high total arc voltage counteracts source voltage (in 800 kV testing: 8 arcs in series)
- Especially with
  - synthetic testing (auxiliary breakers)
  - when testing breakers with multiple arcing chambers
- Current supply sources must have terminal voltage as high as possible to guarantee sufficient arcing stresses
- Risk is to apply too little energy into the fault current arc.
- Testing is too light in that case

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**influence of many series arcs on current**

![Graph showing the influence of many series arcs on current.](image)
Immediately after interruption

Immediately after interruption hot gases are still in the gap and feel fast rising voltage: thermal stresses.

A little later very high voltage is reached across the open gap: dielectric stresses.

circuit breaker arc strongly interacts with TRV circuit

test-circuit topology very important

microsecond scale
high-frequency effects of circuits

- Seldomly specified in standards
- Will affect result of tests in which high-frequency behaviour is important
- Example: interruption tests with vacuum circuit breaker
- Such a breaker is very good in interruption of current of high-frequency

effect of TRV circuit

Research: cable systems have oscillatory TRV, so test should be performed with oscillatory TRV
half-pole tests for (U)HV

Test voltage application across full-pole
Half-pole testing
Quarter-pole testing

Non-full pole ("unit")-testing should consider uneven voltage distribution across circuit breaker, especially when there are no grading capacitors. Full-pole testing eliminates doubts.

800 kV breaker

half-pole testing of GIS

Half-pole test: interrupter stress OK, internal stress NOK...

Full-pole test: interrupter stress OK, internal stress OK
ultra high voltage testing

For metal enclosed breakers, half-pole testing does not represent the conditions in service:

- Dielectric stresses of half-pole tests equivalent to full-pole conditions
  - between phases
  - between phases and enclosure
- Effects of exhaust gases equivalent
- Mechanical stresses equivalent
- Forces (electrodynamical stresses) equivalent

single phase testing of three-phase circuit breaker

- Often practiced when power of test laboratory is insufficient
- In principle possible, but with care
- Not realistic when common mechanism is controlling contact movement (circuit breaker, earthing switch)
- Beware of three-phase interactions, that single phase circuits fail to represent
three-phase testing of three-phase devices

conclusions

- Standards do not cover everything
- Grey zone exists between allowable but different stresses that make life easier/worse for a breaker
- Test-engineers knowledge and test-lab policies must ensure that realistic testing will prevail:
  - supply sufficient arc energy even for highest voltages
  - have knowledge of arc-circuit interactions
  - being aware of high-frequency pitfalls
  - test three-phase when necessary