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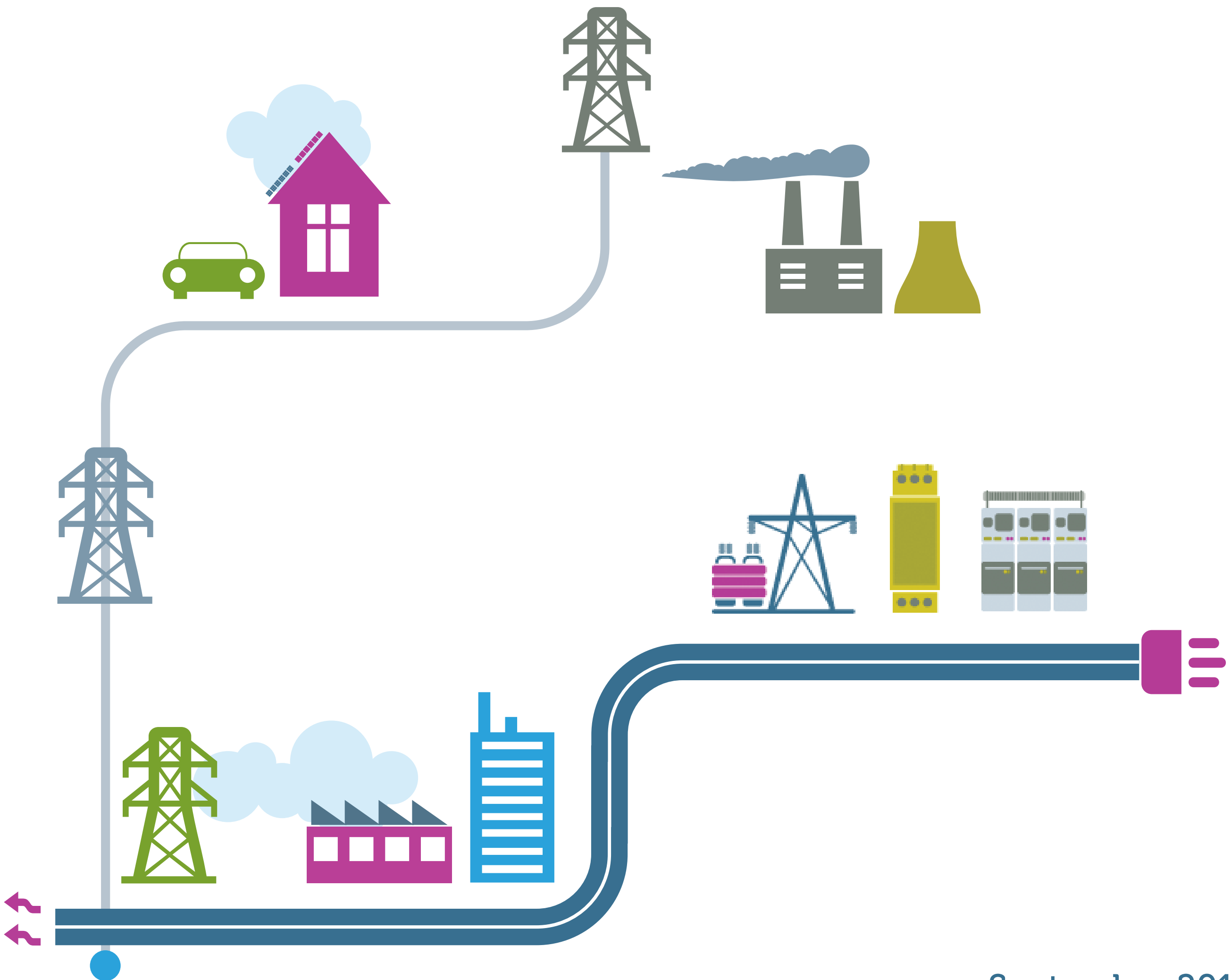
BEAMA NETWORKS – ASSET EXPECTED LIFE FOR TRANSFORMERS AND SWITCHGEAR (2018)



September 2018

ABOUT BEAMA

BEAMA represents manufacturers of electrical infrastructure products and systems from transmission through distribution to the environmental systems and services in the built environment, with 200 members ranging from SMEs to large multinationals.

We work with our members to ensure their interests are well represented in the relevant political, regulatory and standardisation issues at UK, EU & international levels.

BEAMA member products provide a sustainable, safe, efficient and secure UK electrical system. We support our members in ensuring that the UK has a strong electrotechnical industry which is recognised as an essential part of modern society and brings invaluable economic, social and environmental benefits.

Our Networks Sector is made up of members with interests in network products, transformers, switchgear, communications, automation, relays, smart grid, and related safety and energy supply and control technology. As part of the networks section of BEAMA, our aim is to explore and develop opportunities, provide technical services and to foster sustainable growth in new markets.

This paper was produced in coordination with the BEAMA Principal Products Section which has membership from the following organisations:

BACKGROUND

Members of BEAMA's Principle Products Technical Committee requested that BEAMA, in coordination with membership, produce a technical paper on the subject of Asset Expected Life for Transformers and Switchgear.

This paper aims to set out and clarify what Asset Expected Life is, provide guidance to customers, highlight information available and provide links to further reading on this subject. Further support and expertise is available from the manufacturers of network products.

Asset Expected Life

Asset Expected Life is the projected operational lifetime attached to a product, this projection is often requested by customers who are seeking to make long term investment decisions. This is not a product warranty, which is provided separately but rather an indication of the life span of the asset if maintained and serviced in line with manufacturer advice and product guidelines. For high capital cost assets, or when purchasing high volumes of lower cost assets customers seek to understand the expected life of the asset, to better understand their investment and any future spending requirements.

Transformers have been known to last for 80 years or more and switchgear 50 years or more, however the operating conditions, environment and maintenance regimes play a key role in determining how long an asset will last prior to failure, or a replacement is required. It is important to consider that transformers are made up of many diverse materials and that these materials will have different lifetimes. For example, rubber seals may need to be replaced from time to time prior to the end of life of the asset and the point at which it is taken out of service. As such it is essential to ensure that products are maintained in a controlled and routine manner and in line with manufacturer guidance and advice.

For this guide BEAMA defines Asset Expected Life as:

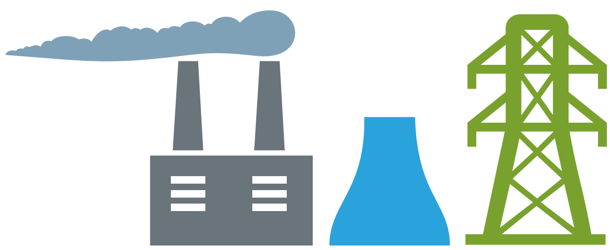
The Changing Use of Assets

Over recent years the Energy System has been exposed to unprecedented levels of change. These changes have resulted in assets being operated in new ways, under new network conditions and assets essentially being 'worked harder' or outside the original scope of their application. Whilst this is safe to do, these changes in application can bring about faster deterioration of an asset and/or its components which brings a new variable into play. Customers working with manufacturers at design stage should provide as much clarity as possible in terms of planned asset usage and application, this will enable the manufacturer to provide guidance and a more detailed assessment of the expected life of the asset. The expected life of an asset is based on assumptions made at the time of purchase and changes to asset operation can result in degraded asset life.

The advent of new technologies installed on the network that were not available at the time of design or installation can adversely impact on older assets e.g. increasing levels of installed renewable generation and changing modes of operation. If assets are operated in line with stated specification performance:

1. An approximate asset life will be provided by the manufacturer or product provider
2. If used in differing conditions or the operation changes over the lifetime of the asset, then the asset life may be affected

"THE MINIMUM LIFETIME IN YEARS A PRODUCT IS EXPECTED TO OPERATE, IF MAINTAINED IN LINE WITH MANUFACTURER GUIDANCE AND RECOMMENDED MAINTENANCE"



Customer Expectations

In recent years customers have sought to attach longer operational lifetimes to installed assets, this is for several reasons:

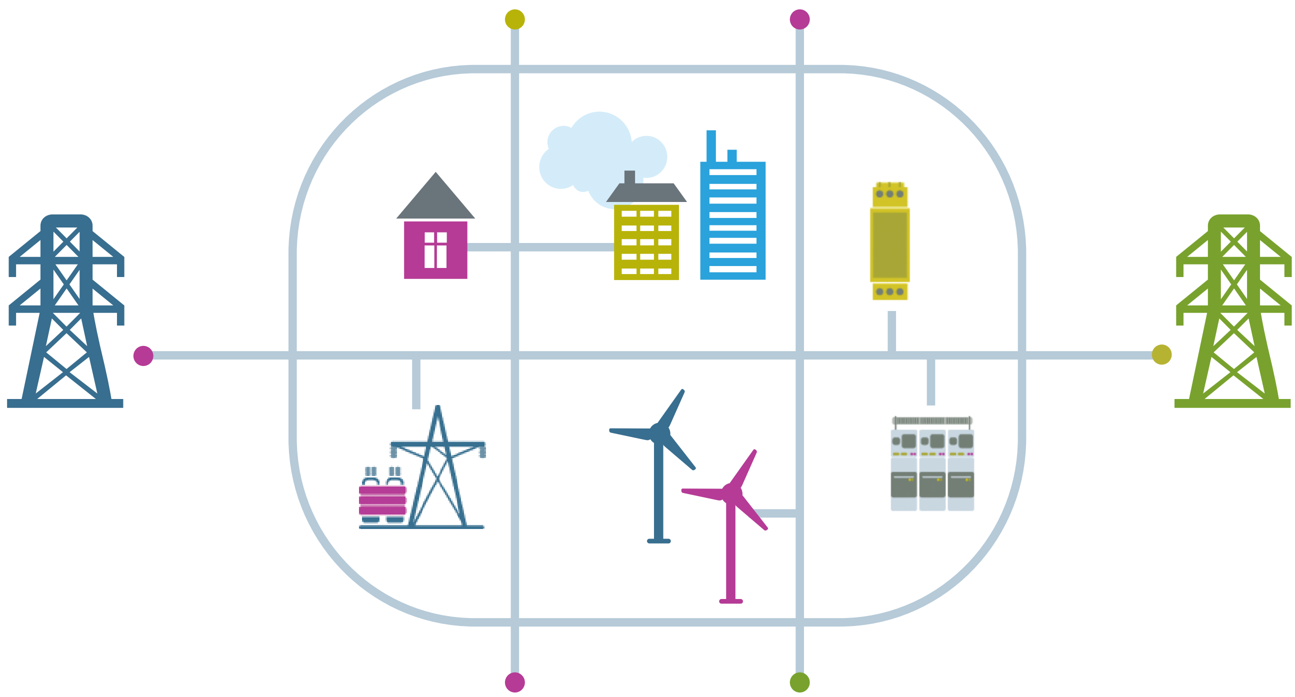
1. Customers are seeking to secure the value of their assets and wider networks over longer periods of time
2. To plan future investment in the networks more accurately and at lower cost.

In addition to the changing network topology, asset operation practices continue to change in order to maximise capacity and ensure that decarbonisation targets can be realised. In practice customers seeking to attach longer lifetimes to products currently achieve this in a number of ways, these include:

1. Long terms service level agreements with manufacturers
2. Paid for warranties and support services
3. Manufacturer service plans and service level agreements

All of the above are outside of a manufacturers standard warranty and guarantee. In practice, customers often attach longer asset lifetimes to installed equipment outside of warranties and guarantees provided by the manufacturer for the purposes of operational and investment planning.

24kV Gas Insulated Ring Main Unit with vacuum circuit breaker and load break switches



Asset Life Variables – Transformers

There are several variables, which, if ignored, can reduce the lifetime of an asset and it should be noted that with appropriate maintenance cycles the asset is more likely to reach or in some cases exceed its expected life. Some of the main asset life affecting variables are included in the graphic below with further commentary in the tables.[1]

VARIABLES	DESCRIPTION
Design	The design of a suitable installation and system is a fundamental principle which dictates how the asset will perform once energised. Equipment that is designed for the intended application and in coordination with the manufacturer should ensure high levels of product performance.
Loading	Operation of products within the loading rating included on the products nameplate. International standards such as IEC 60076-part 7 and IEC60076-12 (dry type transformers) provide guidance on loading regimes. Any deviation of loading conditions away from the standard should be discussed at the design stage with the manufacturer. Excess loading will produce higher than anticipated temperatures within the transformer which will degrade the insulation and shorten its useful life.
Insulating Paper	Over time insulating paper can deteriorate due to the effects of moisture/heat etc. Windings within the transformer could be paperless, normal kraft paper, thermally upgraded paper or high temperature insulation materials as defined in IEC 60076-14. The useful life of the transformer is massively impacted by choice of winding insulation and the temperature it is exposed to.
Liquid Condition	Internal discharges, high temperatures, moisture or particulate contamination reduce the quality of the liquid. The thermal or di-electric properties of the liquid can be compromised. Maintenance of the liquid quality has a large bearing on the transformers expected life. The exact type of liquid will affect the rate of degradation. Mineral liquid, synthetic and natural esters have different solubility properties of moisture and gas and will react differently with paper at different temperatures. However, the same basic principles apply to all the liquid types, a drier, clearer liquid run at lower temperatures will extend the life of the transformer.
System Faults	If an excessive number of faults on a system is anticipated this needs to be communicated at the design stage. Short circuit currents will impact the mechanical integrity of the transformer and the thermal aging characteristics of the insulation.
Maintenance & Spares	Manufacturers should give guidance on the required maintenance of the transformer and associated equipment. They will also recommend certain items are kept as spare parts. Lifetime of the transformer will be extended if the correct maintenance regime and equipment checks are performed.
Environmental Conditions	The transformer will be designed for a particular location and environment. Corrosion protection will be designed for a particular climate and cooling will have been designed for a particular range of ambient temperatures. Any changes to these conditions (such as moving the location from inland to the coast or outdoors to an enclosed space) will impact expected life.
Moisture Levels	Moisture in the transformer can come from cellulose component (insulation) breakdown or leak in from the external atmosphere. Moisture severely compromises the di-electric integrity of the insulation. More water causes further breakdown of the cellulose bonds so creates a self-accelerating process.

[1] IEC Strategic Asset Management of Power Networks – White Paper (2017)

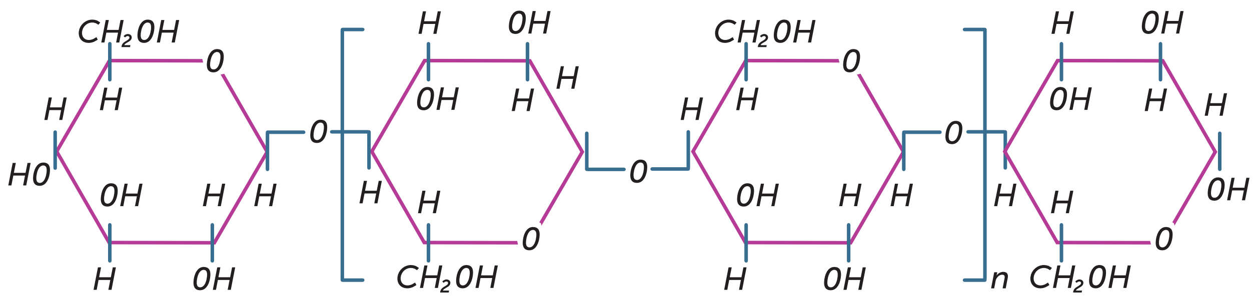


Figure 1: *Breaking of paper/pressboard insulation polymer bonds produces Carbon monoxide, carbon dioxide and water*[2]

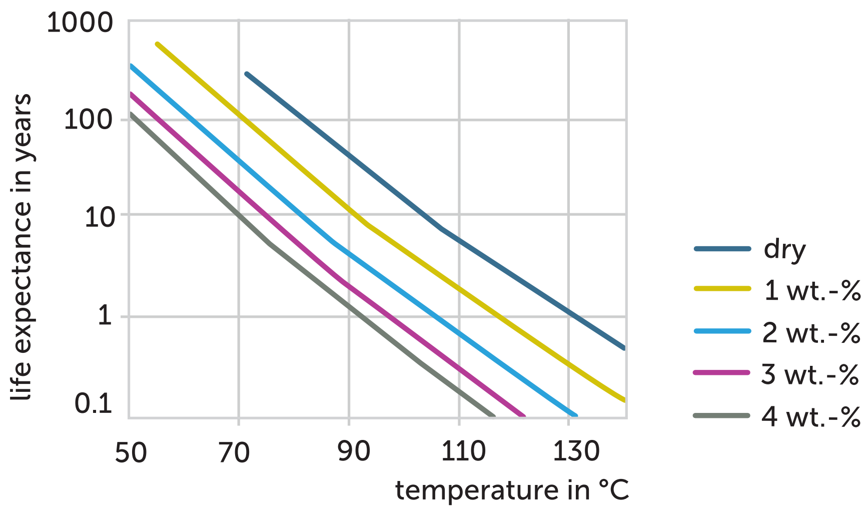


Figure 2: *Dependency of Life Expectance of paper on moisture content and temperature*[3]

IEC 60076-part 7 Loading Guidance and IEC60076-12 Loading for Dry Type Transformer

IEC60076-7 and IEC 60076-12 set transformer loading guidelines and suggest limits for the temperatures in order that asset life consumption is not accelerated. This standard also provides guidance on how to calculate asset life consumption for different loading conditions. Any deviations for loading outside these standards or loading in unusual ambient conditions must be communicated to the manufacturer at the design stage. In this case an evaluation of the real-life loading on asset life can be performed and the equipment parameters can be accordingly changed.

[2] J & P Transformer Book (1998) – Figure 3.13 Chemical formula for cellulose p. 63

[3] L.E Lundgaard "Aging of oil-impregnated paper in power transformers" IEEE Transactions on Power delivery, vol 19, no 1, pp 230-239, 2004

Asset Life Variables – Switchgear

There are a number of different types of switchgear (for example contactors, circuit breakers, switches, earthing switches, disconnectors, switch-fuse combination, busbar connected HV switchgear) each having their own asset life variables as does the insulating medium used e.g. oil, air, SF6, vacuum, etc. Again, some of the main asset life affecting variables are included in the graphic below with further commentary in the tables.

VARIABLES	DESCRIPTION
Design	The design of a fit for purpose installation and system is a fundamental principle which dictates how the asset will perform once energised. Equipment that is designed for the intended application and in coordination with the manufacturer should ensure high levels of product performance.
Loading	Equipment should not exceed the maximum current specified on the rating plate to prevent overheating of the equipment.
Installation	It is important that the equipment is installed in accordance with the manufactures recommendation, especially the interface between the switchgear and the cables or busbar
Environment	Increased ambient temperature may require the equipment load current to be de-rated to prevent overheating and damage to the insulation. Equipment placed in areas of high humidity or in coastal areas may need increased surveillance to inspect for increased rate of corrosion etc.
System Faults	The number of faults on the system can significantly reduce the asset life of the equipment. When the number of fault operations meets the maximum recommendations by the manufacturer the equipment should be replaced.
Spares	To be kept in line with manufacturers recommendation
Maintenance	Maintenance of the equipment to be in accordance with manufacturers recommendations.
Operator Training	Proper training must be given to the operators, so they are fully familiar with the equipment and to prevent damage through misuse
No. of Operations	The number of operations of the equipment will determine the asset life; once this number equals that recommended by the manufacturer the equipment should be replaced.

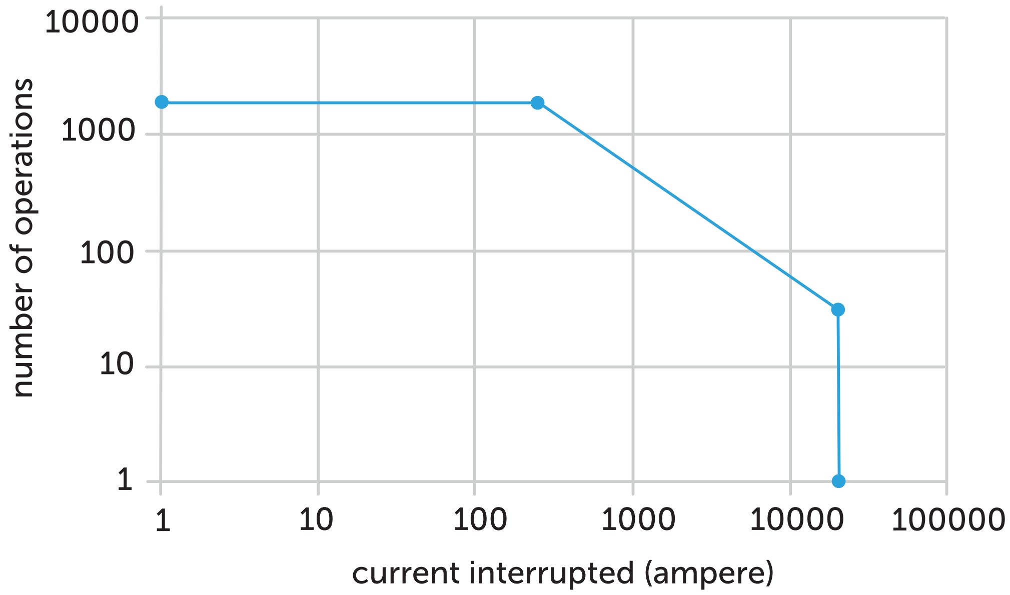


Figure 3: *Typical prospective interrupting capacity of 21kA; 250A circuit breaker class M1*

Design Considerations

At design stage there are a number of key factors that a customer should consider or if unsure discuss in detail with the manufacturer of their product. These are:

- Application
- Systems requirements
- Network type
- Fault level
- System voltage
- Application
- No. of operations the equipment is likely to perform
- Environment

Transformer asset life can be extended at design stage by considering; all modes of operation, environmental conditions, for transformer use of thermally upgraded insulation (referenced in IEC 60076-7 and 60076-14), reduction in temperature compared to standard requirement, equipment monitoring to increase the amount of condition-based maintenance that can be done and training of operators to use and maintain equipment.

This is crucial, and customers need to ensure the appropriate product is installed for the application to ensure that optimum performance is realised in practice.

Eco Design and Transformer and Switchgear Life

Whilst this is not a BEAMA position, this information is referenced from a credible and authoritative source and authored for the EU Commission. The expected life of an asset will be agreed with the product manufacturer and the customer at the time of purchase. The VITO Lot 2: Distribution and Power Transformers Report (2011) offers some useful commentary and analysis on the expected life of transformers as well as describing end of life options. This report states that the average technical life of a power or distribution transformer is 25 years or more. The end-user behaviour has a significant impact on the transformer lifetime for example regular overloading of the transformer.

The average technical life of a transformer is 30 years or more; more than 10% of the European transformer fleet is 40 years old or more. This 10% of the transformer fleet contributes more than 20% of the total no-load losses and more than 15% of load losses in European distribution companies.

The minimum reasonable transformer lifetime in Life Cycle Cost (LCC) calculations could be 20 years and arguments mentioned above indicate that applying 30 years lifetime in industry and commerce, and 40 years lifetime in electricity distribution companies can be justified.[4]

[4] VITO – LOT 2: Distribution and power transformers report (2011) – Study for European Commission DG ENTR unit B1 p.156

Transformer Lifetimes

Application	Lifetime (y,typ.)	Lifetime (y,min.)	Lifetime (y,max.)
Distribution	40	30	50
Industry Oil	25	20	40
Industry Dry	30	20	35
Power	30	25	35
DER (Wind)	25	20	30
Small Industry	10	10	21

Table 3-9 Transformer life times used in this study[5]

Transformer End of Life Extension

At the end of a transformer's lifetime there are options that can be considered to further extend the life of the asset, these could include refurbishment and repair of the asset and the replacement of aged components. In order to understand the cost saving of such approaches, requirements would need to be understood by the customer, or advice requested from the manufacturer as cost will vary dependent on the asset type and the extent of repair or refurbishment required. Currently, a very large proportion of these assets are recycled at the end of their life. This high recycling rate can be explained by the high residual value of the transformer scrap material. Vito estimate recycling of end of life transformers at around 99%.[6]

Switchgear Lifetime

	Lifetime (y,typ.)	Lifetime (y,min.)	Lifetime (y,max.)
ENA – up to 145kV[7]	–	30	–
National Grid[8]	–	40	–

Maintenance

Equipment should always be supplied with documentation that details the required maintenance. An essential element of prolonging asset life is to perform the maintenance in line with the manufacturers expert advice and recommendations.

[5] VITO – LOT 2: Distribution and power transformers report (2011) – Study for European Commission DG ENTR unit B1 p.157
[6] VITO – LOT 2: Distribution and power transformers report (2011) – Study for European Commission DG ENTR unit B1 p.158
[7] ENA Technical Specification 41-36 – Clause 1.5.0.1 and ENA TS: 41-37 -part 1 clause 5.115
[8] National Grid TS 2.02 – Clause 1.1.2 – "Switchgear shall have an anticipated asset life of not less than 40 years"

CASE STUDY

Specification of Transformers for Required Service

The IEC Thermal Model and Accelerated Ageing

The paper 'Specification of Transformers for Required Service (2008)' highlights that the thermal model used in IEC 60076-2 assumes that normal ageing occurs at an average hot spot temperature of 98 °C. For every 6 °C above this figure the ageing rate doubles.

If the winding hot spot reaches a temperature of 180 °C, then the ageing rate will be around 8000 times normal.

If, for the period of start up, the average hot spot temperature for a short period of 15 minutes reaches 160 °C, then the life consumed in this 15 minute period will be roughly equivalent to 10 days normal life and this effect then dominates the ageing of the unit.

Therefore, if the daily start up consumes 10 days of life, then it can clearly be seen that after 5 years of such operation the transformer insulation life consumed would not be the 5 calendar years, but a value closer to 50 years.

Even if for the period of start up the average hot spot temperature for a short period of 15 minutes reaches 140 °C, then the life consumed in this 15 minute period will be roughly equivalent to 1.3 days normal life. The total life consumed would then be roughly 2.3 days every day.

The effect of the excessively high temperature will be to break down the oil producing the typical diagnostic gases of a low temperature thermal fault and this can be detected by routine Dissolved Gas Analysis (DGA).

Any solution to this issue is ultimately dependent on the design of the transformer and its application.[9]

IEC 123 Strategic Asset Management of Power Networks

Lifetime Considerations

Given the age statistics included in the IEC 123 White Paper, in many countries the pace of equipment upgrades significantly lags behind the amount of aging equipment that is approaching end of life. In some countries, at the current rate of replacement, it would take several hundred years to replace all of the aged equipment. Comparatively, the replacement of aged equipment has proceeded comparatively rapidly in other countries.

Asset Life Estimation

The white paper contains an example of the expected life of a transformer asset connected at 110 kV and suggests a mean value and range of asset life estimates at 42 years with a standard deviation of 8 years. This figure also acknowledges the variables in play such as moisture and material degradation and how these can contribute to premature asset degradation.[10]

[9] Tom Breckenridge (2008) – Specification of Transformers for Required Service

[10] IEC Strategic Asset Management of Power Networks – White Paper (2017)

Manufacturer Services, Guidance and Warranties

Outside of a guarantee a manufacturer is only able to offer an expected lifetime which takes a number of assumptions into account on the equipment's loading, maintenance and environment. The exact operation of the equipment, competence, frequency of equipment operation/maintenance and actual environmental conditions are not within the manufacturers control. As such asset lifetimes cannot be guaranteed outside of the term agreed at the point of purchase and installation.

Warranties, Guarantees, Service Level Agreements and Other Services

When purchasing and installing a new asset, manufacturers provide expert advice and literature regarding the installation of the asset, operating requirements and maintenance. Manufacturers of transformers, switchgear and other network equipment offer a number of products to provide peace of mind to the customer and ensure that products are appropriately covered post sale. There is no single standard offering and manufacturers provide several options to the customer that can be built in at design and purchasing stage. These include product guarantees, warranties and extended warranties and more. A number of these standard and optional offerings are included below.

ALL OF THOSE DETAILED ABOVE CAN BE DISCUSSED IN DETAIL AND THE APPROPRIATE OPTIONS REVIEWED WITH THE MANUFACTURER OF THE PRODUCT. THIS ENSURES THAT THE CUSTOMER CAN MAKE AN INFORMED DECISION AND CHOOSE THE MOST APPROPRIATE SERVICE PACKAGE FOR THEIR REQUIREMENTS.

Further Information

If you would like to know more about the topics included in this paper please contact BEAMA or the manufacturer of your network products.

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