Study Committee A2

Power transformers and reactors

Paper ID_11139

Bubble Formation in Power Transformers – a Potential Risk for the Future Network Reliability?

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Motivation

- Implementation of Net-Zero emission targets will lead to changes in the future electricity network
- A possible consequence of the changes could be transformer failure from bubble formation on winding insulation
- Literature to bubble formation is limited and results vary widely
- A coherent study performed with one test setup is missing and would be beneficial to obtain comparable results on different impact parameters
- Aim of the study is the development of a small-scale test setup and the performance of bubble formation tests to conclude on the potential risk of bubble formation in transformer

Background

- Achieving the UKs ambitious Net-Zero emission targets by 2050 will require the integration of low carbon renewable energy technologies and the electrification/decarbonisation of heat and transport
- The changes will lead to fluctuations in both generation and demand of electricity hence may require flexible operating strategies

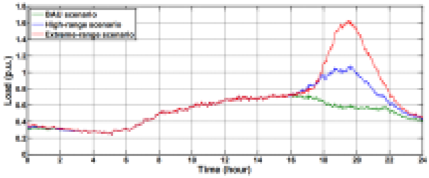

Figure 1: Example of a transformer load profile (BAU: business as usual) throughout the day with different possible level of electric vehicle penetration, leading to an overload scenario in the evening [1].

- Network assets such as transformer could suffer from more stress caused by the changes to the network, considering that many have already exceeded their designed lifetime
- Transformer failure from bubble formation could be a possible consequence, leading to loss of power supply and huge financial losses

Figure 2: Bubble formation as a possible cause for transformer failure? Figure obtained from [2].

Bubble formation in transformer

- Bubble formation from transformer winding insulation is a possible consequence of rapid temperature rise from overload conditions
- If bubbles moved into an area of high electrical field strength it could lead to transformer failure from flash over
- IEC and IEEE standards set loading constraints based on bubble formation temperature and water content in paper (hot-spot temperature of 140 °C with a respective 2% water content in the winding insulation paper)
- Bubble formation results in the literature are limited, vary widely, and are hardly comparable (common agreement is that water content in paper seems to be the most influential one)
- No distinct conclusion on the impact of different parameters can be drawn due to variations in test setups and methods
- A coherent study on different impact parameters and performed with one test setup would provide comparable results

Figure 3: Example of bubble formation

[1] Y. Gao: "Assessment of future adaptability of distribution transformer population under EV scenarios", PhD thesis, The University of Manchester, Manchester, UK, 2016.
[2] electrical-engineering-portal.com, "Arriving at the scene of a substation fire. What should you do first?", 2014 [Online]. Available: https://electrical-engineering-portal.com/arriving-at-the-scene-of-a-power-substation-fire-what-to-do

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Development of a small-scale test setup

- A test setup and procedure has been developed and verified to study bubble formation in transformer insulation systems with a coherent study
- Test setup idea with cartridge heater and glass test tube is based on findings from the literature
- Initial task was the thermal analysis of the test setup
- Following task was to identify the water content in paper measurement strategy

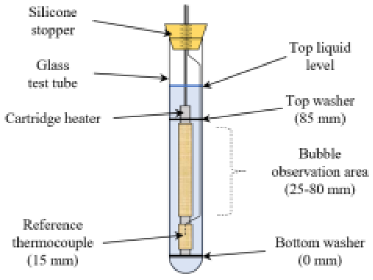

Figure 4: Test setup sketch.

Temperature measurement procedure

- Indirect bubble formation temperature estimation with two steps (heating cycles)
- Reduces the influence on bubble formation process and increases the accuracy from flexible sensor placement

Table 1: Detailed description of the measurement strategy.

Step 1	First heating cycle to observe the bubble formation **location** and **time**.
Transition	Measurement of water content in paper. Preparation of a new sample with thermocouple attached at the location of bubble formation
Step 2	Second heating cycle to determine the **temperature** at the bubble formation location using the extra thermocouple.
Correlation	The time for bubble formation obtained from the first cycle and the temperature profile at bubble formation location from the second cycle were correlated to determine the bubble formation temperature.

Thermal analysis of the test setup

- Temperature measurements at 28 locations, obtained from 28 individual heating cycles (repeatability verified with additional thermocouple at bottom location) and verified with five different cartridge heaters respectively
- Location between 45 mm and 60 mm was confirmed to be the hottest area and hence was selected for observation of bubble formation

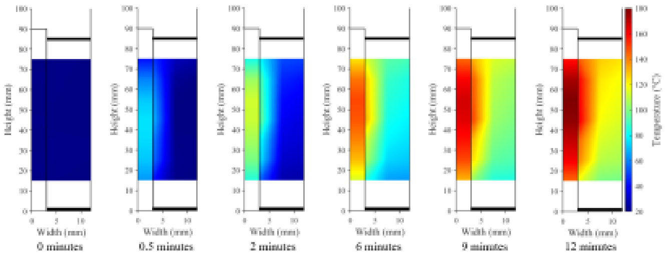

Figure 5: Several heat maps generated from the measurements show the temperature development within the sample during a heating cycle.

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Water content in paper measurment strategy

- Water content in paper migrated out of the paper during the heating process
- Consequently, water content in paper was measured shortly after bubble formation has been observed to obtain a value as close as possible to the inception
- Measurement from the hottest area was used to correlate with the measured temperature within this area

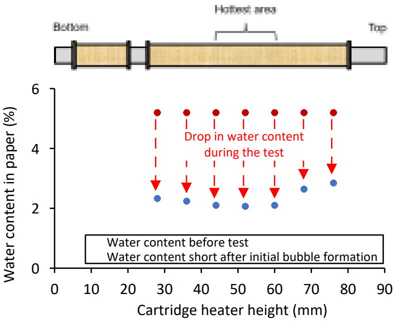

Figure 6: Typical pattern of water distribution in paper at time of bubble formation is clearly showing the effect of moisture dynamics.

Test sample conditioning and bubble observation

- Three test samples have been prepared and evenly conditioned (water content in paper ~ 5.2%) for a preliminary test with non-thermally upgraded Kraft paper and mineral oil
- During the tests, initial bubble formation could be observed in the hottest area, which verifies the chosen location for the paper wrapping

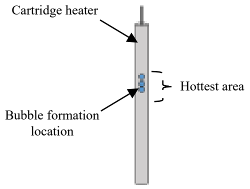

Figure 7: Bubble formation location from the tree samples.

Preliminary test results

- The obtained results are in line with the literature
- Validation of the developed temperature and moisture measurement method after the observed bubble formation
- The designed test setup and procedure is suitable to perform a coherent study on bubble formation impact parameters

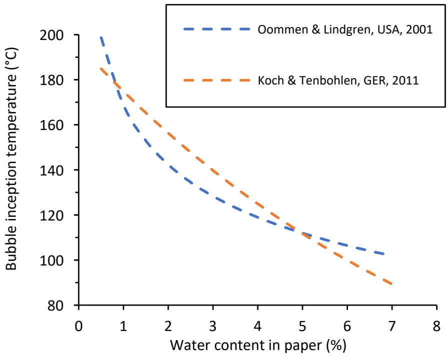

Figure 8: Comparison of own results with literature ones.

Conclusion

- A bubble formation test setup was developed based on a cartridge heater and test tube system
- A test procedure was developed considering the temperature profile and moisture dynamics
- The suitability of the test setup has been verified with initial tests
- A coherent study will be performed to investigate the bubble formation in transformer insulation systems
- The study will help to answer the question if bubble formation in power transformers is a potential risk for the future network reliability

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