

Circular Economy: Contribution to material efficiency applied to transformers

1. Key Message

Circular economy is about saving and using resources in a more sustainable way, by the reuse, repair, refurbishment and recycling of products and materials in an (almost) closed loop, while utilizing energy and resources efficiently and reducing waste to a minimum. Circular economy could reduce negative impacts on the environment, give opportunities for secondary raw materials and in the end it should increase competitiveness and innovation.

Power transformers have very long life times and there are extensive markets for the refurbishment of transformers whilst they are invariably recycled at end of life. This paper explains how power transformers currently address the requirements of materials efficiency.

T&D Europe requests that JTC 10 ensures that the standards developed under Mandate 543 take account of the particular position of power transformers, which have extremely long life and currently many of the objectives of the Material Efficiency Mandate. T&D Europe looks forward to supporting JTC 10 in developing standards that enhance the current compliance of transformers and extending this to meet the full requirement of the Mandate whilst not introducing unnecessary requirements.

2. Introduction

This document covers transformers used in the electrical transmission and distribution systems. Such transformers can be segmented according to their application :

- Distribution Transformers are installed by a Distribution System Operator (DSO) or end-user and most often provide a connection to the Low Voltage distribution grid (230/400 VAC). These transformers include those used for connecting Distributed Energy Resources (DER) such as wind turbines.
- Transformers installed by a Transmission System Operator are also referred as Power Transformers. They are used in the Medium Voltage (MV) and/or High Voltage (HV) grid.

According to EN 60076-1 Power transformers are in general terms considered as transformers (including auto- transformers) above 1 kVA single phase and 5 kVA three phases.

Power Transformers are a combination of several raw materials. The main components are magnetic steel, aluminum, copper, resin, carbon steel, cellulose, insulation liquids and are already optimized for a long-life cycle, whilst complying with Eco-Design Directive No 548/2014.

The durability, repairability, recyclability, waste, are already fully embedded by design in the current industry practices covered by European and International standards. A circular economy business model has existed for transformers for many years thanks to the high-level requirements of utilities and innovative responses provided by manufacturers.

3. Target of the mandate

The European Commission issued Mandate 543 in December 2015 and requested that CEN/CLC would develop standards to meet the following objectives:

Objectives for the standardisation work

This standardisation request is linked to the following material efficiency aspects:

- a. Extending product lifetime.
- b. Ability to re-use components or recycle materials from products at end-of-life.
- c. Use of re-used components and/or recycled materials in products

European standards prepared on the basis of this standardisation request shall take into consideration the aspects listed in the first subparagraph. They shall also cover aspects such as, upgrade-ability, ability to extract key components for reuse, repair, recycling and treatment; calculation of recycled and re-used content in products; methods to identify components by e.g. their environmental impact; reporting formats; reusability, recyclability and recoverability indices

4. Transformers and Ecodesign directive

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 scope: power transformers with a minimum power rating of 1 kVA used in 50 Hz electricity transmission and distribution networks or for industrial applications.

Requirements: Energy efficiency requirements formulated as load losses level and peak efficiency indexes.

Standards are available since 2015: EN 50588-1:2015 for medium power transformers and EN 50629:2015 for large power transformers. These standards were cited as harmonized in the OJEU in September 2015.

This regulation is under review and the corresponding study is finished. It was underlined that:

“However, the existence of a market for the upgrade, repair, refurbishment and retrofitting of transformers makes it necessary to provide guidance on the circumstances under which a transformer that has undergone some or all of those operations can be considered a new product and must therefore comply with the minimum energy performance requirements set out in Annex 1 of the Regulation.

The consultation document is proposing this year to consider the feedback given by stakeholders, including CENELEC Technical Committee 14, to the review study that should be ready in 2019 in order to provide further clarity on this question”

The purpose of this contribution is to give the position of T&D Europe taking into account the last development on material efficiency concepts inside JTC10.

5. Transformers’ durability

5.1. Concepts

A **durability assessment** is an analysis of the equipment’s responses to the stresses imposed by operational use, maintenance, shipping, storage and other activities throughout its specified life-cycle in order to estimate its predicted expected life taking into account the reduction of life time due to operation outside rated parameters.

As the definition indicates, the results of a durability analysis are stated in expected time, cycle, distance to achieve a limiting state due to a failure (failure, wear-out failure, deviation of an analogue function, ...) rather than as a failure rate or MTTF which is standard expression when defining a reliability.

5.2. What does it mean for transformers?

Electrical T&D grids have existed for more than 100 years. Transformers manufacturers have accumulated a strong return of experiment, through successive generations of transformers under real operating and environmental conditions of use in T&D grid.

Parameters for durability for transformers

For transformers, the assessment of durability is linked with thermal aspects, dielectric aspects and to short-circuits and other unexpected events:

- **Thermal aspects**

The thermal aspects are well mastered during the design process where IEC international rules for use of components are relevant and in compliance with the use of the raw material inside the transformers: liquids, insulation, resin,....(IEC60076-2,IEC60085,IEC61100).

The thermal behaviour is the major point for the ageing of the transformers installed under the rules of the art.

The evaluation of thermal aspects on the transformers is under the rules of IEC standards (Loading guide) that consider the relevant factors like Ambient, Load cycle, ... (IEC60076-07 IEC60076-12). These guides give an expected life duration.

- **The Dielectric, short-circuits and unexpected environmental events**

The dielectric aspect doesn't lead to the ageing of the transformers, when transformers are designed with correct rules. Tests given by IEC standard allow to ensure the reliability of the transformers (IEC60076-01, IEC60076-3,IEC60076-11. Another aspect is the ability to withstand short-circuits (IEC 60076-5). Failures can come only as accident events.

Unexpected events can come from definition aspects, environmental aspects (Climate, water drop, wind....), use aspects, ... and can generally lead to accident and not to an ageing.

- **Expected life duration**

The following table defines some values regarding the life span of the transformers under three angles.

The average life span in years, following the standard, is a calculation based on the life duration of the insulation in the nominal conditions of use: continuous full load and normal conditions of services. However, these conditions are only for a niche of applications. For most of the transformers, the load is far away of the maximum and the ambient varies in general under the standard values allowed a longer life duration. The last standard written, considers for life span, the insulation with the hot spot, moisture, kind of paper, and give a value around 20 years.

Regarding the maximum known, some transformers are still in function since more than 50, even 80 Years. But these transformers remain costly in term of usage cost and with a risk in

term of reliability. However, It is usual to say that the life duration for transformers is around 40 years, because this value was in the previous standard.

Type of transformer	Average life span in years following standards	Defined conditions	Maximum known
Medium power transformer' means a power transformer with a highest voltage for equipment higher than 1,1 kV, but not exceeding 36 kV and a rated power equal to or higher than 5 kVA but lower than 40 MVA	Around 20Years at full load following*	EN60076 Series IEC60076-07 IEC60076-12	Over 50 Years
Large power transformers means three-phase and single-phase power transformers with a highest voltage for equipment exceeding 36 kV and a rated power equal or higher than 5 kVA, or a rated power equal to or higher than 40 MVA regardless of the highest voltage for equipment	Around 20Years at full load*	IEC60076-07 IEC60076-12	Over 80 Years

Note: * Average life span in years following standards is given at continuous full load and normal conditions of services

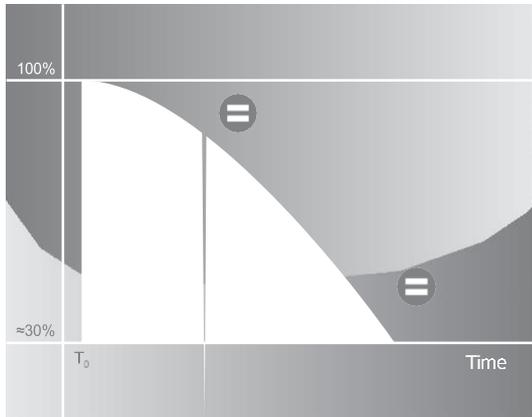
Conclusion:

Transformers are designed to operate for more than 20 years and have a proven lifespan of more than 30 years. Rules to achieve the life duration of the components as well as the transformers are defined by international transformers' standards.

6. Transformers and repair, maintenance, upgrade, retrofit, etc.

6.1. Concepts

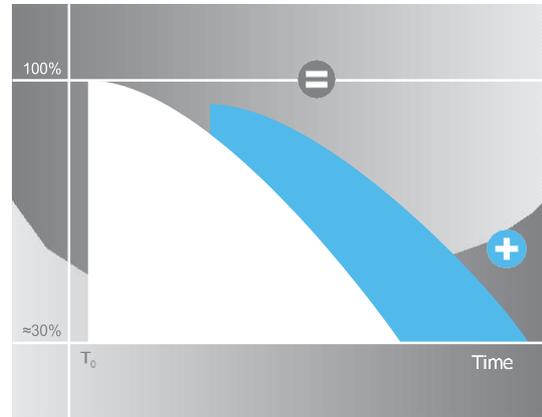
European manufacturers have developed concepts adapted to their services activities for utilities in the Energy Transport & Distribution sector, i.e. electrical energy grids. The following diagrams with performance / Time axes demonstrate quickly how the different concepts impact the products:



Repair

This action restores performances after a limiting event without increasing life span

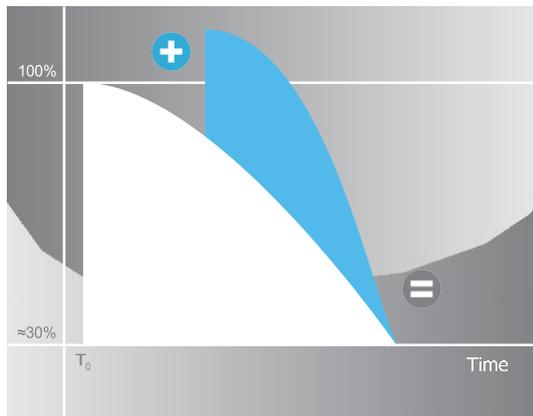
Performance = life span =



Refurbishing

This preventive action aims at increasing life span of equipment with the same level of performances.

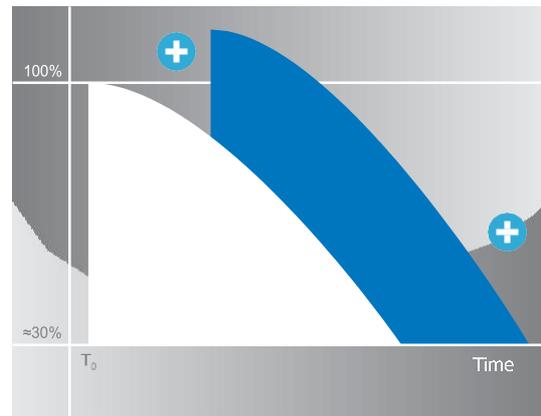
Performance = life span +



Upgrade

This action increases performances through additional functionalities or operating optimization linked to software or hardware changes without increasing life span

Performance + life span =



Retrofit

This action consists in replacing critical or used organs by new generation equipment, in order to increase life span and improve performances.

Performance + life span +

Within the context of circular economy, environmental protection and health and safety safeguard, it is not enough to analyze performance versus time. In European Union, products shall meet requirements to protect environment and health within Chemical regulations such as REACH and energy efficiency improvement under Ecodesign directive. Therefore, the whole environmental assessment can be carried out only after a functional analysis describing and

classifying all functions. The described functions inside this clause complete the functions already covered by the regulations.

The following table describes the different impacts according to definitions as discussed inside JTC10:

- Placed on the market: a product may stay under the same ownership or be sold as used or new product in the European market,
- Performances changed: main functions expected from the product may remain the same, be up- or downgraded,
- Life span extended: according to parts changed and conditions of use, life span may be extended,
- New product: the product resulting from the process may be considered as still the same and named “used product” or become a new product as explained in the Blue Guide.
- Compliance with REACH: REACH regulation is a complete regulation aiming to protect against chemical risks applicable to all substances and articles, but evolving permanently according to the last technical and scientific available data. Therefore, the compliance is linked with a timeframe.
- Compliance with Ecodesign existing regulation: the example of existing regulation on transformers is used to illustrate existing energy savings regulations.

Concept	Placed on the market	Performances changed	Life span extended	New product	REACH compliance	Compliance with EU 548/2014 required
Repair	No	No	No	No	Origin date	No
Refurbishing	No	No	Yes	No	Origin date	No
Upgrade	No	Yes	No	No	Origin date	No
retrofit	Maybe	Yes	Yes	No	Origin date	No
remanufacturing	Yes	To be defined	Yes for components	Yes	Date of new product	Yes
Replacement by a new one *	Yes	To be defined	No	Yes	To be defined	Yes

* in this case, the status of both products should be determined : what happens to the product replaced, which replacement product is made available a new one or a used one?

6.2. Application to transformers

Frame of the repair operation

Transformers' manufacturers have prepared some rules for repair and refurbishment. The EU Eco-design regulation will provide rules for repair in the revision 2021 in compliance with most of the stakeholder points of view. The European Commission is ongoing to define the rules to repair the transformers taking into account the operations to be achieved to repair this transformer.

- When it is considered that a “repaired/refurbished/upgraded/retrofitted” transformer can be **considered a new product**: minimum energy efficiency requirements and product information requirements set out in Annex 1 of the Regulation shall be applicable.
- Power transformers on which “routine repair” operations are performed shall not be considered as having been “repaired/refurbished/upgraded/retrofitted”, and therefore shall not be considered as new products. The “routine repair” operation are limited to the following operations.

In most cases, transformers are indefinitely repairable because of their design, their components and their manufacturing process. Considering this statement, the EU Commission decided to limit reparability in order to encourage the application of Energy Efficiency regulation.

Routine repair operations

- **“Routine repair” operations include in particular following:**
 - Replacing all coils on a specific leg in a three-phase transformer,
 - Replacing one winding of a three-phase transformer, when the other original windings are kept unchanged,
 - Fixing/replacing limited number of core sheets, involving no more than 20% of the core weight,
 - Drying and pressing the active part,
 - Repairing leakages, corrosion protection,
 - Replacement of the tap changer, of the bushings and of the complete insulation.

Those rules were originally developed in October 2015.

It demonstrates that general rules cannot be directly applicable to products, as there is a need for systemic assessment of all dimensions to be taken into account:

- A long life span product: average of 40 years,
- An energy efficiency target between 10 and 40 years according to the user,
- An environment & health target linked with the life duration and the end of life,
- An existing high level of reparability & upgradability.

That is why it is necessary to define systemic global targets at the product range level.

Conclusion:

The reparability of transformers is already proven and managed. The final publication of Energy Efficiency regulation for transformers may require update of the corresponding requirements in the product standards to apply rules of efficiency for repaired transformers.

7. Transformers and recyclability

Medium and large power transformers end of life is managed by utilities, as they are not in the scope of the directive “Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)” where it is clearly noted that the voltage should be less than 1000V in AC currents.

Utilities manage transformers over their long-life time and may value them at the end of their life, thanks to the high proportion of metal. The main components of the transformers are Magnetic Steel, Copper, Aluminium, Liquids, Paper, resin, Carbon Steel.

Conclusion:

The concept of the transformers enables reparability and recyclability

It is economically relevant to manage its end of life due to the high financial value of the raw material which is already managed by final users.

Medium and large power transformers are excluded from the WEEE directive.

General Conclusion:

A circular economy business model (durability, reparability, recyclability, waste) has existed for transformers for many years thanks to the high level of requirements from utilities and innovative responses provided by manufacturers. T&D Europe members are continuously seeking to improve the design of transformers, including in the area of material efficiency and will work with other stakeholders to update standards as required to account for such innovation. Therefore, transformers can be seen as a good example in a circular economy and no considerable additional requirements is needed.

ABOUT T&D EUROPE

T&D Europe is the European Association of the Electricity Transmission & Distribution Equipment and Services Industry, which members are the European National Associations representing the interests of the electricity transmission and distribution equipment manufacturing and derived solutions. The companies represented by T&D Europe account for a production worth over €25 billion, and employ over 200,000 people in Europe. Further information on T&D Europe can be found here: <http://www.tdeurope.org>

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