Development and Testing of HV Instrument Transformers using Natural Ester Fluid

Entwicklung und Prüfung eines mit natürlichem Ester gefüllten Kombiwandlers

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ABSTRACT

Natural esters are on the increase concerning the application as insulating liquids for high voltage apparatus as a possible alternative to mineral oil and also to insulation gases like SF_6. Two main advantages of natural ester fluids are their environmental compatibility and fire safety. Ultimately, the design of high-voltage apparatus which are environmental friendly, safer and which do not pose a hazard to groundwater nor to the urban environment is pursued.

Intensified research activities during the past years have led to an increased knowledge in the fields of electrical, physical and chemical behaviour of natural esters applied in high-voltage apparatus. Recently, power transformers filled with natural esters have been installed and commissioned on the 123 kV and even in the 420 kV level.

For instrument transformers, the situation is a bit different: Due to the very compact insulation system, equipment design and manufacturing processes differs strongly from those of power transformers. This paper investigates some of the challenges during the development and successful testing of combined instrument transformers (123 kV) impregnated and filled with a natural ester.

Keywords: Natural ester fluid, combined instrument transformer, alternative insulating liquids, type testing

1 INTRODUCTION

The oil-paper insulation system has a long history as a proven technology for high-voltage apparatus like transformers and cables. Cellulose in the form of paper and pressboard combined with mineral oil are the typical insulating materials. Thus, although mineral oil has outstanding electrical and physiochemical properties it has also some major disadvantages: Flammability, high environmental impact in case of failures and the raw material being non-renewable.
Natural esters are promising candidates for an alternative insulating fluid due to their performance paired with biodegradability. The high fire point of 360°C and high flash point of >300°C even improves equipment safety in case of abnormal operation. By now, natural esters are utilized quite common as insulating fluid for (distribution) transformers; recently several power transformers with natural ester have been commissioned [1], even in the 420 kV level [2]. Currently, there are no reported installations of natural ester filled high-voltage instrument transformers yet. This paper describes some of the challenges of utilizing a natural ester fluid as impregnating and insulating medium in combined voltage transformers for 123 kV (Figure 1).

1.1 Instrument Transformers

Instrument transformers (ITs) are a key component in energy networks and systems. Although they are inconspicuous and require only low maintenance during operation, especially when compared to other key assets, they are nonetheless necessary for the safe and reliable operation of electricity grids. Metering and protection applications throughout all voltage levels would not be possible without them. Historically, mainly oil-paper insulation systems were used for high-voltage instrument transformers [3]; nowadays also gas-insulated ITs (SF_6) are popular.
Similar to power transformers, long operational times of 30 years or more are aspired and exceeded in general for high-voltage ITs. The main insulation of (oil-paper insulated) instrument transformers is completely different from power transformer, as it will be shown later. However, several design challenges at power transformers with alternative insulating liquids [4] are also applying to instrument transformers.

Key characteristics of instrument transformers

- compact insulation system
- low oil volume
- large paper/insulation thicknesses
- hermetically sealed
- combination of different paper types and thicknesses

Combined instrument transformers, sometimes referred to as “*metering units*”, are quite popular in Europe. Basically, they contain a voltage transformer (VT) and current transformer (CT) in one unit. This is beneficial in terms of infrastructure and space consumption within a substation and they are also more economic in transport and installation when compared to combinations of single CTs and VTs.

1.2 Combined instrument transformers with natural ester

Besides the beneficial physical properties of natural ester the main reason for choosing instrument transformers filled with natural esters is the environment-friendliness of this insulation system. Although natural esters are utilized as insulating fluid in distribution transformers for quite a while now, the application for instrument transformers constitutes a novelty. To specify, design and test this new product, cooperation between the involved parties has been established.
Additionally there is a directive in Germany [5] which prohibits the usage of water hazardous liquids in substations in quantities of above 100 litres without special arrangements. Although the quantities differ from state to state, the regulation is strict to be followed in Germany. Possible arrangements in substations could be special basements to keep liquids from the soil/environment or special sensors for apparatus monitoring. In water protection areas it is not allowed to use any water hazard liquids at all without special permission. Currently, this law is actually in motion and there will be an amendment soon. The water hazard liquids are to be redefined into 4 classes and the allowed quantities may change. Class 1 may be water itself, class 2 for example natural esters, milk or film-forming liquids,

class 3 might be for example mineral liquids and class 4 toxic liquids to water. According to the utilized liquid and the according classifications, different arrangements in substations will be required.

Figure 1: Combined instrument transformers Type IVOKT 123 with natural ester

Figure 2: Manufacturing of active parts

2 NATURAL ESTERS

Natural ester insulating liquids are produced from the oil pressed, extracted and purified from vegetables, plants, seeds and animal oils. The most common natural esters used as electrical insulating liquids in transformers are taken from the seeds of soybean, sunflower and rapeseed plants. Each of these natural ester fluids has unique physical and chemical properties. The electrical performance characteristics of Envirotemp™FR3™ soybean based insulating fluid have been verified to 420 kV as stated previously. The physical and chemical properties are inherent from the molecular composition or chemistry that consists of many different structural types and amounts.

2.1 Chemistry

Natural ester fluids are also known as fats, lipids or triglycerides in the field of chemistry. The properties of natural esters originate from the carbonyl group structure (R-O-C=O) of an ester and the molecular makeup of the three fatty acid chains bonded to the glycerol backbone, which is referred to as the fatty acid distribution (FAD). This distribution of fatty acid chains consists of 10 to 22 carbons (C10-C22) in mostly even-number lengths that can be fully saturated with no double bonds (e.g. C18:0) or can contain unsaturation with one or more double bonds (e.g. C18:1 – C18:3). The FAD creates differences in viscosity, pour point, cold temperature performance, gassing tendency and oxidation stability. The FAD of several more common natural ester fluids is given in Table 1.

Table 1: Fatty Acid Distribution (FAD) of Common Natural Ester Fluids (%)

Fatty Acids	Capric	lauric	myristic	palmitic	stearic	arachidic	behenic	oleic	gadoleic	linoleic	linolenic
Carbon Chain	C10:0	C12:0	C14:0	C16:0	C18:0	C20:0	C22:0	C18:1	C20:1	C18:2	C18:3
Natural Ester	Saturated							Monunsaturated		Polyunsaturated	
Soybean	-	0.2	0.2	9.8	2.4	0.3	0.4	29.3	0.2	50.7	6.5
Rapeseed	-	-	0.1	5.0	1.5	0.7	0.2	65.0	0.5	20.0	7.0
Palm	-	0.3	1.2	42.3	4.7	0.5	0.1	40.0	0.2	10.5	0.2
Sunflower	-	0.1	0.1	6.2	4.5	0.3	0.9	26.5	0.2	61.0	0.2
HO Sunflower	-	-	0.1	3.8	4.5	0.4	-	84.8	0.3	6.0	0.1

Note: The data in Table 1 were taken as averages of the FAD ranges given in the CODEX Standard 210-1999 (amended 2005, 2011, 2013).

2.2 Properties

Natural ester properties and performance characteristics are mainly a function of the FAD and the purification level attained after manufacturing of the fluid. For example, the greater the unsaturation level of the fluid, the lower the viscosity and pour point temperature. Increased double bonding improves gassing tendency and cold temperature performance. The properties of new unused natural ester fluids for use in electrical equipment such as transformers are given in standard IEC 62770 [6] which was published in November 2013. Prior to publishing of the IEC standard, users looked to the natural ester standard specifications published in ASTM D6871 [7] and IEEE C57.147 [8]. The IEC 62770 and ASTM D6871 standard specifications and properties of the natural ester fluid used for the instrument transformer development are summarized in Table 2.

Table 2: Typical Properties and Standard Specifications of Natural Ester Fluid

	Standard Test Methods		ASTM D6871	IEC 62770 Ed. 1	Envirotemp™ FR3™ Fluid
Property	ASTM	ISO/IEC	As-Received New Fluid Property Requirements	Unused New Fluid Property Requirements	Typical Values
Physical					
Color	D1500	ISO 2211	≤ 1.0		0.5
Flash Point PMCC (°C)	D93	ISO 2719		≥ 250	255
Flash Point COC (°C)	D92	ISO 2592	≥ 275		320 -330
Fire Point (°C)	D92	ISO 2592	≥ 300	> 300	350 - 360
Pour Point (°C)	D97	ISO 3016	≤ -10	≤ -10	-18 - -23
Density at 20 °C (g/ml)		ISO 3675		≤ 1.0	0.92
Relative Density (Specific Gravity) 15 °C/15 °C	D1298		≤ 0.96		0.92
Viscosity (mm^2/sec)	D445	ISO 3104			
100 °C			≤ 15	≤ 15	7.7 - 8.3
40 °C			≤ 50	≤ 50	32 - 34
0 °C			≤ 500		190
Visual Examination	D1524	IEC 61099 9.2	bright & clear	Clear, free from sediment and suspended matter	clear, light green
Biodegradation		OECD 301C,B,F		Readily biodegradable	Ultimately biodegradable
Electrical					
Dielectric Breakdown (kV)	D877		≥ 30		47
Dielectric Breakdown (kV)	D1816	IEC 60156			
1mm gap			≥ 20		28
2mm gap			≥ 35		48 - 75
2.5mm gap				≥ 35	73
Impulse Breakdown (kV) (25 °C, neg needle to sphere, 1.0" gap)	D3300		≥ 130		130
Gassing Tendency (µm/min)	D2300		≤ 0		-79
Dissipation Factor	D924	IEC 60247			
% @ 25 °C			≤ 0.20		0.010 - 0.15
tan δ 90 °C				≤ 0.05	0.02
% @ 100 °C			≤ 4.0		0.41 - 3.85
Chemical					
Corrosive Sulfur	D1275	IEC 62697	non-corrosive	non-corrosive	non-corrosive
Water Content (mg/kg)	D1533	IEC 60814	≤ 200	≤ 200	< 100
Acid Number (mg KOH/g)	D974	IEC 62021.3	≤ 0.06	≤ 0.06	0.013 - 0.042
PCB Content (ppm)	D4059		not detectable	Free from PCB's	not detectable
Performance after oxidation stability test in accordance with IEC 61125C[1]					
Total acidity (mg KOH/g)		IEC 62021.3		≤ 0.6	0.1
Viscosity at 40°C (mm2/sec)		ISO 3104		≤ 30 % increase over the initial value	17.1
Dissipation Factor at 90°C (tan delta)		IEC 60247		≤ 0.5	0.1

Note[1] - oxidation tested per IEC 61125C for 48 hours at 120°C

ASTM D6871 "Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus"

IEC Standard 62770: Fluids for electrotechnical applications – Unused natural esters liquids for transformers and similar electrical equipment.

2.3 Performance of natural esters compared to other fluids

The technology of using natural ester fluids in electrical transformers has been improving since 1995 and there are currently over a half-million units operating worldwide. The requirement for using natural ester fluid in electrical equipment is that the devices should be sealed with only brief exposures to ambient air. Certain use and maintenance procedures require equipment to be open briefly to the atmosphere, inspected and repaired. Experience has shown that these procedures can be done within a reasonable time period, such as hours to several days with little to no impact on fluid properties or performance. The main concern of extended air exposure time is oxidation of thin films of natural ester fluid that coat solid insulation surfaces.

Users have learned to work on natural ester devices while minimizing air exposure and high humidity, especially at high ambient temperatures or exposed to direct sunlight. In general, all electrical insulating liquids oxidize with exposures to air, high temperatures and sunlight. However, each of the fluids oxidizes at a different rate depending on chemistry and levels of additives. The higher rate of oxidation of natural ester fluids compared to other insulating liquids must be accepted to benefit from their higher biodegradation rate and environmental benefits. The typical properties of natural ester fluid are compared to other electrical insulating liquids in Table 3.

Table 3: Typical properties of natural ester fluid compared to other fluids

		ASTM Test	Mineral Oil	Natural Ester	Synthetic Ester	Silicone
Electrical Properties						
Dielectric Breakdown (kV)	2 mm gap	D-1816	62	48 - 75	56	43
	1 mm gap		31	28		
	1 mm gap, 80 °C		23	24		
Dissipation Factor (%)	25 °C	D-924	0.010	0.023 - 0.103	0.040	0.007
	100 °C		0.050	0.67 - 3.86	1.10	0.0015
Volume Resistivity (10^{12} Ω-cm)		D-1169	200	10 - 50	33	1000
Dielectric Constant		-	2.2	3.2	3.2	2.26
Impulse Strength (kV)	sph-sph, 1" gap	D-3300	269	226	210	223
	point (neg)-sph; 1" gap		145	168	121	>200
Gassing Tendency (μL/min)		D-2300	+6	-79	Gas liberating	
Physical Properties						
Appearance		D1524	clear & bright	clear, light green	clear & bright	clear & bright
Color		D1500	L 0.5	L 0.5	L 1.0	L 0.5
Flash Point (°C)	open cup	D92	150	306 - 330	270	300
	closed cup	D93	> 135	250 - 260	> 250	
Fire Point (°C)		D92	165	356 - 366	306	343
Autoignition Temperature (°C)		E659	225-228	401-404	373-376	399-402
Viscosity (cSt)	40 °C	D445	9.2	32.5 - 34.5	29.0	37.0
	100 °C		2.3	7.9 - 8.3	5.6	15.5
Pour Point (°C)		D97	-50	-18 - -23	-55	-55
Specific Gravity		D1298	0.869	0.92	0.971 @ 68 F	0.96
Specific Heat		D2766	0.39	0.45	0.45	0.36
Heat Capacity (J/g°C)	50 °C	E1269	1.92	2.11	2.05	-
	70 °C		2.08	2.21	2.18	
	100 °C		2.34	2.39	2.40	
Thermal Conductivity (W m^{-1} K^{-1})	30 °C	D2717	0.119	0.166	0.145	
	50 °C		0.116	0.151		
	75 °C		0.112	0.137		
	100 °C		0.108	0.129		
Thermal Expansion ($°C^{-1}$)		D1903	0.000795	0.00074	0.00073	0.00104
Chemical Properties						
Water Content (mg/kg)		D1533B	12	10 - 50	60	
Acid Number (mg KOH/g)		D974	0.01	0.02 - 0.06	0.02	0.002
Interfacial Tension (dynes/cm)		D971	47	20 - 25	29	44.6
Environmental Properties						
Biochemical Oxygen Demand (ppm)		5-Day SM5210B	6	250	24	0
Chemical Oxygen Demand (ppm)		SM5220D	82	560	-	-
aquatic biodegradability (%)		OECD 301B	30 - 35	> 99	63	0

Notes: Mineral oil data from Shell Diala A and Exxon Univolt product brochures. FR3 fluid and synthetic ester values selected from Cooper Power Systems and Cargill data. Silicone data selected from Dow Corning 561 Silicone Transformer Liquid Form No. 10-278C-91.

The fire safety and biodegradability aspects give natural ester fluids a desired advantage over all other electrical insulating liquids as shown in Figures 3 and 4.

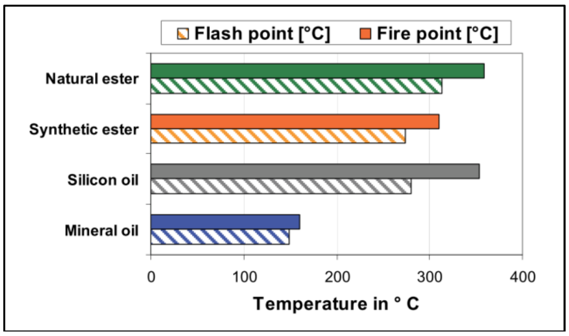

Figure 3: Typical flash and fire points of various insulating fluids [9]

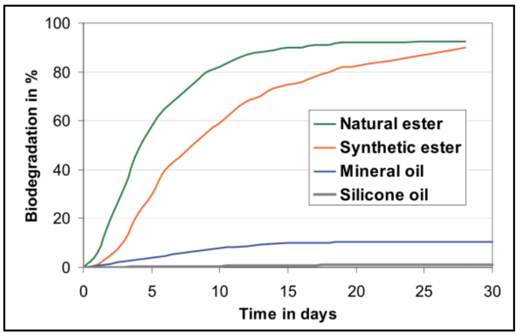

Figure 4: Biodegradability of various insulating fluids [9]

3 PECULIARITIES OF INSTRUMENT TRANSFORMERS AND NATURAL ESTERS

The insulation system of modern oil-paper insulated instrument transformers is the result of decades of research and experience gained from practical operations. Nowadays, oil-paper insulated instrument transformers are using comparable low volumes of oil ("*Ölarme Wandler*") and have a very compact insulation system (Figure 2). In contrast to power transformers, there are no larger free oil gaps within the apparatus. The main insulation of an IT consists of various paper thicknesses and types (Kraft paper, Crepe paper...). It can reach thicknesses of several tens of millimetres, which makes the manufacturing process, especially drying and impregnation a challenge. This is even more the case when using natural esters as impregnating fluid, as for example its viscosity is much higher than that of mineral oil. Therefore, different process parameters have to be defined, most important are a higher impregnation temperature and longer process times [10].
Modern instrument transformers are very efficient and produce very-low and insignificant losses. Therefore, the main task of the insulating liquid here is its electrical insulation duty and not so much of heat transfer for instance. Due to the lower operational temperatures - compared to power transformers - thermal ageing is not a dominant factor[1] for instrument transformers during normal operation. As this is clearly an advantage in terms of ageing, cold-start behaviour is more of an issue here because the self-heating due to thermal losses is much less the case than for power transformers. For example, a typical ambient temperature range for the Black Forest region in Germany can be from -25°C to +35°C, so cold-start behaviour is definitely also a topic for network operators in Central Europe.

4 DESIGN AND TYPE TESTS

Alternative insulating liquids like natural esters differ in several (physical) properties from mineral oil. Some main differences are water solubility and viscosity. Dielectric properties and behaviour have been the subject of innumerable tests within the last years. Some of the key parameters with instrument transformer design in mind are discussed below.

4.1 Relative permittivity of natural esters

In the temperature range from 20 to 105°C, the relative permittivity ε_r of natural ester is around 30% higher [11] when compared to mineral oil. So the electrical field displacement is reduced due to the lower step in relative permittivity between (natural ester impregnated) paper and the natural ester fluid when compared to mineral oil systems.
This is favourable as it reduces the possibilities for discharges on boundary surfaces for instance. However, the field displacement is not reduced in the same or full amount of the permittivity change

[1] Therefore it is not common to use thermally upgraded paper nor inhibited (mineral) oil for instrument transformers

of the above mentioned 30%. Due to a slight, concurrent increase of relative permittivity of natural ester impregnated cellulose, the difference in permittivity between the paper and natural ester is reduced by around 10...15% when compared to mineral oil [11].

4.2 Dielectric design

The electrical behaviour of natural ester can be generally compared to those of mineral oils at AC, even for large(r) oil gaps. At those gaps (10…20 mm [12]; 50…150 mm [13][14]) it seems that there is no significant difference at AC between mineral oil and natural esters. This can be transferred also to impulse voltage, where the dielectric strength of mineral oil and natural ester are more or less equivalent [15]. However, this depends on testing procedure and testing set-up. Under certain conditions, the impulse strength of natural ester fluid can be around 20% lower than mineral oil [16]. Not only the absolute values are different but also the physical behaviour before and during breakdown, e.g. streamers tend to move faster in natural ester [9],[17],[18]. Also, in practical set-ups the dielectric strength may be lower than expected from single material measurements [19], however this strongly depends on test setup.

Testing just the natural ester fluid, e.g. by determining the dielectric strength (=breakdown voltage) does not go far enough but one has to investigate the whole system of oil and paper as well as the complete insulation set-up (active part). Test procedures as defined, for example in IEC 62770 [6] and IEC 60156 [20] respectively, are certainly vital for incoming material testing but for defining design rules, representative set-ups [9] or complete units need to be tested.

Breakdown voltage and field strength respectively of natural ester depends on temperature: Electrical strength at AC at small gaps decreases if temperature drops below the pour point. Recent research of the breakdown voltage at -35°C showed that natural ester fluid decreased more than mineral oil compared to the original strength [21]. In terms of defrosting there is no significant difference between mineral oil and natural ester [21]. However, when comparing these results between mineral oil and natural ester, one has to note that these temperatures are still above the pour point of mineral oil, but at a temperature that water can condense easier from mineral oil.

All in all, higher safety factors are required for insulation system based on natural ester due to the issues discussed above and also due to large(r) scatter of dielectric test data [9].

4.3 Moisture and ageing

The moisture properties and ageing behaviour of natural esters are not critical for the application in instrument transformers. On the one hand, ageing due to oxidation is indeed critical for natural esters but this is strongly hindered in instrument transformers by hermetically sealing the active part.

Temperature as a significant trigger for material ageing on the other hand is also not an issue in instrument transformers as their operational temperature is comparably much lower as for example the ("top-oil") temperature in power transformers.

4.4 Manufacturing and Processing

The paper insulation of the instrument transformer's active part for natural ester impregnated paper was done basically in the same manner as for mineral oil impregnated paper due to the fact, that no internal cooling channels are required in the paper packages. The introduction of venting holes for an improved impregnation from several directions [10] cannot be applied for oil-paper insulated instrument transformers due to their compact insulation system.

The manufacturing process (impregnation) itself differs from "standard" mineral oil processes, due to the physical and chemical behaviour of the natural ester. The processing temperature for degassing and impregnation (autoclave equipment) must be increased, e.g. to 70°C to reach an optimum viscosity of the oil for a good impregnation of the paper insulation [10]. On the contrary to mineral oil applications, vapour pressure characteristics are not critical at typical process pressure/temperature combinations. Material compatibility with natural ester has to be obeyed for all utilized materials [9], but this is generally not an issue for instrument transformers.

Different boundary behaviour between paper and natural ester paired with high viscosity lead to much longer impregnation and rest/soak times after the autoclave process for a thorough impregnation of the entire active part.

Contact of natural ester fluid with moisture and especially ambient (air) has to be reduced to an absolute minimum as thin layers of natural ester tend to polymerize when in contact with oxygen for extended periods of time.

4.5 Type testing

The natural ester filled instrument transformers did undergo the type testing procedure in accordance with IEC 60044 [22]. All conducted tests have passed successfully, which included low-temperature tests down to -35°C at Karlsruhe Institute of Technology [23].

4.5.1 Lightning impulse test

The lightning impulse test was the source for some troubles during development: Two prototype units failed for no apparent reason during lightning impulse voltage test after changing to positive polarity following the 15 negative lightning impulses (-550 kV). Autopsy of the units did not reveal any causes for unit failures but did show correct manufacturing. So it is justified to presume a different failure mode as it seems that the charging behaviour of natural ester is different and that remanent charges reduce the dielectric strength. This can be seen for example in [16] where the electrical strength of natural ester at lightning impulse voltage is significantly lower when compared to mineral oil in the rising voltage tests with 3 applied shots per voltage stage.
However, with a waiting period at polarity reversal and several additional reduced waves (90, 70 and 50%) at both polarities and therefore a charge balancing this test was successfully passed on further apparatus. This is a common practice as described in IEEE C57.13.5 [24] and is also in-line with the IEC 60044 [22] and IEC 61869-1 [25] respectively.

4.5.2 Low-temperature test

Dielectric tests down to -35°C have been carried out on a combined instrument transformer filled with natural ester at Karlsruhe Institute of Technology. Starting from ambient, the IT has been cooled down to -20, -25 and -35°C and has been brought back to ambient through the same temperature steps. At each temperature level several dielectric tests have been carried out. The following tests have been conducted after a waiting period of at least 24 hours at each temperature level to allow temperature adjustment within the unit:

1. Capacitance and tan(δ) measurement at 30, 60, 90, 120 and 135 kV
2. Partial discharge measurement (U = 135 kV)[2]
3. Power-frequency voltage withstand test, U=135 kV, 15 min
4. Capacitance and tan(δ) measurement at 30, 60, 90, 120 and 135 kV
5. Partial discharge measurement (U = 135 kV)

The whole test series has been completed successfully. Partial discharge and tan(δ) results have been within internal specifications and international standards [22].

5 DISCUSSION

When keeping the specific characteristics of natural ester in mind, it is certainly possible to specify design and manufacture instrument transformers filled with natural ester in an efficient and economical way.
In fairness, one has to say that in terms of (operational) experience there is still a big gap to mineral oil-filled insulation systems. This affects especially the fields of electrical and chemical diagnosis like partial discharge measurements and dissolved gas analysis (DGA).

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[2] The maximum applied voltage was limited by the set-up at Karlsruhe University of Technology. To avoid (VT) core saturation at test voltage (U=230 kV), testing needs to be done at higher frequencies, e.g. at f=105 Hz. This was not possible during testing in the low-temperature test cell at Karlsruhe University, therefore the maximum voltage was limited to U=135 kV.

The extension of portfolio to other units and higher voltages needs to be looked upon separately: The utilisation of natural esters for CTs and VTs is feasible as demonstrated with these combined units. However, to bring the technology to higher voltages levels for example 245 kV and 420 kV, one has to solve two main issues: dielectric design and manufacturing process. The latter seems to be tricky due to the comparable high insulation thickness of the active parts which is necessary for such operational voltages. For sure, this will lead to prolonged process times and significantly increased lead time and cost.
A good performing dielectric design seems to be possible, especially also with the successful testing of a 420 kV power transformer filled with natural ester [2] in mind.

6 CONCLUSIONS AND OUTLOOK

The usage of natural esters as impregnation and insulation fluid in high voltage instrument transformers is possible as shown. Due to the environmental compatibility as being not hazardous to waters (“*nwg: nicht wassergefährdend*”) it allows the installation of oil-filled high-voltage equipment in environmental sensitive areas and is further a possible alternative to gas-filled units. Also, the high fire point provides a safer operation near dense urban environments.
However, the process is not straightforward as many parameters have to be taken into account: It is not as “simple as just exchanging the impregnating and insulating fluid” but the whole manufacturing process has to be respected. Besides a careful specification and design phase, the investigations need to reach from incoming material inspection to the final electrical tests at the manufacturers test field.
As a next step after the successful type testing, live trial operations are planned for 2014 and beyond with 3 combined instrument transformers (123 kV) in a substation to collect field data and experience.

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