CONDITION ASSESSMENT METHOD FOR TRANSFORMER INSULATION SYSTEM IN ORDER TO MAINTAIN ITS EFFICIENCY

Harry Gumilang
PT PLN P3B JB - Indonesia
harry.g@pln-jawa-bali.co.id

Rikardo Siregar
PT PLN P3B JB - Indonesia
rikardo_siregar@pln-jawa-bali.co.id

ABSTRACT

Transformers are one of some important equipments on electricity network. Transformer life time is equal with its insulation condition. Each utility, in this case PLN P3B Jawa-Bali has to assure their reliability in order to maintain electrical power system stability by assessing transformer conditions.

Many parameters cause the power transformer insulation system degraded, i.e. operating load that influence the temperature, the existence of acid, oxygen and water. Those all parameter could risk the transformer operation which going to lead to further damage and failure of power system.

PLN P3B JB already implemented a method to assess the condition of transformer insulation system. The methods consist-of electrical test, chemical test and physical test. Electrical test give an image of insulation condition based on electrical response of insulation as a dielectric material i.e. tangent delta and insulation resistance. Chemical and physical test provide a direct analysis of insulation material i.e. oil quality test, furan and DGA.

Trough this assessment condition method, PLN P3B JB already made transformer condition mapping which consist of almost 255 units (Regional1). The condition mapping giving information such as the list of transformer condition starts from the good to the worst one. Based on this information PLN could prevent for any disturbance that may come due to un-proper function of insulation and planning such an action based on each transformer condition.*

.

TRANSFORMER SYSTEM

Based on CIGRÉ standard, transformer as a system could be defined as several sub-systems i.e. dielectric, bushing, electromagnetic-current carrying unit, cooling system, OLTC, mechanical structure and oil preservation-expansion.

One of the most critical sub-system of transformer is dielectric. The key of lifecycle for all high voltage equipment is its insulation (dielectric). Dielectric lifetime will equal with transformer lifetime.

TRANSFORMER INSULATION SYSTEM

Modern transformers include various insulating material which together form an insulation system.

- Pressboard
- Kraft paper
- Manila & hemp paper
- High density particle-board
- Pressboard collars, and end insulation
- Laminated (plywood type) particle-board
- Enamels
- Inorganic and organic core lamination coatings
- Porcelain
- Epoxy powder coating
- Maple wood structural form
- Vulcanized fibre
- Cotton
- Plastic and cement
- Liquid dielectric fluid

This system isolates the transformer winding from each other and from the ground-to insulate the current carrying parts of the transformer from the magnetic iron and structural steel parts. The insulation is thus more than "merely a mechanical means for keeping the wires apart" which were the only acknowledge purpose in the development of early equipment.

Transformer insulation oil

Surrounding the coils, core and solid insulation material of the most power transformers is the most common insulating liquid, mineral oil. This fluid serves three primary purposes:

- Provide dielectric strength of the transformer insulation system
- Provide efficient cooling
- Protect the transformer and core and coil assembly from chemical attack
- Prevent the build up of sludge in transformer

Transformer insulation paper

A solid material insulates because it possesses two distinct properties. First, it has ability to withstand both electrical and mechanical stresses due to the voltage used. Secondly, it such a poor conductor that a negligible but small current can flow through it and leak away. In other words, a good insulator will neither allow current "to break through it" nor "to steal through it".
Consequently, a practical insulation system must contain material that performs these four major functions:

- The ability to withstand the relatively high voltage encountered in normal service (dielectric strength). This includes both impulse and transient surges.
- The ability to withstand the mechanical and thermal (heat) stresses which accompany a short circuit.
- The ability to prevent excessive heat accumulations (heat transfer).
- The ability to maintain desired characteristics for an acceptable service life period given proper maintenance.
- Any weakness of insulation may result in the failure of transformer. Insulation is deteriorated when it has lost a significant portion of its original dielectric, mechanical or impulse strength. The continuation of the deterioration process leads to inevitable mechanical and/or electrical failure.

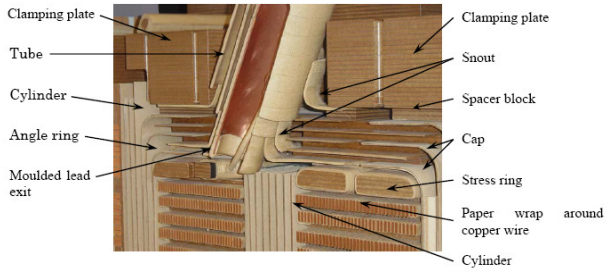


Fig 1. Insulation components

DEGRADATION OF INSULATION SYSTEM

Transformer oil degradation

When the properties of the oil have change enough that the oil can no longer satisfactorily perform anyone its function, the oil is said to be bad. Continuing to operate a transformer with bad oil significantly reduces the transformer's life expectancy.

Transformer oil deterioration usually caused by oxidation that experienced by the oil. Oil oxidation happen when the insulation oil accessed by the oxygen and it react with help of catalyst. The intensity of oxidation process depends on the accelerators.

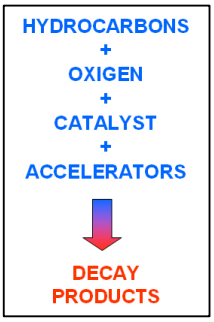


Fig 2. Oxidation process

Oxygen is derived from the air inside the transformer. All oxygen cannot be removed, even by vacuum filling. At least 0,25 percent by volume oxygen still remains even in sealed units. Oxygen is present in oil in solution as a component of dissolved air in higher ratio, due to its higher solubility as compared with nitrogen.

Degrading cellulose especially via heat also supplies a source of oxygen. Oxygen also could supplies from improper of silica gel in breathing system or from conservator which not completed with rubber bag.

The other factors affecting oil-life are catalyst, the primary substance that increases the rate of oil degradation without being consumed in the process. Moisture and copper are the catalyst in transformer oil oxidation process.

Moisture can enter the insulation oil externally via a leak, as condensation, or internally through the chemical process of oxidation. Water is a major catalyst in oil oxidation. All form of water contain additional oxygen.

All of the preceding shows the beginning stages of what is the inevitable process of deterioration. Fortunately, this is a long-term process, catalyzed also by copper (winding) and iron (core) and finally accelerated by several other factors.

Another secondary factors increase oil oxidation; these are called accelerators and consist of:

- Heat
- Vibration
- Shock loading
- Surge voltages
- High electrical stresses

Oil oxidation process will generate by product which can be a catalyst of oxidation process itself. The by products are:

- Peroxide gas
- Water soluble acids
- Low molecular weight acids
- Fatty acids
- Water
- Alcohols
- Metallic soap
- Aldehydes
- Ketones
- Lacquers
- Sludges of asphaltene

By several oil quality/characteristic tests we can identified whether the insulation oil experienced oxidation process or not.

- Oil colour
- Acidity level
- Interfacial tension (IFT)
- Sludge measurement

Fig 3. Several test equipment to indicate Transformer oil quality (Sediment, acidity, IFT & Colour)

When the oil gets oxidized the oil will contain acid, because one of by products of oxidation is acid. The IFT test is extremely sensitive to the presence of oil decay products. Oil oxidation contaminant will lower the IFT even further. These contaminants are hydrophilic which means they have an affinity for water molecules, as well as for oil molecules. At the interface the hydrophilic materials extend across to the water so that a vertical linkage is established and thus the lateral linkage (which makes up the surface tension) is weakened. The interface is now less distinct, and the tension at the interface is reduced. The greater concentration of contaminants will lead to lower of the tension.

Degradation of paper Insulation

Since the transformer put in service, insulation paper/ cellulose paper which has a function as insulation media inside transformer start experience ageing/ degradation. There are many factors which influence to paper ageing process.

Basically, there are three types of cellulose paper ageing:

- Hydrolysis
- Oxidation
- Pyrolysis

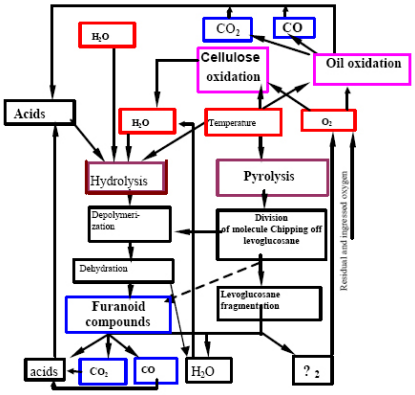


Fig 4. Degradation process

Hydrolysis happens when there is a presence of water which dissociates the acid, and acid itself as catalyst. Low molecular weight water-soluble-acids that are formed by the paper ageing and to some degree also by the oil ageing, are more efficient than the larger hydrophobic acids, which mainly stems from the oil ageing. The fact that acid catalyzed hydrolysis generates organic acids and at the same time is governed by their presence makes the process auto-acceleratory.

Paper oxidation happen when paper accessed by oxygen and accelerated by heat presence suggested to be catalyzed by hydroxyl radicals (HO•), which are produced by decomposition of hydrogen peroxide, H2O2 and of organic hydro peroxides (ROOH).

Paper degradation by pyrolysis is a process that can take place without access to water and/or oxygen, or any other agent to initiate the decomposition. At normal operating or overload temperatures (i.e. <140oC) such processes are considered to be of little relevance. At high temperatures, which may occur at defects such as poor soldering or magnetic induced local failure currents, pyrolysis may well occur. Generation of CO and CO2 may follow.

Diagnostic

There are several tests to identify the presence of paper degradation inside the transformer.

Measure the water content in paper can identify the presence of paper degradation, since water is a product of paper degradation and it can be an accelerator of degradation rate.

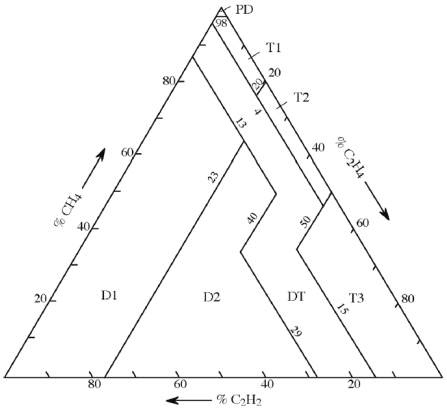
When paper oxidation and hydrolysis process happened it would generated Furanic compounds. So it would be another way to know precisely the insulation paper condition.

The paper degradation process will produce the CO & CO_2 gases. The quantity of those gases depends on the degradation level that the paper experienced. To measure the quantity of CO & CO_2 can be done by using DGA test.

Besides detecting insulation degradation, DGA could also detect another abnormality of transformer behavior. There's several possibility that may happen inside transformer and could be detected by DGA analysis using several methods. DGA test will detects Hydrogen, Methane, Carbon monoxide, Carbon dioxide, Ethylene, Ethane, and Acetylene. The composition that construct by those gases will interpret many conclusions.

Many method that usually used to interpret DGA result i.e. Doernenburg ratio, Rogers ratio, Key gases and Duval

triangle.



Duval Triangle

Duval triangle using only three gases i.e. methane, ethylene and acetylene. The composition based on those three gases could give 7 possibilities of abnormalities.

- Partial discharge
- Low intensity discharge
- High intensity discharge
- Mix discharge and thermal
- Thermal < 300 ^{o}C
- Thermal 300 – 700 ^{o}C
- Thermal > 700 ^{o}C

ASESSMENT METHOD

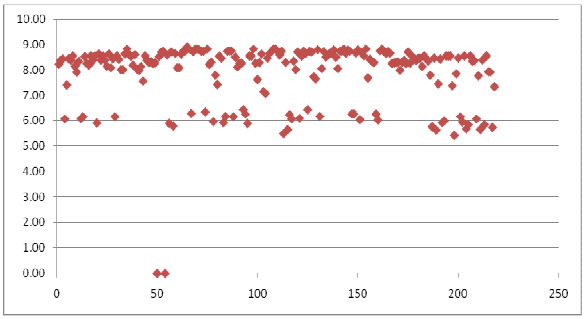
Since oil analysis is the most applicable method to assess the condition of transformer insulation system (Dielectric). We try to make some simple method that could give basic image that could represent the condition of transformer especially in insulation system.

This method consists of DGA (Dissolved gas analysis) and oil quality test (water content, dielectric breakdown, acidity, etc). to produce single value that could represent the equipment condition based on several test we put the weighting factor of each test.

Test	Method	Weighting Factor	Index		
			9	6	1
DGA	Duval	0.625	-	at least one of Combustible gas at cond't 2	
				PD	High energy discharge
				Low Energy Discharge	Mix thermal & Discharge
				Thermal <300 oC	Thermal 300 - 700 oC
					Thermal > 700 oC
	TDCG		Cond't 1	Cond't 2	Cond't 3 / Cond't 4
Oil Quality Test	Water Content	0.1125	good	fair	bad
	Diel Breakdown	0.1125	good	fair	bad
	Acidity	0.0375	good	fair	bad
	Interfacial Tension	0.0375	good	fair & bad	-
	Colour	0.0375	good	fair & bad	-
	Sediment	0.0375	good	fair & bad	-

To make the norm of 1,6 or 9 we used the IEC and IEEE Standard. For oil quality we used IEC 60422 and for DGA we used the IEEE C57,104 – 2008 std.

The maximum value that will appear after all test parameter proceed by this assessment method is 9, an the lowest value that will appear would be 1. So basically we can find out the mapping of transformer condition by looking what is value of each transformer start from 1 to 9.



Mapping of transformer condition
Based on oil insulation assessment method

REFERENCES

[1] CIGRÉ working group WG a2.18, Life Management techniques for transformator, January 2003
[2] CIGRÉ Task force D1.01.10, Ageing of Cellulose mineral-oil insulated transformers, October 2007
[3] Myers S.D, Kelly JJ, Parish R.H, A guide to transformer maintenance, 1981
[4] IEEE C57 104 2008
[5] IEC 60422, 2005