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Qualification of Insulating Liquids for Power Transformers and Tap-Changers

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SUMMARY

Insulating liquids used in electrical equipment such as transformers, tap-changers, bushings etc. must fulfil various requirements, such as electrical insulation, heat transfer, lubrication, arc-quenching, material compatibility or adequate buoyancy.
Current standards for insulating liquids do primarily define quality parameters of the liquid itself, but less its performance in electrical equipment. Therefore, equipment manufacturers use their individual test procedures and processes to approve an unknown liquid, which, from a macroeconomic view, appears inefficient. It is therefore desirable to harmonize test strategies by developing generally accepted methods which are easy to apply, and which can be standardized.
As the number of new liquids, which are launched as an alternative to conventional mineral insulating oils, steadily increases, the need grows for a common understanding how to test all these liquids in a way so that they become comparable. This necessitates an agreed test program with standardized test arrangements. Furthermore, it needs an efficient process to evaluate new liquids in general.
The paper highlights important liquid parameters and their relevance for transformers and tap-changers. The coverage of these parameters in current liquid standards is discussed and improvements are proposed. Missing parameters are clearly identified. Simple test arrangements to evaluate the dielectric behaviour of new liquids are presented and discussed, using electrode configurations which represent real transformer and tap-changer designs.
The aim is to approve a new liquid unknown so far with as less effort as possible, but to respect all relevant parameters. Different opinions and discussions, which today arise from different viewpoints and individual test procedures, can be overcome, if one agrees on a comprehensive set of standardized test procedures.

KEYWORDS

Insulating Liquid, Dielectric Test Arrangement, Lubricity, Arc-Quenching Capability, Liquid Viscosity, Standardization, Approval Process

1. INTRODUCTION

Insulating liquids used in electrical equipment such as transformers, tap-changers, bushings, circuit breakers and transformer accessories must fulfil various requirements. The main purpose of these liquids is to provide electrical insulation and to dissipate heat losses. In order to do so, the liquids have to show appropriate dielectric strength to withstand the electrical stresses imposed by various insulating designs during testing and service. They must also have an adequate combination of thermal conductivity, specific heat and viscosity to ensure sufficient heat transfer. With respect to tap-changers, they must show sufficient lubricity to ensure a long service life of contacts and the drive mechanism, as well as good arc-quenching capability. Liquid deterioration caused by the switching arcs should be as low as possible. Furthermore, they have to be compatible with all materials used in the equipment design and must neither deteriorate themselves nor the material in a manner that would impair proper functioning. Finally, physical parameters like density and viscosity should be in a range to allow an equipment being used without de-ratings.

The majority of liquid-filled electrical equipment has been designed to work with mineral insulating oil which has been refined from naphtenic or paraffinic petroleum crudes. The refining process was set in a way that distillates are suitable to be used as insulating liquids. Measurable parameters were identified which allow a brief characterization of mineral insulating oils. Test methods and limit values have been defined and standardized in IEC60296, ASTM D3487 and comparable standards for mineral oil. Due to economic and technical considerations, the liquid properties are mostly close to the minimum or maximum limit values specified in these standards.

GTL (Gas-To-Liquid) oils and oils from bio-based hydrocarbons are classified as ‘mineral oils according to IEC60296’ but show significantly different values for density and viscosity than conventional mineral oil. A very low density or viscosity may be advantageous for the transformer, but it may have a detrimental impact on the tap-changer at the same time. The dielectric breakdown behaviour is also different, compared to mineral oil from petroleum crudes.
Ester liquids and silicone oils represent a class of liquids for special applications where high fire safety is required. Viscosity and/or dielectric breakdown behaviour are significantly different to conventional mineral oil. Again, typical liquid parameters and limit values are standardized in IEC61099 (synthetic ester), IEC62770 (natural ester) and IEC60836 (silicone oil), or in the according ASTM standards.

Common to all standards mentioned above is that the liquid parameters specified therein do not necessarily allow an estimate on the performance of the equipment where the liquid is used in. Over hundred years of experience have only shown that these parameters are sufficient to describe a mineral oil, made from petroleum crudes, which can be used without problems in all kinds of electrical equipment. For all other liquids mentioned, this cannot be granted without additional effort. Essential liquid parameters, which are important to assess the performance of the liquid-filled equipment, are not defined. For some liquid properties, no standardized test procedure even exists, or the respective standard is insufficient. IEC TC14 Technical Report TR60076-26 [1] contains a comprehensive collection of relevant liquid performance parameters and shows their coverage by standardized test procedures. The gaps have to be closed.

In the following, a subset of said compilation which contains the most relevant liquid performance parameters for power transformers and tap-changers, is being discussed.

2. REQUIREMENTS OF TRANSFORMERS AND TAP-CHANGERS ON INSULATING LIQUIDS

The requirements of electrical equipment on an insulating liquid are manifold. For transformers, electrical insulation, cooling of active parts, material compatibility, oxidation stability, electrostatic charging tendency (ECT) and (stray-)gassing behaviour are crucial parameters [2]. Details and design aspects of some large power transformers filled with ester liquids have been discussed in depth and presented in several publications [3-5].
Regarding on-load tap-changers (OLTCs), basically the same parameters as for transformers are relevant, with some differences concerning importance, and additional parameters which apply. First, one has to distinguish between non-vacuum type and vacuum type models. The switching contacts of non-vacuum type OLTCs make and break the currents directly in the oil, so it is important that the

liquid can cool and quench the switching arcs efficiently. Besides electrical parameters and contact speed, the molecular structure and viscosity of the liquid determine the arcing behaviour and the amount of carbon produced by this pyrolytic degradation. It should be as low as possible. Non-vacuum type OLTCs require regular maintenance, which includes contact wear review (or exchange), cleaning and oil change. A high oxidation stability of the liquid is not required for these OLTC types. On the other hand, vacuum type OLTCs encapsulate the switching arcs inside sealed vacuum interrupter tubes, which means that the liquid is not deteriorated by switching arcs. It remains clean, maintenance intervals (if any) are significantly longer, and the liquid stress conditions are similar as for the transformer. For these OLTC types, oxidation stability and gassing properties are relevant.
A tap-changer consists of numerous mechanically moving parts (gears, contacts, bearings etc.) that are designed in accordance with a transformer service life of 30 years and beyond and to perform up to 1.2 million tap-change operations. It is absolutely necessary that the surrounding liquid provides sufficient lubricity to ensure a corresponding endurance. Furthermore, the spring-loaded drive mechanism of the diverter or selector switch provides a limited amount of spring force to operate the mechanism. It must be ensured that the tap-change operation is completed within the specified time and within the entire permissible liquid temperature range (typically -25 °C to +115 °C). Within this temperature range, the liquid viscosity can vary by a factor of a hundred. An elevated viscosity, as observed with ester liquids, for example, can limit the tap-changer operation in cold liquid (e.g., during cold-start of the transformer), as the switching times may be extended inadmissibly. If, in the worst case, the switching operation starts but cannot be completed, a severe failure will occur. On the other extreme, at high liquid temperatures, lubricity decreases, as it correlates with the decreasing viscosity of the liquid. In case the viscosity is too low, increased mechanical wear may occur, or the load-switching function may be impeded, due to increased friction. Tap-changer designs with a high number of current-carrying contact fingers sliding on their fixed counterparts (e.g., selector switches), suffer from an extremely low viscosity. Some modern bio-based hydrocarbons and GTL oils show such an extremely low viscosity at high liquid temperatures, that temperature restrictions for the operation of the OLTC had to be defined. On the other hand, it has been shown that a very low viscosity can improve the cooling capability of the liquid and so lets the transformer run cooler or allows a higher MVA rating, maintaining the same top oil temperatures [6].
Table I shows the relevance of important liquid parameters for Transformers and tap-changers. It becomes visible that vacuum type tap-changers show the highest demands on a suitable liquid.

Table I
Important Liquid Parameters and their Relevance for Transformers and Tap-Changers

Parameter	**Transformer**	**De-Energized Tap-Changer (DETC)**	**On-Load Tap-Changer (OLTC)**		
			Tap selector	**Diverter switch**	
				non-vacuum type	**vacuum type**
Electrical Insulation	■■	■■	■■	■■	■■
Cooling	■■	■■	■■	■■	■■
Material Compatibility	■■	■■	■■	■■	■■
Oxidation Stability	■				■
ECT	■				■
Gassing Behaviour	■	■	■		■
Arc-quenching Capability			■	■■	■
Viscosity	■			■■	■■
Lubricating Capability		■	■■	■■	■■

■ important ■■ very important

The current practice of designing a new insulating liquid for its use in power transformers does not consider the needs of tap-changers, which again is the result of not yet fully consistent liquid standards.

When designing new transformer or tap-changer models, the specific properties of modern insulating liquids are respected as far as possible. Nevertheless, from a technical and economic perspective it is

not sensible to try to cover all extremes because the resulting product would be clearly oversized. Reasonable boundary conditions have to be defined, which means that the full bandwidth of all liquid properties cannot be used.
For existing tap-changer models, admissible operating conditions and limit values have been defined to allow a safe use with alternative insulating liquids, such as synthetic and natural esters e.g. [7]. GTL oils and bio-based hydrocarbons require different boundary conditions and limit values than ester liquids.

3. DISCUSSION ON STANDARDS

3.1. Status Quo

As stated above, the existing liquid standards like IEC60296 define characteristic liquid parameters for unused liquids, which are grouped in "Function", "Refining/Stability", "Performance" and "Health, Safety and Environment". The limit values are set in a way to avoid potential malfunction of the equipment by repercussion of the liquid on the insulating arrangement (by corrosive sulphur, acidity, gassing) during the long service life, and to fulfil safety requirements (e.g., fire safety).
Functional properties defined in the standards which directly influence the function of the equipment are:

- **Viscosity [mm^2/s]** **max value**
- **Pour point [°C]** **max value**
- **Water content [mg/kg]** **max value**
- **Breakdown voltage [kV]** **min value**
- **Density [kg/m^3]** **max value**
- **Dielectric Dissipation Factor DDF []** **max value**

Corresponding IEC standards for ester liquids, silicone oils and synthetic aromatic liquids specify (more or less) the same parameters and therefore are comparable in this regard. Viscosity, pour point and density allow an estimate on the cooling efficiency. Water content, breakdown voltage and dissipation factor determine dielectric strength and losses of the insulating system under operating voltage and give an indication on the purity and ageing condition of the liquid. These six properties might be sufficient to design a mid-sized network transformer for mineral oil-filling, but they are definitely not sufficient for transformers with higher demands, or when ester or silicone liquids shall be used.

3.2. Standards Improvement for Transformers

The breakdown voltage test according to IEC 60156 or ASTM D1816/D877 only allows a statement on the dielectric strength of the liquid when stressed with AC operating voltage. It is primarily determined by the number of particles, dissolved water, microbubbles and acidity. With respect to modern insulating liquids like esters, GTL oils and bio-based hydrocarbons, an additional measure is needed which describes the dielectric breakdown behaviour, an intrinsic property. Dielectric breakdown in liquids still holds some secrets, but one can say that it is based on streamer initiation and propagation. A comprehensive summary of results from numerous tests conducted on the dielectric performance of liquids, their discussion and conclusions can be found in [8]. It has been found in [9, 10] that in ester liquids a high propagation speed for streamers occurs at lower applied voltages than in mineral oil. "Fast" streamers (propagation speed ≈100 mm/µs) can cross longer gaps during the dwell time of the applied voltage impulse, which increases the probability of reaching the opposite electrode and so causes breakdown. Existing insulating arrangements which worked well in conventional mineral oil may fail when immersed in modern insulating liquids. A measure is needed which allows an evaluation of the dielectric breakdown behaviour in comparison to petroleum-based mineral oil. GTL oils and bio-based hydrocarbons show in some characteristic a similar behaviour to ester liquids, but to lesser extent.

- **Acceleration voltage [kV]** **min value**

A characteristic measure to distinguish between different liquids is the voltage (applied to a suitable test setup) at which streamers become fast, named "acceleration voltage". Different liquids show

different acceleration voltages. If, in a voltage rise test, the time to breakdown is measured, the acceleration voltage can be identified. This would allow an estimate of the changing in breakdown probability, compared to conventional mineral oil.
In [8] it is proposed to upgrade IEC60897, as the current version only provides LI breakdown voltages up to 300kV for needle-to-plate arrangements, which is a value easily exceeded by modern liquids. The proposal includes (amongst others) a different electrode configuration and the measurement of the time to breakdown in combination with the breakdown voltage, whereof the acceleration voltage can be determined. However, the acceleration voltage is an informative parameter but does not directly serve as suitable parameter for the transformer design. Test configurations like explained in chapter 4 will provide results which are more appropriate, and which can directly be used for transformer design.

- **Material Compatibility [%]** **max value**

Another parameter which is unnoticed by current liquid standards is the material compatibility. Up to now, there is no IEC standard which defines tests to allow an estimate on the interaction between solid construction materials and the insulating liquid. Fortunately, a project team from IEC TC112 WG6 is currently working on a first draft and will issue a new standard IEC63177 in 2023. It includes various elements from ASTM D3455 but goes much further, as it includes more materials, different liquids, variable test duration and specifies a variety of evaluation methods, depending on the material and the liquid used in the test. It does not specify limit values for the maximum allowed grade of deterioration (i.e. change in volume, mass, tensile strength, discoloration, dielectric strength, tactile sensation, for gaskets: change in hardness, compression set etc.), as these numbers strongly depend on the application and its individual functional requirements. In the same way, no limit values for the maximum admissible changes of liquid properties (gassing, BDV, IFT, etc.) are given. Due to the not yet fully available standardization, equipment manufacturers had to set up their own proprietary evaluation methods [11]. With this, the end user has to trust the equipment manufacturer that he provides a reliable solution. Standardization would help to ensure a minimum quality standard which has to be followed by all manufacturers.

3.3. Standards Improvement for Tap-Changers

The dielectric issues described in 3.2. also apply to tap-changers, in tightened matter. Tap-changers show numerous different insulating arrangements, including pure oil gaps as well as longitudinal solid/liquid interfaces between two electrodes. Contacts can be bare metal or partially coated, see Fig.1. Tap selectors show numerous different potentials on their terminals, and their contacts and drive mechanism are optimized to perform more than a million operations. This unique combination of mechanical and electrical requirements necessarily leads to electrode shapes that produce moderately inhomogeneous electrical fields. Typical field factors η (also known as utilisation factor or inhomogeneity factor) are between 0.19 and 0.47. Due to the lower acceleration voltages in ester liquids, reduced withstand voltages must be accepted to achieve the same residual breakdown probability as in mineral oil. Based on the experience gained from numerous full-size tests on tap selectors and tests on suitable model setups which roughly represent the diversity of tap-changer electrode arrangements, it should be possible to estimate the dielectric performance of an unknown liquid by regarding the acceleration voltage. At least it should allow a qualitative comparison with conventional mineral oil. See also chapter 4.

Fig. 1: OLTC with various insulating and contact arrangements

As for transformers, material compatibility is an important parameter for tap-changers, in tightened matter. In tap-changers, many more different materials are used than in transformers. Therefore, IEC63177 will also include test methods for typical material groups used in tap-changers, such as polyamides, polyphtalamides, PTFE and other high-performance polymers, polyester- and epoxy-based multi-compound materials, but also coatings, adhesives, and thread locks.

Besides the dielectric issues, additional parameters must be defined, and limit values must be set to allow an evaluation of the mechanical performance:

- **Viscosity [mm²/s]** **max / min value**
- **Friction force (mechanical wear)** **max value**
- **"Cold 'n Hold" behaviour [%]** **max value**

Viscosity needs an additional minimum limit value, as it is related to the lubricating capability. An adequate friction test arrangement must be identified which represents sliding contact fingers. Two crossed cylinders (see Fig. 2) seem to be adequate. It is planned to install a tribometer test with different loads and temperatures, recording the friction force and comparing it with reference data obtained in conventional mineral oil. From the variety of available ASTM and DIN norms on tribology, an appropriate standard must be selected. The "Four-Ball-Wear" test arrangement according to ASTM D4172 (Method B) sued so far is not suitable for all cases, as it can only reveal extremely bad or good lubricating properties. A comparison with mechanical endurance tests on tap selectors has shown that. Fig. 3 gives an overview on "Four-Ball-Wear" test results which have been carried out on different insulating liquids. It does not reveal the slight differences between conventional mineral oils and a low-viscous bio-based hydrocarbon, for example, which might lead to functional disorder at high temperatures on a certain tap-changer model.

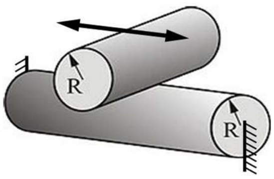


Fig. 2: Simplified model for wear test of sliding selector contact fingers

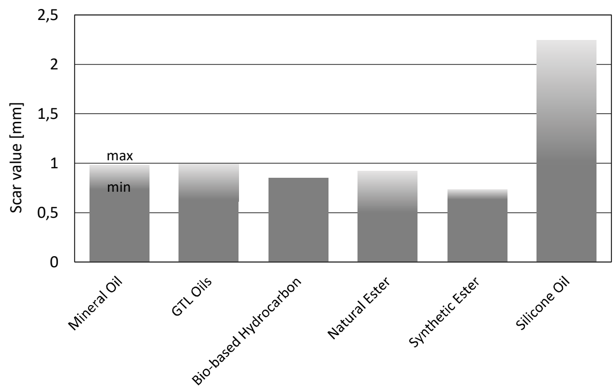


Fig. 3: Results of Four Ball Wear Tests acc. to ASTM D4172 B

The "Cold 'n Hold" behaviour is typical for natural ester liquids and describes the viscosity increase after long standing times at liquid temperatures near the pour point. It is important for the cold start of a transformer, when the tap-changer is mechanically operated to adjust the transformer voltage ratio to a required value, before energizing the transformer.

- **Arc-breaking capability** **min value**

Even if non-vacuum type OLTC models are more and more replaced by vacuum type models, in some cases arc-breaking-in-oil OLTCs may still be used. The capacitive arcs or sparks when operating the change-over selector will remain anyway. It is important that switching arcs are being quenched within defined time limits to ensure a proper switching sequence. In case arcing times are too long, the switching contact on the "making" side may close before the arc on the "breaking" side did extinguish – which can cause a shortcut between two taps or across the complete regulating winding. The physics of switching arcs in oil is a complex issue: the arc energy evaporates a certain amount of oil and causes a plasma. This gas bubble increases its length along the opening path of the moving contact. If the gap between the opening contacts is long enough, the arc will extinguish at the next current zero crossing. The cooling of the plasma is a matter of viscosity and molecular structure of the liquid. As comparative tests have shown, different mineral oils produce different amounts of carbon particulate when pyrolyzed by a switching arc [12]. When exposed to identical arc energy, the amount of carbon may differ by the factor of 8. Up to now, there is no standard how to determine the deterioration behaviour of a liquid under defined arcing stress. This should be developed and a minimum requirement (limit value) for arc-breaking capability should be defined.

- **Density [kg/m³]** **max / min value**

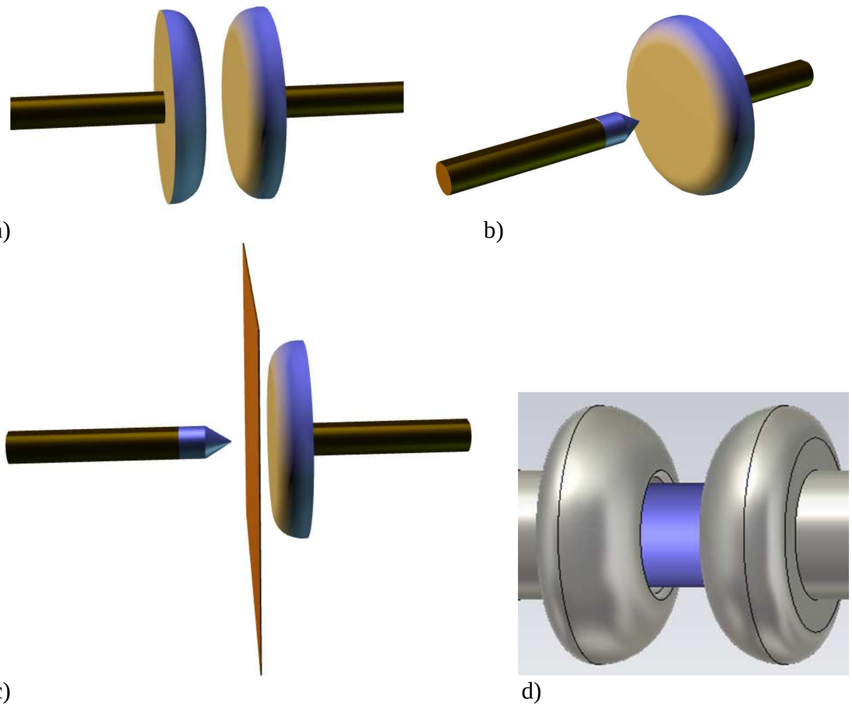
For floater-operated accessories like oil level indicators or Buchholz relays, and protective devices for OLTCs like oil-flow relays, it is necessary to specify a minimum permissible density value, to ensure a reliable operation throughout the whole operating temperature range (typically -25...115 °C). If density is too low, the floater sinks and will provide a false alarm. For oil-flow relays, tests have shown that the sensitivity of the flap is also adversely affected by a low density. However, a low liquid density is advantageous for the overall weight of the transformer. Consequently, the devices have to be prepared for those kinds of liquids.

4. PROPOSED TEST METHOD FOR EVALUATION OF DIELECTRIC BEHAVIOUR

The determination of the breakdown voltage according to IEC60156 (for AC) is not sufficient to allow a statement on the dielectric strength of HV insulating arrangements.

Extensive research on the dielectric breakdown behaviour of insulating liquids has been performed on needle-to plate arrangements with AC and LI, which allow an understanding of pre-breakdown mechanisms (streamer initiation and propagation) in different liquids – but they do not represent real insulating arrangements in electrical equipment, providing uniform or semi-uniform electrical fields. Less investigations have been performed on arrangements with higher field factors, e.g. in [13]. There is consensus that differences in between ester liquids and mineral oil cannot be clearly identified for field factors $\eta > 0.1$. Nevertheless, impurities in the liquid, surface roughness or small protuberances on uncoated electrodes may act as macroscopic needle electrode which can initiate a streamer. Once initiated, the starting streamer has unlimited access to charge from the bare electrode surface, while covered electrodes could restrain streamer initiation and propagation. Tap-changer contacts cannot be completely coated, due to functional needs.

As equipment manufacturers are urged to approve their products for new liquids, test programs were initiated to define withstand voltages for natural and synthetic esters. This empirical approach has been successfully applied to several hundred applications with new liquids so far, without knowledge of the breakdown mechanisms behind them. Based on this experience, suitable test arrangements were designed by the authors which represent typical transformer and tap-changer geometries, and which



a) b) c) d)

Fig. 4 : Test arrangements for the dielectric evaluation of unknown insulating liquids

a) homogeneous test arrangement with coplanar electrodes
b) inhomogeneous test arrangement with point-plate electrodes
c) point-plate arrangement with barrier
d) arrangement with longitudinal solid/liquid interface and oil wedges

allow a similar evaluation of new liquids in comparison to standard mineral oil as the destructive full-size tests used so far; see Fig. 4.
The types of tests applied to these arrangements equal those which are used for transformer final acceptance testing to prove the insulation capability of the transformer, as well as to guarantee the lifetime withstand strength. They are as follows:

- Lightning impulse withstand voltage test, full wave (LI FW): 1.2 µs / 50 µs
- Lightning impulse withstand voltage test with solid insulation, full wave: 1.2 µs / 50 µs
- Lightning impulse withstand voltage test, chopped wave (LI CW): 1.2 µs / (2 – 6) µs
- Switching impulse withstand voltage test, full wave (SI FW): 250 µs / 2500 µs
- Switching impulse withstand voltage test with solid insulation, full wave: 250 µs / 2500 µs
- AC withstand voltage test, procedure according to IEC 60060-1 1 Min / 45-65Hz

Test gaps vary from 5 to 30 mm, the tip radius of the point electrode is 0.5 to 1.5 mm. In arrangement d), the distance between electrodes is 10 mm, the radius of the torus electrodes equals 10 mm. The radius at the wedges was designed so that an overall field factor $\eta = 0.56$ was achieved, which is a typical value for tap selector arrangements.
The following boundary conditions apply:
Moisture during test: <5 % r.H. (<10 ppm) for mineral oil,
5 to <15% r.H. for alternative liquids.
The permissible particle contamination may not exceed the limit values given in IEC 60422 for factory acceptance test and transformer commissioning.
All tests should be run at room temperature (20 … 25 °C), ± 5 K.

Laboratories and test institutes are encouraged to verify the significance of these test arrangement and provide a proof that these arrangements are suitable to allow a qualitative comparison of the dielectric breakdown behaviour of new liquids.

The tests presented above are utilized to at least compare different insulating liquids and their performance for different fields of application in transformer design. A broad variety of mineral oil testing results is available to which the new liquid tests can be compared.
A direct comparison of these results is admissible because

- influences of the test arrangement itself and different environmental conditions are avoided, and
- manufacturing tolerances of the specimen and the test arrangement are being minimized.

The tests allow a direct comparison of mineral oil performance to the new liquid and consequently a categorization of the dielectric characteristic. This characteristic is used to determine different classes for the dielectric performance of liquids. Each class of dielectric performance is directly linked to a coupled set of design rules. When investigating a new liquid with said test arrangements, the liquid can directly be allocated to a class for dielectric performance, enabling easy judgement for the release of an application. However, if the results from a new liquid, tested with the configurations from Fig. 4, strongly differ from the characteristic of known dielectric performance classes, further deep-dive analysis must be performed, like determination of acceleration voltage, etc.

Furthermore, these simple arrangements allow a comparison of test results between different laboratories or institutes, on condition that the defined boundary conditions are considered. In the same way, a comparison with data provided by the liquid supplier is rendered possible. The presented arrangements provide a basis for direct comparison and discussion. Consequently, transparency for the end user or utility is gained by providing direct insight into the dielectric behaviour of the liquids. This will avoid different statements on dielectric performance as per today it is sometimes provided.

5. APPROVAL PROCESS FOR NEW LIQUIDS

The advent of numerous non-petroleum-based new insulating liquids appearing on the market requires efficient evaluation processes. For power transformers, the evaluation of the dielectric performance should be extended beyond the parameters specified today. Therefore, the above-mentioned simple test arrangements are proposed, enabling liquid manufacturers to perform or direct all necessary tests on their own and provide results already during their product presentations, well before the approval process. Having those results available will lead to an accelerated approval or a non-release decision.

For tap-changers, in the past each new liquid has undergone several tests on selected tap-changer models or with proprietary test setups:

- Determination of withstand voltages on typical tap-changer electrode arrangement (destructive test)
- Verification of standard test voltages for phase-to-phase and phase-to-ground insulating arrangements (full-size test, non-destructive)
- Determination of switching capacity of change-over selector (full size or model test)
- Material compatibility test: storage of selected tap-changer materials for 180 days in hot liquid
- Verification of diverter switching sequence (lubrication) at 130 °C liquid temperature
- Determination of lowest permissible operating temperature for cold start; verification of diverter switching sequence
- Mechanical endurance test on tap selector, 1.2 million operations (lubrication ⇨ contact wear)

It is obvious that the low market share of alternative liquids does not pay for this high effort to test every OLTC model in each liquid. Therefore, a simplified evaluation method has been developed, which allows a decision based on the hitherto existing experience with alternative liquids and additional data provided by the liquid manufacturer or initiator. At the beginning of the evaluation process, the range for the requested approval is defined:

- Definition of tap-changer models to be approved
- Applications to be approved (Special / Group / General)
- Expected volume (number of sellable units)
- Strategic importance

A questionnaire containing all requested information is then sent out to the liquid manufacturer / initiator. This catalogue requests a norm compliant Data Sheet, Safety Data Sheet, and all additional parameters listed in chapter 3.2/3.3. In case the customer is not able to provide all data or to draw a plausible comparison to known liquids, tests will be necessary. At this point, a cost estimation for the approval is set up, on which the bearing of costs can be agreed upon. Signing a Non-Disclosure Agreement (NDA) by both sides may be helpful to exchange confidential data. If an agreement can be made, tests will start, or an approval solely based on the provided data is granted.

6. CONCLUSIONS

Today, the knowledge about the dielectric performance of insulating liquids is incomplete, since the established standards do primarily define the quality parameters of the liquid itself, but less its performance in practical applications. Up to now, equipment manufacturers use their individual test procedures and processes to approve an unknown liquid. From a macroeconomic view, this appears inefficient. It is therefore desirable to harmonize test strategies by developing generally accepted methods which are easy to use. New CIGRE working groups, such as WG D1.77 [14], should strive to close the gaps identified in IEC TR 60076-26 and achieve a common understanding between liquid manufacturers, equipment manufacturers and users/operators. It is of outmost importance to create and introduce a common understanding and judgement for new liquids to overcome different opinions and discussions, which today arise from different viewpoints and individual test procedures. The aim is to approve an unknown liquid with as less effort as possible, but to respect all relevant parameters discussed above. Modern liquids can provide answers on current questions of our time like CO2 neutrality and biodegradability and so it is important to evaluate their possible use as insulating liquid. Their partially deviant behaviour (when compared to conventional mineral oil) calls for thorough testing – which needs standardization. If current liquid standards would specify limit values for all relevant parameters, admissible operating conditions of the various equipment could be ensured, and liquid manufacturers would be urged to develop only liquids with properties which stay within these limits. Missing test methods should be developed and standardized as well. This would simplify the approval process significantly.

Well-known liquid characteristics do safeguard the reliability and longevity of transformer and tap-changer, as appropriate design adaptations can be considered already in the design process. And last, but not least, utility and operator should be able to evaluate the liquid behaviour by meaningful test methods to assess the equipment condition during service.

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