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Study Committee B1

Insulated cables

10957_2022

FORMATION OF POTENTIALLY HARMFUL SHRINKAGE CAVITIES DURING OPERATION OF MASS-IMPREGNATED NON-DRAINING HVDC CABLES

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Cavity-induced ageing in MIND cable insulation

Sequence of events:

The cable is operating at a high load

↓

The load (i.e., the current) is turned off

↓

The temperature in insulation falls

↓

The oil ("mass") contracts more than the paper

↓

The pressure in the insulation drops

↓

Vacuum cavities form in butt gaps

↓

Partial discharges ignite in the cavities

↓

The insulation may (or may not) be locally damaged by PD-induced carbonization

MIND cable insulation with carbonization damage caused by partial discharges.

Consequently:

The loading pattern greatly influences the internal pressure dynamics of MIND cables, and thereby the risk of having cavity-induced aging and dielectric failures.

Crucial questions:

- Which loading patterns and ambient conditions cause extended periods at very low internal pressures and thereby large and lasting cavities, and thus an increased risk of cavity-induced damage?
- Which loading patterns are "safe"?

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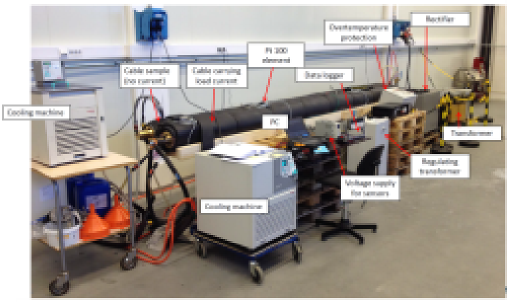
continued

Measurements and simulations of the internal pressure dynamics

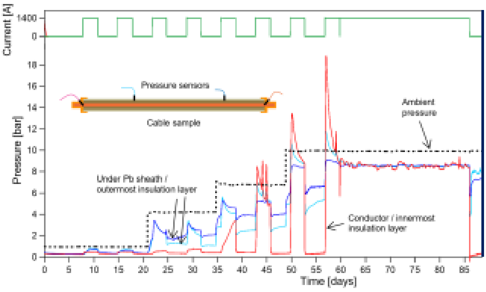
Internal pressure measurements

- 4-m long samples of a 525 kV / 1400 A HVDC MIND cable
- Pressure measured at both sides of the insulation
  - during no-load, full load and load cycling
  - at 1 to 10 bar ambient pressures
  - at 10 to 40 °C ambient temperatures
- Details in:
  - *IEEE TDEI* **26**, 913–921, 2019
  - *IEEE TDEI* **27**, 915–923, 2020
  - *CIGRÉ S&E* **21**, 14–25, 2021
  - *CIGRÉ S&E* **24**, 1–11, 2022



Modelling and simulations

- Pressure, temperature, electric field, mass flow, cable casing mechanics etc. are included in COMSOL model
- The model is calibrated against the measured pressures
- A pressure drop down to virtually zero is assumed to signify formation of shrinkage cavities
- Pressure dynamics and cavity volumes are modelled for 7000 cases (different loads and ambient conditions)
- Details in *IEEE TDEI* **29**, 1135–1142, 2022



Pressure dynamics and combined cavity volume (mass "deficit") under different loading and ambient conditions

- The internal pressure tends to slowly and asymptotically approach the external (water) pressure
- Rapid internal pressure changes become superimposed on the pressure level exerted by the external pressure
- High ambient pressure and/or high ambient temperatures cannot prevent cavity formation after a load turn-off
- A high external water pressure to some extent suppresses cavity formation
- Even modest load reductions create cavities
- Cavities are created quickly and tend to last for long
- A complete ramp-down from full load leads to the largest combined cavity volume

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continued

Recommendations for MIND cable operation when considering the risk of cavity-induced damage

Preferred load patterns:

- High and stable load (current) is favourable. Moderate (20–30%) and brief (hours) load reductions are harmless as they do not result in large and lasting shrinkage cavities.
- After a cold start, the load should be ramped up fast, as this causes any cavities to quickly become filled with mass.
- Whether a ramp-down of load is fast or slow is not important. Cavities will in any case form.

More risky load patterns:

- Low loading over extended time in a cold ambient and with a low external pressure (e.g., a cable directly exposed to cold water in a shallow area) results in many cavities that over time may combine to larger ones that result in powerful partial discharges.
- After an extended time at high load, an abrupt change to low load will result in a particularly large mass "deficit" and many cavities that will last for long. Large partial discharges must be expected.

Do not run this sequence:

1. In winter operate a poorly trenched cable in shallow water at full load for a prolonged time, e.g., a month.
2. Then, turn off or rapidly reduce the load (i.e., the current) to zero.
3. Then, reverse the polarity (to prepare for a power flow in the opposite direction).
4. Then, leave the cable unloaded but energized.