STUDY ANALYSIS OF TRANSFORMER LIFETIME DECREASE IN PT. X

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Abstract

Electrical energy is increasingly needed, since the development of an urban and the rapid of development. The need for electrical energy is increasing as well. PT. X is expected to always be able to provide maximum service to consumers. Good service is influenced by the performance of the equipment owned, especially the transformer. The magnitude of the various electrical charges received by the transformer can affect the performance of the transformer. Distribution transformer is an electric machine that serves to move electricity from medium voltage to low voltage, or vice versa. Transformer is designed with operating environment temperature around 20 ^{o}C but environmental temperature in Indonesia is about 30 ^{o}C, where the higher temperature of operating environment can affect operational life and the life of the transformer. In this study the authors do a calculation analysis of the transformer, to be able to know the relationship between the ambient temperature by the amount of loading on the transformer over its lifetime. The analysis study was performed on the transformer with their respective working time.

***Keywords**: electrical energy, working time, distribution transformer, load, temperature*

INTRODUCTION

The demand for electricity requires PT. X as a company engaged in electricity services to always give priority to service and customer satisfaction.

Especially urban areas where load demand through new installing activities and increased power increases from year to year. The high demand is sometimes not offset by the addition of electrical equipment in an effort to increase power due to limited electrical equipment reserves. These constraints cause the condition of the installed electrical network system to be burdened greater than the rated power of the equipment, especially to the transformer equipment which is an important part in power distribution system.

The amount of loading factor to the transformer in electric power distribution system is the background of the author to analyze the calculation of the shrinkage life of the transformer distribution at PT. X to know the normal condition of transformer age according to IEC standard 354-1991.

This study is limited to discuss only:

a. Analyze the measurement result of the transformer distribution load on the transformer.

b. Describe the influence of ambient temperature and fluctuation of transformer distribution loading on the life of the transformer.

This study aims to study the analysis of the decreased lifetime of the transformer distribution on PT X.

Disturbance on Transformer

Disturbance in the distribution transformer that is the distribution transformer has limits in its operation. In addition, the transformer may also experience short circuit interference either inside or outside the transformer. But the disturbance that needs to be more attention is if there is a rise in temperature on the transformer due to overload.

Short circuit breaks occur between coils caused by damage to insulation. The possibility of damage to isolation is the result of the old age of the isolation. Therefore, the transformer in its operation should be noted that the rise in temperature due to overloading. Transformer in its operation is also equipped with protection equipment. Protective equipment is an equipment that secures the transformer against physical, electrical and chemical hazards.

Failure of a transformer is usually caused by the BAD insulation system that causes a lot of heat effects that occur in the transformer. Therefore, please note or choose an isolation class in accordance with applicable standards [1].

In general the isolation on the transformer is divided into two parts, namely solid and liquid insulation. Isolation itself is a material property capable of separating two adjacent or adjacent carriers, either electrically (preventing current leakage), or as a mechanical shield (protecting the material, magnetic) from damage caused by rusting, operation, transport to the place of installation or at the time of testing [2].

The resistance of insulation systems in electrical equipment is heavily influenced by several factors such as temperature, electrical and mechanical strength, vibration, loss due to atmospheric and chemical pressures, as well as dust and radiation. Temperatures in electrical equipment systems often affect factors in insulating materials and insulation systems. As for the isolation and temperature classes applicable according to IEC standard 354 [3]

The transformer winding is insulated by paper (craft paper) and mineral oil. The paper comes from wood pulp with a cellulose content of about 90%. Cellulose will be aged, degraded in the function of time with the rate of aging determined by temperature, water concentration and oxygen concentration. These factors will simultaneously break the long bond of the glucose ring, reducing the mechanical strength of the paper. This degradation is permanent, so the age of insulation paper is identified with the life of the transformer.

Transformer life is a function of the age of the insulation system. The life of the insulation is defined to be over when its mechanical strength has decreased to 50% initial strength. At this limit the transformer can still operate but is susceptible to various disturbances, although some transformers with residual tensile strengths lower than 50% still can operate [4]

The Cause of Fast Aging

In addition to high temperatures, aging in the insulation system can be accelerated by moisture and oxidation. High temperatures, water and oxygen, will simultaneously form chain cycles through three processes, oxidation (in oil and cellulose material), hydrolysis and pyrolysis which will accelerate the destruction of the insulation system. At normal load temperature levels, oxidation and moisture are likely to play a greater role in damaging the insulation system. The result of this cycle is an increase in acidity in oil [5] [8].

The excessive rise in temperature by loading causes more heat to the transformer to affect the insulation of the transformer or oil-immersed transformer. A method is therefore required to estimate the decreased life of the transformer coil's coil over the loveroading [6] [9].

In the calculation, the formulation used is based on the SPLN 17A: 1979 standard which refers to the International Electrotechnical Commission 354 in 1979 standard. Furthermore, we describe the formulation of the relationship between temperature and lifetime on the distribution transformer.

Causes of Temperature Rise

Inside the transformer there are two parts that actively "generate" heat, i.e. iron core and copper. The heat, if not supplied or cooled, can cause the iron or copper core to reach an excessively high temperature [7].

Distribution Transformer Life

The decrease in the ability of an insulating material due to heat is called aging. This is a major factor limiting the ability to impose / maintain the estimated life of the distribution transformer. In other words, the result of more loading will cause heat to the coils of the transformer so that at one time it will decrease the life of the transformer (shrinkage of age) than expected [10] [13].

Current and Temperature Limitation

For loading on the identification board, it is recommended that the loading shall not exceed the current and temperature limits allowed for the loading of the distribution transformer in accordance with IEC standards 354-1991 [11] [12].

Table 1. Current and temperature limits for loading of distribution transformers based on IEC standard 354-1991

Type of loading	**Distribution Transformer**
The Normal Loading Cycle	
Current	1,5
The hot-spot temperature of the entanglement and the metal part on contact with the cellulose insulation material (°C)	140
Upper oil temperature (°C)	105
A long-time emergency loading cycle	
Current	1,8
The hot-spot temperature of the entanglement and the metal part on contact with the cellulose insulation material (°C)	150
Upper oil temperature (°C)	115
Short-term emergency loading	
Current	2.0
The hot-spot temperature of the entanglement and the metal part on contact with the cellulose insulation material (°C)	More than 160
Upper oil temperature (°C)	More than 115

Formulation of Temperature Rise [1]

The heat point temperature on the transformer is the hottest temperature of the transformer located on its winding. The temperature value of the transformer heat point depends on the ambient temperature conditions. The rise in hot spot temperature is calculated using the following equation:

$$\Delta\theta_{hr} = \Delta\theta_{or}\left(\frac{1+RK^2}{1+R}\right)^x + Hg_r.K^y \quad (1)$$

Information:

$\Delta\theta_{hr}$ = *temperature rise of transformer heat point (°C)*

$\Delta\theta_{or}$ = *the increase in the top of the oil temperature on the load rating (°C)*

$\Delta\theta_{or}$ = *55 ° C for 'ON' condition (natural oil)*

R = comparison of load losses at the rated current to the no-load losses, the value 5 for the ONAN transformer (see Table 2)

K = comparison of ratings imposition

Hg_r *= the temperature of the top oil gradient to the hotspot, amounted to 23 (see table 2)*

Y = exponent winding, magnitude according to IEC pub standard. 354-1972 is 1.6 for distribution transformers with ONAN cooling (natural oil and natural cooling).

X = exponential of the comparison of losses applicable to the calculation of temperature rise, magnitude according to IEC pub standard. 354-1972 is 0.8 for distribution transformers with ONAN coolant (natural oil and natural cooling).

Whereas for calculating the value of hot spot temperature (θh) using the following equation:

$$\theta_h = \theta_a + \Delta\theta_{or}\left(\frac{1+RK^2}{1+R}\right)^x + Hg_r.K^y \quad (2)$$

Information:
θ_h *= hot spot temperature (°C)*
θ_a *= ambient temperature, 30 ° C daily average (SPLN 17: 1979)*
By entering equation (1) into equation (2) we find an equation:

$$\theta_h = \theta_a + \Delta\theta_{hr} \quad (3)$$

To calculate the ratio of loading to the rating using the equation:

$$k = \frac{S}{Sr} \quad (4)$$

Information:
k = comparison of ratings imposition (^{o}K)
S = load power (KVA)
Sr = power with a certain value (KVA)
As a guideline for load calculations, thermal characteristics of the ONAN coolant type distribution transformer are provided in table 2.

Table 2. Characteristics of ONAN thermal transformer distribution based on IEC standard 354-1991

Thermal Characteristic Components	**Distribution Transformer**
	ONAN
Oil Exponent **x**	0.8
Exponent winding **y**	1.6
Exponential loss **R**	5
Hot spot factor **H**	1,1
The ambient temperature θ_a **(°C)**	30
Hot spot temperature rise $\Delta\theta_{hr}$ **(°C)**	78
The average winding temperature rise $\Delta\theta_{wr}$ **(K)**	65
Gradient oil top to hot point Hg_r **(K)**	23
Average oil temperature rise $\Delta\theta_{imr}$ **(K)**	44
Increase in oil turnover temperature * $\Delta\theta_{ir}$ **(K)**	55
Winding temperature rise of the lower oil $\Delta\theta_{br}$ **(K)**	33
* For cooler ON, Δθir value equals to Δθor value	

Transformer Winding Isolation Aging
Relative Value of Life Time

For transformer designs based on IEC 76 and IEC 354 standards, the relative value of usage life depends on the temperature of the hotspots. This relation temperature to operation at a temperature around 30 ° C at the nominal power value of the transformer gives a rise in the temperature of the hotspots of 78 ° C. The relative value of usage life is defined as:

$$V = \frac{Rate\ of\ use\ when\ \theta h}{rate\ of\ lifetime\ use\ at\ 108°C}$$

$$V = 2^{\frac{(\theta h - 108°C)}{6}} \qquad (5)$$

Information:
V = relative aging rate (hours)
θ_h = hot-spot temperature (°C)

Calculate Decreased Lifetime

In calculating the life reduction, the equation is given to determine the amount of life is as follows:

Typical life = (t x lifetime 1) + (t x lifetime 2) + (t x life time $_n$) + ……… (6)

Information:
t = the length of the transformer is overloaded (hours)

Examined Distribution Transformer Spesification

The specifications for each transformer being examined on the PT X substation in table 3, are as follows.

Table 3. Transformator Distribution Data Specification of CP 165 Substation

Spesifcation	CP 165
Brand	HICO
Made by	Amerika Serikat
Standard	IEC 76
Operation Year	1999
Nominal Load	630 KVA
Primary Voltage	20 KV
Secundary Voltage	380 V
Frequency	50 Hz
Coolar	ONAN
Isolation Class	A
Maximum Operation Temperature Limit	105 ˚C

On Field Transformer Data

CP 165 Distribution Transformer Loading- Data

At CP 165 substation with rated power of 630 KVA bearing housing / household burden. Data measurements of daily usage charges within 24 hours for one week on April 1, 2018 to April 7, 2018 from 00:00 to 24:00 on table 4 as follows.

Table 4. Daily use cost of distribution transformer CP 165 for one week (1 to 7 April 2018)

Transformer 630 KVA Substation CP 165 Data Loading								
No.	Measurement Time	Measurement Date of 2018						
		April 1st	April 2nd	April 3th	April 4th	April 5th	April 6th	April 7th
1	0:00	221.22	220.55	220.11	220.96	221.63	220.22	220.18
2	1:00	220.34	**220.11**	221.04	222.11	224.35	220.60	220.21
3	2:00	222.49	223.21	222.59	222.84	225.18	221.60	222.52
4	3:00	222.24	222.77	222.93	224.68	225.37	223.07	223.49
5	4:00	224.18	225.47	224.53	228.35	226.10	224.37	223.73
6	5:00	227.61	229.49	228.12	231.18	227.39	228.04	226.98
7	6:00	227.76	230.50	230.27	232.76	230.91	230.30	228.75
8	7:00	353.07	346.18	347.41	340.06	344.65	357.34	354.72
9	8:00	350.12	342.81	350.77	349.82	347.60	350.97	351.78
10	9:00	350.94	344.27	348.30	349.72	347.81	350.64	350.33
11	10:00	343.14	344.76	348.30	349.50	348.80	350.29	348.66
12	11:00	339.53	350.04	349.38	348.62	347.61	350.28	348.98
13	12:00	342.54	352.26	349.65	348.40	347.80	351.92	348.91
14	13:00	350.63	352.55	354.86	353.38	350.53	353.15	350.84
15	14:00	477.55	480.40	486.54	478.59	468.96	490.56	484.31
16	15:00	479.87	480.63	486.48	482.49	472.03	494.76	488.09
17	16:00	489.34	488.49	492.52	483.37	478.69	502.52	495.04
18	17:00	526.51	524.86	529.75	502.50	510.18	536.68	530.50
19	18:00	602.57	599.84	601.63	578.08	586.66	602.56	598.64
20	19:00	626.40	624.11	619.24	639.14	612.89	622.68	617.28
21	20:00	644.42	640.99	638.14	630.84	635.06	645.03	638.48
22	21:00	648.28	**652.89**	651.12	630.62	645.58	651.38	649.25

From Table 4 above shows that:

- The minimum load of the 630 KVA transformer at the CP 165 distribution substation occurred on April 2, 2018 at 1:00 pm by 220.11 KVA.
- The maximum load of the 630 KVA transformer at the CP 165 distribution substation occurs on 2 April 2018 at 21:00 at 652.89 KVA.

From table 4 the measurement of CP 165 substation load usage within 24 hours during one week can be sampled for the daily loading condition curve on April 1, 2018, to be able to see the graph of the change in the time of loading that can be seen on the curve (Figure 2.) below.

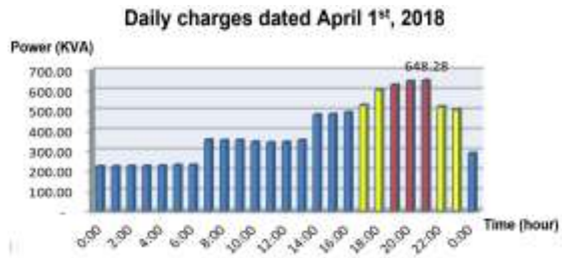

Figure 2. The daily usage load graph at CP 165 substation (April 1, 2018)

Information:
Blue bar : the condition at the time of the transformer is burdened below capacity
Yellow bar: condition at the time of increase of transformer load
Red bar : the condition at the time of the transformer is overloaded

From the results of the data of daily loading dated on April 1, 2018 for 24 hours, it can be seen that the peak load consumption occurs at 19:00 s / d 21:00 which is given a red color, while changes in the increase and decrease in the usage expenses are colored yellow which occurred at 17:00 s / d 18.00 and 22.00 s / d 23:00 and the rest are colored blue is burden below capacity. From the data of the daily loading will be done the calculation of the life of the distribution transformer discussed in the next analysis.

DISTRIBUTION TRANSFORMERLIFETIME CALCULATION ANALYSIS

General

Transformer to be used as research object as much as one with the type of indoor pair transformer. In this case the type of load is the housing / household load, for the data of the transformer distribution specifications at the substation referred to table 2. From the measurement result of daily usage on CP 165 substation contained in Table 5, will be calculated using the equations mentioned in the previous theory to find out how to calculate the life of the transformer.

Distribution Transformer Lifetime Calculation

Calculation of daily usage charges taken from a sample of daily load measurement on a CP 165 substation on April 7, 2018 with a load value at 21:00 of 638.48 KVA, first determining the value of the ratio of more loading to the calculated rating using equation (4) as follows:

$$k = \frac{S}{Sr}$$
$$k = 638{,}48/630$$
$$k = 1{,}012\ ^{o}K$$

Obtained the value of the comparison of over loading to the rating with a maximum load of 638.48 KVA is 1.012 oK.

Furthermore determine the value of heat point temperature (θh) transformer at the distribution substation CP 165, is as follows:

$\theta_h = \theta_a + \Delta\theta_{or}\left(\frac{1+RK^2}{1+R}\right)^x + Hg_r.\ K^y$

$\theta_h = 30 + 55\left(\frac{1+5(1{,}012)^2}{1+5}\right)^{0{,}8} + (23.\ (1{,}012)^{1{,}6})$

$\theta_h = 30 + 55{,}883 + 23{,}443$

$\theta_h = 109{,}326$ °C

Obtained the value of hot spot temperature (θh) of the transformer at the distribution station on April 7, 2018 with the value of usage loading at 21:00 was 109.326 ° C. The hot-spot temperature (θh) of the transformer does not exceed the permitted heat-point temperature limit of 140 ° C, and the state is still permitted.

Then determine the relative aging rate on the overload which can be searched by using following equation (5):

$$V = 2^{\frac{(\theta h - 108°C)}{6}}$$
$$V = 2^{\frac{(109{,}326 - 108)}{6}}$$
$$V = 1{,}1655 \text{ hour}$$

Obtained a relative aging rate of 1.1655 hours. By using the same calculation step as above, it will be possible to calculate to determine the value of the load ratio over the rating (k), the hot spot temperature (θh) and the relative aging rate (V) at each time of daily loading for 24 hours for a week. The calculation table for one week (1 to 7 April 2018) is attached. The following is a table of calculations in one day on 1 April 2018 (Table 5).

Table 5. The result of hot spot temperature calculation and relative aging rate for loading within 24 hours for one day at CP 165 substation (April 1, 2018)

No.	Measurement Time	Power (KVA)	Comparison of Loading (°K)	Hot Spot Temperature (θh) (°C)	Relative Aging Rate (V) (hour)
1	April 1st, 2018 00:00	221.22	0.351	53.372	0.0019
2	April 1st 2018 01:00	220.34	0.350	53.499	0.0018
3	April 1st 2018 02:00	222.40	0.353	53.680	0.0019
4	April 1st 2018 03:00	222.24	0.353	53.658	0.0019
5	April 1st 2018 04:00	224.18	0.356	53.823	0.0019
6	April 1st 2018 05:00	227.01	0.361	54.117	0.0020
7	April 1st 2018 06:00	227.78	0.362	54.130	0.0020
8	April 1st 2018 07:00	353.07	0.560	67.022	0.0088
9	April 1st 2018 08:00	350.12	0.556	66.671	0.0084
10	April 1st 2018 09:00	350.94	0.557	66.770	0.0085
11	April 1st 2018 10:00	343.14	0.545	65.856	0.0077
12	April 1st 2018 11:00	339.53	0.539	65.438	0.0073
13	April 1st 2018 12:00	342.54	0.544	65.788	0.0076
14	April 1st 2018 13:00	350.63	0.557	66.734	0.0085
15	April 1st 2018 14:00	477.53	0.758	83.513	0.0591
16	April 1st 2018 15:00	479.87	0.762	83.853	0.0615
17	April 1st 2018 16:00	489.34	0.777	85.247	0.0722
18	April 1st 2018 17:00	526.51	0.836	90.893	0.1386
19	April 1st 2018 18:00	602.57	0.956	103.272	0.5792
20	April 1st 2018 19:00	626.40	0.994	107.373	0.9301
21	April 1st 2018 20:00	644.42	1.023	110.539	1.3409
22	April 1st 2018 21:00	648.28	1.029	111.225	1.4514
23	April 1st 2018 22:00	518.27	0.823	89.617	0.1196
24	April 1st 2018 23:00	503.67	0.799	87.391	0.0925
25	April 1st 2018 24:00	286.67	0.455	59.685	0.0038

Shows in table 5, it is known that the transformer at the CP 165 distribution substation has a lifetime when the hot spot temperature (θh) is more than 80 oC at 14:00 to 23:00. From the above calculation, we can find the value of the life of the transformer when overloading for 24 hours per day by using equation (6) by using sample data of daily load calculation on the substation CP 165 dated April 7, 2018 as follows:

Decreased lifetime on April 7, 2018:

= (t x lifetime $_1$) + (t x lifetime $_2$) + (t x lifetime $_n$) + …

= (1 x 0.0662) + (1 x 0.0707) + (1 x 0.0796) + (1 x 0.1489) + (1 x 0.5362) + (1 x 0.7748) + (1 x 1.1876) + (1 x 1.4808) + (1 x 0.1158) + (1 x 0.0881) = 4.5488 hour per day

Based on SPLN 17A: 1979, the publication of IEC 354: 1972 the age of a transformer is set for 20.55 years or 7500 days or 180,000 hours. With a calculation of 20.55 years x 365 days x 24 hours = 180,000 hours. Then we get the value of life of transformer CP 165 with daily loading condition for 24 hours or in one day will be reduced its age 4,5488 hours, as for life calculation in determining percentage per day at CP 165 substation dated April 7, 2018 is as follows:

Lifetime decrease in 1 day (%)
= [(4.5488 / 180.000) x 100 %]
= 0.00253 % per day
= 2.53 x 10^{-3} % per day

Using the same equations and steps as above, we get the calculated value of decreased daily life for one week at the following substation of CP 165 at table 6.

Table 6. Decreased lifetime during peak load at substation CP 165 per day (1 to 7 April 2018)

Relative Aging Rate In CP 165 (*V*) (hour)							
Time	**April 1st**	**April 2nd**	**April 3th**	**April 4th**	**April 5th**	**April 6th**	**April 7th**
14:00	0.0591	0.0620	0.0688	0.0601	0.0512	0.0737	0.0662
15:00	0.0615	0.0622	0.0688	0.0642	0.0539	0.0792	0.0707
16:00	0.0722	0.0711	0.0762	0.0652	0.0602	0.0906	0.0796
17:00	0.1386	0.1345	0.1469	0.0906	0.1036	0.1665	0.1489
18:00	0.5792	0.5490	0.5686	0.3605	0.4250	0.5791	0.5362
19:00	0.9301	0.8881	0.8057	1.2039	0.7100	0.8630	0.7748
20:00	1.3409	1.2500	1.1795	1.0171	1.1078	1.3577	1.1876
21:00	1.4514	1.5964	1.5389	1.0125	1.3732	1.5473	1.4808
22:00	0.1196	0.1332	0.1202	0.0980	0.1189	0.1161	0.1158
23:00	0.0925	0.0934	0.0885	0.0809	0.1115	0.0828	0.0881
Total sums per day (hour)	**4.8449**	**4.8401**	**4.6620**	**4.0530**	**4.1154**	**4.9562**	**4.5488**
Lifetime shrinkage per day (%)	**0.00269**	**0.00269**	**0.00259**	**0.00225**	**0.00229**	**0.00275**	**0.00253**

From the result of the reduction of usage life per day in the above calculation table can be calculated to determine the life decrease for one week (7 days) at the substation CP 165 as follows:

Lifetime Decrease on CP 165 Substation (7 days):

= (t x lifetime $_1$) + (t x lifetime $_2$) + (t x lifetime $_n$) + …
= [(2 x 0.00269) + (0.00259) + (0.00225) + (0.00229) + (0.00275) + (0.00253)] / 7 days

= 0.00254 % per week
= 2.54 x 10^{-3} % per week

It has been mentioned that the transformer at the CP 165 substation has been in operation since 1999, until now the transformer has been operating for 16 years.

So far, the transformer is still in good condition, if during operation it does not experience overloading continuously, it is estimated that the life of transformer can operate until 2019 for distribution transformer at CP 165 substation.

If someday there is a disturbance that causes the transformer is damaged, then the lifetime of the transformer will be shringked. To know the lifetime future, it is necessary to calculate the decreased life of each day based on the occurrence of overloading.

Based on the analysis on the two transformers, it was found that the loading conditions and the ambient temperature factor of the transformer were still within the limits of the provisions, not exceeding the SPLN standard loading limit of 80% ideal loading and mentioned that the life of the hotspots (θh) more than 80 ° C in accordance with IEC 345-1979 standards. It is expected that the life of the transformer from existing substations can remain stable despite the addition of power and new installation of prospective customers are increasing each day.

Conclusions and Recommendation

Conclussions

According to IEC 354-1991, the normal life of a transformer ranges from 20.55 years or 7500 days or 180,000 hours of operation. Based on the calculation of the life time decrease of the transformer obtained the following results:

The CP 165 distribution transformer with rated power of 630 KVA that overloading for one week on 1 to 7 April 2018, the decrease is 2.54 x 10-3% per week if the conditions remain linear as the loading of the transformer's ideal life.

Based on the analysis on the transformer, it is found that the loading condition and the ambient temperature factor of the transformer are still within the limits of the provision, not exceeding the SPLN standard loading limit of 80% ideal loading and it is mentioned that the decreased life time if the hotspot temperature (θh) is more than 80 ° C in accordance with IEC 345-1979 standards. It is expected that the decrease life of the transformer from existing substations can remain stable despite the addition of new power and installation of new customers increasing every day.

Recommendation

Based on the results of the analysis that has been discussed above it is advisable to test the life of the transformer on an outdoor transformer that has a higher temperature condition due to uncertain weather factors.

REFERENCES

[1]. Kadir, Abdul. Transformator. *Pradnya Paramita Jakarta.* 1979.
[2]. IEC. Loading Guide For Oil Immersed Transformer. *IEC 354 Publication*. 1991.
[3]. Asset Management of Java - Bali Distribution Transformer. Jakarta: PT. PLN (Persero) Headquarters. 2010.
[4]. Sriwati. Penelitian Penggantian Transformator Distribusi Akibat Beban Lebih Di Kabupaten Maros. Jurnal ILTEK. 2013; Vol.8, No 15.

[5]. Standar PLN No: D3.002-1. 2007 About Specification of Distribution Transformer. Jakarta: PT. PLN (Persero) Headquarters.

[6]. Sulasno. Electrical Energy Conversion. UNDIP Publishing Agency, Semarang. 2003.

[7]. Zuhal. Basic Electrical Power Engineering and Power Electronics. PT GramediaPustaka Utama, Jakarta. 1995.

[8]. Belen Garcia, Tamara Garcia, Victor Primo, Juan Carlos Burgos, Domingo Urquiza. Studying the loss of life of natural-ester-filled transformer insulation: impact of moisture on the aging rate. Paper IEEE Electrical Insulation Magazine. 2017.

[9]. Ricardo David Medina, Andres Arturo Romero, Enrique Esteban Mombello, Giuseppe Ratta. Comparative Study of Two Thermal Aging Estimating Methods for Power Transformers. IEEE Latin America Transactions. 2015.

[10]. Badaruddin, Yudhi Gunardi, Fery Agung F. Analysis on the Quality of Three-Phase Transformator Oil. International Research Journal of Computer Science (IRJCS). 2017.

[11]. Badaruddin. Fluctuation Study of output power to the efficiency of the transformer on PT. X. Unpublished paper. 2017.

[12]. B.Y. Husodo, M. Anwari, S.M. Ayob, Taufik. Analysis and simulations of Z-source inverter control methods. IEEE Singapore Conference. 2011.

[13]. Sirait Fadli, Dani Akhmad Wahyu, Pangaribowo Triyanto. Capacity Improvement and Protection of LTE Network on Ethernet Based Technique.TELKOMNIKA, Yogyakarta. 2018; Vol. 16