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Question 2.5: There seem to be conflicting opinions concerning the use of some alternative transformer technologies at higher temperatures, especially ester-immersed transformers. What is the experience of using alternative transformer technologies at higher temperatures? What further work is needed on this subject?

Experiences

Experiences with high-temperature insulation systems have been gained in the recent years. An IEC standard for insulation materials is existing since several years (IEC 60076-14) [1]. Studies and publications are existing to demonstrate capabilities and limits [2]. Different ways to enhance transformer performances thanks to high-temperature insulation and/or optimized transformer design are proposed and discussed and can be achieved. As a summary, the combination of TUP with pressboard and natural ester can be a good compromise between performance and costs.

In more general, high-temperature solutions for the benefit of weight and cost optimization involve the following aspects:

- Use of conventional and modern materials
- Use of natural ester
- Use of high-temperature conductor insulation materials
- Optional: high-temperature materials for barriers, strips, and spacers
- Material reduction of core and winding as well as liquid and metallic parts

An example of a transformer with a high-temperature insulation system is shared with [2]. The transformer of this example was developed and manufactured for railway traction power supply. Natural ester was used as biodegradable insulating liquid instead of mineral oil. An aramid polymer material, which is extremely temperature and tear-resistant, was selected as insulation material of the windings. In this way, the transformer was designed for a temporary overload operation. It also obtains a higher expected lifetime at normal operation. Other insulation components were still made of conventional materials such as pressboard and/or laminated wood. According to IEC 60076 part 14, the chosen design constitutes a semi-hybrid insulation winding permitting hot spot overtemperatures of 90 K.

The benefits of this solution can be summarized as follows:

- Less environmental impact (excellent biodegradable, pollutant-free)
- Fire protection (higher fire point, flame-retardant)
- Extended service life (protective effect of paper insulation)

Further work

High-temperature insulation systems require a minimum solid insulation thermal class of 130, as introduced in IEC 60076-14, Table 4 [1]. Thus, all materials and components of the transformer shall be capable to withstand higher temperatures.

For the conductor insulation (paper), spacer and insulation liquid qualified materials are existing. Recent developments show that solutions for large solid barriers (cylinders), moulded parts (angle rings) and tap changer are now available. For winding support blocks, winding platforms (static rings) and for support bars for leads and connections solutions have been proposed.

But as of today, not all materials and components used in large power transformers are available with high temperature performance. Still, for some components, introduction and qualification of high-temperature solutions is in progress, as for example for bushings.

A drawback of introducing high-temperature applications is that solutions need to be developed and agreed between materials suppliers, transformer OEM and the user. It has been experienced that transformer costs rather increase while introducing modern materials with higher performance which seems not to be accepted in a larger scale by the buyer. Another drawback of increasing temperature is that transformer losses increase, which is counterproductive as eco-design requirements require ever decreasing losses.

[1] IEC 60076-14:2013, “Liquid immersed power transformers using high-temperature insulation materials”
[2] C. Perrier, T. Stirl, M.-L. Coulibaly, J. Harthun, “Experiences with high-temperature insulation systems & overload requirements, CIGRE 2018, A2-115, Paris, 2018