Analysis of the influence of loading on age of use of transformers in Botupingge substation

M A Adam, Y Mohamad* and A I Tolago
Electrical Engineering, Faculty of Engineering, Gorontalo State University, Jl. Jend. Sudirman No.6, Gorontalo, Indonesia

*yasinmohamad@ung.ac.id

Abstract. The lifetime of a transformer cannot be determined with certainty due to several factors. One of them is the loading and ambient temperature that affects the transformer, especially at the Hot Spot temperature and the shrinkage of its age. The greater the loading, the higher the Hot Spot temperature so that the life span of the transformer is shorter. This study aims to determine the effect of loading on Hot Spot temperatures, loading forage losses and to determine the effect of loading on the 150kV / 20kV transformer life in the Botupingge Substation. The results of research at Botupingge Substation were obtained at 100% loading of 4.47 pu/day with an estimated age of 4.03 years, at 90% loading of 1.14 pu/day with an estimated age of 15.79 years, and at 80% loading of 0.33 pu/day with an estimated age of 54.55 years. Effect of maximum temperature with loading on 20 November 2018 results in a decreasing age of 0.3611 p.u / day on the type of refrigerant ONAN, and the shrinkage of the age of 0.0228 p.u / day on the type of ONAF cooler so that the estimated lifetime of the Botupingge substation transformer will reach 20 years.

1. Introduction
One of the most important equipment in the distribution of electricity is the power transformer. The function of this power transformer is to channel power / electric power from high voltage to low voltage or vice versa (transform voltage). The more electrical energy needed, the more transformers work to deliver electricity to consumers [1].

The load on this transformer affects the temperature of the oil, the greater the load, the higher the temperature, the smaller the load the lower the temperature. Temperature changes cause damage to the transformer oil and heating on the transformer windings causes the insulation to be damaged. An increase in oil temperature will change the composition and properties of the transformer oil. If this change is allowed, then it will cause the insulation value of oil to decrease.

Considering the hard work of a transformer it has endeavored that this equipment can be long-lived and can be used as much as possible, then the transformer must be guarded and cared for by using a load and temperature system as well as good, correct and appropriate equipment [2].

Therefore, the authors analyzed the effect of loading on the life of the transformer at Botupingge substations to know the transformer loading which affects temperature changes so that we can predict the maximum loading and animate the life of the transformer by referring to the International Electrotechnical Commission (IEC) 354 1972 standard in the Botupingge substation [3].
Electric Power System is a system of supplying electrical energy that consists of electricity centers connected by the transmission network to the distribution. The distribution structure of an electric power system is quite large and complex because it consists of several components such as generators, transformers, safety devices, and loads, and related arrangements [1].

The transformer is a static electricity machine that works based on the principle of electromagnetic induction so that it can move energy from an electric circuit to another electrical circuit without changing the frequency [4]. The transformer functions to supply energy from one electric circuit to another, where the voltage ratio between sides primary and secondary are directly proportional to the ratio of the number of turns and inversely proportional to the current ratio [5].

In the transformer, there are primary and secondary coils. This primary coil when connected to alternating voltage sources, then this alternating flux will appear in the core and form a closed network, then the primary current flows. Due to the flux in the primary coil, then the primary coil occurs induction (self-induction). Also, there is a secondary coil induction due to the influence of the primary coil (mutual induction), causing the magnetic flux to appear on the secondary coil. If the secondary circuit is burdened with electrical energy can be distributed as a whole (magnetization) [1].

\[ e = -N \frac{d\phi}{dt} \text{ Volt} \] (1)

1.1. HotSpot temperature
the hottest temperature in the transformer winding. The location of the hottest winding is dependent on the physical design of the transformer (Janny, 2010). The Guide to Loading sets design limits for normal hot-spot temperatures of 110ºC or 80ºC above the assumed ambient temperature of 30ºC (IEEE Standard).

To determine the Hot Spot temperature, the following equation can be used:

\[ \theta_c = \theta_a + \Delta\theta_{bt} + \Delta\theta_{td} \] (2)

1.2. Relative aging rate
The Montsinger relationship has now been used to get the relative value of the service life at temperatures \( \theta_c \), compared to the normal value of service life at \( \theta_{cr} \) temperatures.

\[ V = 10^{0.6\theta_c - \theta_{cr}^{1.1993}} \] (3)

2. Methods
This study aims to determine the loading of the transformer at the Botupingge substation to be able to analyze the effects on the transformer's life loss and know the life span of the transformer about the IEC 354 1972 standard and is also the current PLN standard (SPLN 17 A: 1979), a transformer will experience a normal life span of 20 years under conditions of "Hot Spot temperature 98 ℃" at constant loading "with the ambient temperature of 20 ℃."

3. Results and discussion

3.1. Botupingge substation transformer data
The 150 kV / 20 kV transformer at Botupingge substation has specifications which are:

| Specification       | Value       |
|---------------------|-------------|
| Brand               | Unindo      |
| Operating Year      | 2016        |
| Recognition Power   | 42/60 MVA   |
| Cooling Type        | ONAN / ONAF |
| Primary Voltage     | 150 kV      |
| Secondary Voltage   | 20 kV       |
| Copper Loss         | 220 KW      |
| Zero load loss      | 38 KW       |
3.2. Temperature data
Temperature data used in this study are temperature data from October 2017 to November 2018 with the data taken as follows:

| Month           | Temperature (°C) | Maxi. Air Temperature |
|-----------------|------------------|------------------------|
| December 2017   | 33,5             |                        |
| January 2018    | 32,8             |                        |
| February 2018   | 32,9             |                        |
| March 2018      | 33,2             |                        |
| April 2018      | 32,4             |                        |
| May 2018        | 32,6             |                        |
| June 2018       | 31,8             |                        |
| July 2018       | 32,6             |                        |
| August 2018     | 32,9             |                        |
| September 2018  | 33,5             |                        |
| October 2018    | 34,0             |                        |
| November 2018   | 33,2             |                        |

| Month                  | Temperature (°C) | Ave. daily temperature |
|------------------------|------------------|-------------------------|
| January 2018           | 26,6             |                         |
| February 2018          | 26,8             |                         |
| March 2018             | 26,6             |                         |
| April 2018             | 26,7             |                         |
| May 2018               | 26,8             |                         |
| June 2018              | 26,4             |                         |
| July 2018              | 27,0             |                         |
| August 2018            | 26,8             |                         |
| September 2018         | 27,3             |                         |
| October 2018           | 27,3             |                         |
| November 2018          | 27,2             |                         |
| December 2018          | 26,8             |                         |

3.3. Data transformer loading
Loading data on this Botupingge substation using loading data on November 20, 2018.
Table 3. Loading data of Botupingge substation.

| Hour | Loading data of Botupingge Substation | MW     | MVar  |
|------|---------------------------------------|--------|-------|
| 1:00 | 28.17                                 | 9.03   |
| 2:00 | 26.62                                 | 8.81   |
| 3:00 | 25.89                                 | 8.56   |
| 4:00 | 25.24                                 | 8.48   |
| 5:00 | 24.68                                 | 8.78   |
| 6:00 | 23.45                                 | 9.97   |
| 7:00 | 22.89                                 | 10.19  |
| 8:00 | 24.21                                 | 10.19  |
| 9:00 | 25.9                                  | 10.6   |
| 10:00| 30.3                                  | 11.6   |
| 11:00| 30.2                                  | 11.4   |
| 12:00| 27.1                                  | 10.1   |
| 13:00| 27.4                                  | 10.5   |
| 14:00| 28.3                                  | 9.87   |
| 15:00| 29.3                                  | 10.4   |
| 16:00| 27.1                                  | 11.6   |
| 17:00| 26.9                                  | 11.1   |
| 18:00| 31.8                                  | 10.5   |
| 19:00| 36.1                                  | 10.1   |
| 20:00| 35.8                                  | 10.0   |
| 21:00| 35.1                                  | 10.1   |
| 22:00| 36.8                                  | 10.4   |
| 23:00| 33.2                                  | 10.2   |
| 24:00| 31.3                                  | 10.5   |

3.4. Calculation

3.4.1. Calculate temperature difference between hot spot and top oil. Calculation of temperature difference between Hot Spot and Top Oil (Δθtd) can be calculated using the equation as below:

$$\Delta \theta_{td} = (\Delta \theta_{cr} - \Delta \theta_{br}) K^2$$

$$\Delta \theta_{td} = (78 - 55) 0,7043^{2(0,6)}$$

$$\Delta \theta_{td} = 13,126^\circ C$$

3.4.2. Calculate hot spot temperature. To calculate the Hot Spot temperature value can use the following equation:

$$\theta_c = \theta_a + \Delta \theta_{on} + \Delta \theta_{td}$$

$$\theta_c = 33,2 + 36,1485 + 13,126$$

$$\theta_c = 82,48^\circ C$$

3.4.3. Calculating the relative thermal value. Based on the calculation results of the Hot Spot temperature (θc) above which is 82,48 °C, then the relative thermal aging rate (V) can be calculated with the following equation.

$$V = 10^{(\theta_c - 98)}/19.93$$

$$V = 10^{(82,48 - 98)}/19.93$$

$$V = 0,1665 pu/jam$$
3.4.4. **Calculate the reduced lifespan of a transformer.** The amount of age used every day due to the effect of decreasing the winding isolation without taking into account the influence of the others can be determined by the following equation.

\[ L = \frac{h}{37} \left( \sum 4V_{odd} + \sum 2V_{even} \right) \times 100\% \]

3.4.5. **For ONAN coolant types.**

\[ L = \frac{1}{3 \times 24} \left( \sum 4(0.1665 + 0.0993 + 0.0790 + 0.0625 + 0.1161 + 0.3171 + 0.1576 + 0.2374 + 0.1491 + 1.2414 + 0.9533 + 0.5938) + 2(0.1175 + 0.0865 + 0.0681 + 0.0802 + 0.3302 + 0.1431 + 0.1822 + +0.1626 + 0.4292 + 1.1376 + 1.5329 + 0.3828) \right) \times 100\% \]

\[ L = 36.11 \% \text{ pu/hour} \]

3.4.6. **Calculation of the remaining life of the transformer.** For ONAN cooling types:

Remaining age in year \( n \) = base age - (\( n \times \text{age shrinkage} \))

\[ n = \frac{\text{basic age} - 2}{\text{age loss}} \]

\[ n = \frac{20 - 2}{0.3611} \]

\[ n = 49.85 \text{ years} \]

4. **Conclusion**

Based on the results of research and discussion that has been carried out by analyzing the loading that is on the Botupingge substation, it can be concluded that:

- The transformer loading affects the temperature of the Hot Spot and also affects the shrinkage of life and age of the transformer, the higher the loading the higher the Hot Spot temperature and shrinkage age so the lifetime of the transformer is lower, and the lower the load the lower the Hot Spot temperature and shrinkage so that the life span of the transformer is longer.

- With a loading rate of 100%, 90%, 80% were obtained decreasing age sequentially that is 4.47 pu / day, 1.14 pu / day, and 0.33 pu / day.

- Based on loading data on Botupingge Substation transformer on November 20, 2018, it is estimated that the age of the transformation will reach 49.85 years.

**Acknowledgment**

The author is grateful to the PT PLN (Persero) in Gorontalo Region for providing research data support to complete this research.

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