TRANSFORMERS - FAILURES

INTRODUCTION

A transformer failure can result in significant property damage and serious interruption to a business. Generally, these losses do not start with an electrical breakdown event or fire; they often start much earlier and can be traced to such causes as substandard Maintenance or inadequate Hazard Identification and Evaluation as discussed in *OVERVIEW*. The final event precipitating damage might be high ambient temperature, excessive loading, a deficient power supply or severe exposure. This final event leading to a failure is not the underlying cause of the loss.

Losses involving electrical hazards can require special investigative analyses. Common terms used to categorize the type and cause of a loss, like electrical breakdown, accidental operation, control failure, arcing, fire and electrical overload, oversimplify and do not necessarily identify the prime reason or reasons for a loss-producing event. These common terms do not readily identify system-related failures that initiate such incidents.

For example, a transformer undergoing normal service-aging might fail when exposed to a normal switching surge or normal stress in a circuit. Electrical breakdown, arcing and fire might result. The cause of the loss might be categorized as electrical breakdown, but the root cause might actually be a failure of a management maintenance system that missed scheduled oil maintenance procedures. The loss would not have happened if the root cause had been corrected before the initiating incident.

The root cause of electrical breakdown of an inadequately maintained transformer might be obscured if the electrical failure occurred during a lightning storm. Lightning is too easy a target for blame. Failures in both system design and system maintenance could be root causes of the breakdown and loss. The lightning storm could have been merely coincidental.

Because transformer hazards can be severe, and because transformer failures can result in high value losses, knowing why transformer losses happen, and particularly, knowing root or multiple root causes of transformer failures, can help loss control personnel prevent and reduce succeeding transformer losses.

Components of a transformer, transformer use and transformer maintenance are described in Property Risk Consulting Guidelines PRC.5.4.5, PRC.5.4.5.1, PRC.5.9.1, and PRC.5.9.4. Further transformer loss control information can be found in PRC.5.2.1, PRC.5.2.2, PRC.5.7.1.3, PRC.5.9.0.1, PRC.5.9.2, and PRC.5.9.3. This guideline introduces a basic discussion of conditions that lead to transformer failures, conditions which are factors in a root cause analysis.

POSITION

Thoroughly investigate and document the primary causes of losses involving highly important transformers.

- Address system failures that initiate these losses and examine factors that contribute to the extent of damage.
- Develop sound loss control practices based on such experience.

DISCUSSION

A transformer failure can be a complex occurrence. Learning from it often requires understanding the use of various transformer components and investigating conditions that these components were exposed to before the failure. The story of a loss can start long before "an electrical breakdown occurred, resulting in a fire and the loss of 45 days of production." "Why the breakdown occurred," and "what could have prevented it," provides lessons for those involved in loss control.

Finding the causes of a transformer loss, investigating each step that contributed to bringing the unit to failure, and applying this knowledge can prevent recurrences. Maintenance test records and records of operating conditions before and during the loss are often helpful in such investigations.

As an example of the effect operating conditions have on a transformer, continual operation above its design temperature will shorten the life of the unit. With Class A insulation, a 14°F (8°C) overtemperature can cut the life of a unit in half; a unit that would last 40 years will last 20. At high elevations, because the air is less dense, specified design temperatures (which refer to operating at sea level) will not cool a transformer as effectively. Thus, for altitudes above 3300 ft (1000 m), transformers are derated (full load rating reduced) to help keep internal temperatures down. High temperature will also lead to increased electrical power losses. Thus the temperature at which a transformer is run affects its operating costs, anticipated life and maintenance needs.

Although excessive temperature will rapidly break down transformer insulation, and units sometimes immediately fail when they get too hot, some failures do not occur until long after an overtemperature condition. The overtemperature weakens the insulation so that failure is more easily precipitated by other events. The unit might remain in service long after the overtemperature condition just as if the unit were service-aged longer, but not damaged. Such an overtemperature situation is generally not considered a root cause of a delayed failure, even though the service life of the unit was reduced.

Dry Type Transformers

Large, dry type transformers are more susceptible to failure than are similarly sized wet or fluid insulated units. Dry type transformers are particularly susceptible to influences from hostile environments and poor power quality. Local environments can degrade or contaminate dry transformers. Sunlight and overheating can chemically break down an insulation system. Contamination, such as from particulates from nearby exhaust systems and from dust and lint producing operations, can interfere with cooling, and can form short circuit paths that cause arcing. Wind blown rain can reach components that should remain dry.

Multiple failures of similar dry transformers at a site do not necessarily suggest design problems or poor quality control from a specific manufacturer. The failure of nine dry units in a period of three years at a utility site, and the experience at one industrial facility of four dry units failing in an eighteen month period, have been recorded. In the latter case, the facility contains numerous adjustable speed drives, uninterruptible power supplies and other harmonic-producing equipment.

Generally, dry type transformers of all types fail, and no one model appears to cause any significantly greater exposure to loss. Dry transformers are:

- Not suited to outdoor use. Manufacturers advertise units that can be used outdoors, but a dry unit is more likely to fail outdoors than indoors. The indoor atmosphere is controlled and produces less electrical and mechanical stress.

- Less resilient than fluid insulated units. Repeating problems like harmonics and corona can rapidly deteriorate solid insulation. Special dry transformers are manufactured for applications where these problems exist.
- Mistakenly believed to require little or no maintenance. In fact, dry units are less resilient and require more maintenance.
- Mistakenly believed to be “disposable.” Repairs should be undertaken whenever a unit performs in an unusual manner, as with an unusual sound or at a higher temperature. Dry units should not simply be run until they fail electrically.

Fluid Insulated Transformers

Mineral oil is the most common dielectric fluid used in insulating systems in wet transformers. The oil generally performs three functions. It maintains electric fields, cools heated electrical components and impregnates the paper in the tank of the transformer.

Paper tightly wraps each conductor before it is wound into a coil during the manufacturing process. The paper must be impregnated with oil before the unit is energized to improve the rating of the insulating system and to minimize degradation of the paper.

Aging, heating and electrical stress can break down oil and cause the formation of contaminants in the oil. These can be in the form of solids, moisture, dissolved gases and acids. Paper in a transformer can also degrade from mechanical stress. Physical damage results. Breakdown of either the paper or fluid impairs the dielectric function of the insulation system and can lead to electrical breakdown and transformer failure.

Heated fluid can bring about the accelerated oxidation of transformer oil and weaken it. As the oil slowly breaks down, the contaminants increase and the capability of the oil to withstand designed voltages is reduced. Overheating can be caused by a high electrical demand, low supply voltage, oil that has sludged, high ambient temperature and obstructions to air movement around the unit. A hot spot in a winding can deteriorate oil and also can char and destroy paper insulation wrapped around it.

Changes in temperature affect the water content of transformer oil. As fluid cools in a transformer, it flows to the lower portion of the unit. Since oil is saturated more readily at lower temperatures, the lower temperature frees more water near the bottom of the unit. Excessive free water will damage insulation. Whenever testing for water in oil, control the location of sampling and know the temperature of the oil where the sample is drawn, so that valid analyses can be made.

Oil insulated transformers are more tolerant of the environment and electrical system aberrations than dry units. But particulate contamination on the surface of any transformer bushing and severe voltage surges can cause arcing on any unit. Arcing involving an oil insulated unit can burn a hole in the tank and cause hot oil and flames to spew from the transformer.

Usually, a dielectric fluid does not completely fill a transformer tank. A vapor space exists above the surface of the oil. The oil vapors filling this space are created by temperature and pressure conditions within the unit. Under equilibrium conditions, vapors condense back into the oil at the same time oil forms vapors. This oil and oil vapor cycle generally is not a problem.

Nitrogen is sometimes introduced into the vapor space as an inerting blanket. Adding nitrogen to a transformer space is not usually a problem. However, nitrogen is absorbed into oil as temperatures drop, such as when a unit is shut down for a weekend. This contamination reduces the dielectric strength of the oil. The dielectric strength of the cold oil may be too low for a safe start up when operations resume.

Modern transformers protect the oil dielectric from contact with air and moisture in the environment. In some cases, a rubberized bladder is used to provide this separation. Oxygen is particularly damaging to mineral oil. Oxidation of oil, which accelerates with increasing temperatures, leads to formation of water, acids and sludge. Water can damage the paper insulation. Acids can damage the oil and paper. A sludge buildup on the windings will impair cooling and increase winding temperature. Some transformer designs are more likely to experience rapid sludge buildup than others.

The greater the level of accumulated impurities, the greater the chance of electrical breakdown. Mineral oil continually oxidizes as it ages. Periodic maintenance actions are required to maintain proper oil characteristics.

Arrangement and design are two approaches used to limit losses, but they do not prevent oil deterioration. A good preventive maintenance schedule can prevent losses. Corrective measures such as filtering, dehydrating, and vacuum dehydrating the oil will reduce the level of impurities and improve the insulating strength of the dielectric. Other preventive measures include adding an oxygen inhibitor, such as ditertiary butyl paracresol (DBPC); lowering operating loads and temperatures; repairing components and replacing oil.

Breakdown Gases From Oil

Generally breakdown gases can be detected in the oil before they enter the vapor space. These problematic gases form in the oil and do not escape into the vapor space until the oil is saturated. Such gases can be detected in the oil by sampling and lab testing. Examples of events that can lead to these undesirable gas formations, and the gases they produce, are as follows:

- Loose connections, low dielectric levels, or too high a voltage potential across a dielectric can cause arcing, which may be audible. This arcing produces temperatures of 3100°F (1700°C) to 35,000°F (19,400°C). Arcing in oil will form acetylene. Acetylene in transformer oil is a severely dangerous condition, warranting shutting the unit down.
- High ambient temperature, overload conditions, oil sludge blocking radiators, cooling fan or oil pump malfunction, and poor electrical connections can lead to overheating. Ethylene, ethane, methane and acetylene can be formed when oil is overheated and hot spot temperatures are between 212°F (100°C) and 932°F (500°C).
- Gas in the oil due to poor filling techniques (carrying in air bubbles) or overheating (described earlier) can ionize. Ionization of a gas is called corona which is a limited form of electrical breakdown. Corona causes the oil surrounding the gas space to chemically break down to form hydrogen, further adding to the gases in the oil.

Paper Insulation Failures

Industrial-size oil insulated transformers can easily contain thousands of pounds of paper insulation. Under ideal conditions, oil impregnation keeps the paper dielectric flexible. Moisture, extreme dryness, heat, cold, physical forces and electrical stresses can lead to the one small tear in the paper that causes a failure and results in the whole unit becoming scrap. Conditions leading to such failures include:

- Moderate overheating of the paper which produces carbon monoxide and carbon dioxide gases that accumulate in the oil.
- Severe overheating of the paper which drys it out, removing the natural water common to organic materials, and causes flaking. The flakes become solid particles in the oil, which weakens the dielectric and obstructs cooling.
- Contact with acids and excessive free water which weakens paper fibers. Fibers split or decay leaving a “mulch” which is susceptible to breakdown.

Human Error

Poor handling procedures can physically damage windings and insulation. Unless special care is taken, such damage can occur when repairs require moving the coils of an oil filled transformer to a shop. It is advisable to conduct electrical tests before and after scheduled maintenance involving major repair or overhaul to allow comparing results to verify that such damage has not occurred.

Mechanical Movement

Movement can damage solid insulation. If a force moves or jars the paper insulation on the coils of an oil filled unit, and if the paper is weak due to age, it may not be resilient enough to return to its original shape and electrical clearances. The paper could be brittle or the fibers could be so weak that anything causing the paper to move can cause it to be damaged. Varnish and plastic insulation can be similarly damaged. Thus, shaking, vibration, jarring and even normal magneto-motive movement of windings with rapidly fluctuating loads can lead to insulation breakdown.

Varying magnetic fields in all transformers tend to force parts to move. Strong construction or bracing usually holds the parts in position. The arc furnace transformer produces such high current swings and strong magnetic fields that exceptional restraint is required. Such stresses may eventually weaken the wooden bracing and lead to the abnormal movement of parts, breakdown or both.

Electricity

Surges of current, voltage and power can be devastating to a transformer. Surges from switching and lightning are common in most circuits, and protection is normally easily provided. A transformer nameplate identifies the Basic Impulse Insulation Level (BIL) that a new transformer is designed to withstand at rated conditions. Surge arresters are then installed to hold voltage surges below this level. Additional information is available in PRC.5.2.2.

However, an insulation system weakens as a transformer ages and when exposed to heat. Weakened insulation can fail from even a low-level surge which previously would have been dissipated unnoticed. Thus even a low “let-through” surge level (one below the BIL and below the clamping level of the surge arrester) can cause insulation failure on an old or service-aged unit.

Exposures

Transformers fail for many reasons. Only some are described in this guide. Others include: fire exposures from nearby buildings or equipment; exposures to impact from falling ice, vehicles, or thrown objects; natural events including rain, snow, fog, hail and salt water spray; and catastrophic events including flood, windstorm and earthquake.