IEC TR 60076-26

Edition 1.0 2020-03

TECHNICAL REPORT

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Power transformers –
Part 26: Functional requirements of insulating liquids for use in power transformers

IEC TR 60076-26:2020-03(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 29.180

ISBN 978-2-8322-8016-4

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC/TR 60076-26, which is a technical report, has been prepared by IEC technical committee 14, Power transformers.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
14/1010/DTR	14/1018/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60076 series, published under the general title *Power transformers*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

At the time of writing of this document, many new insulating liquids for power transformers are being offered by various suppliers. The end users of insulating liquids in power transformers assume that a particular liquid has been properly qualified to perform the functional requirements as a coolant and an electrical insulating liquid without failure for the expected lifetime of the specific device.

So far, there is no available IEC International Standard in the form of a roadmap that lays out the many requirements of liquids for use in power transformers, reactors and other high voltage equipment other than simply conforming to a liquid standard specification, as for example IEC 60296, IEC 62770 or IEC 61099.

In this document, the functional requirements of an insulating liquid that are considered necessary for use in a power transformer application, are assembled and listed in a structured manner. Detailed technical information on the individual requirements and their validation is purposely not given. This is because this document is intended to serve as a reference document for the transformer industry, including liquid suppliers as well as relevant scientific and technical bodies dealing with insulating liquids (materials).

Certain functional requirements of an insulating liquid are not independent from design aspects and materials in contact with the liquid. For example, dielectric withstand capability/testing and transformer systems ageing, widely require consideration of solid and liquid insulation materials together as a system. For transformers with tap-changers, additional requirements not yet included in standards are applicable.

To address this, a matrix of functional requirements, including their status of validation (testing) has been developed and is presented in this document. It is recommended to consider the requirements for any insulating liquid to be used in power transformers, including for example reactors, HVDC transformers.

The individual requirements (parameters) in the matrix are given a relevance index as to their importance for design and service. Furthermore, for each parameter the status of the method is indicated as

– already existing as an IEC/ISO International Standard,
– existing as an IEC/ISO International Standard that requires updating / extension, or
– does not exist as an IEC/ISO International Standard, thus would require future development.

Some of the identified tests are only available as ASTM or IEEE standards. Such tests, as well as missing tests, are recommended as future work items for the relevant CIGRE and IEC bodies.

The intention is for this document to be regularly updated based on results produced by the previously mentioned bodies. This will ensure the availability of prevailing information on the functional requirements of insulating liquids used in the transformer industry.

POWER TRANSFORMERS –

Part 26: Functional requirements of insulating liquids for use in power transformers

1 Scope

In this document, the functional requirements of insulating liquids that are considered necessary for use in power transformers, including, for example, reactors and HVDC transformers, are assembled and listed. A relevance index of importance for design and for service as well as the status of validation is given for all individual requirements (parameters). All parameters are assigned to one of the following categories:

– General (physical / chemical)
– Dielectric / Insulation
– Thermal / Cooling
– Ageing and Stability
– Liquid-solid system
– Material compatibility

The document is intended to serve as a general reference document for the transformer industry, including liquid suppliers as well as relevant scientific and technical bodies dealing with insulating liquids (materials).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Explanation of entries used for the categorization in Table 1 to Table 6

Name	Description
Functional category	The function of liquid in the power transformer including all its components. Some of the parameters can be assigned to several categories; they are however indicated only once, in the category considered as most representative.
General (physical / chemical)	Parameters that cannot be explicitly assigned to a specific functional category described in this document.
Dielectric / Insulation	The first primary function of liquids in power transformers is to act as a dielectric.
Thermal / Cooling	The second primary function of liquids in power transformers is to act as a coolant.
Ageing and Stability	Parameters indicating the ageing of the liquid.
Liquid-solid system	Parameters covering liquid interactions with other insulating materials in power transformers.
Material compatibility	Parameters verifying the compatibility of the liquid with all other materials found in the power transformer.
Parameter	A quantity or dimension that covers a specific functional requirement of liquids for use in power transformers. In some cases, the parameter is indicated with a set of quantities and/or explanations, for example, the "Handling and storage" parameter.
Relevance index	A rating of the parameter relevance (important, high, critical) considering the importance for the given utilization aspect. The index reflects indirectly the necessary parameter verification by a type or a routine test. The relevance index given is applicable for mainstream power transformers with U_m > 36 kV and may change for other power transformer types, such as for example distribution type transformers. Furthermore, for extreme environmental conditions, such as very high or low temperatures, the relevance index may have different values for certain parameters.
Design	Covers design, manufacturing, final acceptance test (FAT), transportation. Questions to ask: What is the importance of the parameter for completing the design? What is the impact of the parameter's variation to the design?
Service	Covers installation, operation, maintenance, monitoring, diagnostic. Questions to ask: What is the impact of the parameter's variation to the transformer operation? To what extent does the parameter determine the transformer condition?
IEC/ISO test method	Indicates the actual status of the parameter validation test methods. The status of the test method may not be the same for different types of liquid.
Yes	A proven IEC/ISO validation test method exists for the parameter.
Yes, update	An IEC/ISO validation test method exists for the parameter but needs improvement and/or optimization.
No	An IEC/ISO validation test method does not exist and therefore needs to be defined and/or developed.
Comments	Some details are provided for clarification purposes.
	The description and evaluation of parameters are primarily related to mainstream power transformers with U_m > 36 kV but may also apply for other transformer types. Comments contain references to existing standards, key aspects and additional information. Parameter verification methods given herein may apply for certain types of liquid only.

5 Maintenance

Owing to missing or non-updated tests for a significant number of parameters listed in this document at the time of its drafting, the intention is to regularly update it as further tests are developed.

6 Categorized functional requirements of insulating liquids

6.1 General (physical / chemical)

Table 1 – General (physical / chemical)

		Relevance index Critical (3) High (2) Important (1)		IEC/ISO test method			Comments
Functional category	Parameter	Design	Service	Yes	Yes, update	No	
General (physical / chemical)	Density	2	2	X			ISO 3675 or ISO 12185; temperature dependency (plot vs temp); floater-operated instruments.
	Vapour pressure	1	1	X			ISO 3007, temperature dependency.
	Water content	2	3	X			IEC 60814; relative moisture content % of saturation.
	Moisture solubility	2	2			X	Temperature dependency, changes with degree of ageing.
	Flash / Fire point	1	2	X			ISO 2592, ISO 2719; "High" for less-flammable application and service.
	Acidity	1	2	X			IEC 62021-1, IEC 62021-2, IEC 62021-3
	Gas solubility	1	2			X	For example, N2, O2, H2 and C-, C2- and C3-hydrocarbons, ASTM D2779.
	Gassing tendency	2	2		X		IEC 60628, Method A; relevant for dielectrics.
	Lubricity	2	2			X	ASTM D4172; DIN 51350; relevant for tap-changer operation and pumps.
	Foaming	2	3	X			ISO 6247; relevant for oil processing (degassing).
	Additive consumption	2	3		X		IEC 60666; different performance improvement additives (antioxidants, pour-point depressants, electrostatic charging tendency depressant, metal passivator or deactivators, antifoam agent, refining process improver, etc.) can be present in liquid and it is important to know them and follow up their consumption (ageing).
	Fault gas evolution characterization	3	3			X	IEC 60599, IEEE Std C57.104, IEEE Std C57.155; a test that is used to characterize a new type of liquid's DGA approach and tools.
	Atmospheric exposure	3	3			X	For how long and under which conditions liquid can be exposed to atmosphere (oxidation, moisture uptake, thin film on impregnated surfaces, etc.).
	Biodegradation	1	2			X	OECD 301 B, C, F methods; becomes critical for environmentally sensitive applications (e.g. off-shore).
	Toxicity and carcinogenicity	1	2			X	OECD 201 to 203; REACH compliance, AMES test, IP 346, ECHA, etc.
	Lifecycle and sustainability	1	2		X		ISO 14040; BEES 5.0 test method; can liquid be re-used after transformer end of life?
	Handling and storage	1	2			X	Standard procedures with instructions. Covers also storage of impregnated active part without liquid in tank.

6.2 Dielectric / insulation

Table 2 – Dielectric / insulation

Functional category	Parameter	Relevance index: Design	Relevance index: Service	IEC/ISO test method: Yes	IEC/ISO test method: Yes, update	IEC/ISO test method: No	Comments
		Critical (3) / High (2) / Important (1)					
Dielectric / Insulation	AC dielectric strength	3	3		X		IEC 60156; extend IEC 60156 to cover relevant design breakdown strength over range of gaps and for diverse electrical field inhomogeneity to meet the requirements of IEC 60076-3.
	Lightning impulse strength	3	2		X		IEC 60897; relevant for design is breakdown strength over range of gaps and for both polarities. Following IEC 60076-3, the LI test can be type or routine, based on U_m.
	Switching impulse strength	3	2			X	Could be similar to IEC 60897; relevant for design is breakdown strength over range of gaps and for both polarities. Following IEC 60076-3, the SI test can be special or routine, based on highest voltage U_m.
	DC dielectric strength	3	2			X	Liquid has to be proven for HVDC transformer application as required by IEC/IEEE 60076-57-129.
	PD behaviour	3	3		X		IEC TR 61294; at power frequency, includes inception, extinction and phase resolved pattern. Requirements for transformer testing according to IEC 60076-3.
	Discharge acceleration voltage	3	1			X	Under impulse voltage, both polarities. Describes streamer propagation, including discharge acceleration voltage.
	Permittivity	3	2	X			IEC 60247; basic design parameter.
	DDF / PF	2	3	X			IEC 60247 or IEC 61620
	Electrostatic charging tendency (ECT)	2	2			X	CIGRE TB 170. Transformer-type and cooling-type dependent. Interaction between liquid and different solid insulation is relevant (cellulose, epoxy, aramid, etc.).
	Creepage breakdown strength	3	1			X	Discharge behaviour (propagation) on surface interface between liquid and solid insulation.
	Puncture breakdown strength	3	1		X		IEC 60243-1; breakdown strength of impregnated solid insulation
	Electrical resistivity / conductivity	3	2		X		IEC 60247; HVDC application CIGRE TB 646; temperature and electric field dependency.
	Permittivity impregnated solids	3	1		X		IEC 60250; permittivity of solid insulation impregnated with a given liquid.
	Arcing	2	2			X	Tap-changer application; arc quenching capability and contamination generated by switching arc.
	Parameters influencing dielectric strength	2	3		X		IEC 60156, IEC 60814, IEC 60599, IEC 61125, IEC 60970, ISO 4406; increase of moisture, gases, degree of oxidation, particle content or contamination decrease liquid breakdown strength. Increased temperature improves breakdown strength. At very low temperatures (close to pour point) breakdown strength of liquid decreases.

6.3 Thermal / cooling

Table 3 – Thermal / cooling

		Relevance index Critical (3) High (2) Important (1)		IEC/ISO test method			Comments
Functional category	Parameter	Design	Service	Yes	Yes, update	No	
Thermal / Cooling	Viscosity	3	3	X			ISO 3104; Stabinger method, low-temperature viscosity IEC 61868; temperature dependence
	Cold start	2	2			X	Low-temperature performance. Tap-changer start sequence recommendations. Cold and hold procedure (time and volume effect). LCSET in IEC 60296.
	Specific heat capacity	3	1			X	ASTM D2766; temperature dependence (at least 3 temperatures) DSC test methods are applicable.
	Thermal conductivity	3	1			X	ASTM D7896; temperature dependence (at least 3 temperatures)
	Thermal expansion coefficient	2	1			X	ASTM D1903, density data can be used to calculate TEC.
	Pour point	2	2	X			ISO 3016; Consider the cold and hold pour point after 72 h. Consider hysteresis.
	Cloud point	2	2	X			ISO 3015; consider the cold and hold cloud point after 72 h. Consider hysteresis.
	Cooling / heat transfer	2	1			X	Important for contacts in tap-changers, bushing leads, windings and current leads.

6.4 Ageing and stability

Table 4 – Ageing and stability

		Relevance index Critical (3) High (2) Important (1)		IEC/ISO test method			Comments
Functional category	Parameter	Design	Service	Yes	Yes, update	No	
Ageing and stability	Liquid ageing marker characterization	1	2	X			From the perspective of characterization of a new liquid: observation of acid production, DDF, IFT and other proxy changes to evaluate liquid condition.
	Oxidation stability	3	3	X			IEC 61125 recently updated (2018).
	UV stability	1	2			X	Light exposure stability during storage and handling.
	Thermal and hydrolytic stability	1	2		X		Thermal class of liquids shall be aligned with thermal classes defined by IEC 60076-14. Consider coking of tap-changer contacts due to reaction with metals. Consider formation of acids.
	Stray gassing	2	3			X	CIGRE and IEC bodies are looking for new test methods.