The use of Paperless CTC in Power Transformers

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CTC - Background

Paper covered Continuously Transposed Conductors (CTC) have been in use at all voltage levels in large transformer for nearly 30 years and CTC's have been is undergoing continuous development and improvements over that time. The improvements include:

- Smaller conductor strand sizes and an increase in number of strands which can be accommodated within one CTC cable resulting in a significant reduction in eddy current losses.
- Thermosetting epoxy bonded CTC for increased mechanical strength to withstand higher short circuit forces.
- More lately, paperless or partly paper covered CTC has been offered and used in pursuit of higher cooling efficiency and therefore ability to operate at higher current density and with a higher copper space factor within the core window, enabling reduced core dimensions and overall dimensions, resulting in less active materials and lower cost transformers.
- And most recently - paperless "ventilated CTC"– with axial cooling ducts formed within the CTC's with further improvements in cooling enabling further increase in current density.

As can be seen from the above, both conventional CTC and paperless CTC have many benefits over conventional strip conductors. This short Summary assumes that the many advantages of CTC over rectangular strip conductor (which also apply for paperless CTC) is already a given, and therefore does not need to be discussed further. So only the paperless CTC will be discussed in the following paragraphs.

Benefit of using Paperless CTC

It has superior thermal efficiency, which allows a more compact design and an overall, lower cost transformer. As there is no paper covering on a paperless CTC, - only a thin film of 0.1 – 0.14 mm (diameter increase) of Poly Vynyl Acetate (PVA) or other synthetic enamels, the thermal resistance for heat transfer from the copper conductor to the oil is much lower than for a paper covered CTC.

Also paper wrapping on CTC has a tendency to "bag" (bulge) especially for large CTC's with many strands in the CTC cable. The bagging of the paper on CTC's occurs between the radial spacers and thus restricts the oil flow.

The bagging of the paper also creates a volume of stagnant oil between the bulging paper and the CTC conductors, which increases the thermal resistance from the copper to the moving oil in the cooling duct.

As the paperless CTC has no paper, there is no reduction in the spacing of the radial cooling ducts due to paper bulging, and no stagnant oil between the copper and the active oil flow in the cooling duct.

As the oil flow is only separated from the copper by a 0.05 - 0.07 mm layer of enamel and is moving directly across the enamel surface, both the transfer gradient and the surface gradient are very low, resulting in a very high cooling efficiency.

The absence of bulging paper covering means that the radial cooling ducts of paperless CTC can kept 1-1.5 mm less than for paper covered CTC.

The much higher cooling efficiency of paperless CTC means that the LV winding can operate at a higher current density than paper covered CTC's for HV and Tapping windings and for same or even lower gradient.

Some enamels have higher temperature class than Kraft paper (Class A =105 ^{o}C). The temperature class for CTC in some suppliers catalogues 120 ^{o}C (Class E), and could be higher dependent on the type of enamel used for the conductor covering.

The higher temperature class and the potential capital cost saving from allowing a higher temperature rise for paperless CTC does not seem to have received much attention yet in the market place.

The disadvantages of using Paperless CTC

The main disadvantages of paperless CTC in comparison with paper covered CTC are:

- It Has lower impulse and fast transient voltage withstand strength for same clearances than paper covered conductors. It is well known that an insulation system which contains a paper barrier close to the electrodes has significantly higher impulse strength than bare electrodes for same gap distance. The surface stress of a CTC covered by oily paper is less than the surface stress on a bare or enamel covered conductor in oil. The reason is that the relative permittivity of oil impregnated paper is 3.3 whereas the relative permittivity of oil is 2.2. The surface stress on the paper covered CTC is therefore only 67 % of the stress on a paperless CTC for same electrode configuration. The paper wrapping also increases the corner radii, resulting in a further slight reduction in the stress at the oil interface. It is for these reasons that paperless CTC is in generally only used in windings up to and including 36 kV.
- Extra care has to be used during the winding process for the initial and final turns of a winding and formation of the lead-outs.
- Higher risk that the enamel may be damaged in transit or de-reeling during coil winding and the damage may remain undetected and unremedied than it is for paper covered CTC. Some manufacturers therefore choose to cover paperless CTC with a single paper wrap to minimize the risk of transit and handling damage to the enameled conductor. This protective paper wrapping is then removed at the coil winding stage with the aid of a wound in “rip cord”.

Conclusion

From the above and the survey conducted between the SCA2 members, it is concluded that:

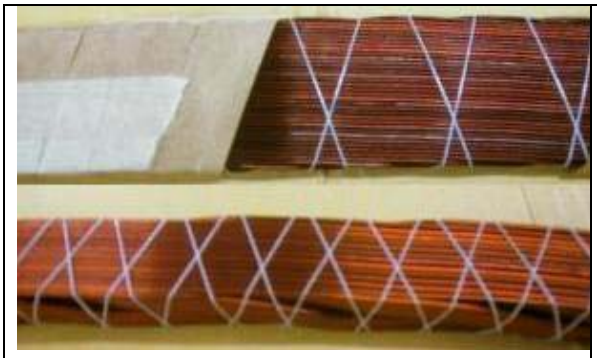
i. There should be no direct turn to turn contact with Paperless CTC. I.e. there must be a radial spacer between turns to separate the turns axially.

ii. There must be a transformer board cylinder or a paper wrap between layers if CTC is used in a double layer helix winding.

iii. Maximum voltage stress at the CTC /oil interface must been verified to be not excessive.

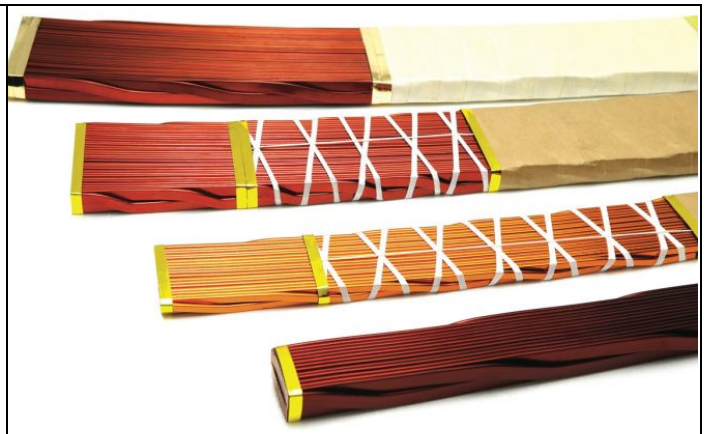
iv. It is consider that with the above precautions, paperless CTC can be use in helix and double layer helix type windings up to Um = 36 kV with an insulation level up to 70 kV SDAC and 200 kV Impulse. This view is also supported by both manufacturers and transformer users with very few exceptions.

CTC



Essex - Paper covered and paperless CTC

ASTA - Netting Tape (paperless) CTC

SamDong 1. Paper covered CTC 2. Paperless CTC with rip cord 3. Paperless CTC with rip cord 4. Bare CTC	
Paperless CTC winding