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Remaining life assessment 150/20 kV trafo with isolation degradation method

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Abstract. The life of a transformer (trafo) is determined by some of the conditions experienced by the trafo when the trafo is loaded. One of the conditions that provide high effect the life of the trafo is the amount of working temperature on the trafo. The high low-temperature trafo at load time is determined by the amount of load generated, the ability of the trafo to release the heat generated and the circumstances surrounding the trafo. In this research, the determination of trafo life by using isolation degradation method by measuring the temperature of top - oil, hot - spot temperature, and the amount of load generated by the trafo. The study was conducted by taking a case study of 150KV / 20KV trafo on Titi Kuning Substation. From the results of research on the trafo type, *trafostar* obtained the rest of the life of the trafo 2 in the Main Station Titi Kuning can survive for 11 years. With a load factor of 0.72 pu, a total hot-spot temperature of 169.20C, and an environmental temperature of 260C.

1. Introduction

The trafo is one of the important equipment in a power system. The main function of the trafo to deliver power / electric power from high voltage to low voltage or vice versa (transform the voltage).

The operation continuity of the trafo is highly dependent on the age and quality of its isolation system.

There are several factors that reduce the life of the trafo in isolation due to thermal influence is ambient temperature, trafo oil temperature and the effect of loading on the trafo. The loading results in an increase in temperature that causes heat to the trafo. Heat results in the breakdown of trafo materials that can accelerate the aging process of a trafo.

2. Materials and Methods

The trafo is a static device that can move and convert electrical energy from one or more electrical circuits to other electrical circuits, through a magnetic coupling based on the principle of electromagnetic induction which can lower the voltage with the same frequency. Trafos are widely used, both in the field of electric power and electronics. In the field of high voltage electric power, trafos are used to transmit electrical power over long distances. While in the field of electronics, the trafo is used as a coupling impedance between the source and the load to separate one circuit from another and to block direct current or the flow of alternating current between the circuit.

The working principle of the trafo is the transformation using the principle of Faraday's induction law and Lorentz's law in channeling power, where the alternating current that flows around an iron core then the iron core will turn into a magnet. And when the magnet is surrounded by a winding, at both ends, there will be a potential difference. Figure 1 shows the working principle of a trafo an electric current surrounding an iron core turning into a magnet.



The current flowing in the primary winding will induce the iron core of the trafo so that inside the iron core will flow the magnetic flux and the magnetic flux will induce the secondary winding so that at the end of the secondary winding there will be a potential difference. From the above working principles of a trafo can be seen in figure 2

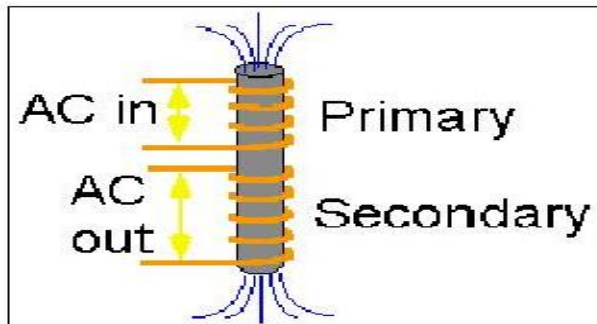


Figure 1. Flow back and forth around the iron core

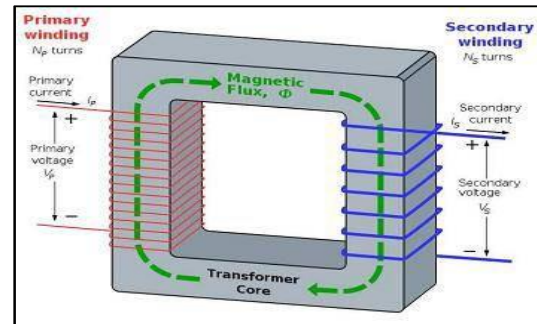


Figure 2. Working Principle of Trafo

The main part of a trafo is a core, two sets or more coils, and isolation. The trafo core is made of silicon steel sheets with one another insulated with varnish. The coil is made of copper material. The coil connected to the energy source is called the primary coil, while the coil connected to the load is called the secondary coil. The insulating material of the trafo is composed of a combination of a liquid dielectric material with a solid dielectric.

If the primary coil is connected to the alternating voltage source, while the secondary coil is unencumbered, then in the primary coil a current flow, called the zero loads current I_0 . This current will generate flux back and forth at the core. This alternating flux is enclosed by the primary coil and the secondary coil so that in both coils the electric motion arises in magnitude:

$$E_1 = 4,44 f N_1 \phi \text{ (Volt)} \quad (1)$$

$$E_2 = 4,44 f N_2 \phi \text{ (Volt)} \quad (2)$$

In the above equation: E_1 is the electric motion force on the primary coil; E_2 is the electric motion force on the secondary coil; N_1 is the number of turns of the primary coil; N_2 is the number of secondary coil windings; f is the source voltage frequency in Hz; and ϕ is the magnetic flux at the inner core of Weber.

If the secondary coil is loaded, then the coil is flowing secondary stream (I_2). The secondary current will generate flux in the trafo core opposite to the generated flux I_0 . In other words, secondary currents cause demagnetization at the trafo core. To compensate, the currents in the primary coil must increase to I_1 , until they are satisfied:

$$N_1 I_0 = N_1 I_1 - N_2 I_2 \quad (3)$$

The heat generated on the winding and the trafo core at the time of the overloaded trafo should not be excessive as it may damage and decrease the insulation resistance of the windings. To overcome the resulting heat is not excessive then used trafo coolant oil. In addition to cooling, trafo cooling oil also serves as an insulator. In addition, trafo cooling also occurs naturally, namely the form of air around the trafo. According to the type of coolant, the trafo can be divided into two types namely Dry Type Trafo and Oil-Immersed Trafo.

a. Dry Type Trafo

This type of trafo is easiest in its operation because the cooling system naturally utilizes the air around the trafo so that it does not require the cost of care.

b. Oil-Immersed Trafo

In this trafo is divided into several kinds, including are as follows:

Table 1. Various kinds of coolers on the trafo

No.	Kinds of Cooling System	Media			
		Inside the Trafo		Outside the Trafo	
		Natural Circulation	Forced Circulation	Natural Circulation	Forced Circulation
1.	AN	-	-	Air	-
2.	AF	-	-	-	Air
3.	ONAN	Oil	-	Air	-
4.	ONAF	Oil	-	-	Air
5.	OFAN	-	Oil	Air	-
6.	OFAF	-	Oil	-	Air
7.	OFWF	-	Oil	-	Air
8.	ONAN/ONAF		Combination 3 and 4		
9.	ONAN/OFAN		Combination 3 and 5		
10.	ONAN/OFAF		Combination 3 and 6		
11.	ONAN/OFWF		Combination 3 and 7		

In a trafo, there are two components that actively generate heat energy, i.e., iron (core) and copper (winding). If the heat energy is not channeled through a cooling system, the iron and copper will reach the highest temperature so that it can damage the insulating oil. Therefore, the winding and iron core are immersed in the trafo oil. This oil has a dual function that is as coolant and insulation.

The function of trafo oil on high voltage equipment can be divided into several parts:

- Oil Trafo As Coolant, trafo oil serves as a coolant because trafo oil is able to conduct heat well.
- Oil Trafo as an insulator on high voltage equipment. A good trafo oil should be a voltage separator between the parts that have a phase difference. This is meant that among the parts that have a phase difference does not occur electric jump (flash over) or electric spark (spark over).

Increasing the load of the trafo will increase the temperature of the insulating oil, the load above the design rating poses a risk. One of the disadvantages of the trafo during the over-temperature condition is the loss of the life of the insulation. The age of fine paper insulation is based on temperature, moisture, and oxygen levels over time. The use of oil to minimize the impact of moisture and oxygen on the life of the insulation. Therefore, the study of the age of the trafo using the hottest point temperature of the oil has a relationship related to determining the life of the trafo. Table 2 shows the trafo temperature and trafo age at 30°C ambient temperature.

Table 2. The temperature limitations and the age of the trafo at a temperature of 30°C

Variables	Temperature (°C)	Information
The average winding temperature rise	65	Above the ambient temperature
Hot-point temperature rise	80	Above the ambient temperature
Increase in oil-top temperature	65	Above the ambient temperature
Maximum heat-point limit	110	Absolute
Average normal trafo age	20.55 years (180,000 hours)	

The temperature of the top oil is the temperature of the insulating oil that is measured at the top of the trafo tank. The rise in top oil temperature is equivalent to the current quadrature according to the IEEE standard, the upper oil temperature rise rating is 65°C above the ambient temperature.

The initial rise in top oil temperature is the load current factor set by the following equation 4:

$$\Delta\theta_{TO,i} = \Delta\theta_{TO,R} \left(\frac{1+RK^2}{1+R} \right)^n \quad (4)$$

with: K=Factor load, R=Ratio of loss (total loss / loss, no burden), n=value of oil exponent

$\Delta\theta_{TO,R}$ = Increase in temperature of top oil early twigload

The rise in top oil temperature is directly related to the load current and the trafo thermal characteristics, set by the following 5 equations:

$$\Delta\theta_{TO} = (\Delta\theta_{TO,u} - \Delta\theta_{TO,i}) (1 - e^{-\frac{1}{\tau TO}}) + \Delta\theta_{TO,i} \quad (5)$$

with: $\Delta\theta_{TO,u}$ = the largest increase in the temperature of the top oil, $\Delta\theta_{TO,i}$ = initial rise in temperature in top oil, τTO = top oil constants.

Then the total temperature of the top oil, set with the following equation 6:

$$\theta_{TO} = \theta_A + \Delta\theta_{TO} \quad (6)$$

With θ_A = ambient temperature

The hot-spot temperature is the hottest temperature inside the trafo windings. The hottest turning location is dependent on the physical design of the trafo. The Guide for Loading establishes the design limit for a normal heat-point temperature of 110°C or 80°C above the assumed environmental temperature of 30°C (IEEE Standard). For more embedded load situations, the Guide for Loading allows the hot-spot temperature not to exceed 110°C (IEEE Standard). Due to excessive temperatures can cause unacceptable losses from the age of isolation.

An initial rise in hot spot temperature is a load current factor, set by the following 7 equations:

$$\Delta\theta_{H,i} = (\Delta\theta_{H,R}) (K^{2y}) \quad (7)$$

with: K = load factor, y = exponent winding, $\Delta\theta_{H,R}$ = rise in hot-spot temperature of twigs

The hot spot temperature rise of the winding depends on the trafo load and the trafo's thermal characteristics, set by the following equation 8:

$$\Delta\theta_H = (\Delta\theta_{H,u} - \Delta\theta_{H,i}) (1 - e^{-1/\tau W}) + \Delta\theta_{H,i} \quad (8)$$

with: $\Delta\theta_{H,u}$ = the largest hot-spot temperature rise, τW = winding constant

Hotspot temperature depends on ambient temperature and total temperature of the top oil, set by the following equation: Then the total hot-point temperature, set by the following equation 9:

$$\theta_H = \theta_A + \Delta\theta_{TO} + \Delta\theta_H \quad (9)$$

The decrease in the ability of an insulating material due to heat is called aging. The main factor that limits the loading ability / ability to maintain the approximate age of the trafo, due to more loading will cause heat to the winding of the trafo coil so that at one time it will decrease the life of the trafo (shrinkage of age) than expected. Trafo life is normally expected to be around 30 years when operating with a predetermined rating. But in some circumstances, the possibility of overloading the trafo.

The worsening of insulation will be faster if the isolation works with a temperature that exceeds the allowed limit (hot spot temperature). A trafo will experience a normal life under "980 c hot spot temperature on continuous loading" conditions. If the trafo experiences a hot spot temperature greater than 980c, the shrinkage of its age will accelerate so that it can shorten its expected lifespan. In calculating the value of trafo age with isolation degradation method known as FAA (aging acceleration factor) or aging isolation rate factor, determined by the following equation 10.

Rate Factor of Isolation Aging

$$F_{AA} = \frac{dL}{dT} = e^{\left[\frac{39,164 - 15,000}{0e + 273} \right]} \quad (10)$$

The Loss of Life, defined by the following equation 11:

$$F_{EQA} = \int_{T_0}^T F_{AA} dt \quad (11)$$

After obtaining FEQA value, we can calculate the value of the percentage reduction of trafo life with the following 12 equations:

$$\% \text{ trafo age decay} = \frac{F_{EQA} \times T}{\text{NormalAge}} \times 100 \quad (12)$$

With: T = time period

The time period value is assumed for 24 hours, and the normal life value of the trafo is assumed to be 180,000 hours.

The age of the trafo by the isolation degradation method can also be seen in the flow diagram in figure 3 below.

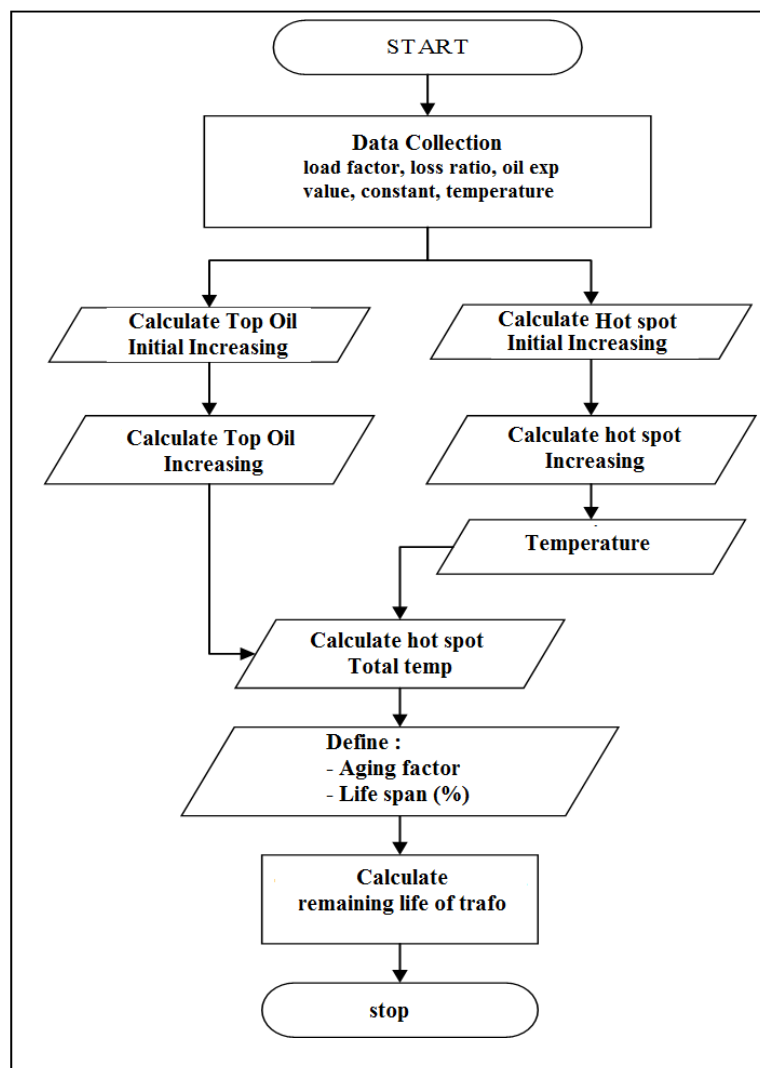


Figure 3. Flow diagram of the research

3. Results and Discussion

The data of research operation condition are load, top - oil temperature, hot - spot temperature, ambient temperature (obtained from yellow titi substation), calculation of temperature rise of top - oil and hot - spot temperature can be seen in Table 3.

Table 3. The result of calculation of temperature rise of top - oil and hot - spot temperature

Type Cooler	Top - Oil ($^{\circ}\text{C}$)		Hot - Spot ($^{\circ}\text{C}$)	
	Increase		Increase	
	Initial	End	Initial	End
ONAN	34.26	56.22	47.27	82.98
OFAF	33.15	63.89		

Table 3 shows the results of the study, which calculated the rise of top-oil temperature and hot-spot temperature in September 2016. The initial top-oil and end temperature was 34.26°C and 56.22°C . And the initial and final hot - spot temperature of 47.27°C and 82.98°C . It appears that the top-oil temperature is smaller than the hot-spot temperature.

For the research result data, the total value of hot - spot temperature in September 2016 that has been done can be seen in table 4.

Table 4. Effect of Ambient Temperature on total hot-spot temperature

Type of Cooler	Ambient Temperature $^{\circ}\text{C}$	The increase of End Temperature		Total Temperature Hotspot $^{\circ}\text{C}$
		Top-Oil $^{\circ}\text{C}$	Hot-Spot $^{\circ}\text{C}$	
		ONAN	30	
OFAF		63.89		176.87

Table 4 shows the results of a study of Ambient Temperature Effect on the total hot-spot temperature in September 2016. Total Hot-spot temperature with ONAN refrigerant type was 169.2°C , and OFAF coolant type was 176.87°C . Then the rest of the life of the trafo can be seen in table 5.

Table 5. The result of Hot-Spot Temperature Rise and Residual Trafo Age

Type of Cooler	Total Temperature Hot Spot ($^{\circ}\text{C}$)	Trafo Age
ONAN	169.2	11 Months
OFAF	176.87	6 Years 2 Months

From Table 5 it can be seen that at the hot-spot temperature with the ONAN refrigerant type = 169.2°C , the trafo's age is 11 years. And OFAF cooling type, hot - spot temperature = 176.87°C , trafo age 6 years 2 months.

From the analysis of data obtained that the greater the total value of hot - spot temperature then the remaining life of the trafo is shorter. This is due to several factors namely:

- The load factor and cooler type values on the trafo have a major effect on the large calculation of the initial rise in hot-spot and top-oil values.
- Peak temperature ever achieved by hot - spot temperature and top-oil temperature.
- Sums of hot-spot temperature rise and increasing top-oil temperature and increasing environmental temperature, the total value of hot-spot temperature is also greater and vice versa.

4. Conclusion

The remaining life of the trafo from the calculation result is about 11 years with a load factor of 0.72 pu, total hot-spot temperature of 169.2°C, and the environmental temperature of 30°C. The load generated by the trafo has a great effect on the residual life of the trafo, if the load factor is greater than 1, then the remaining life of the trafo will be faster. Environmental temperature greatly affects the total hot-spot temperature. The higher the ambient temperature, the higher the total hotspot temperature so that this condition results in the rest of the life of the trafo quickly.

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