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What is the experience of reliability in service of alternative transformer technologies, especially for demanding applications? Is there any significant difference from the reliability of conventional oil-immersed transformers?

Historically, dry-type transformers had been limited to relatively low voltages, typically up to 36 kV insulation level. Only since the year 2009 we are having in service experience with the level 72.5 kV and since 2020 with the level 145 kV. By now 30 units are in service without problems, among them:

- 4 x 31.5 MVA - 66,000/22,000 V with OLTC for an urban substation in Spain
- 2 x 25 MVA - 69,000/13,800 V with OLTC installed in a soccer stadium in Brazil
- 30 MVA - 69,000/4,160 V in a combined cycle power station in USA
- 3 MVA - 100,000/600 V in a hydro power station in USA

These high voltage ratings are usually associated with high power ratings, typically some tens of MVA. The main issues that may affect the reliability of these kind of transformers are:

- Ageing of the insulation caused by hot spots
- Breakdown of the insulation caused by over-voltages due to manoeuvres or lightnings

Regarding hot spots, multiple inherent characteristics of these transformers have influence in the magnetic stray fields: increased clearance distances, high power ratings and mainly the use of OLTC (On-Load Tap-Changers) with wide voltage ranges without a dedicated tap winding. Care needs to be taken to minimize eddy currents in windings and structural components, otherwise load losses substantially increase and create intolerable hot spots.

The solution consists in the combination of conductors with different cross sections, changing its height as well as its thickness, optimizing the design of the disks until the hot spots are below the required limit. It is also possible to use a combination of aluminium and cooper disks in the same HV winding to control the hot spots. To get an accurate result coupled magnetic-thermal FEM (Finite Element Method) simulations are used, 2-D for the windings and 3-D for the structural components.

Regarding over-voltages, dry-type transformers withstand the same high frequency surges than oil-filled transformers. For the insulation level 145 kV, it has been proved by the demanding lightning impulse of 550 kV. Finally, the safety margin of the design was found increasing the voltage level of the lightning impulse in steps of 10 kV up to failure.

In that sense, to control the electric stress in the insulating air, technology well known in oil-filled transformers has been adapted to be used in dry-type transformers, including among others: grading rings in the windings; conductive shielding pieces for the clamps and magnetic yokes; insulating collars; and an optimized number of barriers to control the electric field in the insulating air. Apart from that, to control the electric stress in the solid insulation, a precise knowledge of the voltage distribution along the HV winding is a must. This has been obtained by the help of an in-house developed FEM simulation tool. The accuracy of the tool has been validated with an extensive campaign of tests.