Study Committee A2

Power Transformers and Reactors

Paper ID 11125_2022

Type Testing of 80 MVA Power Transformer with a new Bio-based, Biodegradable and Low Viscosity Insulating Liquid

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South Africa[1,3], Germany[2,4]

Motivation

- End users are demanding more options regarding the insulating fluid in power transformers.
- Drivers include sustainability, biodegradability, safety, performance optimization and overloading.
- In this study a bio-based hydrocarbon (NYTRO BIO 300X) is fully type tested in an 80 MVA ONAF transformer.

Approach

- Two transformers of identical design are compared with regards to their Factory Acceptance Test, one filled with GTL and other with BIO 300X.
- The focus was mainly on the temperature rise due to the low viscosity of the BIO 300X to compare with the GTL one.

Figure 1. Photograph of the completed 80 MVA unit filled with NYTRO BIO 300X.

Table 1. Key nameplate details of the transformers.

Frequency	50 Hz
Power Rating	80 MVA
Cooling	ONAF
Voltage	115 ± 9 ×1.778% / 21 kV
Impedance	16%
Vector group	YNyn0(d)
Test voltages	HV: LI 550 AC 230
Temperature rise guarantees	60K (Top oil) / 65K (Winding) / 78K (Hot Spot)
Tap changer	OLTC
Liquid volume	18000 litres
Sealing	Conservator, Free Breathing

Insultation Liquids and FAT

- Both GTL and BIO 300X are IEC 60296 Ed. 5 compliant.
- NYTRO BIO 300X is readily biodegradable, fully bio-based and has very low viscosity.
- A design review was done for the BIO 300X and for the voltage level (550kV BIL, no changes were required) .
- Full type testing was done, all tests passed on the transformer filled with BIO 300X.
- Detailed heat run analysis was done to see the potential of the low viscosity characteristics of the BIO 300X in comparison to the GTL.

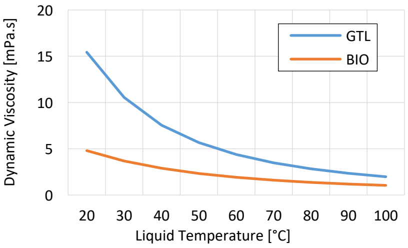

Figure 2. Dynamic Viscosity comparison between NYTRO BIO 300X and the GTL.

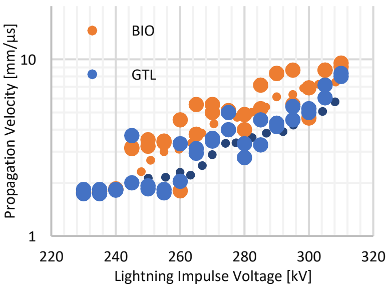

Figure 3. Average streamer velocity versus applied peak impulse voltage - 40mm Gap, Negative Polarity

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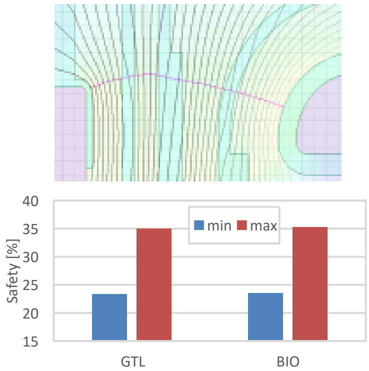
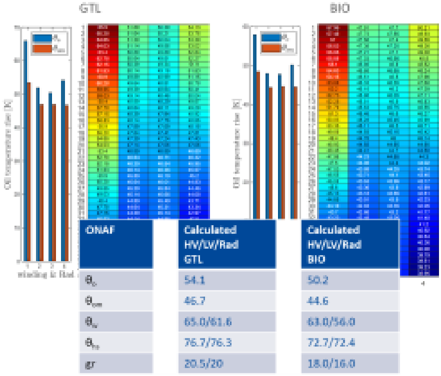


Figure 4. Risk assessment for the main gap



ONAF	Calculated HV/LV/Rad GTL	Calculated HV/LV/Rad BIO
θ_o	54.1	50.2
θ_{om}	46.7	44.6
θ_w	65.0/61.6	63.0/56.0
θ_{hs}	76.7/76.3	72.7/72.4
gr	20.5/20	18.0/16.0

Figure 5. Thermal modelling

The lower viscosity profile across the functional temperature range of the NYTRO BIO 300X means that one expects higher convective heat transfer and thus improved heat dissipation from winding to oil and therefore a reduced winding temperature gradient. Therefore, additional heat will be transferred to the cooling system, at a faster rate, and then dissipated to the ambient air. Due to the low density of the BIO an improved thermal buoyancy force is expected which is the key factor for improving the resulting oil axial gradient and hence, achieving lower top oil temperature.

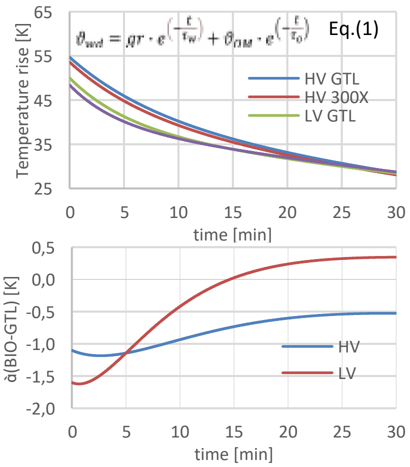


Figure 6. Cooling curve analysis (FAT, cooling equation).

The two-exponential equation (Eq.1) is the most accurate physical interpretation for the cooling process, which includes detailed information about the thermal parameters of both winding and oil presented in the winding gradient to the oil flowing through the winding itself gr and the average oil temperature rise ϑ_{om} for this winding. The main challenge to accept the parameters of the cooling equation is to know the range in which the thermal time constant of oil would be reasonable. The standards give guidelines of oil thermal constant like for ONAN cooling 210 minutes, which for ONAF is 150 minutes. However, these values cannot be taken as facts because the resulting τ_o could be far below or above these ranges independent of the cooling system. In this study it has been found that the dissipated heat from the windings to the oil, which is the injected total losses during heat run, and the mass of oil used are not only influencing the average oil temperature rise but also the resulting thermal time constant. This type of analysis was also applied on tertiary winding of the unit, despite it was not loaded during heat run, in order to investigate the change of ϑ_{om} from the active part towards the radiators.

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Results

- Both transformers passed all FAT requirements fully.
- Obvious reduction in temperatures, top oil, gradient and hot spot were seen for ONAF case with BIO 300X.
- The improved cooling is due to improved convective heat transfer due to lower viscosity.
- Long duration PD testing during FAT of both transformers was also done, minor differences were seen.

Table 3: Measured results from the temperature rise tests of the two transformers during FAT.

Position	Temperature rise		Δ
	GTL	BIO	
Top oil [K]	54.5	50.5	-4
HV winding average [K]	55.0	53.6	-1.4
LV winding average [K]	49.7	47.7	-2
HV to oil Gradient [K]	18.5	17.6	-0.9
LV to oil Gradient [K]	13.2	11.7	-1.5
HV hot spot [K]	75.4	70.4	-5
LV hot spot [K]	69.3	63.6	-5.7
Oil Thermal Time Constant [min.] (average τ_o, Eq.1)	88.7	85.8	-2.9
Windings thermal time constant [min.] (average τ_w, Eq.1)	6.8	5.7	-1.1

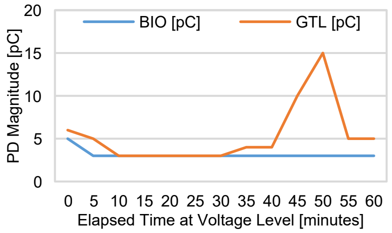

Figure 7: Phase U PD result for each transformer During 104.9 kV (1.58 Un) at FAT.

Discussion

- NYTRO BIO 300X was successfully tested and used in an 80 MVA 145 kV ONAF unit.
- An LV hot spot reduction during FAT (at rated current) of -5.7 K was observed compared to the unit filled with GTL.
- There is potential for improved dynamic rating of transformers filled with NYTRO BIO 300X.
- In this case no dielectric changes were needed, but a liquid specific dielectric design investigation is usually necessary when evaluating a new liquid type (regardless of its specification compliance).
- When using a new type of liquid, checking with OLTC and component (e.g. Buchholz relay) suppliers for compatibility is also important.

Conclusion

- NYTRO BIO 300X is a new bio-based, biodegradable and low viscosity hydrocarbon liquid meeting and exceeding IEC 60296 Ed. 5.
- The bio-based liquid was tested in an 80 MVA ONAF unit, passed all type test requirements, and compared to the GTL filled case yielded temperature reduction.
- Bio-based hydrocarbon liquid with low viscosity is an interesting alternative liquid option and transformers and there is optimization potential for transformers using it.