On-Site Transformer Oil Regeneration

An Essential Element of Preventative Transformer Maintenance

Introduction

The life of the transformer is really the life ofthe insulation system. The most widely used transformer insulation system comprise of liquid insulation (transformer oil) and solid insulation (Kraft paper, pressboard, wood, i.e. cellulose products). The insulating oil provides approximately 80% of the dielectric strength of a transformer. The majority (Approximately 85%) of transformer breakdowns are attributable to the failure of the insulating system.

Transformer oil is a good liquid insulation medium and when impregnated in paper, boards and cloths, increases the dielectric strength of these winding insulation materials. The low viscosity of the oil allows it to penetrate the solid insulation and allows convection currents to form, conveying the heat of the core materials to the radiators. The liquid insulation therefore also serves as a coolant. Its oxidation stability allows it to operate at high temperature for long periods without serious breakdown.

The Ageing Process

The ageing or deterioration of insulating oil is normally associated with oxidation. Due to the omni presence of oxygen and water, insulating oil oxidizes even under ideal condition. The insulating properties of the oil also affected by contaminants from the solid materials in the transformer dissolving in the oil. The reaction between unstable hydrocarbons in the oil, oxygen and other catalysts such as moisture, with the assistance of accelerators such as heat, results in decay products (oxidation by-products) in the oil.

Heat and moisture are the "main enemies" of the solid (paper) insulation with oxidation as the primary accelerator. Ageing of the insulation system could accelerate by 40 to 60 years through an increase in operating temperature.

Oil oxidation can unfortunately not be eliminated but it can be controlled (slowed down) through applying preventative maintenance procedures. The key to preventative maintenance of transformers is annual oil analysis. The results of oil analysis reveal information regarding the condition of a transformer's insulating system.

Moisture consists of free water, suspended water (trapped in oil decay products), dissolved water and chemically bound water (part of the chemical structure of the glucose molecule and necessary to maintain the mechanical strength of the cellulose). The complete removal of moisture from cellulose insulation is therefore impossible.

Transformer oil dissolves more moisture at higher temperatures than at lower temperatures. If the oil and water combination is cooled, the water will precipitate out. The water phasing out of solution will be absorbed by the insulation or attracted by the decay products in the oil (water in suspension). The moisture will divide between the paper and the oil in a definite ratio ensuring a state of equilibrium at any given temperature. The paper insulation therefore absorbs the water from the oil and stores it in the worst possible place, i.e. the core where the electrical stress is highest.

Sludge formation is the terminal stage of deterioration process. The acids formed in the process of oxidation attack the cellulose fibers and metals forming metallic soaps, lacquers, aldehides, alcohol and ketones, which precipitate as an acidic sludge (a heavy, tarry substance) on the insulation, the side walls of the tank, in ventilating ducts, cooling fins, etc. Sludge appears faster in heavily loaded, hot running and abused transformers.

Sludges increase the viscosity of the oil, thereby reducing its cooling ability. Sludge cause shrinkage

of the insulation through leeching out varnishes and cellulose materials. It is also partially conductive, hygroscopic and a heat insulator. Sludge deposits on the core and windings will therefore increase the transformer operating temperature.

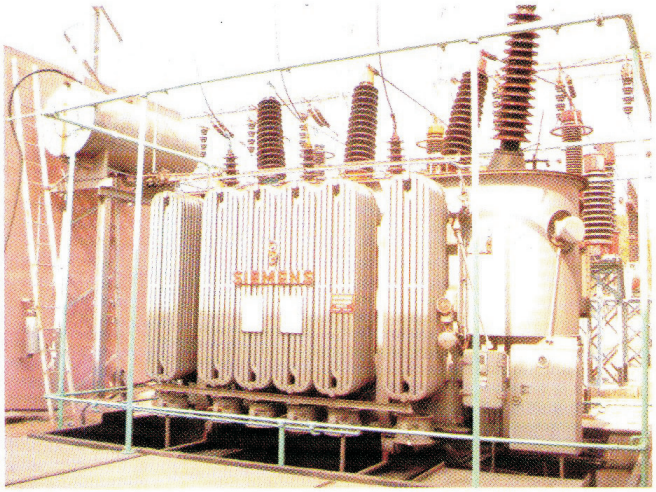
What is The Impact of Preventative Maintenance on The Transformer's Life Expectancy?

The cellulose materials are the weakest link in the insulation system. Since the life of the transformer is actually the life of the cellulose insulation, and degradation of the cellulose is irreversible, it makes sense to remove the decay products before they can do any damage to the cellulose. Under a proper preventative maintenance program, the cellulose can virtually have indefinite life.

A properly maintained power transformer should have a practical life between 50 and 75 years. However, the condition in which the insulation system is maintained largely determines the difference between 20 and 50 plus years of transformer life. The greatest cause of premature transformer failure is neglectance.

The transformer oil could be "restored, making it as good as new oil". Insulating oil, when properly maintained, can be given practically "unlimited extension of life". Only a very small percentage of crude's available (+/- 3%) are of the type used for transformer oil. Since it is a limited resource it requires proper usage and its recycling is justified from both conservation and an economical point of view. The disposal of badly oxidized oil has to be reviewed continuously in the light of the higher cost of new oil, better reclamation techniques, and government regulations regarding disposal, e.g. the National Environmental Management Act (Act no. 107 of 1998).

The modern transformer designs resulted in smaller units with less oil per kVA rating. This means a higher ratio of solid insulation per liter of oil, higher internal temperatures and more insulating materials under maximum permissible electrical stress. It has therefore become increasingly important to eliminate moisture and to maintain the insulation at a higher level of dryness. The presence of moisture increases the ageing rate. Insulating paper with one percent moisture content ages ten times faster than one with 0.1 percent.



On What Principles should Preventative Maintenance Criteria Be Based?

Transformer oil treatment is a preventative maintenance tool with the aim of extending the life of the transformer. Whether the treatment is done inside or outside of the transformer tank and on-line or off-line depends mainly on economic and production considerations.

The aim of a preventative transformer maintenance program is to remove the decay products from the oil before they cause damage to the transformer insulation system. A well-planned preventative maintenance strategy will prevent a wet core condition and ensure that the transformer always operates in the sludge free zone.

Preventative Transformer Maintenance: Oil Maintenance Options

To arrest or retard the process it is necessary to keep the oil in good condition. This can be done by:

- Monitoring the oil condition on a regular basis Maintain silica gel breathers in an active condition. (Do not allow a color change above one third of the volume).
- Repair oil leaks as soon as they occur.
- Start off by using a good quality IS - 335 oil dried to equal or less than 10 PPM moisture.
- Do not top up with wet oil from previously opened containers.
- Purify oil as soon as the moisture rises above 20 PPM or the dielectric strength drops below 50kv.

Monitor the acid levels of the oil and replace or regenerate before it reaches the critical level of 0.10 mg KOH/g of oil.

Oil Exchange (Draining, Flushing and Refilling)

This procedure is normally performed on site. The transformer is drained of the oil; its interior is flushed with hot Naphthenic oil to remove the accumulation of bulk sludges and then refilled with new oil. The old oil is disposed of or sent for regeneration elsewhere. If flushing of a dirty transformer of a dirty transformer is done through an inspection hole, it reaches only approximately 10% of the interior surface. If the top cover is removed, approximately 60% could possibly be reached. A film of the contaminated oil therefore remains on large parts of the interior surface. Up to 10% of the volume of oil in the transformer is also entrapped in the cellulose insulation; this oil contains polar compounds and can ruin large quantities of new oil. Neither flushing nor hand cleaning can remove the sludges that accumulate in the voids of the insulation. Only approximately 25% of the surface of the transformer winding can be reached through flushing and cleaning in a workshop. Changing the oil does not remove all the deposited sludge, especially those in the cooling fins, trapped in the solid insulation and in between the windings. These residual sludges will dissolve in the new oil and trigger the oxidation process immediately.

On-site Regenaration and Desludging

With on-site regeneration and desludging, the oil is processed on site in the transformer tank. It is circulated from the bottom of the main tank, heated and directed through 'structural clay columns', then filtered to particulate removal of 1 micron, vacuum treated and dehydrated before it is returned to the top of the unit via the conservator tank. The process is continuous until the oil exceeds the IS 335 specifications. The method employs adsorption and thermo vacuum (dehydration and degassing) treatment in restoring the oil. All leaks should be repaired prior to on-site oil treatment to prevent subsequent degradation of the oil.

The difference between regeneration and purification is that purification cannot remove substances such as acids, aldehides, ketones, etc. in solution, and can therefore not change or improve the colour of the oil. The regeneration process incorporates the thermo vacuum (purification) and fine filtration processes.

Through on-site, on-line regeneration and desludging of the oil, the following results are achieved:

- The moisture in the oil is reduced to below 10 ppm.
- The acidity is reduced to less than 0.01 mg KOH/g oil.
- The dielectric strength is improved to better than 70 KV
- The IFT (Interfacial tension) is improved to up to 40 Dynes.
- The Tan Delta (loss tangent) of the oil is improved to equal or less than 0,001.
- Sludges dissolved or in suspension in the oil as well as sludge deposits are Removed.
- Particulate removal to 1 micron is achieved
- The oxidation stability of the oil restored to equal that of new oil.
- The color of the oil is restored.
- The dielectric strength of the solid insulation is improved.
- Degradation of the solid insulation has been halted.

Although the regeneration process will remove Sludges dissolved or in suspension in the oil, it will not remove solid sludge deposits during the short regeneration process. A desludging procedure also referred to as hot oil cleaning of the transformer, would need to be performed. When oil analysis reveals a neutralization number greater than 0.20 mg KOH/g of oil and an interfacial tension of less than 24 Dynes / cm, desludging or hot oil cleaning is required.

This is achieved by the regeneration process where the oil is elevated to its aniline temperature at which it acts as a solvent for dissolving its own deposited Sludges, which is then removed by physical separation through the 'structural clay columns'.

Technical Comparison

Table I: Comparison of oil exchange vs. on-site regeneration

Item	Oil Exchange	Onsite Regeneration
1	Off-line only	On or off-line by choice
2	Used oil must be drained and transported to regen facility	Used oil regenerated in the transformer on-site, i.e. no removal or transportation costs
3	Cost of new oil required for flushing	No new oil required
4	Flushing is not very effective in that it reaches only approximately 10% of the interior surface if done through an inspection hole. If the top lid is removed, only approximately 60% of the interior surface could be reached.Cooling fins are difficult to flush. Approximately 20% of the contaminated oil remains trapped in the cellulose insulation	Regeneration does more than restore the oil to its original, new condition. It also dissolves and removes the deposited sludges on the core and coils, in the cooling fins and ducts and in between the windings. The absorbed sludge (decay products) in the cellulose insulation is also removed.
5	The film of old remaining in the transformer and cellulose insulation contains polar compounds and can ruin large quantities of new oil	No decay products are left. The transformer is purged of contaminants that could not be removed by any other means.
6	Vacuum needs to be drawn on the transformer before retro filling	No vacuum drawing costs.
7	Danger of spillage in oil handling and transport	No spillage danger through handling of oil.
8	Downtime estimated between 8 and 36 hours depending on the size of transformer, revenue loss	No downtime with on-line regeneration, no revenue loss.

On-line Treatment of Oil

Insulation Shrinkage and Dehydration of Transformer Oil

Insulation shrinkage could result in coil movement under load and specifically shock loading, causing premature failure. Because insulation shrinkage is a direct result of cellulose degradation, this process is immediately halted through on-site, on-line regeneration transformer oil as this effectively removes acid and other decay products that cause cellulose degradation. All though insulation shrinkage can also occur through the dry-out process of wet insulation, more than 40 years of experience in the USA indicate that, unless the transformer core is super dried (+/- 2% dry weight), insulation shrinkage does not occur.

The period required for the purification, regeneration or desludging process is not sufficient to dry out the transformer core. Extended dry-out periods, using specialized equipment is required to achieve such levels of moisture extraction from the solid insulation. The migration of moisture from the wet core to the dry oil is natural, unforced process and aims at restoring equilibrium between the two mediums. It is a slow process and depends on the rate of diffusion of water through the paper.

Removal of Sludge in the Active Parts of the Transformer

The regeneration plant is capable of online desludging, this is a unique process of removing sludges already deposited on, and in transformer windings and insulation etc., and is achieved by utilizing the aniline temperature of the oil to dissolve its own deposited sludges, which are then removed by the plant before the oil is returned to the transformer. It is important to remember that with the regeneration plant, each liter of oil returned to the transformer meets or exceeds the IS: 335 requirements for new transformer oil. On-site regeneration and desludging therefore does more than restore the oil to new oil specifications. It also purges the transformer of contaminants that could not be removed by oil replacement or by any other means presently available to the industry, and which is the primary cause of transformer failure.

Loss of Furanic Data

It is true that any treatment (regeneration, purification or replacement) of the transformer oil destroys the furanic data used to predict the degree of polymerization (DP) of the cellulose insulation. However, it makes no sense to comprise the life of a transformer in the process of preserving historic data.

If the transformer oil deteriorates to levels exceeding specifications, it will certainly reduce the transformer life if not attended to. One will always have to choose between preserving historic data and treating the oil in order to extend the transformer's remaining life. One's focus should be on extending the life of a transformer rather than its past history.

A furanic analysis could be done on the transformer oil before treatment commences. After treating the oil, a new baseline is established. Future furanic tests could then be referred to the new baseline. The degree of polymerization could then still be predicted over a period of time.

Removal of Aromatics

Some type of aromatics may function as natural oxidation inhibitors. Most specifications require that the Poly aromatic hydrocarbon content should be equal or less than 3%. Too many aromatics reduce dielectric or impulse strength and increase the solvency action of the oil for many of the solid insulating materials immersed in it. In a recent experiment involving the desludging of a 20 MVA transformer, the poly aromatic hydrocarbons were only reduced from 4.75% to 3.75%. The oxidation stability of the regenerated oil (after 164 hrs @100^0 C) was 0.06% by mass, which is well below the specified max. level of equal or less than 0.1% by mass.

Damage to Transformer Oil

If improper equipment or plant is used, the oil can be damaged and its oxidation stability destroyed. Should this be the case, the oil will deteriorate at a much faster rate. Badly designed equipment often damages the oil by incorrect heating and de-watering methods which unfortunately is too often the case.

It is important to note that only regeneration equipment to regenerate mineral insulating oil in respect of specification IS: 335, be used for transformer oil treatment purposes.

More than forty years of experience in the United States has proven that with properly designed and operated equipment, on-line treatment of transformer oil is a safe and economical procedure that extends the useful life of a transformer.

Economics Considerations

Insitu treatment of the oil on an energized transformer requires no down time, reduced labor

costs and eliminates transportation or rigging expenses. Table 3 indicates that it should normally be between 30 % and 60% less expensive to regenerate transformer oil within the transformer tank compared to the alternative of draining, flushing and refilling the transformer with regenerated oil. This saving margin shedding requirements.

The oil treatment costs normally differ for the following four oil quality brackets:

- Acidity equal to or below 0.10 mg KOH/g of oil and moisture below 20 ppm.
- Acidity between 0.11 and up to 0.20 mg KOH/g of oil and moisture below 30 ppm.

(Beyond an acidity level of 0.11 and interfacial tension (IFT) of 24 Dynes / cm, the oil is unable to keep sludges in solution).

- Acidity between 0.20 and up to 0.3 mg KOH/g oil and moisture below 40 ppm.
- Acidity above 0.3 mg KOH/g of oil and moisture equal and above 40 ppm.

The difference in price is mainly due to the fact that both the treatment period and the filter replacement frequency depend on the oil quality.

Through following a proper preventative maintenance program, and depending on the transformer condition before treatment, it is reasonable to expect a further 10 to 20 years of operation from each unit.

After the first on-line regeneration treatment, five years of "service free life" could be guaranteed, if the preventative maintenance program is applied correctly. The transformer will eventually only require bi-annual oil sampling and analysis and occasional (heated vacuum and degassing) purification.

Treatment of a Wet Transformer

Moisture in Oil

If the transformer core (insulation) is wet, the level of moisture in the oil is expected to increase again after treatment. Moisture will migrate from the wet solid insulation to the dry oil until equilibrium is reached between the cellulose and the oil at any given temperature, thus requiring periodic, follow-up purification treatment until a satisfactory equilibrium is reached.

Dielectric Strength

The dielectric strength of the oil will decrease as the moisture in oil increases in the weeks following treatment.

Acidity

If the acidity increases significantly over a short period following regeneration or desludging, it is indicative of either incorrect or insufficient treatment or that the oil has been damaged by the equipment used. For this reason it is important to remember that the success of the treatment depends entirely on the type of equipment used and the accuracy of the oil sample analysis. Therefore ensure that only reputed manufacturer equipment is used and an independent and accredited laboratory for the analysis.

Experienced operators in the filed are often able to determine the accuracy of an analysis by means of a visual inspection of the oil.

A reliable regeneration service provider should be willing to guarantee the quality of the oil regenerated by them for a period of at least five years following treatment, provided that the transformer is not leaking, only Dryed (ppm <5 ppm) oil is used for top-up purposes, the explosion vent and Silica Gel is properly maintained over that period and the transformer temperature specifications (oil and winding temperatures) are not exceeded.

Follow Up Oil Tests

Follow up oil analysis are recommended in the months following any maintenance procedure in order to monitor the transformer's operation and should include combustible gas-in-oil analysis, moisture in oil and dielectric strength tests.

Recommended Transformer Oil Maintenance Strategy

Whether the treatment of transformer oil is done inside or outside of the transformer tank and on-line or off-line depends mainly on production and economics considerations. It should be at least 30% to 60% less expensive to regenerate transformer oil within the transformer tank compared to the alternative of draining, flushing and refilling the transformer with regenerated oil. This margin should increase substantially whenever online regeneration prevents revenue loss due to load shedding requirements.

Regeneration of transformer oil is an important preventative maintenance tool and transformer oil should therefore be treated before it reaches levels of deterioration that is known to cause damage to the transformer insulation. If an maintenance program is followed, the accumulation of moisture and sludge in the transformer's solid insulation could be prevented. The following preventative maintenance strategy is recommended.

- Purify when the acid levels is still below <0, 10 mg KOH/g, color is still yellow to light amber, and the moisture is '20 ppm and / or when the dielectric strength is <50kv.
- Regenerate when the oil reaches 0, 10 mg KOH/g, to avoid precipitation of sludge. If transformer oil is regenerated from an acidity level of 0.10 mg KOH/g oil, the moisture in oil levels will be reduced at the same time, thereby preventing a wet core condition.
- Desludge when acid level is'0, 20 mg KOH/g.
- Dry out when solid insulation is wet '3.5%

We also recommend that, if a preventative maintenance program is introduced for the first time, the transformers that have not yet reached half-life stage, i.e. those with a DP between 1200 and 700 should be targeted first.

However, the older transformers of which the oil is in a very bad state of deterioration should not be left unattended. Very old transformers (forty years and older) and even ones with a DP value (degree of polymerization) below 210 have been successfully desludged while energized.

For ON-LINE regeneration, the following criteria should be met

- The transformer should not contain free water.
- The dielectric strength should not be below 20 kv.
- The oil should not have a moisture content of more than 60 ppm.
- The transformer should not be overloaded while the oil in a very bad state.

If these criteria are not met initially, the regeneration process should commence off line until the above criteria are met, thereafter the process could be continued on line.

As transformers were installed in 1964, the only oil treatment ever done was in the year 2003. i. e. was purification. When we have observe the oil sample physically in the year December 2006, it was black / tam in colour, the oil result before was taken in the year 2003. That was the only data available, finally we decided to process "On – Line Regeneration".

The transformer was connected at the bottom of the transformer to suction of Regeneration plant & delivery of the machine was connected to conservator of transformer.

Machine was started and the moderate flow of oil was set. The suction oil was process through heating chamber, set of filter chamber. Series of clay columns & degassing column.

The process was reputed 30 + times, during the process, the clay in site were recharge without replacement and handling of clay.

After 30 days of continuous process the oil result were achieved successfully at MALCO. Refer enclosed CPRI report.

Conclusion

Experience gained different suite in India & abroad has proved that the on-site regeneration process is less stressful on the transformer insulation than the alternative process of draining, flushing and refilling the transformer with new oil. The on-site process is substantially less expensive and technically superior to the alternative, and if done on-line, avoids long outage periods and consequent revenue losses. Most utilities practicing on-line oil treatment recorded a noticeable drop in transformer failures.

The extension of the life of a transformer through implementing a preventative transformer maintenance strategy from the outset effective approach. If the transformer oil is regenerated as soon as the acidity level exceeds 0.11 mg KOH/g, degradation of the transformer oil, a wet core condition, sludge forming and subsequent damage to the transformer insulation will be prevented and the life of the transformer could be extended by up to 20 years.

Through on-site regeneration, Lac of Rupees could be saved on the maintenance budget and through improving the general condition of the oil, the risk of insurance disputes will also be minimized.

As a manufacturing of machine and with experience behind, we recommend to process oil according to the oil parameter status. The process available are

- Purification,
- Regeneration, and
- De – Sludging.

Slduge Formation in Transformers and Desludging of Transformers

With reference to various discussions on the above subject and requests received, this paper is supplied to clarify certain facts pertaining to this subject.

Sludge Formation in Transformers

An ASTM concluded that the formation of soluble decay products starts to form in transformer oil as soon as the oil is put into service, due to the unavoidable presence of oxygen with moisture,

copper and iron as catalysts and accelerators like heat, acid, vibration, shock loading, surge voltage and high electrical stresses.

These soluble by-products of oxidation become insoluble as oxidation continues and eventually precipitates as sludge first in the cooler areas like cooling fins and later also on hooter parts, core and windings.

During this process the insulating paper and spacer boards acts as filters and start clogging, with the resultant reduction of dielectric strength.

Polar compounds already start forming between Neutralization Numbers (NN) 0.05 and 0.10, with a resultant drop in interfacial tension (IFT). From a NN of 0.11 to 0.15 fatty acids coat the windings, sludges in solution becomes insoluble and starts to precipitate during cold spells in the cooling fins and then builds up in the insulation voids.

From NN 0.16 to 0.20, sludge is precipitated in the cooling fins as well as on the core and coils irrespective of ambient temperatures.

Once deposited, oxidation continues to harden the deposits. Almost all transformers with acid levels between 0, 2 and 0, 3 showed heavy sludge deposits upon inspection.

American Society for Testing and Materials (ASTM) conducted a research on 500 transformers during a period from 1946 to 1957, and found that 38% with NN between 0.11 and 0.20 showed sludge present and 72% with NN between 0.21 to 0.60 heavy sludge deposits. 100% of all transformers with a NN>0.6 was engulfed with sludge deposits.

Sludge deposits in the transformers obstruct the heat exchange between the active parts of the transformer and the insulating oil and continue to embrittle the solid insulation materials by attacking the cellulose. It is therefore of utmost importance to keep a transformer free from sludge deposits.

All transformers with NN of greater than or equal to 0,2 mg KOH/gm oil should be desludged, as the deposited sludges leech out of the insulation materials, varnishes and cellulose materials, resulting in severe embrittlement and shrinkage of the insulation, causing premature failure of the transformer.

Desludging of Transformers

There are two methods which can be used for desludging transformers.

Conventional Method

- Drain transformer of oil.
- Remove top cover.
- Heat new oil and high pressure, spray-wash entire interior, core and coils.
- Drain transformer of all oil.
- Remove top cover.
- Heat up new oil and spray-wash the entire interior, core and coils with a high power spray gun.
- Flush out the coolers. If possible remove fins and clean out sludge as far as possible.
- Re-assemble transformer.
- Draw vacuum and hold vacuum for a number of hours to evacuate air from the solid insulation system.
- Fill the transformer with preheated new oil.
- Purify the oil in the transformer for at least 4 cycles.

Comment

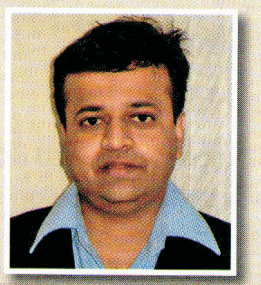
- Time consuming.
- Labor intensive.
- Has to be done off-line (production downtime).
- Must be done under perfect weather conditions.
- Original oil charge and flushing oil no more suit able for reuse and must be disposed of.
- Environmentally unfriendly (spillage hazard)
- Expensive process.
- Partially successful only. Adsorbed sludge in the cellulose insulation is not removed.

Today's Solution

On line Transformer Oil Regeneration machine can operate on – line with single person in operation avoid down time of transformer. The filter machine can remove sludge's & change oil colour back to new oil. All the sludge's inside the radiator on the insulation will be removed from transformer.

The foremost important feature in the system is the reflowshing media used in process to remove unwanted substance from oil can be reactivated against for 250 – 300 times without handling the media.

Machine used is Environmental friendly.



Nitin Dhamale
CEE DEE Vacuum Equipment Pvt Ltd, Pune