ABSTRACT

The EU's minimum energy performance standards differentiate power transformers by rated power, rated voltage and technology. The first two are self-evident and performance-based. This article addresses whether technology is pertinent as a differentiator. The main differentiation is between liquid-filled and dry-type transformers. Higher losses are considered acceptable for dry-type transformers to compensate for their ability to fulfil certain requirements. This technology-based concession has resulted from its historical development but hampers innovation and creates unfair competition. Differentiation to avoid excessively high costs is reasonable, but a better approach would be to formalise the concession for all transformers meeting the same requirements.

KEYWORDS:

regulation, standardisation, technology neutrality, fire performance, innovation

Angelo BAGGINI

Technology neutrality in power transformer regulation and standardisation

A proposal for a general approach

1. Introduction

Technical solutions to improve the energy performance of power transformers are mature and commercially available. They are driven by minimum energy performance standards (MEPS) mandated by policy measures in major countries and regions around the world. This article analyses some of the implicit assumptions in these policy measures, which have resulted in the variation in MEPS for different types of power transformers.

2. Current regulations and standards

The electrical power sector is characterised by its many technical standards and legislative regulations. Their number and importance continue to increase due to the greater attention given to the environmental impact of human activities and the growing share of electricity in the energy mix.

2.1 Legislative regulation

Every major economy worldwide has policy measures in place to promote the use of energy-efficient power transformers through MEPS, high-efficiency performance specifications (HEPS), energy labelling, the Chinese JB/T standard, or the Japanese Top Runner programme. MEPS apply to every power transformer on the market. Utilities and other customers may decide to purchase transformers

Every major economy worldwide has policy measures in place to promote the use of energy-efficient power transformers through MEPS, high-efficiency performance specifications or energy labelling

IEC TS 60076-20:2017(E) states its objective as: 'to promote a higher average level of energy performance for transformers' due to the 'need for energy saving and reduction of the emission of greenhouse gases'

with higher performance levels, but cannot purchase units below MEPS. HEPS promote higher performance levels, but do not set a minimum standard, so customers may still purchase a transformer with energy performance levels below the HEPS.

The US Department of Energy (DOE) has set mandatory energy efficiency standards for distribution transformers [4] covering liquid-filled and dry-type units, both single-phase and three-phase, rated at 60 Hz frequency and a primary voltage of 34,500 V or less. The power ratings are set between 10 and 2,500 kVA for liquid-immersed units and between 15 and 2,500 kVA for dry-type units. In this respect, the DOE has established the following in the Code of Federal Regulation (CFR):

- 10 CFR Part 431 – Energy Efficiency Program for Certain Commercial and Industrial Equipment. These regulations include energy conservation standards and test procedures for distribution transformers;
- 10 CFR Part 429 – Certification, Compliance, and Enforcement for Consumer Products and Commercial and Industrial Equipment. These regulations cover statistical sampling plans, certified ratings, certification reports, record retention, and enforcement.

MEPS refer to 10 CFR 431 and are differentiated by rated voltage, rated power and technology [5].

The European Commission adopted Regulation (EU) No. 548/2014 [2] on 21 May 2014, which implemented Directive 2009/125/EC on Ecodesign for small, medium, and large power transformers. The regulation applied to transformers put into service from 1 July 2015 and purchased after 11 June 2014 with a minimum power rating of 1 kVA, designed for a frequency of 50 Hz and used in transmission and distribution networks or in industrial applications. Energy performance requirements have been defined according to the types of transformers identified in the regulation. The Ecodesign MEPS are introduced in two phases, the first set of requirements entering into force on 1 July 2015 and the second, more stringent set of requirements on 1 July 2021. The main basic MEPS are based on the IEC 60076 series of standards and are differentiated by maximum voltage (Um), rated power, and technology [1]. Article 7 of the Amending Regulation 2019/1783 [3] mandated a review no later than 1 July 2023 to address a series of issues, including 'the possibility to adopt a technology-neutral approach to the minimum requirements set out for liquid-immersed, dry-type and, possibly, electronic transformers'.

2.2. Technical standardisation

The current legislative regulations addressing power transformers are based on applicable technical standards resulting from historical development. The expanding range of transformer technologies meant that new standards were added to ensure that all types were covered. As a consequence, standards are structured by technology, as are the regulations based on those standards. This has led to differences in the regulatory approach and minimum energy performance requirements depending on the transformer technology.

The set of international standards covering power transformers is published under IEC 60076. It is prepared and maintained by IEC Technical Committee 14, which is responsible for standards for power transformers, tap-changers, and reactors for use in power generation, transmission and distribution. The IEC convened a technical committee to develop a guiding specification on energy performance levels for power transformers. The published specification, IEC TS 60076-20:2017(E), states its objective as: 'to promote a higher average level of energy performance for transformers' due to the 'need for energy saving and reduction of the emission of greenhouse gases'. It proposes three methods of evaluating a transformer's energy performance:

- the Peak Efficiency Index (PEI), which implicitly minimises the Total Cost of Ownership (TCO);
- the no-load and load losses at rated power, mainly leading to an efficiency optimisation of transformer cores and coils for units produced in large volumes; and
- the efficiency at a defined power factor and particular load factor (typically EI50, i.e. at 50 %).

Each method is then further specified with reference to IEC and IEEE practices, resulting in a total of 2 x 3 = 6 alternative methods. In the technical specification, the IEC recommends two levels of requirements for each of these methods. Level 1 relates to basic energy performance, and level 2 relates to high energy performance.

3. Main MEPS comparison

As discussed in the previous paragraph, current MEPS are different depending on the transformer technology. The main difference reflected in the MEPS is based on whether transformers contain liquid insulation or not. Table 1 compares the required energy performance of corresponding dry-type and liquid-filled transformers, as stipulated in Regulation (EU) No. 548/2014. It shows the ratio between maximum-load losses and no-load losses allowed for dry-type transformers and those allowed for liquid-immersed transformers under Tier 1 and Tier 2 of Regulation (EU) No. 548/2014. The figure ranges between 0.8 and 2.86.

4. Need for a technology-neutral approach

The absolute values of minimum energy performances were set based on preparatory studies analysing the available technologies, market needs, and the current population of power transformers (for an example of an EU preparatory study, see [7]).

MEPS required for power transformers decrease with voltage and increase with rated power. In case of increasing voltage, this approach balances the increase in unit dimensions and weight due to the additional need for electrical insulation. In case of decreasing rated power, it balances the relative increase in manufacturing material required to achieve energy savings. In the author's view, this type of differentiation is needed since it balances the various performance requirements. Under the current regulation, however, MEPs imposed on liquid-filled power transformers also differ from the ones imposed on dry-type units for the same voltage and rated power. This approach was recommended in the preparatory studies with the aim of avoiding excessively high costs where specific performance levels – such as fire-safe behaviour and leak-proof design – were required. Higher losses were accepted to facilitate the alternative design or technology needed to achieve these performance levels. While this aim was reasonable, the mitigation of MEPS, as currently formulated, applies only to dry-type technology instead of being formalised for all transformers exhibiting the requisite performance, no matter the technology used. Dry-type technology was probably the only technology available for achieving the required fire behaviour at the time when the regulatory process started.

MEPs imposed on liquid-filled power transformers differ from the ones imposed on dry-type units for the same voltage and rated power

By taking a technology-based approach for a goal that is, in principle, performance-based, unfair competition between technologies was introduced.

Most power transformers manufactured today are made of conventional materials and fit into the current approach, but the electrical energy sector in general, and power transformers in particular, are expected to see significant changes in the near future:

- New technologies are emerging or are expected to emerge, providing the same performance that had been exclusive to one particular technology until recently. Examples include electronic power transformers and ester-insulating liquids.
- There is now a greater focus on performance factors other than energy

Table 1 – The ratio between maximum-load losses and no-load losses allowed for dry-type transformers under Tier 1 and Tier 2 of Regulation (EU) No 548/2014, and those allowed for liquid-filled transformers (ref. single- or three-phase, 50 Hz, 2 windings, MV Um ≤ 24 kV, LV Um ≤ 1.1 kV, OLTC range ≤ 5 %).

Rated power	Tier 1		Tier 2	
IEC 60076-1	Load losses	No-load losses	Load losses	No-load losses
kVA	W	W	W	W
≤25	189%	286%	250%	286%
50	155%	222%	200%	222%
100	117%	193%	144%	194%
160	123%	190%	149%	190%
250	117%	173%	145%	173%
315	--	--	--	--
400	120%	174%	138%	174%
500	--	--	--	--
630	117%	183%	154%	183%
800	95%	200%	133%	200%
1	86%	201%	118%	201%
1.25	100%	189%	116%	189%
1.6	93%	183%	108%	183%
2	89%	179%	107%	179%
2.5	86%	177%	103%	177%
3.15	80%	173%	96%	173%

The ISO/IEC Directives formulated the performance principle: 'whenever possible, requirements shall be expressed in terms of performance rather than design or descriptive characteristics like a technology'

efficiency, including sustainability, fire behaviour, noise, maintainability, and material efficiency and recyclability.
- Minimum performance levels are updated continuously, becoming increasingly demanding.
- New, special application areas, such as smart grids, are appearing on the market.

A regulation which limits concessions to only some technologies hampers innovation. Manufacturers are discouraged from developing alternative technologies to achieve the required performance because these technologies are artificially disadvantaged by law. To avoid such market distortion, the ISO/IEC Directives formulated the performance principle: 'whenever possible, requirements shall be expressed in terms of performance rather than design or descriptive characteristics like a technology' [6, chapter 5.4].

A classic example revealing the consequences of neglecting this principle is the design of castor-wheeled and swivelling office chairs. In the 1950s, when these products came on the market in greater volumes, stability was a concern. When using four-legged office chairs especially, users tended to tip the chair over when reaching for something. The test standard did not design a stability test for office chairs. Instead, it simply prescribed that all castor-wheeled office chairs should have five legs. But this inevitably stifled any innovative ideas for alternative ways to resolve the stability issues, and, in fact, there has been no innovation in this field since.

Conversely, if mobile phone standards had limited their application to wireless phones with physical buttons, the smartphone would never have entered the market.

The concession of allowing higher energy losses was a way of facilitating another equally important performance factor and must therefore not be abandoned but rather reformulated.

To follow the technology-neutral principle in the case of fire behaviour, to give just one example, the following actions would be required:

- Defining "a transformer with increased fire safety" in an unambiguous, technology-neutral way, for example as a power transformer in which flammability is restricted and the emission of toxic substances and opaque smoke is minimised.
- Developing technical standards that set maximum levels of flammability, emission of toxic substances and opaque smoke, as well as corresponding tests[1] covering all the technologies.

Currently, such a standard is available only for dry-type transformers. This would continue to be, for the moment, the only transformer type to benefit from energy performance concessions in the proposed new regulatory system. However, by naming and defining this class of concession based on how it performs rather than the technology on which it is based, a historical error would be rectified, and potential future innovation would not be hampered.

A similar approach would have to be followed for other aspects of performance where:

- modified design or technology is required;
- combining the modified design with minimum energy performance levels (and, in the future, possibly with other Ecodesign requirements such as material efficiency) is technically impossible or would be too costly.

[1] For the present, available in the power transformer sector, IEC 60076-11:2018 Power transformers - Part 11: Dry-type transformers.

In general, this technology-neutral approach should be used to balance Ecodesign requirements with other performance factors. It should be taken into account when evaluating the adequacy of all upcoming regulatory documents and technical standards[2]. The choice of performance factors to be included would first require rigorous investigation and diligent deliberation and might include – but not necessarily – fire-safe behaviour, internal arc safety, leak-proof design, and noise restriction, among others.

A technology-neutral approach and harmonised test procedures facilitate technological innovation and provide fair trade conditions. Well-designed regulations and standards encourage trade, the execution of conformity assessments, performance level comparisons, technology transfer, and the adoption of best practices. Governments, as much as manufacturers, stand to gain from neutral, harmonised, consistent, and stable standards. Benefits to governments include:

- lower development costs for test methods;
- comparative test results;
- the ability to incorporate innovative technical solutions;
- reducing the number of exceptions in regulations;
- the ability to adopt a common set of upper thresholds that can be used for market pull programmes, such as labelling and incentive schemes; and
- faster and less costly testing – for compliance and other purposes — since harmonised testing leads to a wider range of laboratories able to conduct product testing.

For manufacturers, having one harmonised test method with specified measurement uncertainties used by markets around the world will reduce testing costs associated with demonstrating regulatory or product labelling compliance. In an ideal world, every manufacturer would always conduct exactly the same tests in exactly the same way, and the results would be universally accepted as being accurate and representative of the performance of their product. A harmonised test method also means they can look forward to long-term rewards for innovative product designs.

A technology-neutral approach and harmonised test procedures facilitate technological innovation and provide fair trade conditions

Having a consistent test method encourages national governments to establish harmonised energy efficiency thresholds broad enough to encompass all current market circumstances, as well as aspirational efficiency thresholds as pointers for future market development.

Table 2 illustrates a possible scheme for implementing a technology-neutral approach.

As can be seen, MEPS could be defined based on the requisite performance, not on the technology itself. A given performance can be provided by multiple technologies. The market will deliver all those technologies which comply with both the requisite performance and the required MEPS level while offering the right attributes to the user (cost, lifespan, maintenance…).

Table 2. Scheme for a possible technology-neutral approach

Requisite performance	MEPS	Applicable technologies
No particular requirement	Level 1	Liquid-filled, dry-type, and other emerging technologies
Fire performance without the presence of people	Level 2	Dry-type and other emerging technologies
Fire performance/explosion proof (involving the presence of people)	Level 3	Dry-type, other emerging technologies
No environmental damage in case of leakage	Level 4	Ester-filled, dry-type, and other emerging technologies
Low noise	Level 5	Oil-filled, ester-filled, dry-type, and other emerging technologies
…	…	…

5. Conclusions

The analysis demonstrates that:

- current legislative regulations addressing power transformers are based on applicable technical standards;
- these technical standards have been developed on a technology basis;
- this approach was adopted based on preparatory studies analysing the available technologies, market need, and the existing population of power transformers and aimed to avoid the disproportionately higher cost in cases where particular aspects of performance – such as fire-safe behaviour and leak-proof design – were required;
- this aim was reasonable, but the way the mitigation was formalised introduced a technology bias;
- energy performance requirements are

[2] From "ISO/IEC GUIDE 77-2:2008 Edition 1.0 (2008-09-01): Guide for specification of product properties and classes - Part 2: Technical principles and guidance / Introduction": "The capability to characterize products in an abstract way, independently of any particular manufacturer, is a fundamental aspect of engineering knowledge. Such a characterization is done by the name of a category of products that fulfils the same function, […]. Such a category is called a characterization class. This first level of characterization is further detailed by means of some property-value pairs, which describe more precisely the target product within its characterization class. Examples of such properties are inner diameter, threaded length and capacitance."

The market will deliver all those technologies which comply with both the requisite performance and the required MEPS level while offering the right attributes to the user (cost, lifespan, maintenance…)

reduced for only one particular technology instead of these lower requirements being formalised for any transformers providing the required performance, no matter the technology used.

In the context of legislative regulations and technical standardisation of power transformers, the approach should be updated to one that is technology-neutral.

- MEPS should be differentiated based on other performance attributes of the unit;
- Performance should be classified in a technology-neutral way;
- A harmonised way to test each performance aspect should be developed.

This will:

- stimulate innovation;
- prevent unfair competition between technologies included in the legislation;
- define the limits and application domains of exemption categories;
- avoid major deployment of applications that escape standards and create an unfair market.

Adopting a technology-neutral approach to transformer MEPS is mentioned among the aspects to be considered in the upcoming review of EU Regulation No. 548/2014. To develop such an approach for the case of fire behaviour, to give just one example, the following actions would be required:

- Defining "a transformer with increased fire safety" in an unambiguous, technology-neutral way, for example, as a power transformer in which flammability is restricted and the emission of toxic substances and opaque smoke is minimised;
- Developing technical standards that set maximum levels of flammability, emission of toxic substances and opaque smoke, as well as corresponding tests covering all the technologies.

Such a standard is currently only available for dry-type transformers. This would continue to be, for the moment, the only transformer type to benefit from energy performance concessions in the proposed new regulatory system. However, by naming and defining this class of concession based on how it performs rather than the technology on which it is based, a historical error would be rectified, and potential future innovation would not be hampered.

A similar approach would have to be followed for other aspects of performances where:

- modified design or technology is required;
- combining the modified design with minimum energy performance levels (and, in the future, possibly with other Ecodesign requirements) is technically impossible or would be too costly.

In general, this technology-neutral approach should be used to balance Ecodesign requirements with other performance factors. It should be taken into account when evaluating the adequacy of all upcoming regulatory documents and technical standards. The choice of performance factors to be included would first require rigorous investigation and diligent deliberation and might include – but not necessarily – fire-safe behaviour, internal arc safety, leak-proof design, and noise restriction, among others.

Bibliography

[1] IEC 66076 series – Power transformers

[2] Commission Regulation (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers

[3] Commission Regulation (EU) 2019/1783 of 1 October 2019 amending Regulation (EU) No 548/2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers

[4] EN 50708 series: "Power transformers - Additional European requirements"

[5] DOE 78 FR 23335: "Energy Conservation Program: Energy Conservation Standards for Distribution Transformers"

[6] ISO/IEC Directives, Part 2:2018, edition 8.0 (2018-05) "Principles and rules for structure and drafting of ISO and IEC documents"

[7] Lot 2 Ecodesign Preparatory Study for small, medium and large power transformers, https://transformers.vito.be/

PEER REVIEWED

Authors

Angelo Baggini has a PhD in electrical engineering in the University consortium of Pavia, Pisa, Cagliari, Firenze (Italy) in 1997. He is an aggregate professor of Electrical Engineering at the University of Bergamo (Italy) and an international consultant in the electrical energy sector (ECD Pavia Italy). Since 2013 he has been chairman of Cenelec TC14. He started his research work both in CESI Metrological Lab in Milan and in the Electrical Engineering Department of the University of Pavia, focusing on EMC and PQ aspects of electrical measurements and electrical machines. Author of over 200 technical and scientific papers and PQ Handbook (2008) and Electrical Energy Efficiency (2012), both published by Wiley and Sons. Prof. Baggini is a member of IEC TC14, convenor of IEC TC14 AHG35, and chairman of CEI TC97.