

## Analysis of Age Transformer Due to Annual Load Growth in 20 kV Distribution Network

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Received : February 20, 2021

Revision : March 14, 2021

Accepted : March 16, 2021

### Abstract

Distribution transformer is a component in distributing electricity from distribution substations to consumers. Damage to distribution transformer causes continuity of customer service to be disrupted. The length of the PLN electricity network requires a transformer to distribute electricity to serve consumers. The curves of daily peak loads for housing, shops and factories / industries vary. The 200 kVA distribution transformer load cannot serve housing, shops and factories / industries. The method used is the replacement of a distribution transformer with a capacity of one stage greater or the replacement of a distribution transformer with a capacity of two levels larger. The distribution transformer carried out by the research is a capacity of 200 kVA replaced by 250 kVA. The ability of a distribution transformer cannot accommodate a load which will increase as an area is advanced. Observations made by calculating the age of the transformer by assuming the annual load growth ( $r$ ) = 3% = 0.3. Annual peak load ( $P$ ) = 1.8 p, u increase in oil temperature at peak load ( $\theta_o$  = 96.21 °C; 84.16 °C). The increase in the hottest temperature above the oil cover, the increase in the temperature of the hottest place above the oil ( $\theta_g$  = 20 °C; 20 °C). The ratio of the load loss to the nominal load excitation loss ( $Q$  = 3; 30). By assuming the values of these methods it can be estimated that the life of a distribution transformer is 20 kV, a capacity of 200 kVA is 18 years.

Keywords: Age of power transformers, load growth, 20 kV distribution

### Introduction

The transmission and distribution system depends on the capability and effectiveness of the transformer itself. The non-optimal ability of a transformer will cause the flow of power sent to the load will also decrease and in the end do not match the load demand. The distribution transformer is a component that is very important in distributing electricity from distribution substations to consumers. Damage to the distribution transformer causes continuity of service to consumers to be disrupted (there is a power outage or blackout) (Junaidi, 2008). As a result of continuous use of very large loading conditions, the transformer will generate heat in the internal area / part of the transformer or it can be called a hotspot temperature which if left unchecked will cause degradation of the transformer insulation, especially liquid insulation in the form of oil commonly referred to as transformer oil. High temperatures can cause the transformer to heat and can reduce the working reliability of the transformer. Blackout is a loss that causes generation costs to increase depending on the unsold kWh price (1 et al., 2018). Selection of a distribution transformer rating that is not in accordance with the load requirements will cause the efficiency to be small (Roza, 2018). Unsuitable placement of distribution transformer locations affects the end voltage drop on the consumer or the drop / drop in the end / consumer end voltage (Studi & Elektro, 2018).

### Literature Review

A transformer is an electrical device that can transfer electrical energy from an electrical circuit to an electric circuit through a magnetic coupling based on the electromagnetic principle. The greater the capacity and the longer the use of the transformer for consumers, the damage and interference to the transformer can occur, such as internal and external faults. The transformer in the power system for large capacity can be connected three phases and for small capacities it can be connected one phase. In electronic circuits, the transformer is used as an impedance coupling between the source and load, separating one circuit from another, can inhibit direct current while conducting alternating current, the power is quite small (Indra Roza et al., 2018).

Transformers are generally widely used for electrical power systems and for electronic circuits (1 et al., 2018). In

electric power systems, transformers are used to transfer electrical energy from one electrical circuit to next circuit without changing the frequency. It can usually increase and decrease the voltage and current, thus allowing extra high transmission, the transformer functions are as follows:

- a. A step-up transformer, or called by a power transformer, is used to increase the generator voltage into a transmission.
- b. A step-down transformer can be called by a distribution transformer, to reduce the transmission voltage to a distribution voltage.

**Working Principle of Transformer**

Transformers are used widely. Both in the field of electric power and electronics, its use in power systems allows the selection of an appropriate and economical voltage for each need, for example the need for high voltage in the delivery of electrical power to consumers over long distances. The transformer provides a simple way of converting an alternating voltage from one value to another. When a transformer receives energy at a lower voltage and converts it to a higher voltage, it is called by a step-up transformer. When a transformer is energized at a certain voltage and converts it to a lower voltage, it is called by a step-down transformer. Each transformer can be operated as either a step-up or step-down transformer, but transformers designed for a given voltage must be used for that voltage.

To transmit a certain amount of energy, a smaller current is required at high voltages than at low voltages. It means that energy can be transmitted with  $I^2 \cdot R$  or less line losses when higher transmission voltages are used. To get a high transmission voltage, for example 345,000 or 765,000 V, a step-up transformer is used at the generating station, because it is impossible to generate a voltage of this high, then at the place where energy will be used, the drop transformer is used to reduce the high transmission voltage to a safe voltage value and can be used. The distribution transformer allows for economical transmission of electrical energy over long distances. Since the transformer has no moving parts, it requires little attention and low costs to maintenance. The efficiency of the transformer is quite high and can reach 98% or 99% at full load in the larger sizes.

**Transformer on No-Load Condition**

When the primary coil of a transformer is connected to a voltage source sinusoid  $V_1$ , it will flow the primary current  $I_0$  which is also sinusoid and assuming the  $N_1$  winding is pure reactive,  $I_0$  will fall  $90^\circ$  from  $V_1$  (Figure 1).

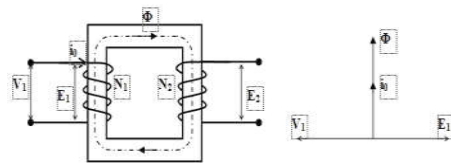


Figure 1.  $I_0$  will fall  $90^\circ$  from  $V_1$

$$e_1 = - N_1 \cdot d\Phi / dt \tag{1}$$

$e_1 = - N_1 \cdot d(\Phi \text{ maks } \sin \omega t) / dt = -N_1 \cdot \omega \cdot \Phi \text{ maks} \cdot \cos \omega t$  (lagging  $90^\circ$  from  $\Phi$ ). the effective price is

$$E_1 = N_1 \cdot 2\pi f \Phi \text{ maks} / \sqrt{2} = 4.44 n_1 \cdot f \Phi \text{ maks} \tag{2}$$

In the secondary circuit, the joint flux ( $\Phi$ ) gives rise to:

$$e_1 = - N_2 \cdot d\Phi / dt$$

$$e_1 = - N_2 \cdot \omega \cdot \Phi \text{ maks} \cdot \cos \omega t$$

$$E_2 = 4.44 N_2 \cdot f \Phi \text{ maks} \tag{3}$$

$$E_1 / E_2 = N_1 / N_2 \tag{4}$$

Ignoring the resistance loss and the presence of leaky flux,  $E_1 / E_2 = V_1 / V_2 = N_1 / N_2 = a$ .

$a$  = transformation comparison.

In this case the induced voltage  $E_1$  has the same magnitude but is opposite to the source voltage  $V_1$ . When an alternating voltage  $V$  is applied to the primary winding ( $N_1$ ) of the step-down transformer shown in Figure 1 with the load switch open, a small current called the exciting current flows. Because, in each inductive circuit, the current is limited by the counter-emf of the self-induction induced in the winding, the transformer winding is planned to have a high enough inductance so that the counter-emf at no load is practically the same as the applied voltage. This limits the no-load current or the excitation current, so the price is very low (Roza et al., 2019).

**Transformer on Load Condition**

If the load switches in secondary circuit of the transformer as Figure 2 is closed, a current equal to  $V$  divided by the load impedance flows. Lenz's law states that any current flow caused by induced emf will flow in such a way that the direction is opposite which causes the induced emf to occur in the transformer (PLN, 2017). It means that  $I_p$  will always flow in such a direction that its magnetizing action will oppose the magnetic action of the primary winding. So the  $I_s$  current will reduce the flux in the transformer core. Still if the flux decreases, the opposite emf decreases, thereby increasing the primary current flow  $I_p$ , which will return the magnitude of the flux to its original value. If the load is increased it will cause  $I_p$  to increase, this magnetic action will reduce the flux, which increases the size of the primary current flow. Then the magnetic action of the primary winding will adjust to each change in secondary current. This action is similar to the conditions in a dc motor where the magnitude of the current drawn by the anchor depends on the magnitude of the opposing emf generated. Increasing the meter load causes the counter-emf to decrease, resulting in an

increase in armature current flow. Increasing the load on the secondary causes a decrease in the primary emf in a transformer.

Primary ampere-winding = secondary ampere-winding

$$\text{or } I_p = I_s \tag{5}$$

So that the current ratio in transformer is inversely proportional to the windings ratio. If the load current flows and the secondary winding of a transformer, a small voltage drop occurs in the transformer due to impedance. Then the terminal voltage is slightly lower than the induced emf. But the difference is often ignored and V is considered to be the same as E, so equation (1) remains valid, resulting in:

$$\frac{V_H}{V_X} = \frac{I_X}{I_H} \text{ dan } V_H I_H = V_X I_X \tag{6}$$

Equation (3) shows that equations (1) to (3) are only approximate equations. This equation is only true for ideal transformers, i.e. transformers without losses. But these equations are fairly accurate in almost all practical applications because the losses in the transformer are very small.

There are two different types of transformer cores that are commonly used, namely the core type and the shell type. These cores are made of a special steel which is low loss enough and is fabricated to reduce core losses. 2 = load work factor. If the secondary coil is connected to the load Z1, I2 flows on the secondary coil where I1 = I2 = load work factor.

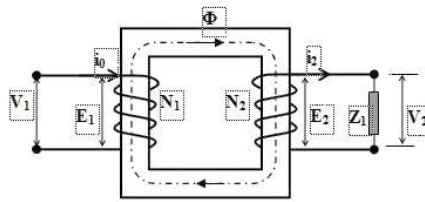


Figure 2. Loaded Transformer

This load current I2 will cause magnet motion N2I2 which tends to oppose the existing joint flux (Φ) due to the magnetic current IM. + I2 If the iron loss is neglected. So that the common flux does not change in value, the primary coil current I2 must flow, which opposes the flux generated by the load current I2, so that the overall current flowing in the primary coil becomes I1 = I0 + I'2 If the iron loss is neglected = IM0(Ic is ignored) then I0=IM

To keep the flux unchanged by the ggm produced by magnetic current IM alone, the following applies:

$$N_1 I_M = N_1 I_1 - N_2 I_2$$

$$N_1 I_M = N_1 (I_1 - I'_2) - N_2 I_2$$

$$\text{to } N_1 I'_2 = N_2 I_2$$

because IM ≈ Small, so I'2 = I1N1I1= N2I2s.

### The Function of Parts of the Transformer Main section

#### a. Transformer Core

The iron core serves to facilitate the path of flux, which is generated by an electric current passing through the coil. It was made of thin insulated iron plates, to reduce heat (as iron losses) caused by "Eddy Current"(SAYOGI, 2011). The iron core (electromagnetic circuit) is used as a medium for the flow of flux arising from the induction of alternating current in the coil that surrounds the iron core so that it can induce a return to the other coil.

#### b. Transformer Coils

The transformer coil is several turns of insulated wire forming a coil. The coils are insulated both against the iron core and against other coils with solid insulation such as cardboard, pertinax and others. Generally, in transformers there are primary and secondary coils. When the primary coil is connected to an alternating voltage/ current, then the coil arises a flux which induces a voltage, if the secondary circuit is closed (load circuit), current will flow in this coil. So the coil as a means of transforming voltage and current.

#### c. Tertiary Coils

Tertiary coils are needed to obtain tertiary voltages or for other purposes. For both purposes, the tertiary coil is always delta connected. Tertiary coils are often used also for connecting auxiliary equipment such as synchron capacitors, shunt capacitors and shunt reactors, however not all power transformers have tertiary coils.

#### d. Transformer Oil

In a transformer, there are two components that actively "generate" heat energy, namely iron (core) and copper (coil). If thermal energy is not channeled through a cooling system it will result in iron and copper reaching high temperatures, which will destroy their insulation value. For this purpose of cooling, the coil and core are subjected to a type of oil, which is called by transformer oil. The oil has a dual function, namely cooling and insulation. This isolation function causes various sizes to be reduced. It should be noted that transformer oil must be of high quality and always be in a clean state. Due to the heat energy generated from the core and the coil, the oil temperature will rise. This will result in changes to transformer oil. Most of the power transformers core are immersed in transformer oil, especially large-capacity power transformers, because transformer oil has properties as a heat transfer medium (circulated) and also acts as insulation (high breakdown voltage) so that it functions as a cooling and insulation media. For this reason, transformer oil must meet the following requirements:

- high insulation strength

- Good heat transfer with small density, so that the particles in the oil can settle quickly
- lower viscosity for easier circulation and better cooling capability
- high flash point, non-volatile which could be harmful
- does not damage solid insulating materials
- stable chemical properties.

#### **e. Bushing**

Bushing is an important component of the transformer which is on the outside of the transformer. Its function is as a liaison between the transformer coil and the network outside the transformer. The connection between the transformer coil to the external network is through a bushing, which is a conductor covered by an insulator, which also functions as an insulator between the conductor and the transformer tank. The bushing consists of a conductor connected to the coil inside the transformer and the conductor is covered by an insulating material. The insulating material serves as an insulating medium between the bushing conductors and the transformer main tank body. The bushing consists of four main parts, namely conductors, insulators, connection clamps, and accessories. The connection between the transformer coil to the external network is through a bushing, which is a conductor covered by an insulator, which also functions as an insulator between the conductor and the transformer tank.

#### **Transformer on Load**

An electric power distribution system is aimed at delivering power or electric power from a large power source (Bulk power substance) to the users (consumers) who need it. The planning of an electric power distribution system is influenced by the characteristics of the load that must be served. The load characteristics will be effective if the use of the load characteristics is known. If the information or information required is incomplete, an approach can be made. It should be noted that the analysis result is only an approach and its use is only a guide .

In general, a distribution system is planned by noticing to the load development in the future. It is related to determination of distribution transformer capacity to be installed and will also be profitable in arranging the replacement or changeout of the distribution transformer.

#### **House Load**

The amount of house load in a certain time interval varies, changes from time to time according to the habits of the local population to use electrical energy and is influenced by the geographical or climate/ weather conditions where the housing is located. When the load served is greater than the rating of the distribution transformer, it means that the transformer operates to serve more loads. So, it affects the ability of transformer in the future. In general, the daily load curve of a house load has two peak loads that occurs, namely in the morning and at night. And also annual load has various forms of changes in highest peak load in dry or rainy season (Yani et al., 2019). Generally, house load consists of electrical equipment such as lamp, television, radio, iron, refrigerator, air conditioning (AC) etc. House load is the load that must be served by a distribution transformer in large part of the residence or residence of the population.

#### **Shopping/ Trading Expenses**

The amount of change in shop loads during certain time, for example, the size of changes in shop loads is relatively smaller when it is compared to house load so that the load factor will be greater. The types of equipment (loads) that the distribution transformer must serve for shop loads are generally lamps, small capacity machines, air conditioning or regulation and so on. The peak load in this shopping / trading area generally occurs in the morning until noon, and at night as well as for lighting. For shopping loads, the issue of continuous power distribution is a priority that must be maintained considering the safety and security factors of the area (F.A. et al., 2018).

#### **Industrial/ Factory Expenses**

Industrial/ factory loads are loads consist of a group of industrial areas, which must be served by a distribution transformer. Industrial/ factory loads are usually located separately from densely populated residential and shopping areas, this is intended to prevent voltage drops that often occur in industrial areas because this affects electrical equipment found in housing and shops. The loads that must be served by distribution transformers in industrial areas/ factories are generally electric motors which are the main equipment in a factory/ industry. They usually operate for 24 hours with relatively small load changes. It means that in industrial / factory areas that must be served by a distribution transformer is relatively fixed or almost the same size every day.

#### **Materials & Methods**

An observation method on 1-phase and 3-phase transformers often occurs overload disturbances so that the loading is uncontrollable, the final transformer capacity is inadequate. The transformer operates continuously at its nominal load if the load served is 100% greater, the transformer will get more heating. This condition will cause damage to the transformer, if it continues, it will result in a shorter insulation life (Garniwa et al., 2012). This observation can be carried out on the loading on houses, shops / trade and industry / factories.

Replacing distribution transformer

The method for dealing with the replacement of transformers, paralleling the distribution transformer with identical transformers, can also be replaced (changeout) with another distribution transformer with a larger capacity. In the observation to change the distribution transformer, there are two ways that can be done, namely:

- a. First rate replacement

Replacement is made to a standard distribution transformer with a capacity of one stage larger

b. Larger rate replacement

Replacement is carried out on a standard distribution transformer with a larger capacity of two levels.

Typically the method to be performed with a commonly used Standard rating distribution transformer is 200; 250; 315; 400; 500 and 630 kVA. Initially the load can be served with a 200 kVA distribution transformer. Because the load served continues to increase, one day this 200 kVA transformer can no longer serve the existing load. To overcome this, the distribution transformer is replaced with another transformer with a larger capacity. This will continue as long as the load continues to increase (Roza et al., 2019).

Ordinary method used Replacement in the first way, namely the first size changeout sequence is: 250; 315; 400; 500 and 630 kVA. The second is the second size changeout, the sequence is: 315,500 and so on. The basis for consideration of making replacement in the first or second way is:

- a. Load growth rate
- b. The operating costs of the changeout
- c. Matters relating to service to consumers.

**Results and Discussion**

Transformer Lifetime Calculation

The calculated of transformer lifetime can be calculated by multiplying the EL of this equation by the length of the changeout period. With a first size changeout transformer 200 kVA replaced with 250 kVA. the estimated life of the transformer is 200 kVA. Data:

- Annual load growth (r) = 3% = 0.03
- The annual peak load (P) = 1.8 p, u
- The increase in oil temperature at peak load (θ<sub>0</sub>) = 40°C
- The warmest temperature rise above the oil cover is 20°C
- Increase in temperature of the hottest place above oil: (θ<sub>g</sub>) = 20°C
- The ratio of the load loss to the nominal load excitation loss (Q) = 30

The changeout period can be found using the equation:

$$Ln = (1+r)^{2n} \quad \frac{250}{200} = (1 + 0.03)$$

$$1.25 = 1.03^n$$

$$n = \frac{\ln 1.25}{\ln 1.03} = 7,45$$

Periode changeout = 7,45

Assuming the basic value used:

- QB = 30      PB = 1.8
- RB = 1.09    NC = 11tahun
- N = 20 tahun

The equations are obtained:

$$\theta_0 = 38,25 \left[ \frac{PB^2QB+1}{QB+1} \right]^{0.8}$$

$$\theta_0 = 38,25 \left[ \frac{1,8^2 \cdot 30 + 1}{30 + 1} \right]^{0.8}$$

$$\theta_0 = 96,21 \text{ } ^\circ\text{C}$$

From the equation we get:

$$\theta_h = \theta_g \cdot P^{1,6}$$

$$\theta_h = 20 (1,8^{1,6})$$

$$= 51,22 \text{ } ^\circ\text{C}$$

From the equation we get:

$$T = \theta_0 + \theta_h$$

$$= 40^\circ\text{C} + 20^\circ\text{C}$$

$$T = 60^\circ\text{C}$$

$$TB = 96,21 + 51,22 + 60 = 207,43 \text{ } ^\circ\text{C}$$

With the price equation on the data

$$P = 1.8 \text{ p,u}$$

$$Q = 3$$

$$RB = 1.09$$

$$R = 1,03$$

obtained:

$$\theta_0 = 38.25 \left[ \frac{1,8^2 \cdot 3 + 1}{3 + 1} \right]^{0.8}$$

$$= 84,16 \text{ } ^\circ\text{C}$$

$$\begin{aligned}\theta_h &= 20 \times 1,8^{1,6} \\ &= 51,22 \text{ }^\circ\text{C}\end{aligned}$$

$$\begin{aligned}T &= \theta_0 + \theta_h \\ 40^\circ\text{C} + 20^\circ\text{C} &= 60^\circ\text{C}\end{aligned}$$

$$T = 84,22 + 51,22 + 60 = 195,38$$

Using the values for TB and T into this equation we get:

$$Ar = \frac{\log RB}{\log R} \chi_{\log^{-1}} \left[ 6250 \frac{1}{TB} - \frac{1}{T} \right]$$

$$Ar = \frac{\log 1,09}{\log 1,03} \chi_{\log^{-1}} \left[ 6250 \frac{1}{207,43} - \frac{1}{195,38} \right]$$

$$Ar = 2,91 \times 0,258 = 0,750$$

From the equation:

$$EL = \frac{N}{NC \cdot Ar} = \frac{20}{11 \times 0,750} = 2,42$$

So the estimated life of the transformer according to the calculations :

$$= 2,42 \times 7,54$$

$$= 18,24$$

$$= 18 \text{ year}$$

By means of a 200 kVA transformer cangout size replaced with 250 kVA with predetermined variables, it can be predicted that the age of a 200 kVA transformer is 18 years.

## Conclusions

1. The daily load curve of a peak load in housing, shops and factories / industries will vary will affect the performance of the transformer..
2. The ability of a distribution transformer cannot accommodate the load which will increase every year
3. Parameters affecting the 200 kVA transformers are replaced by 250 kVA. Annual load growth (r) = 3% = 0.3 Annual peak load (P) = 1.8 p, u
4. Increase in oil temperature at peak load ( $\theta_0 = 96.21 \text{ }^\circ\text{C}$ ;  $84.16 \text{ }^\circ\text{C}$ )
5. The increase in the hottest temperature above the oil cover, the increase in the temperature of the hottest place above the oil ( $\theta_g = 20 \text{ }^\circ\text{C}$ ;  $20 \text{ }^\circ\text{C}$ )
6. Ratio of load loss to nominal load excitation loss (Q = 3; 30)
7. There is an increase in load growth per year so that the estimated age of the transformer is 200 kVA according to the calculation of 18 years

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