Transformer life expectancy

How long will your transformers last?

ABSTRACT

As grid operators navigate climate change, aging infrastructure, and increasing demand from electric vehicles, transformer life expectancy has become a critical issue. The article explores the factors influencing transformer longevity, highlighting the impact of efficiency regulations and supply chain constraints on transformer availability. The article covers advanced transformer monitoring technologies, such as dissolved gas analysis, which identify which transformers in an aging fleet need replacement rather than waiting for them to fail..

KEYWORDS:

maintenance, monitoring, life expectancy, fleet management, maintenance

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1. Introduction

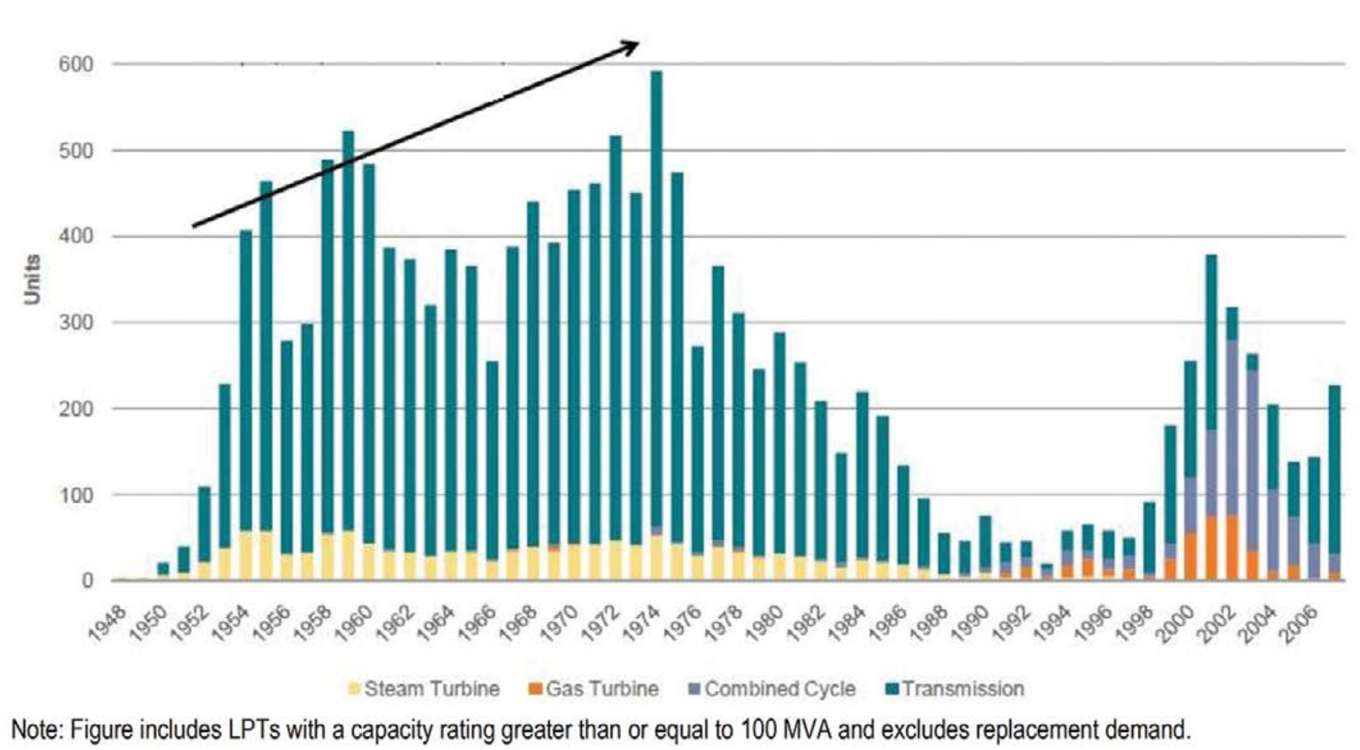
As grid operators grapple with recovery from COVID, global warming, severe weather events, carbon-neutral goals, electric vehicles, renewable energy, and extreme challenges with the supply chain, one concept is universally accepted: the lights must stay on. In the United States, these challenges are exacerbated by government regulations requiring more efficient transformers. On average, transformer efficiency is approximately 94-98% or even higher. Creating stricter requirements to increase transformer efficiency will lead to more constraints and increased lead times.

Most people don't realize the challenges utilities face in providing reliable power. However, they may stop taking their electricity for granted if they lose power, and it cannot be restored immediately for a variety of reasons. One of those reasons may be that their local utility no longer has stock of the transformer they need to restore power. In places like California, where more than 1,000 electric vehicles are being added per day, the grid is being stressed like never before. Unplanned loads on transformers in locations with charging vehicles can shorten transformer life. The stress may include harmonics induced by charger electronics. The harmonics can increase transformer load loss, increase transformer temperature, and consequently further reduce the life expectancy of the transformer. Residential chargers may also cause voltage imbalance across phases [1]. Not only is there a shortage of transformers to support replacements, but there is also a shortage of transformers to support grid additions like new homes and electric vehicle charging stations.

2. Factors in determining life expectancy

When trying to understand how long a transformer will last, we can think of it like buying a used car. A car's life expectancy is going to depend on how it is driven, where it is driven, the maintenance history, and so on. It will also depend on its current operating conditions. Has the recommended maintenance been performed? Has the car been in any accidents, and so on? There is a lot to consider. Likewise, not surprisingly, the questions for power transformers are a little different, but the general approach is the same. In order to understand how long a transformer will last, you need to look at a number of important factors, including the manufacturer, the age, and how hard its life has been.

As the current lead time for new power transformers ranges from 1 to 3+ years, how are asset managers coping with their aged transformer fleets? Age, by itself, is not necessarily an indicator of deterioration—but the longer a unit has been exposed to high temperatures and repeated through faults, the less likely it will survive future system disturbances. These real-world operational "bumps in the



Note: Figure includes LPTs with a capacity rating greater than or equal to 100 MVA and excludes replacement demand.
Source: EIA; SPX Electrical Products Group, May 2010.

Figure 1. In North America, a low number of large power transformers were added to the grid in the 90s, causing manufacturing to shift to Asia [4]

One common theory often applied to transformer failure is the bathtub curve, and after the transformer has been in service for about five years, owners expect to see a reliable life of up to about 30 years

road" reduce the mechanical strength of the solid insulation, exposing the unit to an increased chance of failure from future faults or contingency loading.

One of the key things every asset manager wants to know is how long to expect their transformers to last. Replacing transformers takes considerable effort from many parts of a utility, including Operations, Engineering and, don't forget, Finance. Money needs to be available to cover those costs. In addition to money, managers face long wait times for new transformer orders. Of course, it is not as easy as looking into a crystal ball to estimate when a transformer will fail. Many factors must be considered. The transformer specification, design, manufacturer, factory test performance, maintenance history and operational history all affect transformer life.

One way to estimate the life of transformers is to look at publicly available data. Rough guidance can be obtained from looking at the data that was used to derive dissolved gas standards in transformer insulating liquid for the 2019 Std IEEE C57.104 – IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers [2]. The data set used to derive the standard contained nearly 1.4 million oil samples from over 300,000 transformers. Many labs and utilities provided data to support this effort. The data shows very few oil samples were analyzed for transformers aged 60 years and older.

Similar data published in the 2015 CIGRE Transformer Reliability Survey shows the age profile of over 7000 transformers from a North American data set of in-service transformers [3]. While the rise and fall of the data from year to year indicates, to some extent, periods of grid expansion, it is significant that the trend from 45 to 60 years indicates that after 45 years, it's much more likely transformers will be removed from service, and there is virtually no expectation a transformer will last past 65 years old.

In Fig. 1, a chart from a 2014 US Department of Energy study on large power transformers shows that–as the buildout of electrical infrastructure in North America was planned for expected future capacity–very few transformers over 100 MVA were added to the grid in the 1990s, which is why many factories making large power transformers in North America closed during that time or soon thereafter. Consequently, many new, large power transformers in North America need to be imported from countries that still make these expensive, critical assets.

Besides data available at IEEE and CIGRE, a few entities accumulate data on in-service transformers and on transformer failures. One of those entities is Doble Engineering. In addition to accumulating data on various failures, they work with

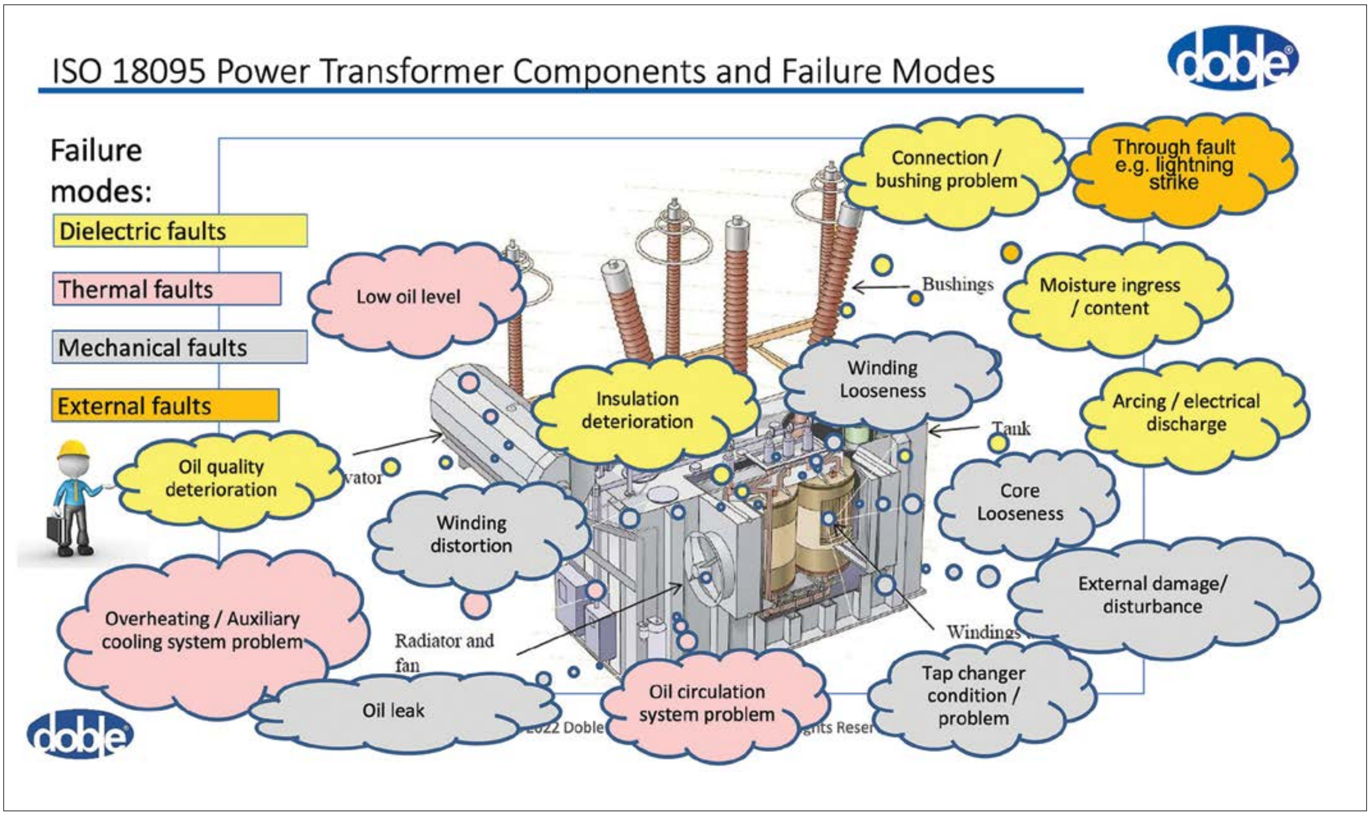


Figure 2. There are many potential modes of transformer failure per ISO 18095 [5]

Transformers manufactured in the 1950s had very low failure rates until the transformers were about 40 years old, in contrast to transformers made in the 1980s, those had high failure rates in the 11-30-year range

transformer owners to understand how to extend the life of these critical assets. As the diagram in Fig. 2 depicts, transformers are much more complex than most people realize. Many things contribute to the reduction in a transformer's life.

Most of the time, people try to simplify transformer failure rates into concepts that are easy to understand based on statistical theory. One common theory often applied to transformer failure is the bathtub curve (Fig. 3). This concept seems to make sense because there are failures when transformers are new due to design, manufacturing, or transportation issues. After the transformer has been in service for about five years, owners expect to see a reliable life of up to about 30 years. After 30 years, the failure rate starts increasing rapidly.

Unfortunately, this model has not proven to be accurate since it does not account for real-world design, construction, operation, and maintenance. If transformers are subjected to repeated through-faults or cooling systems are not maintained, these types of operational issues will likely cause premature failure.

The diagram in Fig. 4 illustrates actual data from over 25,000 transformers in the Doble database. Each line represents the failure rate of transformers produced in a particular decade. For instance, transformers manufactured in the 1950s had very low failure rates until the transformers were about 40 years old. Contrasting that with transformers made in the 1980s, those had high failure rates in the 11-30-year range.

3. Strategies and technologies to manage transformer fleets

Now that transformer lead times have extended from months to years and prices have doubled or tripled, what are some strategies being deployed by asset managers to contend with increasing demand and reduced supply? One strategy many like is the "Do Nothing" strategy. In other words, let the transformers hum along with minimal to no maintenance and hope for the best. For many small transformer classes, that's exactly what most utilities do. If the transformer fails, they'll replace it. That strategy works well when there is a sufficient supply of units on hand and if standard transformers are easy to find in distribution transformer ranges. Unfortunately, supplies are dwindling.

The next strategy most asset managers deploy on larger transformers is to take periodic fluid samples and attempt to identify issues prior to failure. Everyone prefers to change out transformers on a scheduled basis rather than in an emergency. This strategy works well if faults are slow to progress and there's time to analyze the sample, resample to confirm,

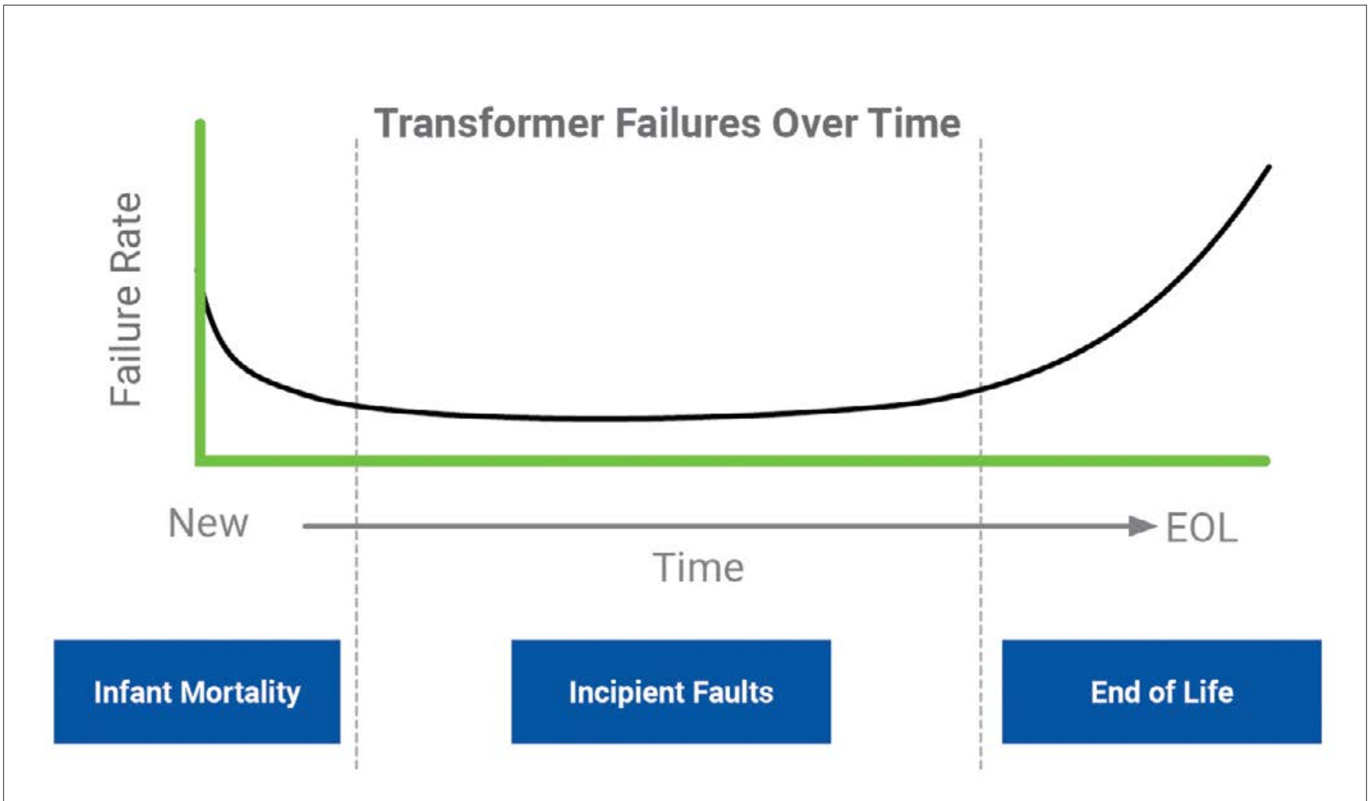


Figure 3. Transformer failure over time

assess the condition, and determine the next actions, such as offline testing to understand whether the transformer can remain in service. Unfortunately, as the grid becomes more stressed, labs are having a hard time keeping up. It normally takes 15 days or fewer to get results, but recently, in North America, it may take up to 30-90 days to get results. This strategy is becoming increasingly difficult to manage. In rare cases, transformers have failed before results come back from the lab.

Luckily, technology is now available to assist asset owners in their efforts to manage their transformer fleets in real-time. For many years, utilities have relied on data such as temperature and load to help them understand the real-time operation of their transformers. Today, there are many online monitoring choices available that vary from large monitoring solutions to less complex, compact solutions. As these solutions have evolved, technology now allows online monitoring of almost every aspect of the real-time operation of transformers. The goal is to detect issues well before failure so the transformer can be repaired in the field or taken out-of-service on a scheduled basis rather than dealing with an unplanned outage.

The most widely used tool to understand the health of the transformer is to measure the dissolved gases in the transformer insulating fluid. When thermal and or arcing faults occur inside the transformer, the insulating fluid and solid insulation degrade and form gases in the fluid. By analyzing these gases, the health of the transformer can be assessed. The value of online monitoring solutions is that they alert operators when fault gas levels are increasing inside the transformer.

The 2019 IEEE C57.104 not only provides information on DGA (dissolved gas analysis) typical values but also provides guidance on gas rate-of-change and sampling recommendations up to and including daily sampling, depending on the condition identified. Due to the difficulties in managing such a task, online monitors can provide the data without sending personnel to transformers that are at high risk of failure. Of course, this is also a safety concern.

So, how do asset managers evaluate which of their transformers will be the next to fail? While some critical transformers may get multi-gas DGA, bushing monitoring, partial discharge monitoring, and other forms of monitoring, most utilities are in no position to deploy large monitoring systems on all their transformers. They must choose a strategy that will provide the most value for every dollar spent.

Transformer owners must pay not only to evaluate the up-front costs of the

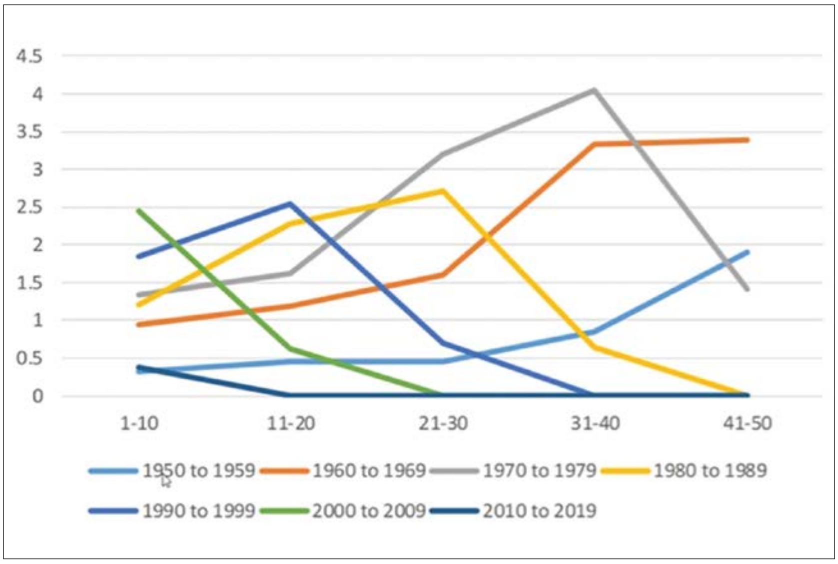


Figure 4. The failure rate of power transformers. Each line represents the failure rate of transformers produced in a particular decade

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Because determining transformer life expectancy is a complex task, online monitoring can alert users to changes in a transformer's health so they can focus on their most troubled units

monitoring solutions but also the maintenance required to keep the solution working over the life of the transformer. Most utilities in North America are incentivized to spend capital dollars and want to minimize the amount of maintenance dollars spent. Therefore, the reliability of the monitoring solution is key to ensuring the system provides the most benefit for the life of the transformer. Solutions with low or no maintenance are normally preferred.

For over 40 years, online monitors have used the hydrogen concentration in the insulating fluid as a primary indicator of a change in transformer health. When significant issues occur inside the transformer, the hydrogen concentration increases, which is a key indicator that there may be something that needs to be addressed urgently. When the hydrogen concentration increases, operators can perform a manual DGA to understand the severity of the issue. For large transformers where multi-gas monitors are justified, these gases can be evaluated in near real-time. For smaller transformers or large transformers with no multi-gas DGA monitoring, hydrogen monitoring alerts users that gases are being generated, and action can be taken to understand the severity of the situation. Many utilities deploy a strategy where hydrogen monitors alert them to issues, and then a portable multi-gas monitor provides more complete information when workers arrive on-site.

4. Conclusion

Because determining transformer life expectancy is a complex task, online monitoring can alert users to changes in a transformer's health so they can focus on their most troubled units. Depending on the transformer asset class, design, and other factors, most utilities expect their transformers to last 40 to 60 years. Since the average age of a transformer in North America is around 40 years old, asset managers must evaluate how to manage their fleets best, given today's challenges. It is far more likely that a transformer can be repaired if faults are detected prior to failure. With transformer shortages and rapid grid expansion due to the integration of renewables and electric vehicles, it is more important than ever to ensure every transformer remains in service as long as possible. Any major transformer failure will stress the grid if a spare transformer strategy is not in place. Proper transformer asset management allows utilities to meet customer expectations and keep the power flowing.

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