

The Locomotive

An Analysis of Transformer Failures, Part 2 – Causes, Prevention and Maximum Service Life

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Introduction

Over the years, Hartford Steam Boiler has investigated thousands of transformer failures, compiling an extensive database of loss information. In part one of this article, the author used data from HSB's latest 10-year study of transformer claims to examine the types of breakdowns, frequency, severity, and the issue of transformer age. In part two, he discusses the causes of transformer failures, recommends a maintenance program and concludes with ways to help achieve maximum service life.

Cause of Failure

Hartford Steam Boiler has collected information about transformer failures for decades. Analysis has shown that while aging trends and utilization may change (see part 1), the basic causal factors of these failures remain the same. In the article "Factors Affecting the Life of Insulation of Electrical Apparatus," published in the July 1949 issue of The Locomotive, HSB's J.B. Swering, chief engineer of the Electrical Division, wrote:



"There are a number of factors which affect the life expectancy of insulation and these should receive the careful consideration of persons responsible for the operation of electrical equipment. These factors include:

- Misapplication
- Vibration
- High Operating Temperature



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All recommendations are general guidelines and are not intended to be exhaustive or complete, nor are they designed to replace information or instructions from the manufacturer of our equipment. Contact your equipment service representative or manufacturer with questions.

- Lightning or Line Surges
- Overloading
- Care of Control Equipment
- Lack of Cleanliness
- Care of Idle or Spare Equipment
- Improper Lubrication
- Careless or Negligent Operation

It's still good advice, a half-century later. Table 3 shows the primary cause of transformer failures reported to HSB over the last several decades, and identifies those areas where failure-reducing efforts can best be directed. The table lists the most common causes of failures and the percentage of all the failures they represent for the studies conducted in 1975, 1983 and 1998. However, the 1998 study did not use the same methodology for categorizing the causes. The information is presented here for comparison purposes, but no conclusions on trends should be made.

	1975	1983	1998
Lightning Surges	32.3%	30.2%	12.4%
Line Surges / External Short Circuit	13.6%	18.6%	21.5%
Poor Workmanship/Manufacturer	10.6%	7.2%	2.9%
Deterioration of Insulation	10.4%	8.7%	13%
Overloading	7.7%	3.2%	2.4%
Moisture	7.2%	6.9%	6.3%
Inadequate Maintenance	6.6%	13.1%	11.3%
Sabotage, Malicious Mischief	2.6%	1.7%	0
Loose Connections	2.1%	2.0%	6%
All Others	6.9%	8.4%	24.2%

Table 3

Table 3: Cause of Transformer Failures

Lightning

Lightning surges are considerably less than previous studies, because of our changes in categorizing the cause. Today, unless we have confirmation of a lightning strike, a surge type failure is categorized as "Line Surge." This is one of the departures from the previous studies.

Line Surges

According to our database, the Line Surge (or Line Disturbance) is the number one cause for all types of

transformers failures. This category includes switching surges, voltage spikes, line faults/flashovers, and other transmission and distribution (T&D) abnormalities. This significant portion of transformer losses indicates that more attention should be given to providing surge protection, or testing the adequacy of existing surge protection.

Poor Workmanship/Manufacturer

In the 1998 HSB study, only a few percent of the total claims were attributed to Poor Workmanship or Manufacturer's Defects. Among the conditions found were such things as loose or unsupported leads, loose blocking, poor brazing, inadequate core insulation, inferior short circuit strength, and foreign objects left in the tank.

Deterioration of Insulation

Insulation Deterioration was the second leading cause of failure over the past 10 years. The average age of the transformers that failed due to insulation deterioration was 17.8 years — a far cry from the expected life of 35 to 40 years! In 1983, the average age at failure was 20 years.

Overloading

This category pertains to those cases where actual Overloading could be established as the cause of the failure. It includes only those transformers that experienced a sustained load that exceeded the nameplate capacity.

Often, the overloading occurs when the plant or the utility slowly increases the load in small increments over time. The capacity of the transformer is eventually exceeded, resulting in excessive temperatures that prematurely ages the insulation. As the transformer's paper insulation ages, the strength of the paper is reduced. Then, forces from an outside fault may cause a deterioration of the insulation, leading to failure.

Moisture

The Moisture category includes failures caused by floods, leaky pipes, leaking roofs, water entering the tanks through leaking bushings or fittings, and confirmed presence of moisture in the insulating oil.

Inadequate Maintenance

Inadequate Maintenance was the fourth leading cause of transformer failures. This category includes disconnected or improperly set controls, loss of coolant, accumulation of dirt and oil, and corrosion. Inadequate maintenance has to bear the blame for not discovering incipient troubles when there was ample time to correct it.

Sabotage and Malicious Mischief

This category is usually assigned when willful damage was evident. Surprisingly, there were no reports of transformer damage in the last 10 years due to this cause.

Loose Connections

Loose Connections could be included in the Maintenance category, but there was a sufficient number of reports to list it separately. This is another departure from previous studies. This category includes workmanship and maintenance in making electrical connections. One problem is the improper mating of dissimilar metals, although this has decreased somewhat in recent years. Another problem is improper torquing of bolted connections.

All Others

This category encompasses all that could not be attributed to the above categories, including "Cause Undetermined."

Summary

A review indicates that a planned program of maintenance, inspection and testing would significantly reduce the number of transformer failures, and the unexpected interruption of power. From a cost standpoint, not only has the cost of repair increased dramatically, so has the cost of downtime. Rewinding or rebuilding a large power transformer can take six to 12 months. A good maintenance program should include the following re-recommendations to help achieve maximum service life.

Installation and Operation

- Keep the electrical loading within the design range of the transformer. In liquid-cooled transformers, carefully monitor the top oil temperature.

- Install transformers in locations that are compatible with their design and construction. If placed outdoors, make sure the unit is rated for outdoor operation.
- Protect transformers from surges and other external hazards.

Test the Oil

"The dielectric strength of transformer oil decreases rapidly with the absorption of moisture. One part water in 10,000 parts oil has been known to decrease the dielectric strength 50 percent. Oil samples from each tank, except of course small distribution transformers, should be given a breakdown test at least once each year ... so that moisture may be promptly detected and removed by filtering." (From The Locomotive, April 1925).

- Gas-in-oil analysis should be performed annually to measure the dissolved gases in the oil that are created by developing faults in the transformer. The specific gas and the amount of gas can identify the type of fault. The fluid screen test should be performed annually to determine the oil's ability to perform as an insulant. These tests include dielectric breakdown, acidity, interfacial tension, etc.

Additional Maintenance

- Keep the porcelain bushings and insulators clean.
- On liquid-cooled units, check the radiators for leaks, rust, accumulation of dirt, and any mechanical damage that would restrict the oil flow.
- Keep electrical connections tight.
- Inspect tap changes on a regular basis. Check the contacts for tightness, burning, pitting, freedom of movement, and alignment.
- The transformer windings, bushings, and arresters should have a Power Factor test on a three-year basis.
- Check the ground connection on the surge arrester annually. The connection should be tight, and the lead should be as short as possible. The earth resistance should be checked during the dry season, and should not exceed 5 ohms.

- Consider on-line transformer monitor system for the most critical transformers. There are a number of on-line systems currently on the market. The system vendors assemble a variety of probes and sensors, connect them to a data acquisition unit [DAU] and provide for remote telecommunications through a modem. The systems also incorporate an "expert system" to diagnose the problem and distinguish between events that are harmless and events that are dangerous.

About the Author

William Bartley received a Bachelor of Science degree in electrical engineering from the University of Missouri at Rolla. Bill joined Hartford Steam Boiler as an electrical inspector in 1971 and is now a Principal Engineer in HSB's Engineering Department, specializing in the assessment and analysis of large electrical apparatus, primarily generators and transformers. He is responsible for developing standards, OEM relations, fleet problems, large failure investigations, repair procedure development, and new testing technologies.