Power Transformer

ABSTRACT

The concept of life for an electrical asset, such as a power transformer, is sometimes not properly understood. In this article, the first from the series of three articles, we review what we mean when we refer to the "life" of a transformer and what constrains determine the design and operational parameters of these assets.

Keywords:

power transformer, life, asset management, condition assessment, life extension

Part 1: What does "transformer life" mean?

In our industry there are often terms or buzzwords that many of us use with liberty but might not fully understand their meaning.

Justifiably, we use a particular word often because the concept it conveys is of critical importance to the safe and reliable operation of any electrical asset. We use this word to convey the idea of a time period in which an asset performs its intended function so it is important for any person involved in specifying, purchasing, testing, commissioning, maintaining, operating or disposing of these assets to have a clear understanding of what life means in the context of power transformers.

In this series of articles, I am going to talk precisely about this concept. Throughout the articles in the series, we will try to establish what life is and what it means for a power transformer. We will also explore the factors that affect it and consider the options that an asset owner can utilise to extend and optimise the transformer life.

In the first article, I will try to establish the common definition and understanding of

Carlos GAMEZ

Wait, what? ... Are transformers not supposed to last 35 to 40 years? The simple answer is: not necessarily, it depends.

what transformer life is. This will hopefully serve as the foundation for the articles to follow in this series.

This topic is vast and there are as many opinions as there are experts in our industry. I have tried to remain objective and base my comments on evidence and facts but I anticipate that my personal experience has found its way into these articles in one way or another.

I have also assumed that the reader is familiar with the basic power transformer concepts and has seen or worked around these assets at least once in their career.

WHAT DOES "TRANSFORMER LIFE" MEAN?

When we talk about concept of the transformer life or any other electrical asset for that matter, we also hear related terms and phrases that almost invariably show up in the same conversation. We often hear terms like: "life management", "life expectancy", "life extension", "life cycle", etc.

We will somehow touch on all those concepts but with some luck, we will mention them following a logical sequence of ideas. I will attempt to explain these concepts in a clear and understandable way; how they relate to day to day operation of a transformer fleet and most importantly, what the user/owner of these assets can do in order to minimise the operation and maintenance costs as well as mitigate the risks of unexpected failures.

The common denominator in the terms mentioned above is the word "life" so it seems only fair that we start by setting some fundamental understanding of what "life" means from the perspective of a power transformer.

There are many types, designs and ways of manufacturing power transformers but for the purpose of this discussion, please consider insulating liquid - filled power transformers while you are reading articles in the series. However, the concepts explained and reviewed here can also be applied to dry transformers, instrument transformers, gas insulated transformers and other classes of specialty transformers to some extent.

Common sense tells us that the life of an asset can be regarded as the period of time in which the asset will reliably perform its intended function. This is not a bad start, but we can do better.

Life can also be defined in statistical terms which are particularly useful for insurance companies as the "Mean Time Between Failures" or MTBF. This basically means that out of a population of transformers the time between initiation of service and failure is measured and averaged, providing a good idea of the life expectancy for a transformer belonging to that population or of one with very similar characteristics.

Another good reference is to look at what the different standard committees worldwide have to say on the matter.

The Australian Standard, AS 2374.7 – Power Transformers – Part 7: Loading Guide for Oil-Immersed Power Transformers establishes in:

> *"1.4 General limitations and effects of loading beyond nameplate rating*
>
> *...*
>
> *1.4.1.1 Factors influencing life duration*
>
> *The actual life duration of a transformer depends to a high degree on extraordinary events, such as overvoltages, short-circuits in the system, and emergency overloading.*
>
> *...*
>
> *The normal life expectancy is a conventional reference basis for continuous duty under normal ambient temperature and rated operating conditions. The application of a load in excess of nameplate rating and/or an ambient temperature higher than*

rated involves a degree of risk and accelerated ageing. ...”

Another good reference would be IEEE C57.91 – Guide for Loading Mineral Oil Immersed Transformer which establishes the following.

“3. Definitions

...

3.5 Transformer Insulation Life: For a given temperature of the transformer insulation, the total time between the initial state for which the insulation is considered new and the final state for which dielectric stress, short circuit stress, or mechanical movement, which could occur in normal service, and would cause an electrical failure”

It is also not a coincidence that none of the standards mentioned above define what the life expectancy of a particular transformer should be.

Further to this definition, IEEE C57.91-1995 provides calculation formulas for “loss of life” as a percentage of “per unit” life expectancy, providing a normalised life loss equation under various overloading and stress circumstances. This relationship is commonly represented in the form of a Life vs.Temperature curve, as shown below.

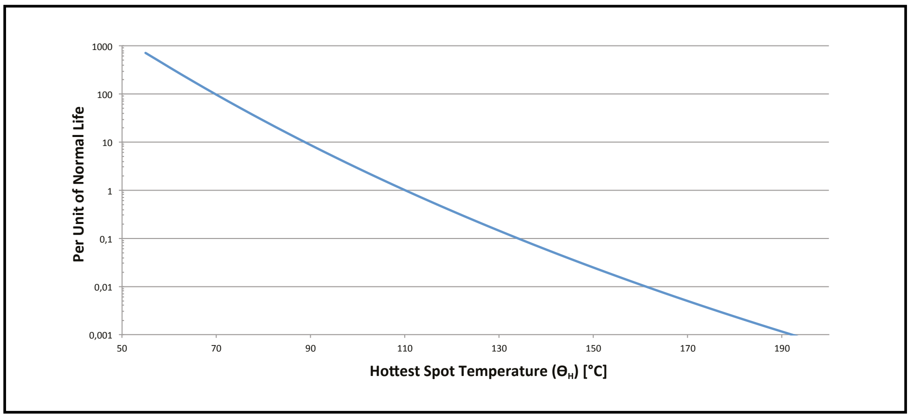


Figure 1: Transformer insulation life

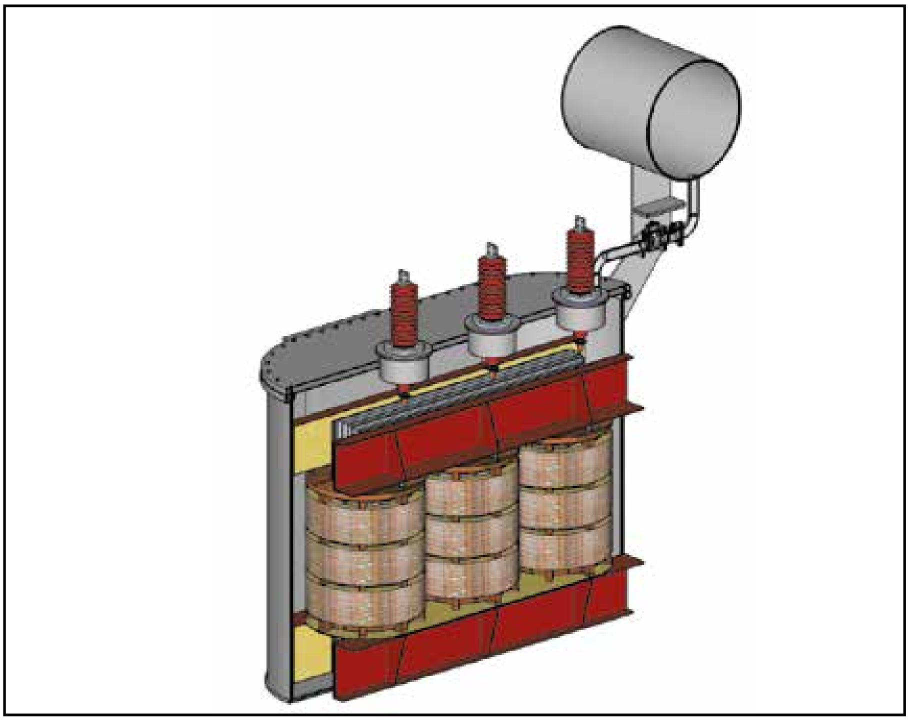


Figure 2: Internal construction of a typical power transformer

And finally from IEC 60076-7 – Loading guide for oil-immersed power transformers we read the following:

“3 Terms and Definitions

...

3.10 transformer insulation life

total time between the initial state for which the insulation is considered new and the final state when due to thermal ageing, dielectric stress, short-circuit stress, or mechanical movement, which could occur in normal service and result in a high risk of electrical failure

3.11 per cent loss of life

equivalent ageing in hours over a time period (usually 24 h) times 100 divided by the expected transformer insulation life.

The equivalent ageing in hours is obtained by multiplying the relative ageing rate with the number of hours”

The discerning readers would have noticed that there is a common thread across these standards. They relate to transformer loading guidelines, mention temperature as an important factor and talk about the insulation and the insulation life. This already provides a hint into where we have to look to understand transformer life.

It is also not a coincidence that none of the standards mentioned above define what the life expectancy of a particular transformer should be. Wait, what? ... Are transformers not supposed to last 35 to 40 years? The simple answer is: not necessarily, it depends. As we will discuss in these articles, the various mechanisms affecting the life duration of a particular unit are difficult to predict. Trying to anticipate events during the operation of any given transformer and how they will ultimately affect its life is an extremely complex problem.

In short, the life of the transformer as a whole is directly linked to the life of its insulation system.

TRANSFORMER CONSTRUCTION

As we might suspect, the "heart" of a transformer are the core and the coils (see Figure 2.). They provide the critical function of transforming the incoming power into different levels of voltage and current by means of electromagnetic induction.

When one thinks about the materials this subassembly comprises, one thinks of copper or aluminium for the conductors; structural steel for the tank, clamps and radiators; magnetic steel for the core; mineral oil for cooling and dielectric insulation; wood for the lead holding structure; ceramics for the bushings; paper boards and sheets, and tapes for electrical insulation. Out of all these components, the ones that are most sensitive to temperature and age are the ones with a cellulose constitution.

Cellulosic materials are those which are derived from natural vegetable fibres such as wood, pressboard, Kraft paper, etc.

You might ask, why paper? The fact is that paper in combination with an insulating liquid provides an excellent and versatile dielectric medium that can be applied to complex geometries. Paper also provides a good economic balance between the cost of the material and the function that it performs.

However, paper is also the first material amongst the constituents of the core and the coils to degrade under thermal stress. While it would take several hundred degrees Celsius of temperature to melt or cause significant damage to the components made of steel, copper or metal, it takes merely around 120°C to start causing significant degradation of cellulosic materials. In fact, the main limitation of what temperatures are allowed to develop in a particular design is set by the paper. The transformer designer will make sure that not a single part of the insulation system is exposed to these kinds of temperature.

And if the paper degrades? Why would that affect the functionality of the transformer? We know that the primary energy conversion function is performed by the conductors and the core, right? Well, it turns out that the insulation system is responsible for ensuring that conductive elements subject to a voltage difference stay electrically insulated. Should the insulation break down between two high voltage elements, it would cease to perform this function, the currents would flow through paths they are not supposed to follow and the eventual consequence is a catastrophic failure.

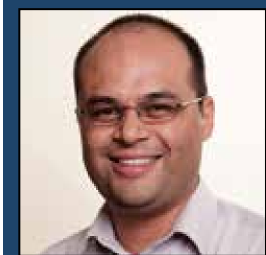
In short, the life of transformer as a whole is directly linked to the life of its insulation system. If any part of the insulation system breaks down, the whole transformer stops working. Albeit failures can occur in other components, such as core, bushings, current transformers, etc. it is commonly a failure in the insulation system that leads to catastrophic outcomes.

Unsurprisingly, most of the efforts in the transformer manufacturing, operation and maintenance industries are aimed at improving, monitoring and maintaining performance of the insulation system.

I hope you now have a better understanding of what life means in the context of power transformers.

In the next article, we will delve a bit more into the molecular structure of the paper, what it means for its electrical and mechanical properties and what various mechanisms by which it degrades or loses those properties are.

Author:



Carlos Gamez currently works as a Principal Consultant and Product Manager at TxMonitor and is a member of the MM Group Holdings where he focuses in developing innovative solutions for the electrical asset management industry using both his technical and business acumen.
After graduating in Electrical and Mechanical Engineering in 1996, Carlos started working as a Transformer Design Engineer at PROLEC-GE, the biggest transformer factory for General Electric on the American continent.
Over the course of the following years, he gained expertise working in various roles in product development, manufacturing improvements, technology and software development, field engineering and customer service.
In 2007 Carlos was seconded by General Electric to move to Perth, WA to start up the Transformer Division in order to provide field and workshop maintenance and repair services to customers across Australia.
Having fulfilled this mission, in the early 2011 Carlos accepted the position of Principal Consultant with Assetivity, a leading consultancy firm in Asset Management.
Over this period, Carlos developed a holistic point of view by working on projects within the Asset Management frameworks which eventually shaped the ISO 55000 set of standards published in 2014.